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Master Thesis:
Corrosion Under Pipe Support Strategy

Autumn 2018

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ABREVIATIONS

Abbreviation	Definition
ADNOC	Abu Dhabi National Oil Company
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
BU	Business Unit
CL-SCC	Chloride Stress Corrosion Cracking
CPY	Company
CoF	Consequence of Failure
CUI	Corrosion Under Insulation
CUF	Corrosion Under Fireproofing
CUL	Corrosion Under Labels
CUPS	Corrosion Under Pipe Support
CVI	Close Visual Inspection
DSC	Differential Scanning Calorimetry
EFC	European Federation of Corrosion
EMAT	Electro Magnetic Acoustic Transducers
EUR	Euros
FRP	Fibre Reinforced Plastic
GVI	General Visual Inspection
ISO	International Organization for Standarization
MT	Magnetic Particles Testing
NDE	Non Destructive Examination
NDT	Non Destructive Testing
NFPA	National Fire Protection Agency
NPS	Nominal Pipe Size
LLPDE	Linear Low Density Polyethylene
OMV	Österreichische Mineralölverwaltung
PE	Polyethylene
PCC	Post Construction Code
PO	Polyolefin
PoF	Probability of Failure
PP	Polypropylene

Abbreviation	Definition
Q3	3rd Quarter
RBI	Risk Based Inspection
RP	Recommended Practice
RTR	Real Time Radiography
R&D	Research and Development
SCC	Stress Corrosion Cracking
SH Waves	Share Horizontal Waves
SME	Small and Medium Size Enterprises
TM	Trademark
UAE	United Arab Emirates
UT	Ultrasound Testing
WP	Working Party

1. ACKNOWLEDGMENT

I would first like to thank Eng. Gino De Landtsheer, Senior Group Expert Piping & Valves at Borealis. He proposed to work with this problem in order to have a solution for Borealis Group and he was always open for discussion on how to deal with it. He consistently allowed this paper to be my own work, but steered me in the right direction.

I would also like to thank Eng. Marcel Thijert, Manager Integrity, BU Engineering Solutions at Sitech Services B.V. for letting me be part of this project and being able to present it as my Master Thesis.

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Finally, I must express my very profound gratitude to my parents and to my spouse for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

Sebastian Mauro Tarantino

2. ABSTRACT

Due the increment of the incidents related with corrosion under pipe supports (CUPS) at Borealis Plastomer Plant at Chemelot Site located in Geleen, Netherlands, it was decided by the management to face this problem and develop a CUPS Strategy to handle the more than 4000 piping supports located at the plant, and extend the implementation to other Borealis plants.

For this strategy it was decided to develop a Risk Based Inspection (RBI) methodology to handle such amount of supports and prioritize them. The RBI approach provides a likelihood and consequence assessment that are developed and can be used separately, and when combined a risk value is obtained, a very powerful prioritization tool. Likelihood and consequence can be calculated in many different ways, depending the degree of complexity that wants to be used, more information is going to be needed and more time must be spent in the development of the tool and its implementation. Also, flexibility is being reduced with the increase in complexity. Usually when less information and general characteristics are used it is called a qualitative approach, and when more information is needed and complexity increased, it is called a semi-quantitative up to reach a quantitative approach.

For this strategy a full development of a qualitative probability was performed. The consequence calculation is described and it is intended to be used the system already implemented at Borealis. However, an easy qualitative consequence calculation was developed for the cases that a full RBI approach is not yet implemented at the site. The intention of this calculation is to get an easy and fast calculation method for the consequence and have a first prioritization to start with the needed jobs to reduce the risk at the plant. Indeed, it is recommended to implement a full RBI methodology and use the consequence calculated in that implementation for the CUPS strategy.

The Risk Based Inspection (RBI) is a very good method to prioritize a process or a part of a process equipment based in the likelihood and consequence of failure, given the risk. After evaluation of the piping supports and risk calculation a prioritization by risk is obtained and it can be decided how to manage them, plan the necessary actions for inspection, maintenance and replacement if needed in order to operate the plant safely.

3. INTRODUCTION

Corrosion Under Pipe Supports (CUPS) is a known cause of external corrosion failures on above-ground piping systems in aging facilities, some industrial facilities are entering now to an age of above 30 years, that is not addressed systematically by the industry, mainly due:

- CUPS it is not easily visible
- CUPS may be underestimated

As a consequence, in order to tackle CUPS related threats, it is necessary to define and implement a CUPS management system based on proactive reviews and systematic inspection & maintenance plans.

3.1 BACKGROUND & PROBLEM DESCRIPTION

During the 2017 Borealis plastomer plant at Chemelot had several leakages and a fire incident at the end of the year affecting several areas of the plant. After concluding that several of the leakages and the fire were caused due to corrosion under pipe support (CUPS), Borealis management decided to create a dedicated team to deal with this problem in the short and long term.

For the short term, the team was conformed by integrity engineers, project managers, inspection engineers, production engineers among others, and the aim was to decide *what*, *when and how* to inspect, assess the results and decide what actions to take and when shall they be executed in order to have an overview of the status of the supports in the plant and reduce the risk of failure. Also, it was responsibility of the team the research of different inspection methods and company providers, including further execution evaluation to decide which company will provide the service. This work started at the beginning of 2018 and it is outside of the scope of this Master Thesis. However, it is important to mentioned it to have a full overview on how Borealis is approaching the CUPS issue.

For the long term, it was decided to develop a corrosion under pipe support strategy in order to evaluate, using a Risk Based Inspection approach, the status of the piping at the pipe support location, the probability and consequence of failure, when replacement or inspection is needed, how and when to inspect and which inspection methods shall be used. Also, this approach will give information about the pipe supports status and the need of replacement in order to improve the integrity while reducing the probability of failure. To develop this strategy, Engineer Sebastian M. Tarantino was responsible to lead and write the CUPS strategy with support of the Integrity Engineers and Materials & Corrosion Engineers at Sitech Services, and support from Gino De Landtsheer and a multidisciplinary team from Borealis Group.

3.2 MASTER THESIS GOAL

To provide to Borealis Group and Sitech Services a detailed strategy on how to manage the integrity of the piping affected by corrosion under pipe support using a risk approach.

3.3 MASTER THESIS SCOPE OF WORK

After several discussion with Borealis Group and Sitech Services representatives, the following milestones are agreed to be achived in order to deliver a CUPS Strategy:

- Identify clearly the corrosion mechanism and its key factors
- Recommend the integrity strategy to be implemented and a detailed process on how to follow it
- Detail the information needed to be able follow the integrity strategy recommended
- Propose how to calculate the probability of failure and the consequence of failure
- Present the actual alternatives for corrosion under pipe support inspection, its advantages and limitations
- Contact different inspection services providers, arrange a full day with each one to perform the inspection in real cases, evaluate them and select the most suitable for the company needs.
- Investigate and present the methods to prevent future corrosion under pipe support

The document has been elaborated according to the following sections:

- CUPS general information and literature review (corrosion mechanisms, contributing factors, risk assessment)
- Inspection and maintenance strategy recommendation during operations.
- Prevention and mitigation during design and construction

3.4 LIMITATIONS

The limitations of this thesis are:

- The CUPS Strategy applies only to carbon steel, low alloy steel and stainless steel piping.
- If the piping is insulated the strategy shall be used together with a Corrosion Under Insulation (CUI) Strategy which is under development but not part of this Master Thesis.
- Company timing do not allow to perform a full validation of the strategy proposed in the timeframe of this Master Thesis. However, future steps are presented at the end of this document which allows this Thesis can be continued by future students.
- Due lack of standards and literature about this subject, many of the information and decisions taken, have been done using Borealis and Sitech in house experience.
- The application of the procedure proposed will not compensate for:
  - Inaccurate of missing information
  - Improper installation or operation
  - Operating outside design limits
  - Deficient implementation of the inspection plans
  - Lack of qualified personnel or workteam for the implementation

4. BASIC CONCEPTS

4.1 RISK

Every single person in the world lives with risk, known or unknown, and people are taking decisions based on risk. Driving in a highway, walking on the street, taking an elevator, invest in a start up company or buy a house involve risk [3] [7]. Risk can be reduced, but never be eliminated, not even by the most cautious persons.

For our purpose in this document we definy risk according to API [3] and ASME [7]: Risk is the combination of the probability of failure of some event occurring during a time period of interest and the consequences of failure, (generally negative) associated with the event. In mathematical terms, risk can be calculated by the equation:

$$\textbf{Risk} = \textbf{Probability (PoF)} \times \textbf{Consequence (CoF)}$$

It is important to mention the risk value can be expressed in a cualitative, semi-quantitative or quantitative way.

4.2 RISK MANAGEMENT

After the risk is calculated it is needed to know what to do with it, it is time for manage the risk. The risk management shall be a logical and structured process in order to use in the best way the available knowledge to assess the risk, implement mitigation measures to reduce the risk down to acceptable levels when required, plan to maintain risk at an acceptable levels, identify when risk reduction is no needed to implement and monitoring of risk [3] [7] [10]. It is important to point that the risk management process shall be a continuous activity.

4.3 RISK ANALYSIS

According to Aven [34] risk analysis can be carried out at various phases in the lifetime of an asset, from early concept up to decommissioning phase, and the main reason to perform a risk analysis is to support decision-making, by providing a risk picture and comparing various alternatives and their effect on the risk and risk evolution in combination with the implementation cost in order to choose the most cost-effective alternative.

Risk analsys is the structured and systematic use of the information and data, such as design information, historical data, company know how and expertise, etc. to estimate the probability and the consequence of events. The risk analysis can have be performed at different complexity levels, going from cualitative (based on rankings) to a qualitative approach (rigorous calculations) depending on the company needs and the information available. It must be pointed the precision of the results will also vary accordingly to the risk analysis complexity

4.4 INSPECTION OPTIMIZATION

Once it is know the risk of an individual equipment it is possible to start "playing" with the inspection effectiveness (inspection extension) and inspection interval in order to reduce the risk, reduce costs, and optimize inspections and other related task (other equipment inspections, maintenance, shutdowns, etc).

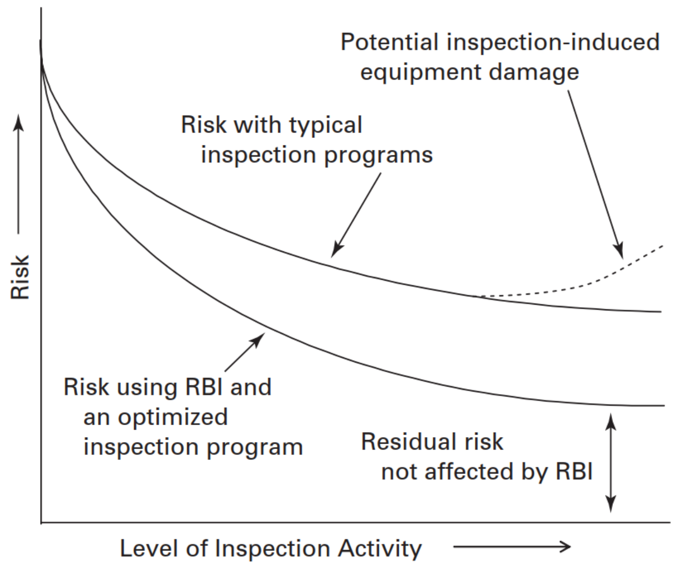


Figure 4-1 Management of risk using RBI [7]

Figure 4-1 shows the risk reduction according to the increase in the inspection activity performed, while more activity (effectiveness or frequency) more risk reduction. It can be seen from this figure the risk never fell down to cero, this is due the residual risk that can be not affected by RBI. Also, it must be notice that the excess of inspection can be detrimental in the integrity of the equipment and the risk can start increasing again. This mainly appears in certain cases when using invasive inspection (e.g. corrosion under insulation).

A good RBI program will provide with the necessary inspection methodology to be used to detect the corrosion mechanism assessed to be active, its effectiveness (inspection extension), where shall be inspected and the inspection interval, see Figure 4-2.

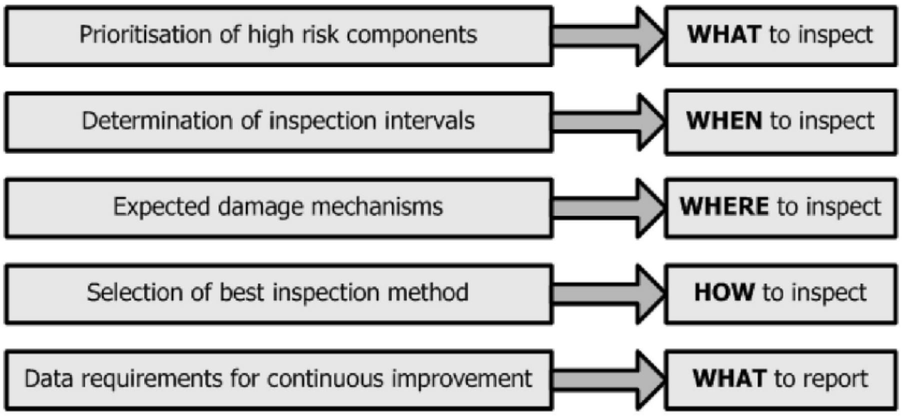


Figure 4-2 Deliverables of an RBI assessment to the inspection program [10]

4.5 RISK BASED INSPECTION (RBI)

Risk Based Inspection (RBI) it is a known and proved decision making technique for risk assessment and inspection planning based on risk. This methodology has its origins in the refining and petrochemical industry in the early 90's, when several companies, in cooperation, sponsored a project leading to publish the standards API RP 580 [3] and API RP 581 [4]. Nowadays, exist several international standards for RBI as API [3] [4], ASME [7], DNV [10], etc. and several companies as British Petroleum and Total have developed their own standard, usually based in one or more international standards plus their own know how and with focus in the particular company issues and philosophy.

Usually, in the industry the risk distribution follows a Pareto-style, meaning approximately a 80% of the risk is concentrated concentrated in the 20% of equipment. Therefore, the equipment with higher risk requires more focus than the rest. The aim of the RBI is to identify the equipment with higher risk and shift the effort and money to this equipment and reduce or eliminate the effort in the equipment with low risk in order optimize the company resources. Its approach provides a detailed analysis of the corrosion mechanism affecting each equipment individually, resulting in custome made inspection plans with specific inspection methods, inspection intervals and inspection extension, avoiding the use of generic inspection plans with fix inspection intervals.

RBI will allow users to:

- Define, measure, and use risk for managing important elements of facilities or equipment
- Manage safety, environment, and business interruption risks in an integrated, cost-effective manner
- Systematically reduce the overall facility risk by making better use of inspection resources

4.6 TYPES OF RBI APRROACH

As mentioned previously, a Risk Based inspection assessment can be carried out at several levels (see Figure 4-3), may be quialitative, quantitative or semi-quantitative (a combination of both), been some of the key factors to choose one or the other the following:

- Objective of the assessment
- Number of facilities and equipment items to study
- Available resources
- Assessment time frame
- Complexity of facilities and processes
- Nature and quality of available data

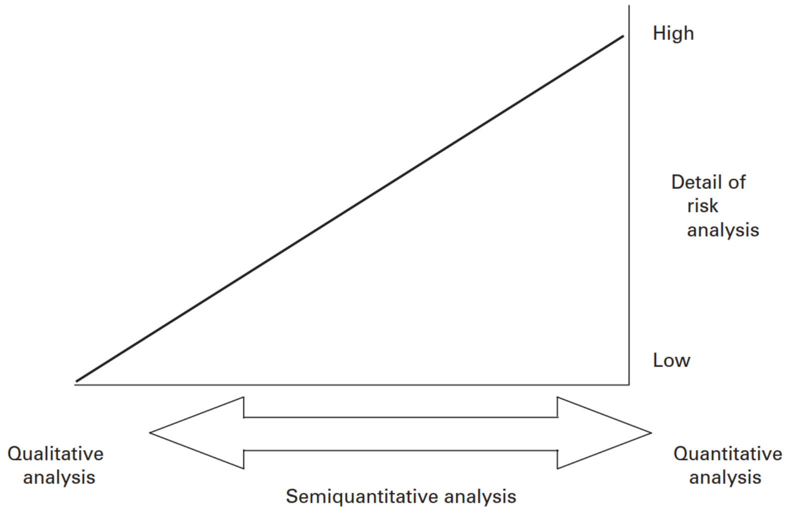


Figure 4-3 Continuum of RBI approaches [3]

4.6.1 QUALITATIVE APPROACH

The data needed for this approach is based on descriptive information using mainly engineering judgment and experience for the PoF and CoF assessment. Usually, data is given in ranges and results given in qualitative terms as high, medium and low. The benefits of this approach is the assessment can be completed quickly with no need of too much precise information and the cost of implementation it is low. However, the results are subjective and the accuracy depends on the background, expertise and commitment of the risk analysts and team members. Also, the conservatism on this type of results shall be considered for decision-making. However, these values can be expressed in qualitative terms in order for simplicity by assigning bands for PoF and CoF (risk ranks).

4.6.2 QUANTITATIVE APPROACH

The data needed for this approach is very exhaustive (design, operating practices, operating history, component reliability, human actions, inspection history, etc) in order to be able to perform numerical calculations, and usually logic models as event trees or fault trees are used. Results are typically presented as quantitative values (e.g. cost per year). The benefits of this approach is the precision of the calculation and the database created in order to perform the requested calculations. However, the need of so much detailed information brings as consequence long time implementation, high costs, needs of specific software for calculations and usually this type of approach are not finished/used.

4.6.3 SEMI-QUANTITATIVE APPROACH

This describes any approach that combines elements from the qualitative and quantitativea approaches in order to obtain the major benefits from both. Usually PoF assessment is done using a quantitative approach while CoF assessment using a qualitative approach.

4.7 RISK BASED INSPECTION PROCEDURE

The aim of this section it is to shown the tipical Risk Based Inspection process regardless of which RBI approach is applied. Figure 4-4 shows the essential elements needed to complete a RBI program. It can be seen that API, ASME and DNV uses similar philosophy [3] [7] [10].

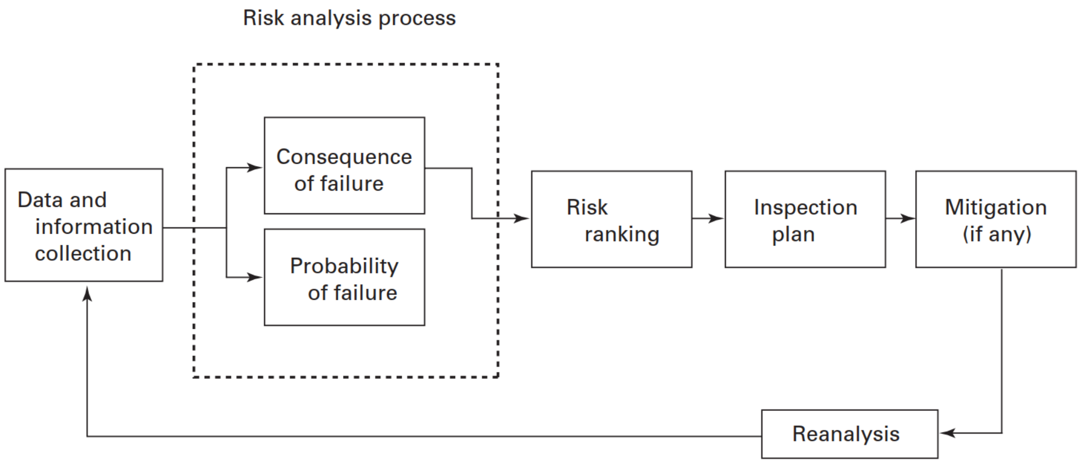


Figure 4-4 Risk Based Inspection planning process [3]

It is important to notice the RBI it is not a static approach, how Figure 4-4 shows, the results and actions obtained from the assessment and implementation must be used to feed the system and improve it. Process parameters, fluids, materials, inspection methods, etc. can change with time and so the inspection plans, these will change with time and new actions can arise or disappear. For this, it is important to review the assessment on a regular basis and perform the necessary changes

5. CUPS MECHANISM

The term Corrosion Under Pipe Supports (CUPS) describes the external corrosion of piping due to Crevice Corrosion (oxygen concentration cell) caused by water/dirt/moisture accumulation at the point of contact between the pipe and the support. Metal loss is increased by thermal variations or vibration that removes corrosion scales, and exposes metal to further corrosion. Also, acid deposits can increase the metal loss (e.g. bird excrement) [25] [27] [28].

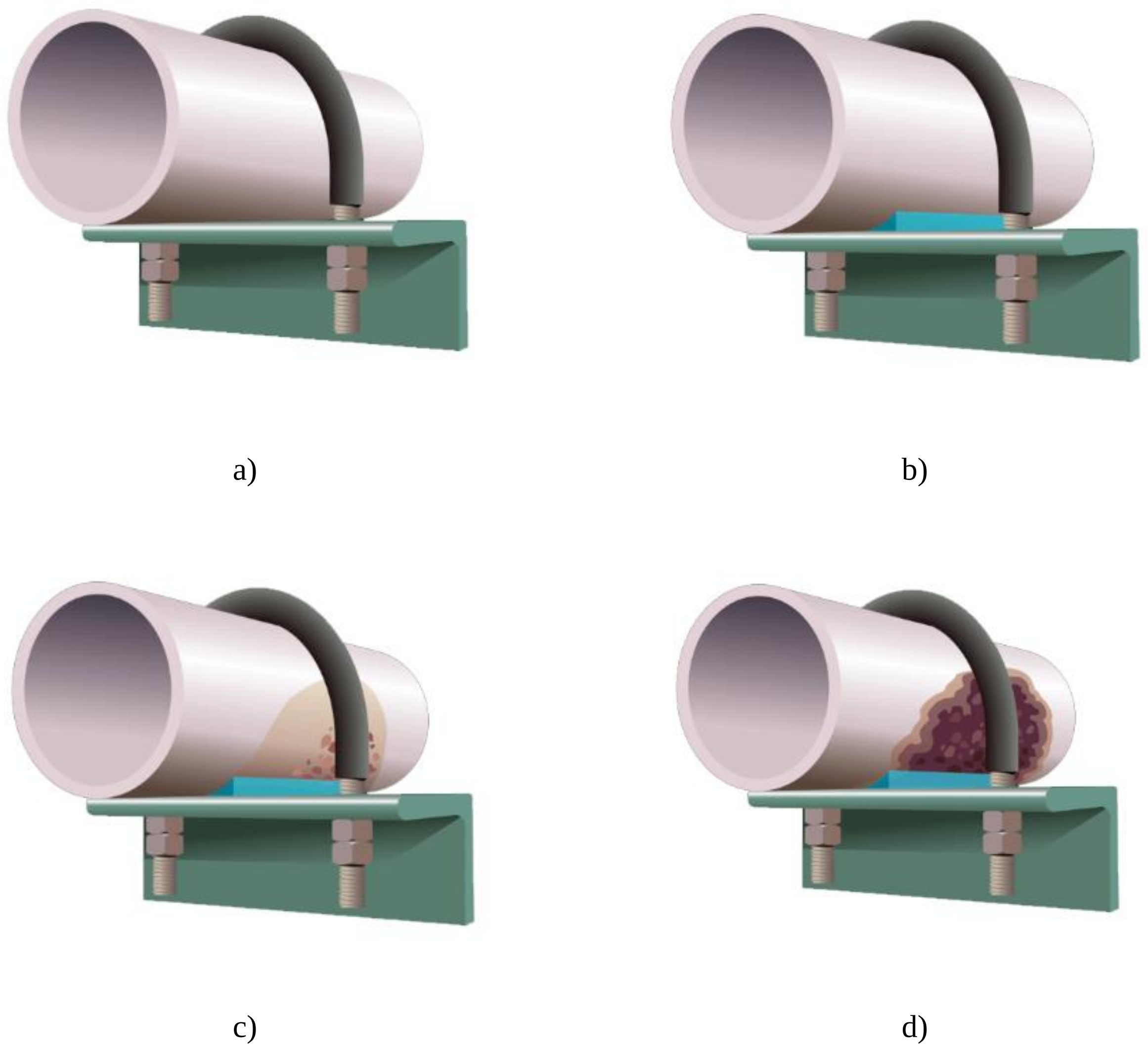


Figure 5-1 CUPS mechanism

a) ***Flat Surface:*** Piping on a flat surface has a high probability to trap water from condensation, rain, wash down, etc. and can remain there for long time depending on weather conditions.

b) ***Crevice Formation:*** The water becomes trapped in the crevice created between the pipe and the flat surface. The piping coating will start to debilitate

c) ***Corrosion Begins:*** Begin the process of softening the coating on the piping until the coating separates from the bare steel. The pattern of crevice corrosion is very recognizable as it spreads from the point of initial paint failure

d) ***Wall Loss:*** As soon as the bare steel is in contact with water the corrosion cell is formed and the crevice will grow exacerbating the problem.

5.1 TEMPERATURE AND ENVIRONMENTAL FACTOR

Temperature is a key factor since it strongly influences the kinetics of the corrosion process. Carbon steel and low alloy steel piping are susceptible to CUPS for continues or intermittent temperature range of -12°C – 175°C, while austenitic stainless steel and duplex stainless steel piping are susceptible between 50°C – 205°C [2] [5]. This is the temperature range in which the material surface could potentially be in contact with "free water" (e.g. steel surface not dry).

For insulated components, the temperature range of 100°C – 121°C is considered the most critical since free water retention is likely and the corrosion kinetics are accelerated by temperature. The corrosion rate rises with the increase of temperature to the point where it begins to evaporate. At very high temperatures, the surface will remain dry [5] [29].

Caution should be observed when applying this temperature criteria to systems operated in intermittent or cyclic service. Indeed, operating temperatures can fluctuate outside and inside the critical range (e.g. heating medium drain lines, dead-legs and piping to expansion tanks are normally not flowing and may operate at lower temperatures, within the critical range). When the temperature range is cyclic or intermittent the corrosion rate may increase.

Carbon steels / low alloy steels and stainless steels are affected by CUPS in different ways as described in the following sections. The corrosion rate in these locations is function of the external environment, pipe temperature, amount and nature of deposits and support design.

Except of extreme conditions, corrosion at pipe supports it is normally exclusive for carbon steel and low alloy steel. However, stainless steels may suffer of crevice corrosion if they are in permanent contact with wet and salty deposits. Also, Cl-SCC is possible on austenitic stainless steel at temperatures above 50°C.

5.2 CARBON AND LOW ALLOY STEEL CUPS MECHANISM

The mechanism of corrosion under pipe support of carbon and low alloy steels is a form of "oxygen corrosion" which means that the corrosion process is controlled by dissolved oxygen in the water phase, see Figure 5-2.

The CUPS process is strongly influenced by [2]:

- Presence of water at the bare material surface (continuously or intermittently)
- Temperature
- Presence of contaminants

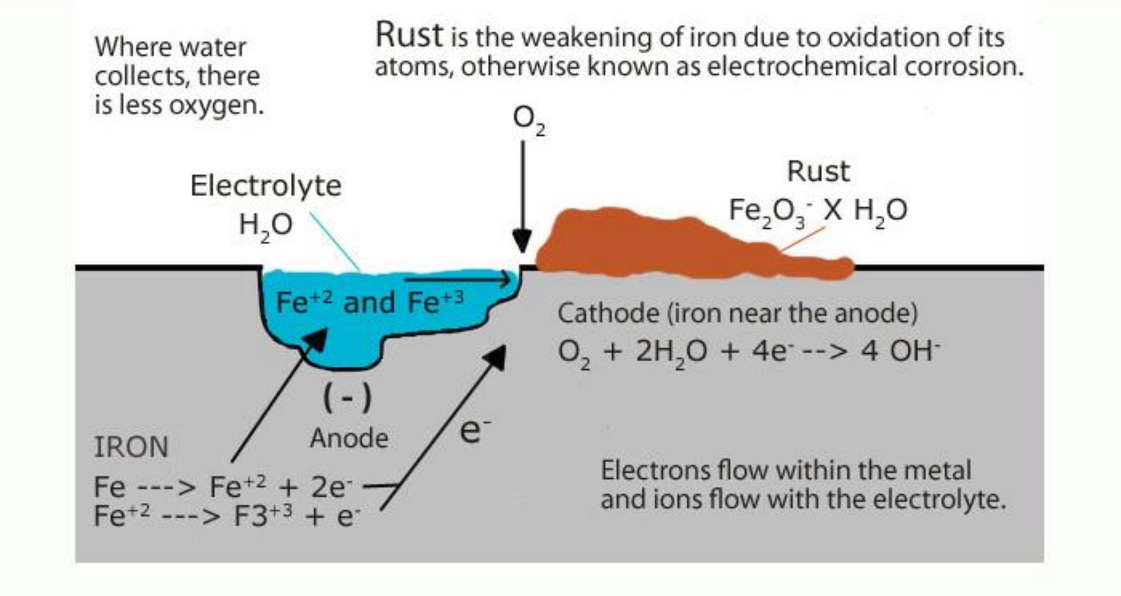


Figure 5-2 Oxygen corrosion mechanism

Rust films accelerates the corrosion process in the CUPS mechanism. An electrochemical corrosion cell is formed due to the oxygen concentration difference between the high oxygen areas at the extremity of the "rust film" and the low oxygen areas within the film itself, see Figure 5-2. The presence of chlorides can also cause a local depression in pH and further corrosion.

As corrosion rates can vary depending on the development of rust films, contaminants, temperature, wetness, piping movement, etc. it is difficult to predict the actual corrosion rate. Sitech experience shows:

- Not insulated piping a corrosion rate ≤ 0.1 mm/year
- Insulated piping a corrosion rate can vary from 0.4 to 0.9 mm/year depending site location

5.3 STAINLESS STEEL CUPS MECHANISM

Stainless Steels (e.g. Series 3xx austenitic stainless steels and duplex stainless steels) rely on a protective chromium oxide film to ensure protection against external corrosion. Once this chromium oxide film is destroyed, then highly localized corrosion can occur at the breakdown area.

Stainless Steels can suffer from external corrosion effects in the form of:

- Pitting, Crevice Corrosion
- Chloride Stress Corrosion Cracking (Cl-SCC).

As mentioned previously, the CUPS process is strongly influenced by:

- Presence of water at the bare material surface (continuously or intermittently)
- Temperature
- Presence of contaminants as Chlorides

5.3.1 PITTING AND CREVICE CORROSION

In atmospheres with chlorides presence, temperatures of 20-25°C (even lower in crevice areas) are enough to produce the corrosion process on stainless steels where coatings breakdown has occurred [2].

- 304L stainless steel is very susceptible to this form of corrosion
- 316L and Duplex stainless steels are more resistant but not immune, particularly under crevice conditions

Pitting corrosion is usually very fine and the pit depth is often difficult to see from visual inspection.

5.3.2 STRESS CORROSION CRACKING (SCC)

The key factors are similar to the ones presented for pitting and crevice corrosion.

- On austenitic (Series 3xx) and duplex stainless steels, SCC rarely occurs below 50°C
- Stresses must be present

5.4 CUPS SUSCEPTIBILITY

The susceptibility to CUPS is related to the susceptibility to water trap at the bare steel surface (equipment without coating or with coating breakdown), in combination with some other factors. The main factors contributing to CUPS are:

- Presence of water
- Piping material (carbon steel, stainless steel, etc.)
- Operating temperatures (considering intermittent or cyclic service)
- Type of support (loose, fix, U-bolt, welded, etc.)
- Type and condition of coating / painting on the steel surface
- Age of piping and coating
- Design and material of pads used
- Atmospheric condition (presence of chlorides, etc)
- Exposure to deluge testing / periodic water cleaning
- Presence of cooling water towers in the vicinity

6. COMPANIES PRESENTATION

6.1 CHEMELOT

Chemelot is a chemically oriented area of more than 800 hectares in South Limburg, Netherlands. The site is unique because of numerous elements: the central location in South Limburg, the good accessibility by rail, road, pipeline and airport, the presence of a large number of factories that are complementary, the umbrella license, the unique collaboration between factories, research and development and pilot plants. The site also offers a number of central facilities such as utilities, fire brigade, maintenance, company emergency organization, infrastructure and regulations. Approximately 8,000 people are currently working on the site [17].

Figure 6-1 Chemelot site map location

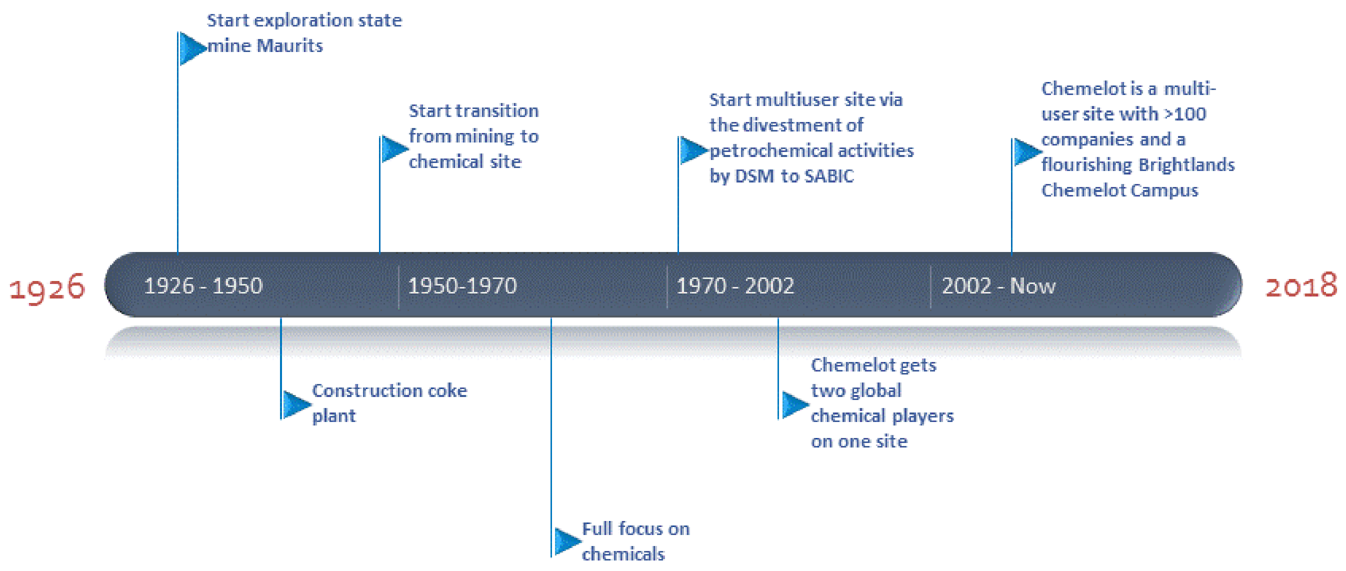


Figure 6-2 Chemlot site timeline

Its unique chemical and materials community ensures accelerated business growth through the open exchange of ideas. Chemelot has been planned around one central idea: to bring together the knowledge and skills normally found only in major organizations, and to apply these within a flexible community of small and large chemical businesses, radically changing the view of the chemical industry. A growing environment for economy and working space, in 2025 belonging to the world top of chemistry and new materials.

The combination of Industrial Park and Campus makes Chemelot rare in its kind. There are more than 100 organizations on-site and 30 new companies since 2005 such as SABIC, Arlanxeo and DSM develop sustainable products and materials in their research facilities. The Campus also houses a lively group of start-ups and (SME) companies, such as Flowid, Isobionics, Pharmacell and Xilloc. There are extensive R&D and pilot facilities for these (SME) companies.

Figure 6-3 Chemelot facts and figures

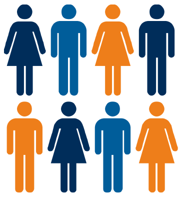
The companies on site produce plastics for the packaging and automotive industry (SABIC); safety glass for cars, trains, buses and planes (Seki); technical plastics, nylon and legoblocks (Fibrant & AnQore); synthetic rubber for cars (Arlanxeo); ammonia and fertilizers (OCI Nitrogen); melamine laminate and banknotes (OCI Nitrogen); artifical turf, plastic foils and corks (Borealis); tubes, plates, breathable film (DSM Stanyl), among other products [33].

Figure 6-4 Aerial picture of part of Chemelot site

6.2 SITECH SERVICES

Sitech Services was set up in 2008 from several DSM departments that provided on-site services. Ever since then, the team of specialists have worked closely together, using their vast knowledge and experience of the process industry to serve the best interests of customer as AnQore, Fibrant, OCI Nitrogen, Arlanxeo, Borealis and DSM among others [21].

Sitech activities focus on a number of important areas of work within the process industry as maintenance, integrity, inspection, fire brigade, asset management, etc [33].



1.000 employees

> EUR 300 millons turnover in 2017

Figure 6-5 Sitech facts and figures

6.3 BOREALIS GROUP

Borealis is a leading provider of innovative solutions in the fields of polyolefins (mainly plastic granulate in the form of pellets), base chemicals and fertilizers. The corporate head office is based in Vienna, Austria, Borealis currently employs around 6,600 people and operates in over 120 countries. The majority of Borealis' production is located in Europe, with two overseas manufacturing facilities in the United States and Brazil. It generated EUR 7.2 billion in sales revenue and a net profit of EUR 1.1 billion in 2016. Mubadala, through its holding company, owns 64% of the company, with the remaining 36% belonging to OMV, an international, integrated oil and gas company based in Vienna. Borealis provides services and products to customers around the world in collaboration with Borouge, a joint venture with the Abu Dhabi National Oil Company (ADNOC), who operates the largest petrochemical complex in the world [21].

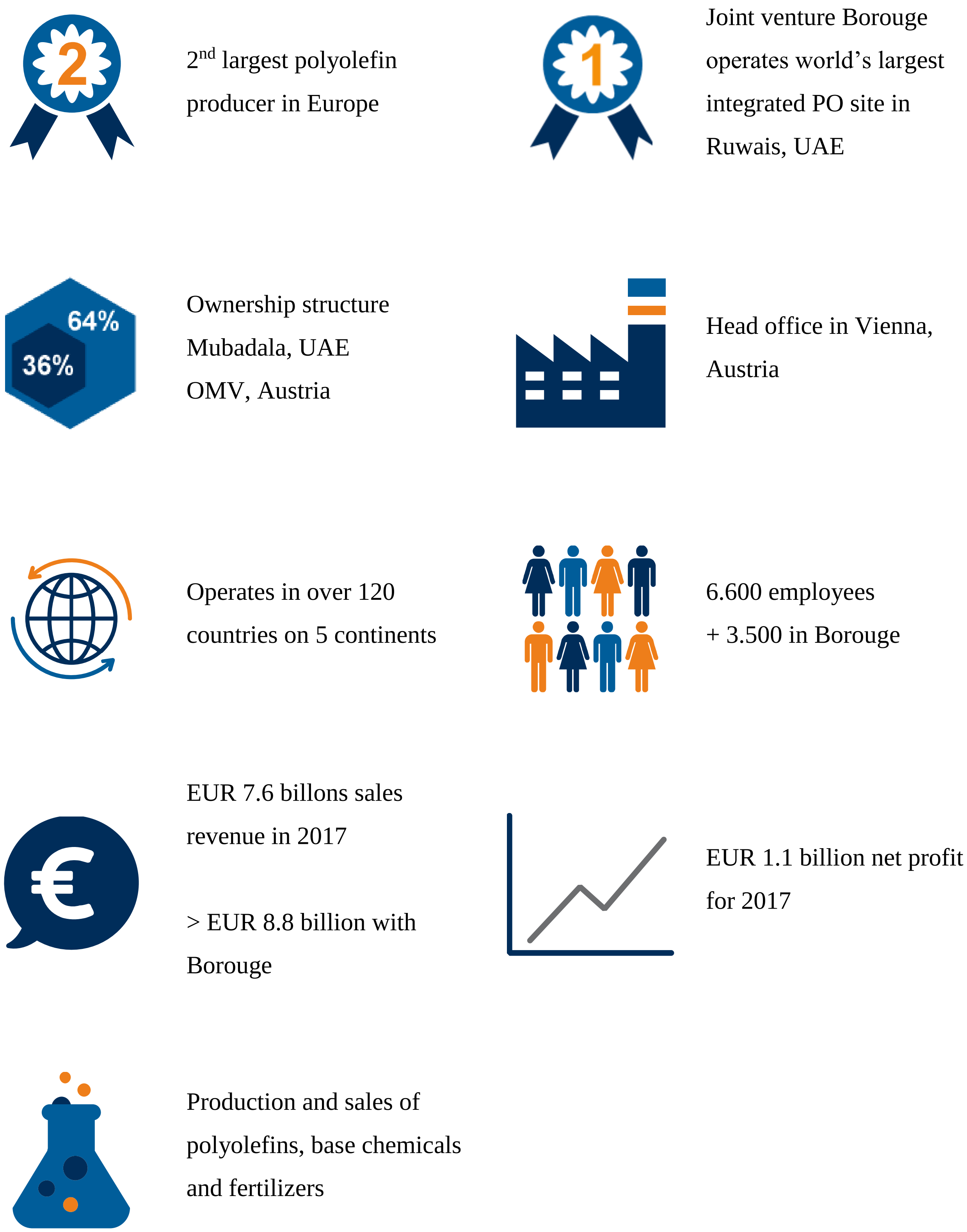


Figure 6-6 Borealis facts and figures

7. BOREALIS PLASTOMERS PLANT

7.1 HISTORY AND TIMELINE

The LD2 (Lage Druk = Low Pressure) plant was established by DSM in 1972 with the construction of Line 1, also known as Street 1. It is a solution plant based on DSM Compact™ technology (now owned by Borealis and rebranded to Borceed™). The plant was built to produce LLDPE with C3/C4 comonomer (propylene, 1-butene) with densities between 935-965 kg/m^3 with conventional Ziegler-Natta catalyst. The LLDPE was (and is still) sold under the brand name Stamylex™.

In 1981 C8 comonomer (1-octene) was introduced, lowering the density window to 910 kg/m^3 [30]. In 1987 Line 2, also known as Street 2, was built using an improved Compact™ design. Current name plate capacity is 50 KT for line 1 and 70 KT for line 2.

Figure 7-1 Borealis plastomer at Chemelot

In 1996 DSM and ExxonMobil formed a joint venture DEXPlastomers to produce plastomers in LD2 based on metallocene catalyst. C8-based plastomers with density 880-910 kg/m^3 were sold under the brand name Exact™.

In 2013 Borealis acquired the LD2 plant and the Compact™ technology from DSM and Exxon. Borealis Plastomers was formed, Exact™ was rebranded to Queo™. In 2015/215 both lines were modified to be able to produce even lower density LLDPE up to 860 kg/m^3. These low density polymers are sold as Polyolefin Elastomers (vs. plastomers). In 2016 Compact™ was rebranded to Borceed™. Figure 7-2 shows a resumed timeline of Borealis plastomer history.

Nowadays at Borealis site in Chemelot work approximately 90 employees.

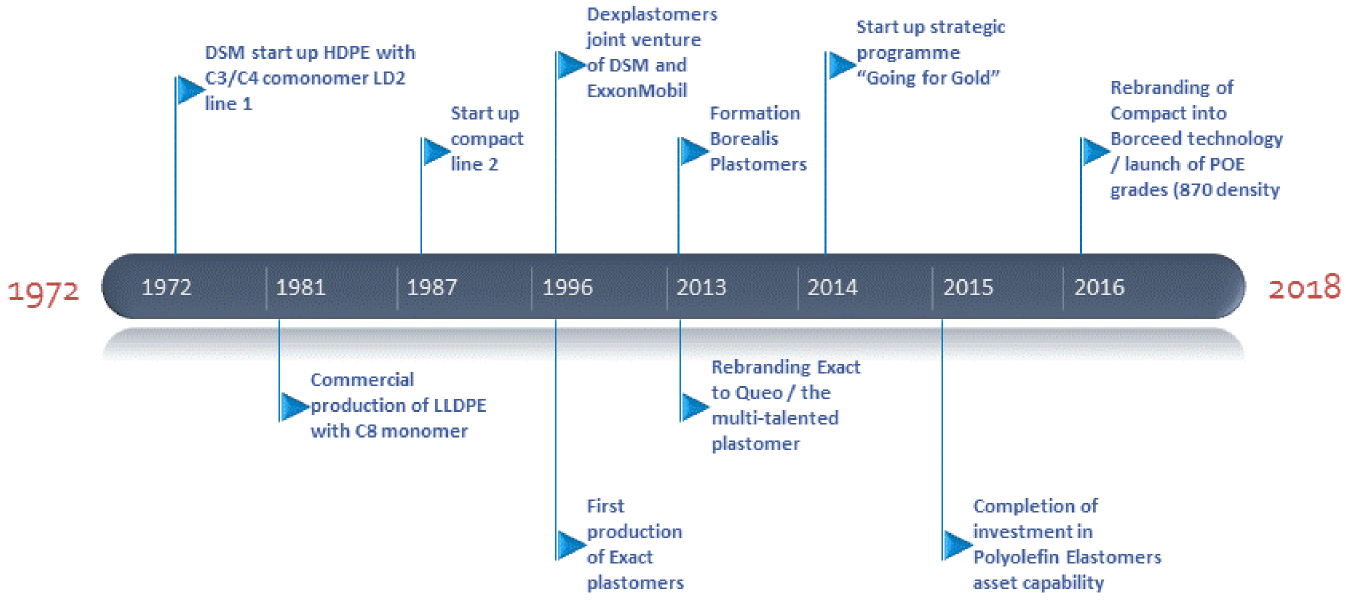


Figure 7-2 Borealis plastomer at Chemelot timeline

7.2 PRODUCTS

As mentioned previously, Borealis Plastomers produce two products families, Queo^{TM} (Metallocene based Plastomers) and Stamylex^{TM} (Linear polyethylenes).

7.2.1 QUEO^{TM}

Queo plastomers are a range of low-density ethylene copolymers made possible by combining metallocene catalyst technology with the Borceed™ solution polymerisation process. The comonomer used by Borealis plastomers is octene. As the name implies, plastomers bridge the gap between plastics and elastomers. They exhibit many of the physical properties of a rubber and combine this with the processing advantages of a thermoplastic [19].

Table 7-1 Queo products properties

			Polyolefin Elastomers		Polyolefin Plastomers			
Density	kg/m³	ISO1183	860	870	880	890	900	910
DSC Peak melting point	°C	ISO11357	40	60	75	85	95	105
Flexural modulus	Mpa	ISO178	5	10	20	40	70	130

The key attributes of Queo^{TM} in film are:

- Sealing and hottack properties for flexible packaging
- Flexibility and softness in film structures
- Mechanical properties
- Optics including low gel levels
- Cling properties




The key attributes of Queo™ in non-film are:

- Flexibility
- High filler acceptance
- Mechanical properties
- Low extractables
- PP/PE compatibility
- Wide variation of application
    - Wire and cable
    - Geoliners,, membranes
    - Flexible moulding applications
    - Artificial wine corks
    - Low temperature PP impact modification, etc.




7.2.2 STAMYLEX™

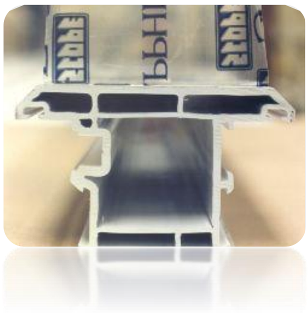
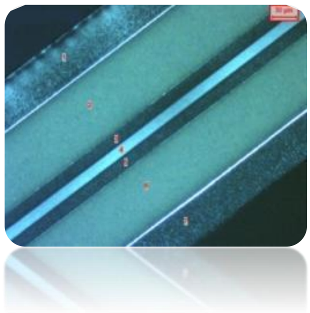
Stamylex is an octene based linear low density polyethylene produced in a solution polymerisation process using a Ziegler-Natta catalyst [20].

The key attributes of Stamylex™ in film are:

- Sealing and hot-tack properties for flexible packaging
- Mechanical properties
    - Extrusion coating
    - Cast films
    - Laminates
    - Bi-oriented shrink film
    - Speciality sealing layers
    - Medical (IV bags)

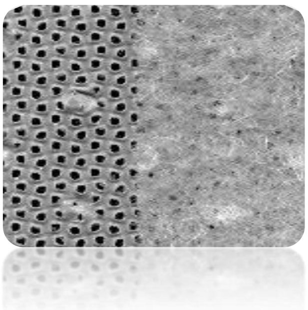
- Surface protective films
- Tie resin manufacturing, etc.



The key attributes of Stamylex™ in non-film are:

- Mechanical properties
- Flex crack resistance
- High Flow
- Low warpage
    - Masterbatches
    - Veterinay syringes
    - Flexible lids for pails
    - IM caps and closures
    - Artificial grass
    - Rotational moulding, etc.




The products manufactured by Borealis Plastomers are the basis of many valuable applications that are an intrinsic part of our daily lives. Figure 7-3 shows an approximated distribution a variety of industries and segments where Borealis products are used [31].

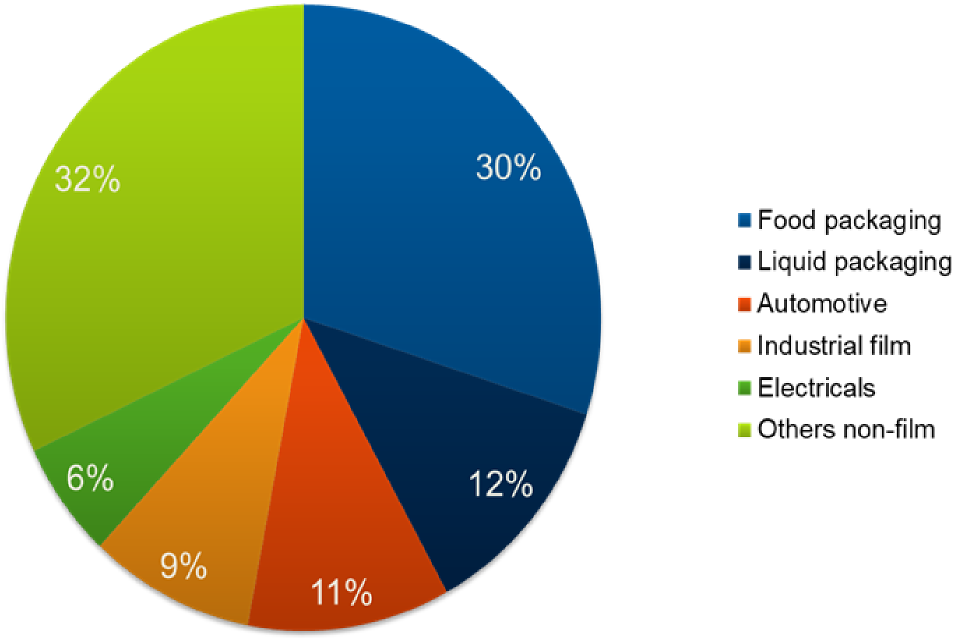


Figure 7-3 Borealis products main uses

8. INSPECTION AND MAINTENANCE STRATEGY FOR CUPS

Risk Based Inspection (RBI) methodology with a qualitative approach is the recommended inspection strategy since allows CUPS risk assessment and optimization of inspection efforts (reinforcing inspection on critical equipment / limiting inspection on non-critical equipment) [3]. Scopus and google scholar was used in order to look for different papers or normatives that helps us to face this problem. However, after finding approximately 60 hints regarding to "Risk Based Inspection" none of them provided the specific approach we were looking for. Also, several Engineers working in Oil & Gas, Refineries, Petrochemical and Chemical companies around the world were contacted in order to know how they approach; surprisely the answer was that this issue is not addressed systematically by the companies at the moment, and some of them not even taken into account. Due this lack of information, it was decided to develop or own procedure to address this problematic.

There is no need to implement any CUPS Inspection strategy for equipment permanently operated out of the range -12°C – 175°C on carbon steel and low alloy steel, and between 50°C - 205°C for austenitic stainless steel and duplex stainless steel. However, it is decided to implement this strategy to all piping supports in the plant.

The inspection & maintenance strategy overview is shown in Figure 8-1, while detailed decision tree for CUPS strategy is shown in Figure 8-2.

In order to develop our CUPS strategy flow diagram shown in Figure 8-2 we based principally in the Risk Based Inspection principles from:

- API RP 580 [3]
- API RP 581 [4]
- DNVGL RP 0002 [8]
- DNV RP F-116 [9]
- DNV RP G-101 [10]

Due company timing and top management decision, the validation of the model will be done during year 2019 when the implementation at Chemelot Site is performed. However, the perspective of this strategy was well received by Borealis worldwide experts, Sitech experts and by the presents at the EFC WP15 Conference ″Corrosion in Refinery and Petrochemical Industry″ where this strategy was presented.

8.1 INVENTORY AND REGISTRATION OF PIPE SUPPORTS

As first step, a full inventory of supports shall be done creating a tag for each support according to Borealis tagging and numbering procedure. If this kind of document is not available, it is recommended the creation of one.

The following data shall be recorded as minimum to be able to assess the CUPS risk:

- Atmospheric condition (according to ISO-9223 [11])
- Number of failures in the piping (not only related with CUPS)
- Piping material and nominal wall thickness
- Support material
- Operating temperature
- Cyclic service
- Support type
- Type of coating/painting and date of application
- Exposure to deluge testing, cooling water towers in the vicinity, etc.
- Piping history (inspection history)

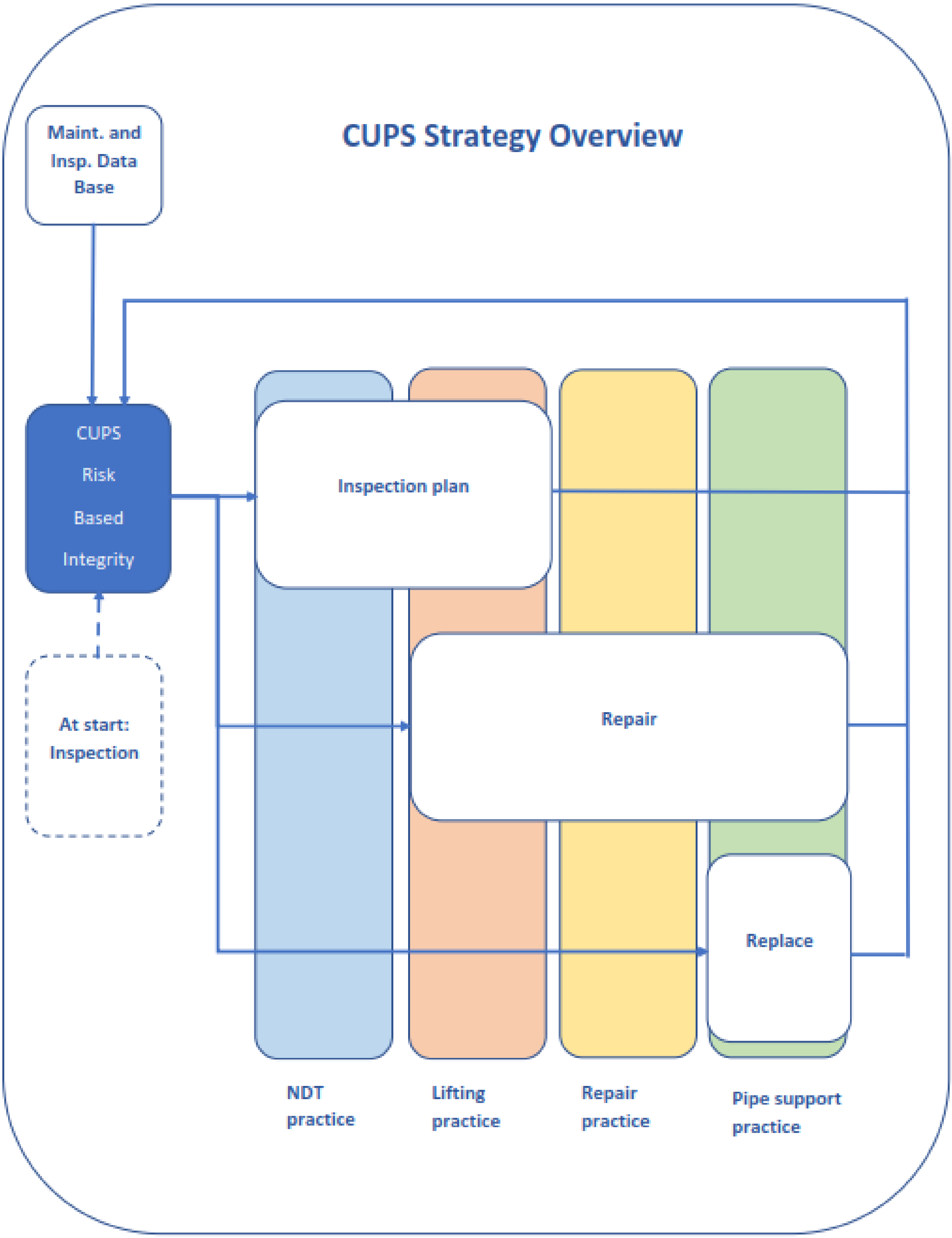


Figure 8-1 CUPS strategy overview

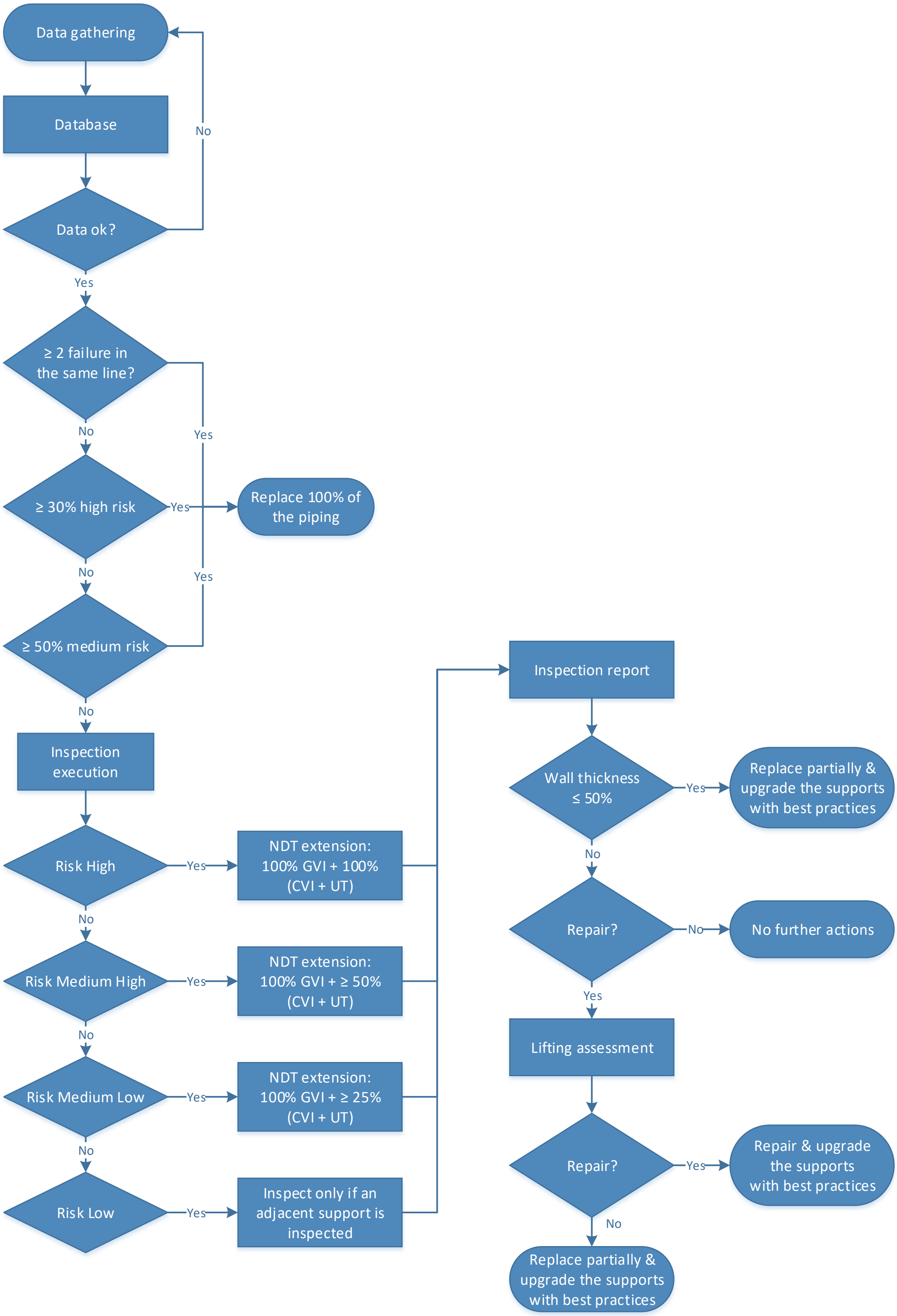


Figure 8-2 CUPS strategy flow diagram

8.2 CUPS RISK ASSESSMENT

A risk assessment procedure was developed in order to prioritize inspections, decide the inspection extension and inspection methods to be used. The risk assessment follows the same philosophy proposed by API RP 580 [3] and API RP 581 [4], where the probability and consequence of failure is assessed.

This document describes the procedure to apply a qualitative approach of the risk. This analysis uses broad categorizations for probabilities and consequences of failure, using primarily engineering judgment and experience as the basis for the determination of probabilities and consequences of failure. The results of qualitative risk analyses are dependent on the background and expertise of the analysts and the objectives of the analysis.

This approach provides a systematic way to screen for risk, identify areas of potential concern, and develop a prioritized list for more in depth inspection or analysis. Develop a risk ranking measure to be used for evaluating separately the PoF and the potential CoF. These two values are then combined to estimate the risk of failure. This approach requires data inputs based on descriptive information using engineering judgment and experience as the basis for the analysis of PoF and CoF. Inputs are often given in data ranges instead of discrete values.

Results are typically given in qualitative terms such as high, medium, and low, although numerical values may also be associated with these categories. The value of this type of analysis is that enables completion of a risk assessment in the absence of detailed quantitative data. The accuracy of results from a qualitative analysis is dependent on the background and expertise of the risk analysts and team members.

The qualitative approach may be used for any aspect of inspection plan development; however, the conservatism generally inherent in the more qualitative approach should be considered when making final mitigation and inspection plan decisions.

The following sections shows the adopted risk matrix, and the calculations to assign a probability and consequence ranking to each piping support.

8.2.1 RISK MATRIX

Presenting the results in a risk matrix is an effective way of showing the distribution of risks without numerical values. This facilitate the risk understanding of every item for all people in the organization, from inspectors to managers. In the risk matrix, the consequence and probability categories are arranged such that the highest risk components are toward the upper right-hand corner. Figure 8-3 shows the risk matrix proposed by API RP 581 as an example of a risk matrix [4]. However, this procedure can be used with any corporate risk matrix.

Risk categories (i.e. High, Medium High, Medium, and Low) are assigned to the boxes on the risk matrix. In API RP 581 [4] the risk categories are asymmetrical to indicate that the consequence category is given higher weighting than the probability category.

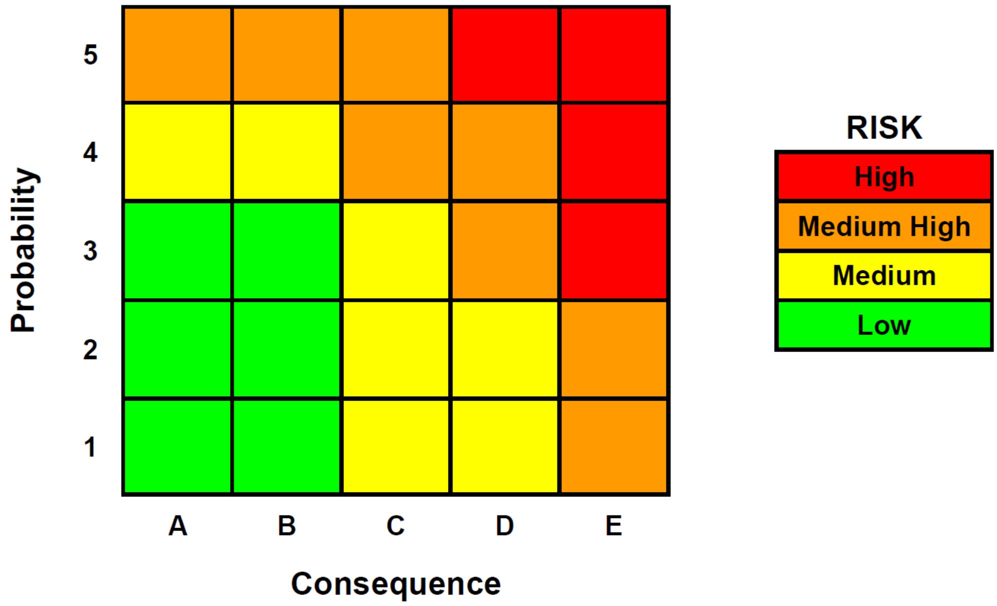


Figure 8-3 API RP 581 risk matrix [4]

8.2.2 PROBABILITY ASSESSMENT

The probability of failure analysis is performed to estimate the likelihood of a specific adverse consequence resulting from a loss of containment that occurs due to a damage mechanism(s). The analysis should be credible, repeatable and documented. This section provides guidance only on determining the PoF.

The PoF is determined by the calculation of a "Probability Factor", consisting on the multiplication of 9 factors, which each of them affects the corrosion mechanism. For each factor it was assigned a probability ranking (from 1 to 5) and a "probability value" which is used for calculation purposes. These values were assigned gathering bibliographic information, Sitech and Borealis employees experience and engineering judgment in order to weight each factor.

$$\begin{matrix} Probability \\ factor \end{matrix} = P_{AC} \times P_{PF} \times P_{PM} \times P_{WT} \times P_{T} \times P_{YSP} \times P_{YSC} \times P_{ST} \times P_{Pad.M}$$

Where the different probabilities values represent,

P_{AC}	=	Atmospheric condition	P_{YSP}	=	Years in service (piping)
P_{PF}	=	Piping failure	P_{YSC}	=	Years in service (coating)
P_{PM}	=	Piping material	P_{ST}	=	Support type
P_{WT}	=	Piping wall thickness	$P_{Pad.M}$	=	Pad material
P_{T}	=	Process temperature			

When the probability factor is calculated the following conversion table is used to return to the probability ranking to be used in the risk matrix

Table 8-1 Probability factor value conversion

Probability Ranking	Probability Factor Value
5	> 15
4	8 – ≤ 15
3	6 – ≤ 8
2	2 – ≤ 6
1	≤ 2

8.2.2.1 ATMOSPHERIC CONDITION

In order to evaluate the effect of the environment were the piping is immersed, standard ISO-9223 [11] have been used to correlate the corrosivity categories shown in the standard with a probability of failure.

Table 8-2 Prob. Ranking: Atmospheric condition

Prob. Ranking	Prob. Value	Criteria
5	1.4	Tropical and subtropical zone (very high time of wetness), atmospheric environment with very high pollution (SO_2 > 250µg/m^3) including accompanying and production factors and/or strong effect of chlorides, e.g. extreme industrial areas, coastal and offshore areas, occasional contact with salt spray. (similar category C5)
4	1.3	Temperate and subtropical zone, atmospheric environment with very high pollution (SO_2 : 90µg/m^3 to 250µg/m^3) and/or significant effect of chlorides, e.g. industrial areas, coastal areas, sheltered positions on coastline. (similar category C4)
3	1.2	Temperate zone, atmospheric environment with medium pollution (SO_2 : 5µg/m^3 to 30µg/m^3) or some effect of chlorides, e.g. urban areas, coastal areas with low deposition of chlorides. Subtropical and tropical zone, atmosphere with low pollution. (similar category C3)
2	1.1	Temperate zone, atmospheric environment with low pollution (SO_2 < 5µg/m^3), e.g. rural areas, small towns. Dry or cold zone, atmospheric environment with short time of wetness, e.g. deserts, subarctic area. (similar category C2)
1	1	Dry or cold zone, atmospheric environment with very low pollution and time of wetness, e.g. certain deserts, central artic / Antarctica (similar category C1)

8.2.2.2 PIPING FAILURE

In order to assess the piping failure, the history of the piping shall be investigated. It must be noticed that for this factor any failure shall be taking into consideration, even the ones not related with corrosion under pipe support. The aim to take into account all failures is to decide if the piping shall be replaced together with the upgrade of the piping supports, instead of spending money and time on further assessment, NDT (including piping lifting) and piping supports upgrade. The timeframe to take into account the number of failures for this assessment is five years.

Table 8-3 Prob. Ranking: piping failure

Prob. Ranking	Prob. Value	Criteria
5	4	≥ 2 times
4	--	--
3	2	1 times
2	--	--
1	1	0

8.2.2.3 PIPING MATERIAL

It varies depending on the construction piping material, the type of corrosion mechanism, temperature susceptibility and inspection methods.

Table 8-4 Prob. Ranking: piping material

Prob. Ranking	Prob. Value	Criteria
5	1.4	Carbon steel and low alloy steel
4	1.3	--
3	1.2	--
2	1.1	Austenitic Stainless Steel
1	1	Duplex Stainless Steel

8.2.2.4 PIPING WALL THICKNESS

The failure of the piping will depend mainly of the wall thickness, at equal corrosion rate bigger is the probability of failure when smaller the wall thickness.

Table 8-5 Prob. Ranking: piping wall thickness

Prob. Ranking	Prob. Value	Criteria
5	1.4	≤ 5mm
4	1.3	5mm – ≤ 8mm
3	1.2	8mm – ≤ 12mm
2	1.1	12mm – ≤ 18mm
1	1	> 18mm

8.2.2.5 TEMPERATURE

Due corrosion mechanism are affected by temperature differently depending of the piping material, 2 different tables are shown below in order to evaluate the probability of failure for carbon and low alloy steel, and Austenitic and duplex stainless steel. Also, if the temperature is steady or cyclic affects differently this is shown in the respective tables.

Table 8-6 Prob. Ranking: temperature for carbon steel and low alloy steels

Prob. Ranking	Prob. Value	Criteria Steady Service	Criteria Cyclic Service
5	1.4	--	60°C - 121°C
4	1.3	60°C - 121°C	-12°C – 60°C
3	1.2	-12°C – 60°C	121°C - 175°C
2	1.1	121°C - 175°C	--
1	1	< -12°C or > 175°C	< -12°C or > 175°C

Table 8-7 Prob. Ranking: temperature for stainless steel and duplex stainless steel

Prob. Ranking	Prob. Value	Criteria Steady Service	Criteria Cyclic Service
5	1.4	--	50°C - 121°C
4	1.3	50°C - 121°C	121°C - 205°C
3	1.2	121°C - 205°C	--
2	1.1	-12°C - 50°C	-12°C - 50°C
1	1	< -12°C or > 205°C	< -12°C or > 205°C

8.2.2.6 YEARS IN SERVICE (PIPING)

In order to evaluate the effect of the years in service on the piping.

Table 8-8 Prob. Ranking: piping years in service

Prob. Ranking	Prob. Value	Criteria
5	1.4	> 30 years
4	1.2	25 – ≤ 30 years
3	1.15	15 – ≤ 25 years
2	1.1	5 – ≤ 15 years
1	1	≤ 5 years

8.2.2.7 YEARS IN SERVICE (COATING)

In order to evaluate the status of the coating system.

Table 8-9 Prob. Ranking: coating years in service

Prob. Ranking	Prob. Value	Criteria
5	1.4	> 15 years / Condition don’t known
4	1.3	10 – ≤ 15 years
3	1.2	5 – ≤ 10 years
2	1.1	3 – ≤ 5 years
1	1	≤ 3 years

8.2.2.8 SUPPORT TYPE

Table 8-10 Prob. Ranking: support type

Prob. Ranking	Prob. Value	Criteria
5	1.4	Cold layup (concrete)
4	1.3	Cold layup / U-bolt / special supports not protected without underlay protection (metal) / welded guides
3	1.2	--
2	1.1	Underlaying parts with U-bolt / cold layup / special supports protected
1	1	Standard pipe shoe

8.2.2.9 PAD MATERIAL

Pads have been used for a long time with a misconception of the materials used due lack of research on the corrosion mechanism present. The belief in using a rubber pad to avoid the formation of a galvanic cell between the pipe and the metal support was the main misconception. However, rubber created a bigger problem than they are intended to solve. Rubber has very low compressive strength and breaks down easily, and under pressure, the pad will adopt a curved shape creating a bigger crevice than if the pipe were sitting directly to the steel support, trapping more water and holding it for longer periods. Also, FRP / Fiberglass pads are promoted as the ideal "wear pad" solution for protecting the pipe from the damage caused by pipe movement. This is another costly misconception. While there is a need to protect a metal pipe from rubbing against a metal support, using a curved fiberglass pad to cover a large section of the pipeline, creates a substantially larger crevice than if the pipe were sitting directly on the steel support [22] [23] [24].

Table 8-11 Prob. Ranking: pad material

Prob. Ranking	Prob. Value	Criteria
5	1.4	No pad, open cellular pads
4	1.3	Rubber (closed cellular pads), FRP
3	1.2	Wood
2	1.1	PTFE (strip), Fiberglass cloth
1	1	Plastic with convex shape (PTFE, PFA, PEEK)

Note: if asbestos is fund, work must be stopped and must be informed before to continue with the work.

8.2.3 CONSEQUENCE ASSESSMENT

The consequence analysis provides discrimination between piping items on the basis of the significance of a potential failure. The consequence analysis should be a repeatable, simplified, credible estimate of what might be expected to happen if a failure were to occur in the piping item being assessed. The consequence of loss of containment is generally evaluated as loss of fluid to the external environment. The CoF analysis should be performed to estimate the consequences that occur due to a failure mode typically resulting from an identified damage mechanism(s) [3]. Consequence should typically be categorized as:

a) Safety and health impacts
b) Environmental impacts
c) Economic impacts

An integrity engineer will normally manage risk by managing the PoF with inspection and maintenance planning. They will not normally have much ability to modify the CoF [3].

Similar to what was proposed for the PoF assessment, a qualitative approach is used in this document to calculate the CoF. On the basis of expert knowledge and experience, the CoF (safety, health, environmental and financial impacts) can be estimated for each individual piping. For a qualitative method, a consequence category (such as "A" through "E") is typically assigned, and it may be appropriate to associate a numerical value with each consequence category.

Different types of consequences may be described best by different measures. The following provide the units of measure of consequences that are used in this procedure.

- ***Safety***

Safety consequences are often expressed as a numerical value or characterized by a consequence category associated with the severity of potential injuries that may result from an undesirable event. For example, safety consequences could be expressed based on the severity of an injury (e.g. fatality, serious injury, medical treatment, first aid) or expressed as a category linked to the injury severity (e.g. A through E).

- ***Environment***

A common unit of measure for environmental damage is not available in the current technology, making environmental consequences difficult to assess. The typical parameters used that provide an indirect measure of the degree of environmental damage are:

a) Acres of land affected per year;
b) Miles of shoreline affected per year;
c) Number of biological or human-use resources consumed;
d) The portrayal of environmental damage almost invariably leads to the use of cost, in terms of dollars per year, for the loss and restoration of environmental resources.

- ***Cost***

Cost is commonly used as an indicator of potential consequences. Consequences may be expressed in relative monetary units (e.g. Euros) to the maximum extent practical with an understanding that the numbers are typically not absolute. In this procedure only production loss due to rate reduction or downtime is taken into consideration.

Once identified each factor, safety, environment and cost, the CoF is taken from the maximum value of these 3 factors and assigned a consequence from A through E.

$$Consequence\ Ranking = max[C_S\ , C_E\ , C_B]$$

Where the different consequences values represent:

C_S	=	Safety
C_E	=	Environment
C_B	=	Business loss

It is recommended to use the consequence assessment from the RBI implemented in the plant. Usually the pipings are clustered in piping groups which they will have the similar corrosion mechanism and consequence of failure. However, if this kind of assessment is not in place, a simple qualitative approach to evaluate the CoF can be based in the NFPA diamond (see Appendix I: NFPA Diamond) of the fluid transported by the piping, plus adding a factor for business loss (only production loss due to rate reduction or downtime is taken into account). The consequence ranking (from "A" through "E") is determined by taking the maximum value of the 4 factors as shown below:

$$Consequence\ Ranking = max[C_F\ , C_H\ , C_R, C_B\ ]$$

Where the different consequences values represent,

C_F	=	Flammability (red)
C_H	=	Health (blue)
C_R	=	Reactivity (yellow)
C_B	=	Bussiness loss

Table 8-12 Consequence ranking based in the NFPA diamond

Consequence Ranking	Flammability (red)	Health (blue)	Reactivity (yellow)	Business Loss
E	4	4	4	> 5 M€
D	3	3	3	1 – 5 M€
C	2	2	2	0.1 – 1 M€
B	1	1	1	10 – 100 K€
A	0	0	0	< 10 K€

Due to the many different cases, the evaluation of the special hazards (white background) is recommended to assess it case by case and assign the correspondent risk ranking according to experience and company policy.

Note: *As mentioned previously, this CoF assessment using NFPA diamond shall be only used for the purpose to have a quick qualitative evaluation of the consequence of failure for CUPS when a proper CoF is not in place, and it is not intended to be the consequence assessment to be used in the plant for long term.*

8.3 REPLACEMENT ASSESSMENT

Piping replacement, totally or partially, may be performed and in order to evaluate what shall be done, a procedure linked to the history of the piping and risk value of the piping supports for each line was developed and it is shown in Figure 8-2.

The aim of this section is to avoid spending time and money on data gathering, risk assessment and inspection (build scaffolding, lift pipes, NDT personnel, etc) on piping with advanced corrosion or with high risk value, choosing for replacing in order to reduce costs, downtime, and mainly have a considerable reduction in the risk value by minimizing the probability of failure.

The main points to have a full line replacement are:

- 2 or more incidents in the same line, related or not to piping supports, or
- 30% or more of the piping support locations with a risk value equal to “High”, or
- 50% or more of the piping support locations with a risk value equal to “Medium High”

To have as minimum partial piping replacement the main point is:

- Remaining wall thickness < 50% of the nominal thickness

For other cases, integrity or piping engineer shall perform an assessment case by case and advice if replacement, completely or partially, repair or continue in operation as it is.

8.4 CUPS INSPECTION

The Inspection & Maintenance Strategy for CUPS is based on the combination of the following periodic tasks:

- General visual inspection (GVI) / close visual inspection (CVI) for detection of damaged coating, corrosion areas, missing supports, water trapped, presence of pads, etc.
- NDT, usually UT for carbon steel piping and MT for stainless steel piping, used as an option in order to optimize inspection intervals.

The technician in charge of visual examination and/or NDT method shall possess at least valid ISO-9712 [12] level 2 certificate in the relevant category, or equivalent accepted by CPY. The Inspector shall be, preferentially, experienced in carrying out visual inspection of pressure systems and structures. He/she shall have knowledge of vessel and piping construction techniques and codes and be able to assess pressure systems as a whole. He/she must be familiar with recognition and mitigation of corrosion mechanisms and mechanical deterioration of wide range of process equipment. The inspector shall also have knowledge of coating systems and issues related to coating, inspection and maintenance. Also, the inspector shall have the awareness of the possibility to have CUx degradation mechanism. Only when the awareness is there, the inspector will always search for it in a dedicated way.

Personnel responsible for NDT activities shall hold a valid ISO-9712 level 3 certificate in the relevant category.

8.4.1 GENERAL & CLOSE VISUAL INSPECTION

Visual examination by qualified piping inspectors or piping engineers is key. The objective is to detect any damaged piping related with its supports and the piping & coating conditions around it. When corrosion product build up or other debris is noted at pipe support contact areas, it may be necessary to lift the pipe off such supports for thorough inspection. When lifting piping that is in operation, extra care should be exercised and consultation with a knowledgeable engineer may be necessary [1]. Based on the support type/configuration, screening techniques such as guided wave testing/EMAT or Lamb-wave inspections can be used to locate areas of interest for follow-up inspection using more quantitative NDT methods, see Section 8.4.2.

External inspections shall include surveys for the condition of piping hangers and supports. Instances of cracked or broken hangers, "bottoming out" of spring supports, support shoes displaced from support members, or other improper restraint conditions shall be reported and corrected. Vertical support dummy legs also shall be checked to confirm that they are not filled with water that is causing external corrosion of the pressure piping or internal corrosion of the support leg. Horizontal support dummy legs also shall be checked to determine that slight displacements from horizontal are not causing moisture traps against the external surface of active piping components indicates

The following damage or anomalies will be looked for and recorded for corrective action :

- Deterioration of protective coatings or fireproofing
- Evidence of corrosion, especially at or near the foundation attachments
- Piping deformation/distortion
- General physical damage
- Movement or deterioration of concrete footings
- Failure or loosening of foundation bolts
- Insecure attachment of brackets and beams to the support
- Restricted operation of pipe rollers or slide plates
- Insecure attachment or improper adjustment of pipe hangers
- Broken or defective pipe anchors

- Wet piping or water pooling at low points
- Piping support (if it is supported or not)
- More than one type of support?
- Pad material and condition

Note: If used, spring hanger loads should be checked under both cold and hot conditions, and the readings obtained should be checked against the original cold and hot readings. Improper spring support settings can cause excessive pipe loads on rotating equipment that can result in misalignment. Other factors such as differential settlement and creep can make alternate settings necessary [1].

If any finding, this shall be properly documented with pictures and location marking in the correspondent isometric for further assessment and follow up. If isometric is not available, an updated isometric must be performed or as minimum a proper sketch

Figure 8-4 General and close visual inspection example

8.4.2 NON DESTRUCTIVE TESTING

As pipe support corrosion is typically a hidden threat, it is not always feasible to perform a proper visual examination. Lifting the pipe from the support for inspection is not ideal due to increased risk of product release and associated health, safety and environmental risks. Therefore, NDT techniques are necessary to quantify the corrosion detected by visual inspection or to inspect areas where visual inspection is not enough.

NDT techniques are considered for Carbon Steel piping only and not for stainless steel piping (CUPS effects on stainless steel, such as pitting or stress corrosion cracking, are very localized resulting in a poor probability of detection by NDT).

The objective is to determinate the remaining wall thickness of the piping in contact with the support in order to know the corrosion rate, evaluate their fitness for service and optimize the inspection intervals.

Nowadays, several companies on the market offers different inspection techniques as radiography, ultrasound, and from manual to automated scan systems for detecting and sizing corrosion under pipe supports including pitting.

Note: Users of screening techniques should be aware of the possibility that some of those techniques may miss significant localized corrosion

Table 8-13 summarizes the main NDT methods applicable to CUPS, highlighting for each technique advantages and limitations.

Table 8-13 NDT methods for CUPS

NDT Technique	Application	Advantages	Limitations
Guided Waves (UT)	Piping ≥ 1”ϕ	Dry inspection. EMAT does not require couplant, which makes it very well suited for inspection of very hot and very cold parts, and automatization Less sensitive to surface condition. EMAT can inspect through coatings and aren’t affected by pollutants, oxidation, or roughness Easier sensor deployment. Snell’s law of refraction does not apply, and the sensor angle does not affect the direction of propagation EMAT can generate shear waves with horizontal polarization (SH waves) without high mechanical pressure or low-density couplants that impede scanning of the part	Not reliable for Pitting and SCC of stainless steel Confidence in detecting metal loss depends on corrosion profile (lower probability of detection for smooth progressive thinning and for longitudinal defects) Not reliable for defect sizing (does not give actual remaining wall thickness): Metal loss estimated as cross section loss (%). Detection threshold : 5% of the total wall cross section Effective for temp. < 60°C
Real Time Radiography	Piping ≤ 8” ϕ	Low source of radiation allows for safe operation without disrupting surrounding work Inspector can use the real time display	Only a screening tool, can’t get accurate wall loss measurements and requires adequate clearance to scan 100% of desired area. Usually piping support does not allow to perform this type of inspection Use of radiation

NDT Technique	Application	Advantages	Limitations
Profile Radiography	Piping ≤ 8” ϕ	Not only a screening tool but can also produce accurate measurements of wall loss Used in conjunction with RTR will result in high confidence levels of inspection Can take profile at multiple different angles to catch area of interest	Requires adequate clearance to scan 100% of desired area. Usually piping support geometry does not allow to perform this type of inspection Time consuming Restricted to max. NPS 6”/8” Use of radiation

Actually, the most used technique is the guided waves using EMAT technology (Electro Magnetic Acoustic Transducers), which is capable of rapidly scanning, detecting and sizing anomalies on inner and outer surfaces of a piping, especially at pipe-to-support interfaces. The EMAT probe generates the sound waves, in the part inspected instead of the transducer, and receives them back via an electro-magnetic mechanism without making direct contact with the metal surface, therefore no couplant is needed.

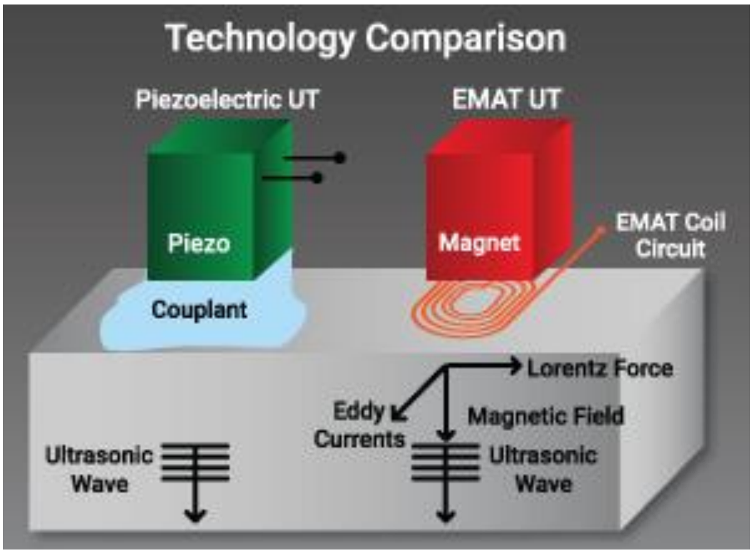


Figure 8-5 EMAT and piezoelectrict UT comparison

8.4.2.1 EMAT COMPANIES PROVIDERS

One of the main goals while this procedure was in development, was to check different companies that provides this NDT services and compare them to conclude which company is the most suitable to be used for our needs. In order to accomplish this the next steps where followed:

1) Internet research and sharing information/experiences with colleagues (internal and external)
2) Select 3 or 4 companies and contact them
3) Invite the companies, individually, for a meeting and to perform the inspection in some real cases preselected by Sitech
4) Evaluation of results, costs, working procedure, etc
5) Selection of the company to provide us the NDT service

The NDT companies consulted were:

- ***ApplusRTD:*** After several mails and contacts the service provided decided that they cant fulfill our needs and did not come to perform the inspection test

- ***Rosen:*** As outcome, they can only provide the location of the area where the wall thickness is reduced, but they can’t provide with and estimated wall thickness value. Also, they need to remove the upper part of the support to perform the inspection.

- ***Verkade NDT Services:*** They where able to provide the area where the wall thickness is reduced with an approximated value of the reduction shown in % compared with the nominal thickness or with a near thickness measurement. Their technique was possible to execute it without the need to remove the piping support and the maximum metal temperature it is 60°C. Also, their working procedure was very well accepted by Sitech and Borealis.

8.4.2.2 EMAT INSPECTION METHOD

The inspection is based on ultrasonic testing and the principle is as follow; one probe sends a sound pulse through the material, another probe receives it. This makes the signal visible on the screen of ultrasonic equipment and adjusts it to a certain screen height.

The following drawings show one situation without corrosion, on the left, and with corrosion on the right. Due to the corrosion the signal is more spread or even stopped in case of heavy corrosion, and by comparing with the signal of the material next to the support, it is possible to make a statement about the presence of corrosion, and how much material is approximately left.

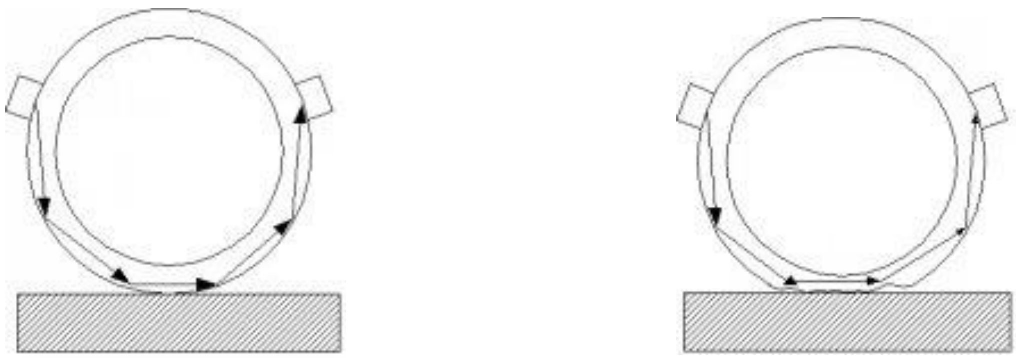


Figure 8-6 EMAT inspection without piping clamp

Also, this technique can be used to perform inspections where clamps or U-bolt are found. This drawing shows the investigation of the piping underneath pipe clamps. The principle of investigation is the same as in the previous one, only now the signal is sent in longitudinal direction, instead of in circumferential direction.

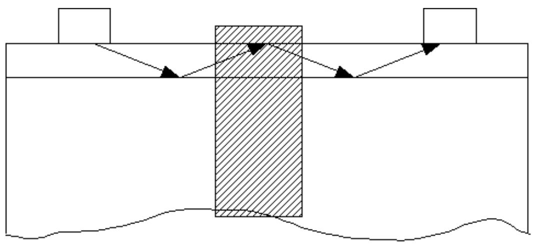


Figure 8-7 EMAT inspection with piping clamp

The principle of detecting the corrosion is very simple. The execution of the investigation and the interpretation of the detected results are much more difficult and can be influenced by factors like internal corrosion and inclusions. Tools and Range of Inspection:

- Inspection can be made until a surface temperature of 60°C.
- It is possible to inspect pipes with the diameters from 2” to 48” (when the pipe is lying on supports, depending of the surface condition and permeability of the coating).
- Pipes supported by the pipe clamp can be inspected from a diameter of 2” and above.
- The width of the clamp should have a maximum of 300mm and a maximum height of 200mm above the surface.
- The distance between the pipes should be at least 100mm.

9. CUPS PREVENTION

In order to prevent the CUPS, it is required to know the root causes of the corrosion and figure out how to avoid it in a practical application. The main problem for CUPS is the water accumulation between the pipe support and the piping [22]. Therefore:

- The crevices at the pipe surface and their ability to trap water must be eliminated.
- As a secondary concern, metal-to-metal contact should be eliminated in order to avoid possible galvanic corrosion.
- The solution should allow easy maintenance and inspection of the pipe at the support location.
- The system must provide complete support to the piping system.
- It must be applicable to new construction and retrofits, and should not require hot work to install

9.1 HALF ROUND, HIGH-STRENGTH THERMOPLASTIC

The most advanced solution found nowadays in the market is the half round, high-strength thermoplastic configuration which minimizes the crevice at the pipe and avoids water accumulation. The standoff provided allows easy inspection and maintenance at the support. The metal-to-metal contact is eliminated, and if used with an insulated bolt, the pipe can be totally isolated from the support structure [22].

The half round thermoplastic from I-Rod™ seems to be the most suitable material for this application. It is a special type of plastic with a high compressive strength and very low creep over time, with a design life up to 20 years [28]. This solution it is planned to be implemented by Borealis and Sitech for testing during Q3/Q4 of 2018.

Also, to minimize the crevice on saddle clamps supports, Grinnell clamps and pipe shoes, I-Rod™ Clips snaps into the inside diameter of the support, providing a low-profile standoff allowing ventilation and drainage that prevents water accumulation (see Figure 9-1).

Figure 9-1 Half round high-strength thermoplastic

Figure 9-2 Half round high-strength thermoplastic producing deformation in a pipe

A special consideration must have when half round high-strength thermoplastic or clips are used due the load points are considerably reduced. Piping with thin walls, filled with liquid and medium/big diameter are susceptible to deformation due the high level of local stresses. Therefore, it is recommended to perform stress calculations before taking the decision to use this type of solution. Figure 9-2 shows a real case.

9.2 COMPOSITE WRAPPING

Nowadays several companies offer various composite repair solutions to ensure the repair of pipes, pressure vessels, etc. suitable for non-leaking defects which can be implemented for CUPS. The advantage of using composite wrapping is the no need of welding for installation; therefore, no need of hot work permit, a very simple installation procedure and the posibility to be performed on an operative piping without taking it out of service.

Whiting this technology it is possible to have 2 types of solutions:

- Composite pads
- Full composite wrapping

Composite pads isolate the pipes from contact with other metals preventing galvanic corrosion and friction damage. Figure 9-3 shows typical composite pads installed. However, Borealis experience using this type of pads is not satisfactory and ***is not recommended to be used*** mainly due to the following issues:

- Edges pad may not be properly sealed allowing moisture/water ingress. Even with a proper sealing, with time and agening water ingress was detected
- Disbonding
- Not possible to perform visual inspection

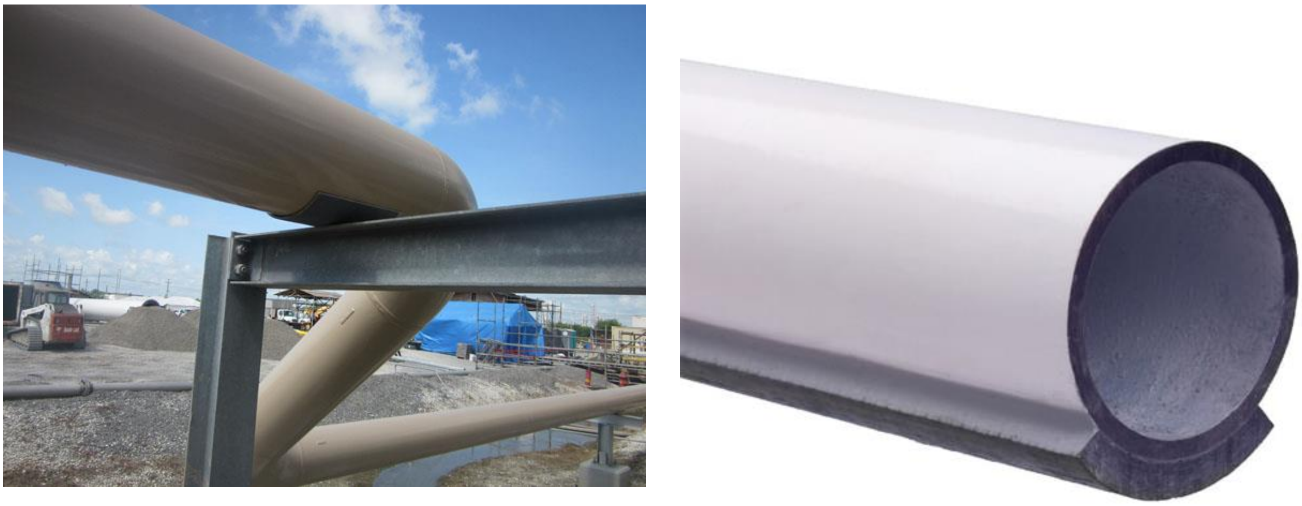


Figure 9-3 Composite pad

A full composite wrapping is usually used for pipe repair and ASME PCC-2 [6] and ISO 24817 [13] standards set out the requirements for engineered composite repairs. This solution is not recommended for new pipes, but can be applied for pipes that are in service and corrosion under pipe support is noticed, allowing to continue to operate the plant safely and avoid non-planned shutdowns and provide time for maintenance planning up to the next planned shutdown.

Note: *Wrapping is only recommended for temporary solution and not has a permanent solution.*

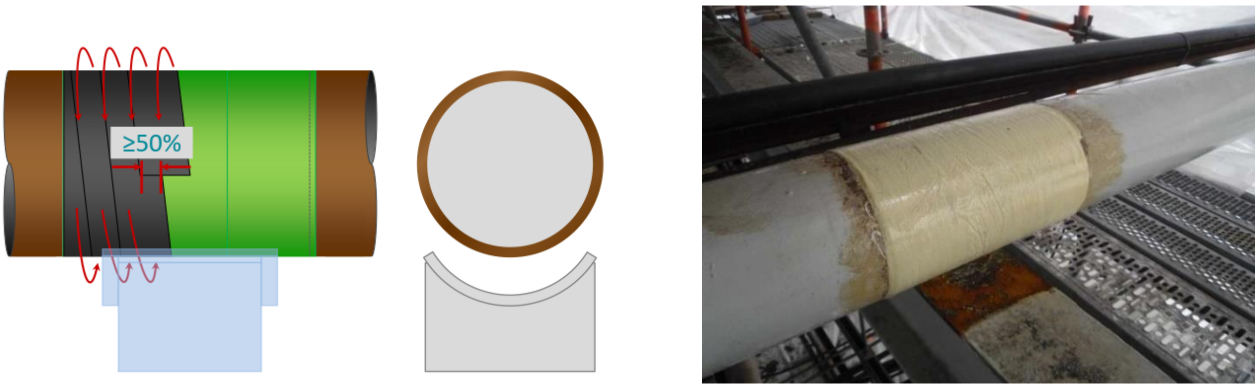


Figure 9-4 Full composite wrapping

9.3 NEW AND INSTALLED PIPES STRATEGY

New piping systems shall be designed using last best practices available in order to minimize the corrosion and maximize the inspectability, minimize the contact between the pipe and the support to avoid significant crevice area by using round bars as mentioned previously. Therefore, it is recommended within the Borealis organisation to use pipe support shoes as a standard practice. This is to avoid a direct contact between the pipe and the structural beam members, as in this concept the pipe will move over the structural beams and the wall thickness will be reduced over time.

For installed pipes, old supports must be replaced with new ones using last best practices. Therefore, piping lifting shall be performed. To execute the piping lifting a lifting procedure shall be developed and test it in order to perform a safe lifting, being wall thickness inspection and stress calculations the main pillars of the procedure to accept/reject the lifting execution.

10.CONCLUSION AND NEXT STEPS

At the time of the writting of this Master Thesis, this strategy was already reviewed by several Engineers within Sitech Services, the static equipment & inspection team from Borealis Group, and their feedback incorporated. Also, this strategy was presented to several Inspection Managers from Borealis, whom their received it with a very positive view.

This strategy was presented by Gino De Landtsheer and Sebastian Tarantino at the EFC WP15 Conference ″Corrosion in Refinery and Petrochemical Industry″ which took place the 3rd of May 2018 at Tenaris University in Dalmine, Italy. Looking to the feedback of the participants, the CUPS strategy was seen as an interesting piece of work, and a basis for our companies to start to implement CUPS, beside other damage and degradation mechanisms (e.g. CUI, CUL, CUF, etc) in the RBI inspection strategy.

The strategy is already introduced to Borealis Group and the implementation at Chemelot site started. The plan for the near future related with this strategy was agreed as follows:

- 2018 (Q4) - Borealis Plastomers will lead the implementation phase performing data gathering for risk assessment, pipe lifting for visual inspection and replacing old piping supports with new U-Bolt I-Rod system and replacing full pipes and upgrading the support at the same time.
- 2018 (Q4) - Implementation of the strategy at Chemelot site kick off
- 2019 (Q1/Q4) - Implementation of the strategy at Chemelot site and Sitech Services
- 2019 (Q1/Q4) - CUPS Strategy implementation at all Borealis sites around the globe (Austria, Belgium, Brazil, France, Finland, Germany, Italy, Netherlands, Sweden, and United States). This project will be managed by Gino De Landtsheer from Borealis Group.
- 2019 (Q3/Q4) - information from all Borealis sites coming from the implementation of this strategy will be gathered and assessed in order to adjust the procedure as necessary.
- 2019 (Q3/Q4) - Advantages and limitations of the strategy shall be assessed and clarified.
- 2019 (Q3/Q4) - Probability formula and parameters weights shall be reviewed
- 2020 (Q1) - Develop a strategy revision if needed.
- 2020 (Q1/Q2) - Implementation of the strategy at the rest of the companies in Chemelot site.

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12. APPENDIX I: NFPA DIAMOND

The National Fire Protection Agency (NFPA), in section 704 (Standard System for the Identification of the Hazards of Materials for Emergency Response) of the National Fire Code, specifies a system for identifying hazards associated with various materials [15]. This is a standard maintained by the U.S.-based National Fire Protection Association.

According to NFPA website, NFPA 704 Standard provides a simple, readily recognized, easily understood system for identifying the specific hazards of a material and the severity of the hazard that would occur during an emergency response. The system addresses the health, flammability, instability, and special hazards presented from short-term, acute exposures that could occur as a result of a fire, spill, or similar emergency [16].

The system is characterized by the "diamond" that is actually a "squareon-point" shape. It identifies the hazards of a material and the degree of severity of the health, flammability, and instability hazards. Hazard severity is indicated by a numerical rating that ranges from zero (0) indicating a minimal hazard, to four (4) indicating a severe hazard. The hazards are arranged spatially as follows: health at nine o'clock position, flammability at twelve o'clock position, and instability at three o'clock position. In addition to the spatial orientation that can be used to distinguish the hazards, they are also color-coded as follows: blue for health, red for flammability, and yellow for instability [16]..

The six o'clock position on the symbol represents special hazards and has a white background. The special hazards in use include W, OX and SA. W, indicates unusual reactivity with water and is a caution about the use of water in either firefighting or spill control response. OX, indicates that the material is an oxidizer. SA, indicates that the material is a simple asphyxiant gas (nitrogen, helium, neon, argon, krypton or xenon.). For further information it is recommended to check Section 8.2.1 through 8.2.4 of NFPA 704 [15].

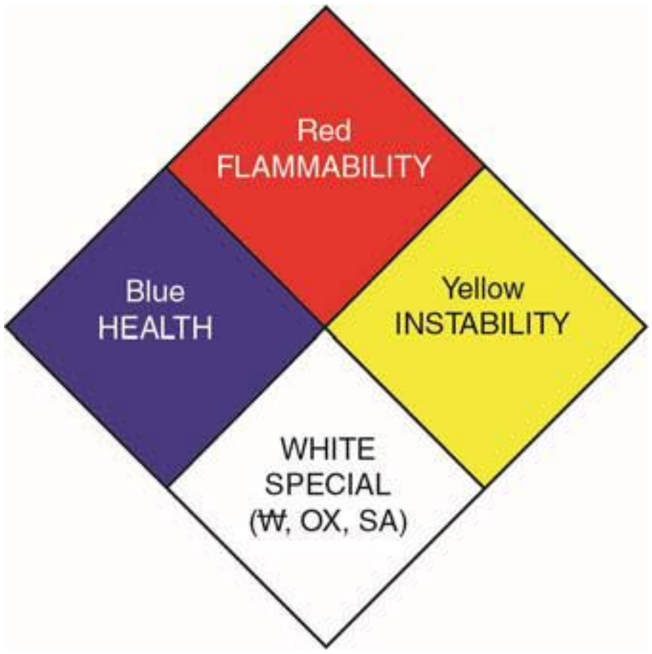

Figure 12-1 NFPA Diamond

Table 12-1 NFPA description classification for flammability, health and reactivity

	Flammability (red)
0	Materials that will not burn under typical fire conditions (e.g. Carbon tetrachloride), including intrinsically noncombustible materials such as concrete, stone, and sand. Materials that will not burn in air when exposed to a temperature of 820°C for a period of 5 minutes.
1	Materials that require considerable preheating, under all ambient temperature conditions, before ignition and combustion can occur (e.g. mineral oil, ammonia). Includes some finely divided suspended solids that do not require heating before ignition can occur. Flash point at or above 93,3°C.
2	Must be moderately heated or exposed to relatively high ambient temperature before ignition can occur (e.g. diesel fuel, paper, sulfur) and multiple finely divided suspended solids that do not require heating before ignition can occur. Flash point between 37,8 and 93,3°C.
3	Liquids and solids (including finely divided suspended solids) that can be ignited under almost all ambient temperature conditions (e.g. gasoline, acetone). Liquids having a flash point below 22,8°C and having a boiling point at or above 37,8°C or having a flash point between 22,8 and 37,8°C.
4	Will rapidly or completely vaporize at normal atmospheric pressure and temperature, or is readily dispersed in air and will burn readily (e.g. acetylene, propane, hydrogen gas). Includes pyrophoric substances. Flash point below room temperature at 22,8°C.

Health (blue)	
0	Poses no health hazard, no precautions necessary and would offer no hazard beyond that of ordinary combustible materials (e.g. wood, paper)
1	Exposure would cause irritation with only minor residual injury (e.g. acetone, sodium bromate, potassium chloride)
2	Intense or continued but not chronic exposure could cause temporary incapacitation or possible residual injury (e.g. diethyl ether, ammonium phosphate, iodine)
3	Short exposure could cause serious temporary or moderate residual injury (e.g. liquid hydrogen, carbon monoxide, calcium hypochlorite, hexafluorosilicic acid)
4	Very short exposure could cause death or major residual injury (e.g. hydrogen cyanide, phosgene, methyl isocyanate, hydrofluoric acid)

Instability / Reactivity (yellow)	
0	Normally stable, even under fire exposure conditions, and is not reactive with water (e.g. helium, N2)
1	Normally stable, but can become unstable at elevated temperatures and pressures (e.g. propene)
2	Undergoes violent chemical change at elevated temperatures and pressures, reacts violently with water, or may form explosive mixtures with water (e.g. white phosphorus, potassium, sodium)
3	Capable of detonation or explosive decomposition but requires a strong initiating source, must be heated under confinement before initiation, reacts explosively with water, or will detonate if severely shocked (e.g. ammonium nitrate, caesium, hydrogen peroxide)
4	Readily capable of detonation or explosive decomposition at normal temperatures and pressures (e.g. nitroglycerin, chlorine dioxide, nitrogen triiodide, chlorine trifluoride)

Table 12-2 NFPA description classification for special notice

Special Notice (white)	
The white "special notice" area can contain several symbols. The following symbols are defined by the NFPA 704 standard.	
OX	Oxidizer, allows chemicals to burn without an air supply (e.g. potassium perchlorate, ammonium nitrate, hydrogen peroxide).
~~W~~	Reacts with water in an unusual or dangerous manner (e.g. caesium, sodium, sulfuric acid).
SA	Simple asphyxiant gas (specifically nitrogen, helium, neon, argon, krypton, xenon). The SA symbol shall also be used for liquefied carbon dioxide vapor withdrawal systems and where large quantities of dry ice are used in confined areas.[2]

Non-standard Symbols (white)	
These hazard codes are not part of the NFPA 704 standard, but are occasionally used in an unofficial manner. The use of non-standard codes may be permitted, required or disallowed by the authority having jurisdiction (e.g. fire department).	
COR **ACID**, **ALK**	Corrosive; strong acid or base (e.g. sulfuric acid, potassium hydroxide) Acid or alkaline, to be more specific
BIO or ☣	Biological hazard (e.g. flu virus, rabies virus)
POI	Poisonous (e.g. strychnine, alpha-Amanitin)
RA, **RAD** or ☢	Radioactive (e.g. plutonium, cobalt-60)
CRY or **CRYO**	Cryogenic (e.g. liquid nitrogen)