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CRITICALITY ASSESSMENT OF PIPING SYSTEMS FOR OIL & GAS FACILITIES

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INTRODUCTION

Ensuring the integrity of process piping systems in the Oil & Gas industry (specifically those related to the ASME Code B31.3) is a key issue with respect to the process, business, safety, and the environment. However, in the current cost reduction environment, some companies are adopting a very risky strategy for piping systems where maintenance and inspection tasks are reduced and eliminated indiscriminately, without considering the relative importance of piping for the process. Other Oil & Gas facilities have not implemented an inspection program for pipework due to their asset integrity management program just being focused on pressure vessels, heat exchangers, and fired heaters. Even though the potential consequence of failure of a piping system is typically less than the consequence of failure of a pressure vessel (from a risk-based inspection perspective), a process piping system failure could have a strong impact on the business due to interruptions in production, and a catastrophic effect if an explosion or fire occurs or a hazardous chemical is released. In fact, the probability of failure of a pipe is greater than that of a pressure vessel. The Health Safety Executive Report RR672 "Offshore Hydrocarbon Release 2001-2008" revealed that piping is the most common equipment type to experience releases, and the most frequent equipment failure cause is mechanical failure, then mechanical fatigue. This is due to the fact that piping systems are subjected to vibration and mechanical and thermal fatigue loads that generate constant movement on the system. Moreover, most process piping is not piggable and sometimes the access for inspection is not an easy task when compared to pressure vessels.

This article presents a methodology to assess piping system criticality in order to help inspection and maintenance managers make the right decisions when developing and managing inspection and maintenance plans. Moreover, this methodology can help managers do this in a cost-effective way, without compromising the asset's safety and mechanical integrity performance.

CRITICALITY ASSESSMENT METHODOLOGY

This methodology assesses two important parameters: the probability of failure of the piping system as well as its consequence of failure. The combination of both parameters is a metric called "risk" and the piping criticality is associated with a risk value for the pipe. This methodology will permit focused maintenance and inspection resources over those piping systems that possess the higher criticality or risk value.

$$Risk = P_{failure} \times C_{failure}$$

Where

$P_{failure}$: Probability of failure

$C_{failure}$: Consequence of failure

Risk Model

The probability of failure is estimated in a qualitative way (High, Low, Medium) according to the following factors:

- Degradation mechanisms that can affect the pipe
- Fluid type (chemical composition,% CO_2,% H_2S)
- Process parameters (pressure, temperature, pH,% H_2O, Cl, flow)
- Pipe material (carbon steel, stainless)

The consequence of failure is estimated in a qualitative way as well according to the following factors:

- Piping Class according to API 570
- Pipe diameter
- How the failure affects production
- Costs associated with the piping reparation
- Operation frequency

$P_{failure}$ = f (Design, Corrosion, fatigue, SCC, mechanical damage)

$C_{failure}$ = f (API 570 Class, PipeØ, production, reparation cost, operating frequency)

The probability of failure increases with the type of damage mechanism and the number of mechanisms that may potentially affect the pipe. For instance, if a pipe has general corrosion as the main potential damage mechanism, the likelihood of failure will be higher than a pipe with the same diameter with fatigue as main potential damage mechanism (this is based on the HSE study, corrosion failure is more frequent that fatigue failure in piping systems). The consequence of failure increases with the diameter of the pipe, according to API 570 class, and the impact over production and costs. The risk calculation model is shown in **Figure 1.**

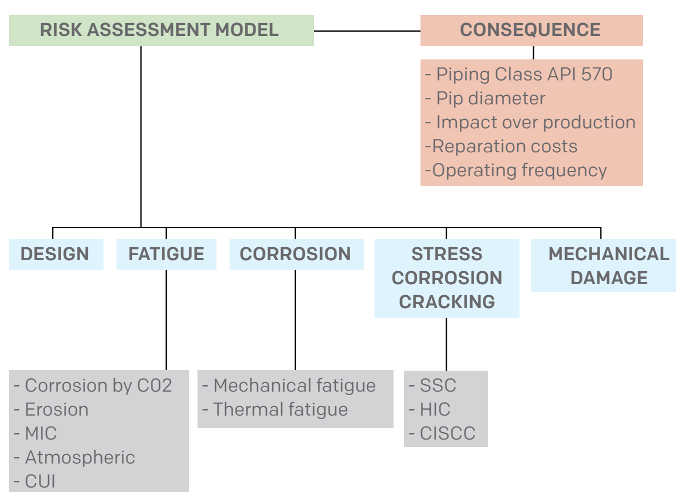

Figure 1. Risk Assessment Model for piping systems.

The likelihood of failure is calculated as follows:

$$P_{failure} = \text{DESIGN} + 1.5\,(\text{CORROSION}) + 1.15\,(\text{FATIGUE}) + 1.3(\text{SCC}) + \text{MECHANICAL DAMAGE}$$

Design evaluates the susceptibility of the pipe to suffer a leakage due to aspects related to the piping design. Basically assess if the pipe was designed according to the appropriate standards, if the state of piping supports is correct, and if there is adequate access for inspection. The result of this qualitative calculation is the susceptibility of the pipe to suffer a failure due to aspects of design and construction. Susceptibility to damage due to piping design is graded as follows: "None" (zero value for the calculation), "Low" (value of 1), "Medium" (value 10) and "High" (value 100).

Corrosion evaluates the susceptibility of the pipe to suffer leakage due to corrosion. The following types of corrosion mechanisms are evaluated: atmospheric corrosion, corrosion under insulation (CUI), erosion, microbiologically-induced corrosion (MIC), general and localized corrosion. If the pipe has more than one type of corrosion, they are added in the susceptibility calculation. The way to rate the corrosion damage is done in the same way as for the mechanism design. This mechanism has a multiplication factor of 1.5 in the calculation model because it is the most common failure mechanism in the industry and, as such, is weighted with greater probability of failure.

Fatigue evaluates the susceptibility of the pipe to suffer a leakage due to fatigue. This module considers mechanical fatigue (mainly due to the vibration) and thermal fatigue (generated by the cycles of heating and cooling of process equipment). This mechanism has a factor of 1.15.

SCC (Stress Corrosion Cracking) evaluates the susceptibility of the pipe to suffer a leakage due to stress corrosion cracking. For carbon steel, the damage mechanisms SSC (Sulfide Stress Cracking) and HIC (Hydrogen Induced Cracking) are considered. The CLSCC (Chloride Stress Corrosion Cracking) damage mechanism is considered for piping made in stainless steel. This mechanism has a factor of 1.3.

Mechanical damage evaluates the susceptibility of the pipe to suffer a leakage due to mechanical damage. Mechanical damage considered were those piping with external grind marks or gouges (due to grinding during erecting phase), wearing out under piping support (the contact zone between pipe and support) and indentations that can be evaluated by the API 579 "Fitness for Service" standard.

Table 1. Damage Susceptibility qualification.

SUSCEPTIBILITY	VALUE
None	0
Low	1
Medium	10
High	100

Table 2. Probability qualification.

PROBABILITY	VALUE
Low	<10
Medium	10-100
High	>100

The consequence of failure is calculated as follows:

$$P_{failure} = \text{PIPING CLASS} + \text{PIPE DIAMETER} + \text{PRODUCTION} + \text{OPERATING FREQUENCY} + \text{REPARATION COST}$$

Piping Class Factor: For the consequence of failure, consideration is given to the class factor defined by API 570 "Piping Inspection Code standard: Inspection, Repair, Alteration and rerating of In-service Piping Systems". Those piping systems defined as Class-1 are tagged with a higher consequence due to fluid containment (i.e NGL), piping rated Class-2 are medium consequence (i.e gas), and piping rated Class-3 are lowest consequence (i.e. hot oil, process water). This is the most important factor for the consequence of failure calculation.

Pipe Diameter Factor: This factor considers that the bigger the pipe, the greater the potential severity of failure. For instance, the consequence factor for a pipe of 12 inches in diameter is higher than a factor for a pipe of 8 inches in diameter.

Production Factor: This factor takes into account the impact of a failure on the business. It considers the case of pipe leakage, what the impact over process production is. Qualifications are: without impact, low impact to production (1-3 days), medium impact (1 week with process interruption), and big impact to production (> 1 week).

Operating Frequency: This factor takes into account the operating frequency of the piping system. For instance, if the pipe is operating 24hours a day every day, the factor is bigger than a pipe that is used as by-pass where their operating frequency is less.

Reparation Cost Factor: This factor takes into account the impact of piping system repair in terms of maintenance costs. The higher the repair cost, the larger the factor.

The rating of the consequence of failure is defined in **Table. 3**:

Table 3. Consequence classification.

CONSEQUENCE	VALUE
Very Low	0-13
Low	14-60
Medium	61-130
High	>130

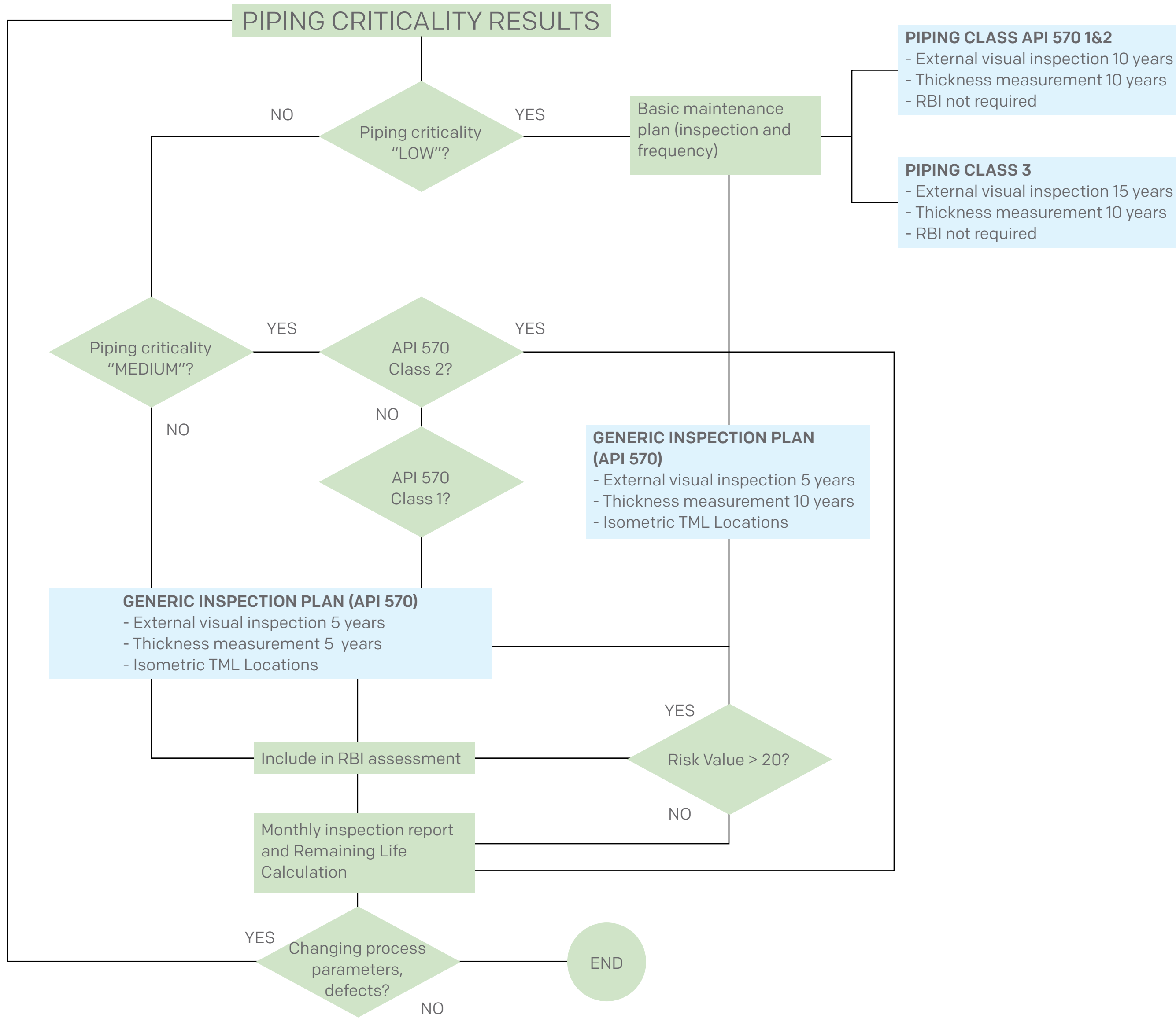

Figure 2. Piping integrity management flowchart.

The consequence factor value is calculated by dividing the value of the result by 100 (Consequence Factor = Consequence value / 100). Risk value is then calculated by multiplying the probability of failure by the consequence factor.

Risk and Criticality Rating

The criticality of each piping system is calculated based on the risk value obtained during the calculation of likelihood and consequence of failure. **Table 4** shows the qualitative classification used to determine the criticality of piping based on the risk.

Table 4. Risk and Criticality rating.

CRITICALITY	RISK
Low	< 10
Medium	10-100
High	> 100

Maintenance and inspection optimization process

With the information obtained from the piping criticality assessment results, a basic maintenance plan can be developed for all piping systems with a "Low" criticality rating. For those piping systems with a "Medium" and "High" criticality rating, the maintenance plan can be developed via RBI semi-quantitatively. The following flowchart shows the maintenance management decisions based on criticality value. **Tables 5, 6,** and **7** show the inspection frequency for a generic inspection plan.

CRITICALITY ASSESSMENT TYPICAL STUDY RESULT

To perform the piping system criticality assessment in a typical gas plant, a piping database is required due to the large volume of data to be processed. For the following project, 292 piping systems were assessed.

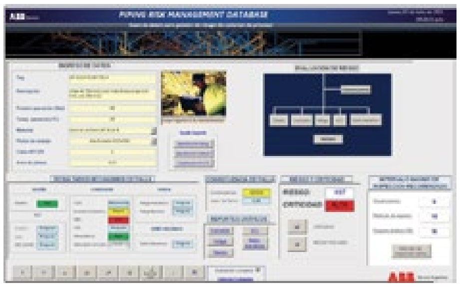

Figure 3. Piping Risk Management Database.

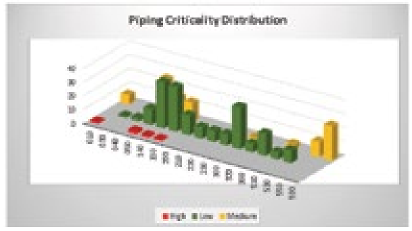

Figure 5. Piping criticality distribution per area of process plant.

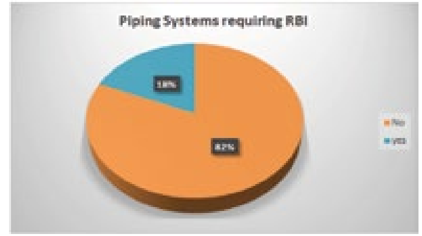

Figure 6. RBI requirement for piping systems.

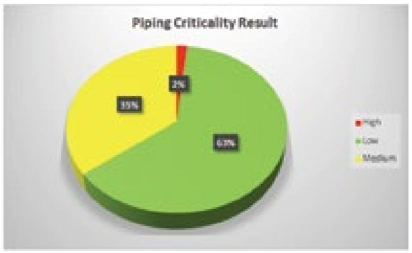

Figure 4. Piping criticality results for typical gas plant.

Table 5. Inspection frequency for piping class 1.

Class 1

CRITICALITY	EXTERNAL VISUAL INSPECTION	THICKNESS MEASUREMENT UT	RBI REQUIRED?
High	5	5	Yes
Medium	5	5	If Risk > 20
Low	10	10	No

Table. 6. Inspection frequency for piping class 2.

Class 2

CRITICALITY	EXTERNAL VISUAL INSPECTION	THICKNESS MEASURE-MENT UT	RBI REQUIRED?
High	5	5	Yes
Medium	5	10	If Risk > 20
Low	10	10	No

Table. 7. Inspection frequency for piping class 3.

Class 3

CRITICALITY	EXTERNAL VISUAL INSPECTION	THICKNESS MEASUREMENT UT	RBI REQUIRED?
High	10	10	No
Medium	10	10	No
Low	15	15	No

CRITICALITY RESULTS

In **Figure 4** it is clear that not all piping systems have the same importance for the plant, meaning that not all piping systems should have the same inspection frequency. Only 2% required a very well detailed inspection and integrity management program. **Figure 6** shows that just 18% of piping systems require an inspection plan developed via RBI assessment.

CONCLUSIONS

The criticality analysis shown in this article clearly proves the advantages of having selected the pipes that are important for successful operation, with respect to production, business, safety and the environment. Furthermore, this criticality assessment helps optimize the inspection and maintenance efforts focusing on those pipes that really deserve such care, and determining where you might need to increase or decrease the current inspection frequency. This is an important benefit of RBI; it helps ensure the right things are done at the right times, and that resources are available to manage those items that pose the greatest risks and vulnerabilities.

Piping integrity is an important safety and environment issue. Despite advances in asset integrity and reliability management in the general area of Pressure Systems, failures of piping systems in the oil &gas, chemical and petrochemical process industries continues to be a significant problem. It is well established that failure of piping systems is more likely to occur than the failure of a pressure vessel. ■

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