CHEMICAL ENGINEERING TRANSACTIONS

VOL. 98, 2023

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Sauro Pierucci, Carlo Pirola

ISBN 978-88-95608-97-6; **ISSN** 2283-9216

DOI: 10.3303/CET2398039

The Integrity of Equipment by Setting up RBI and Applying the OBRA Method

Karima Bitchikh*, Aboubakar Kertous, Halla Khennous, Meriem Hammal

Laboratoire des sciences et techniques de l'environnement (LSTE), Ecole Nationale Polytechnique, Alger, Algérie
karima.bitchikh@g.enp.edu.dz

Industry professionals rely on increasingly complex infrastructures where risk management is a key issue. Today, the primary interest for the different sectors of industry is to face the challenges related to the reduction of maintenance and inspection costs of equipment caused by scheduled or unscheduled shutdowns (following leaks or incidents) while preserving the integrity of the equipment and improving the company's competitiveness.Indeed, it has become crucial to properly manage and control the risk related to the production tool through efficient inspection practices and proper planning of maintenance work.
After an assessment of the risk by the RBI approach, the main objective is to generate an inspection program focusing the inspection and control activities on equipment considered as a priority and then an optimal exploitation of the available resources. The risk in the framework of the RBI approach is the combination of the probability of failure which depends on the potential mechanisms of degradation and the consequence related to a failure which can be expressed in terms of physical damage for the personnel and the economic loss related to the production tool, the effects on the environment, and also the various costs of maintenance.
Keywords: gas explosion, risk based inspection, natural gas pipeline, atmospheric corrosion, API

1. Introduction

In the mid-1980s, following a series of serious chemical accidents around the world, such as the major chemical accident in Bhopal (India 1985), companies, industries and governments began to identify management systems as the underlying cause of these accidents, committed to policies and published standards to follow, and governments adopted regulations all aimed at accelerating the adoption of a management systems approach to process safety. (CCPS, 2007),
Integrity is the state of preventing any leakage or loss of fluid or energy in facilities. The management of integrity encompasses the equipment and structures that support the equipment, as well as other systems that prevent, detect, control, or mitigate major accident hazards (Nwankwo, 2020). In order to maintain the integrity of a natural gas pipeline, a meticulous process is necessary. Regular inspections are conducted to identify any potential leaks or damages to the pipe. As a result, the RBI (Risk-Based Inspection) technique is employed as the preferred method to ensure the pipeline's safety.

Problematic

The key to maintaining the integrity of natural gas pipelines within an industrial workplace involves employing the requisite tools for analyzing and managing the risks associated with natural gas explosions. Additionally, determining the optimal inspection techniques and frequency for the pipeline is crucial to ensure its safety.
In this study, we will discuss the concepts of Process Safety Management and Asset Integrity; as well as risk-based inspection and its detailed approach based on API RP 581;

Process Safety Management (PSM)

PSM is a multidisciplinary field that encompasses many important aspects of preventing, preparing for, mitigating, responding to or restoring chemical releases or energy from a process associated with a facility.

Paper Received: 10 November 2022; Revised: 20 January 2023; Accepted: 14 April 2023
Please cite this article as: Bitchikh K., Kertous A., Khanous H., Hammal M., 2023, The Integrity of Equipment by Setting Up RBI and Applying the OBRA Method, Chemical Engineering Transactions, 98, 231-236 DOI:10.3303/CET2398039

Process Safety Management System (PSMS)

In order to promote PSM excellence and continuous improvement across the process industries, CCPS has created Risk Based Process Safety (RBPS) as a framework for the next generation of process safety management. (CCPS, Guidelines for Risk Based Process Safety, 2007)

Risk based Process Safety (RBPS)

This approach uses risk-based implementation strategies and tactics that are commensurate with the demand for process safety activities, the availability of resources and the existing organisational culture for designing, correcting and improving process safety management activities. Its main objective is to help organisations build and operate a process safety management system more effectively, and help to implement several strategies at the same time in different functions within a department, or the same function at different times. (CCPS, Guidelines for Risk Based Process Safety, 2007)

The pillars and elements of RBPS

Process security is basically based on four functional pillars represented by the following figure

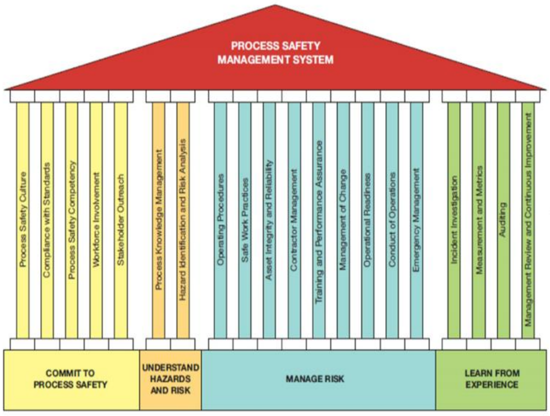


Figure 1: the pillars and elements of process safety management

Risk-based inspection

An installation has a large number of components that need to be inspected, and the time between inspections should not be too long. This can be a big challenge, and it is beneficial to prioritise the components that need to be inspected. To do this, risk-based inspection (RBI) can be a useful tool. (Márcio das Chagas Moura, 2015).

API RP 580 / API RP 581

API 580, Risk-Based Inspection, provides quantitative calculation methods for determining an inspection plan.
API RP 580 provides a framework for developing risk-based inspection (RBI) programmes for stationary equipment in refineries, petrochemical plants, chemical processing plants and oil and gas production facilities (API, 2020).
API RP 581, Risk-Based Inspection Methodology, provides quantitative procedures for establishing an inspection programme using risk-based methods for equipment such as pressure vessels, piping, tanks, heat exchangers.
the purpose of the RBI is to create an efficient inspection plan and to continuously monitor and test the system. (coll, 2016)

Methodology

As asset integrity management is one of the key points of the PSM, to ensure the integrity of the natural gas pipeline, we have opted for the RBI method, which is a combination of the probability that will be calculated with reference to the API RB 581 and the consequences will be estimated by developing the OBRA method, prior to this, it is necessary to gather the system-specific data.

Plant Data Collection – Essential data relating to the equipment/system being assessed is critical. Equipment manufacturing guide, solvents, Material Safety Data Sheets, process flow diagram, P&IDs, and material compatibility charts should be used to help the RBI team better understand the process flow, chemical reaction, material compatibility and chemical properties of the process.

2. Detailed RBI

The assessment consists of determining the two parameters for calculating the risk level

2.1 Probability of failure PoF

There are different approaches to determining the probability ranging from qualitative to semi-quantitative to quantitative. The PoF for static equipment such as pipes is determined by evaluating the degradation for the different corrosion groups in combination with the nominal wall thickness (Rod, 2015).
In our study we will determine the probability of failure using the quantitative approach based on API RP 581. The failure probability used in API RBI is calculated from the following equation:

$$P_f(t) = gff \times D_f(t) \times F_{MS} \qquad (1)$$

With
gff : generic failure frequency
D_f: Damage factor
F_{MS}: Management systems factor
The recommended scale for converting a management system assessment score, Score, into a management system factor is based on the assumption that an "average" plant would score 50% (500 out of a possible 1000). According to this ranking, equation (2) and equation (3) are used to calculate a management system factor, F_{MS}, for any management system assessment score, Score. The management score must first be converted to a percentage (between 0 and 100) as follows:

$$pscore = \frac{score}{1000} \times 100\ (unit\ in\ percent) \qquad (2)$$

$$F_{MS} = 10^{(-0.02 \times pscore+1)} \qquad (3)$$

According to the condition and location of the system being studied "natural gas pipeline made of API 5L X60 steel which is located in the open air in a high humidity area, supported by brackets to prevent fatigue of the pipeline. And according to API RP 571, which describes the damage mechanisms affecting fixed equipment in the refining industry, we find that the applicable failure mode on our system is indeed loss of material through atmospheric corrosion.

2.2 Calculation of the atmospheric corrosion damage factor

The following procedure is used to determine the DF
STEP 1- Determine the supplied thickness, t, and the age of the component from the date of installation.
STEP 2- Determine the corrosion rate, C_r, as a function of conductor and operating temperature.
Drivers
The external corrosion rate is affected by the operating temperature, weather conditions based on the location of the equipment, and the surface condition of the equipment (external coating or paint...).
The conductor chosen for the corrosion rate C_r should best match the external corrosion rate observed at that location.

2.3 Basic corrosion rate

Severe High wetting (e.g. >60 % of time); very high rainfall [e.g. >2250 mm/year (100 in./year)]; frequent deluge testing; highly corrosive industrial atmosphere; in a coastal zone with very high atmospheric chloride content (e.g. >1500 mg/m2/day).
Moderate Frequently wet (e.g. 30 % to 60 % of time); downwind of a cooling tower; high rainfall [e.g. 1524 to 2250 mm/year (60 to 100 in./year)]; corrosive industrial atmosphere; near the coast with high chloride content in rainwater (e.g. 300 to 1500 mg/m2/day).
Mild Occasionally wet (e.g. <30 % of time); moderate rainfall [e.g. 762 to 1524 mm/year (20 to 60 in./year)]; low chloride content in rainwater (e.g. 60 to 300 mg/m2/day).
Dry Very dry or cold zone with very low pollution and time of wetness; low rainfall [e.g. <508 mm/year (<20 in./year)]; inside building (operating above dew point); low chloride content in rainwater (e.g. <60 mg/m2/day).
STEP 3- Determine the time in service, age_{Tke}, since the last known thickness inspection t_{rde}.
Note
If no measured thickness is available, t_{rde}=t and age_{Tke}=age.
STEP 4-Determine the time in service, age_{coat}, since the coating was installed.

STEP 5-Determine the expected age of the coating, C_{age}, based on the type of coating, quality of application and service conditions.

- The expected life is 0 years for unapplied or poorly applied coatings.
- Lower quality coatings generally have a service life of 5 years or less.
- High quality coatings or coatings in less harsh external environments may have a C_{age} of 15 years or more

STEP 6-Determine the coating fit, $Coat_{adj}$, using one of the following two equations:

If $age_{tke} \geq age_{\ coat}$ so $\mathrm{Coat_{adj}} = \min(\mathrm{C_{age}}, \mathrm{age_{coat}})$

If $age_{tke} \geq age_{\ coat}$

If the coating has failed at the time of inspection when age_{Tke} was established, then $\mathrm{Coat_{adj}}$ =0

If the coating has not failed at the time of inspection when age_{Tke} was established, use Equation:

$$\mathrm{Coat_{adj}} = \min\left(\mathrm{C_{age}}, \mathrm{age_{coat}}\right) - \min\left(\mathrm{C_{age}}, \mathrm{age_{coat}} - \mathrm{age_{tke}}\right)$$

STEP 7-Determine the time in service, the age, during which external corrosion may have occurred using the following: $\mathrm{age} = \mathrm{age_{tke}} - \mathrm{Coat_{adj}}$

STEP 8-Determine the allowable stress, S, the effectiveness of the weld joint, E, and the minimum required thickness, t_{min} according to the building code.

STEP 9-Determine the parameter A_{rt} as a function of age and t_{rde}according to the equation:

$$A_{rt} = \frac{C_r \times age}{t_{rde}} \tag{4}$$

STEP 10-Calculate the flow stress, $FS^{extcorr}$ by the following equation:

$$FS^{extcorr} = \frac{YS+TS}{2} \times E \times 1.1 \tag{5}$$

With:

YS: yield strength, MPa (psi).

TS: tensile strength, MPa (psi)

STEP 11-Calculate the power ratio parameter, $SR_P^{extcorr}$.

$$SR_P^{extcorr} = \frac{P \times D}{\alpha \times FS^{extcorr} \times t_{rde}} \tag{6}$$

With:

P: is the pressure in MPa (psi)

D: the internal diameter of the component, in mm (inch)

α: The form factor of the component geometry, α = 2 for a cylinder, 4 for a sphere, 1.13 for a head.

STEP 12-Determine the number of inspections, $N_A^{extcorr}$, $N_B^{extcorr}$, $N_C^{extcorr}$et $N_D^{extcorr}$ and the corresponding inspection effectiveness category .

STEP 13-Determine inspection effectiveness factors, $I_1^{extcorr}$, $I_2^{extcorr}$ et $I_3^{extcorr}$ using prior probabilities $Pr_{p1}^{extcorr}$, $Pr_{p2}^{extcorr}$ et $Pr_{p3}^{extcorr}$ and conditional probabilities $CO_{p1}^{extcorr}$, $CO_{p2}^{extcorr}$ et $CO_{p3}^{extcorr}$.

$$I_1^{extcorr} = Pr_{p1}^{extcorr} \left(CO_{p1}^{extcorr}\right)^{N_A^{extcorr}} \left(CO_{p1}^{extcorr}\right)^{N_B^{extcorr}} \left(CO_{p1}^{extcorr}\right)^{N_C^{extcorr}} \left(CO_{p1}^{extcorr}\right)^{N_D^{extcorr}} \tag{7}$$

$$I_2^{extcorr} = Pr_{p2}^{extcorr} \left(CO_{p2}^{extcorr}\right)^{N_A^{extcorr}} \left(CO_{p2}^{extcorr}\right)^{N_B^{extcorr}} \left(CO_{p2}^{extcorr}\right)^{N_C^{extcorr}} \left(CO_{p2}^{extcorr}\right)^{N_D^{extcorr}} \tag{8}$$

$$I_3^{extcorr} = Pr_{p3}^{extcorr} \left(CO_{p3}^{extcorr}\right)^{N_A^{extcorr}} \left(CO_{p3}^{extcorr}\right)^{N_B^{extcorr}} \left(CO_{p3}^{extcorr}\right)^{N_C^{extcorr}} \left(CO_{p3}^{extcorr}\right)^{N_D^{extcorr}} \tag{9}$$

STEP 14 - Calculate posterior probabilities $Po_{p1}^{extcorr}$, $Po_{p2}^{extcorr}$et $Po_{p3}^{extcorr}$

$$Po_{p1}^{extcorr} = \frac{I_1^{extcorr}}{I_1^{extcorr}+I_2^{extcorr}+I_3^{extcorr}} \tag{10}$$

$$Po_{p2}^{extcorr} = \frac{I_2^{extcorr}}{I_1^{extcorr}+I_2^{extcorr}+I_3^{extcorr}} \tag{11}$$

$$Po_{p3}^{extcorr} = \frac{I_1^{extcorr}}{I_1^{extcorr}+I_2^{extcorr}+I_3^{extcorr}} \tag{12}$$

STEP 15-Calculate the parameters, $\beta_1^{extcorr}$, $\beta_2^{extcorr}$ et $\beta_3^{extcorr}$:

$$\beta_1^{extcorr} = \frac{1-D_{s1} \times A_{rt} - SR_P^{extcorr}}{\sqrt{D_{s1}^2 A_{rt}^2 COV_{\Delta t}^2 + (1-D_{s1} \times A_{rt})^2 \times COV_{sf}^2 + (SR_P^{extcorr})^2 \times COV_P^2}} \tag{13}$$

$$\beta_2^{extcorr} = \frac{1-D_{s2} \times A_{rt} - SR_P^{extcorr}}{\sqrt{D_{s2}^2 A_{rt}^2 COV_{\Delta t}^2 + (1-D_{s2} \times A_{rt})^2 \times COV_{sf}^2 + (SR_P^{extcorr})^2 \times COV_P^2}} \tag{14}$$

$$\beta_3^{extcorr} = \frac{1-D_{s3} \times A_{rt} - SR_P^{extcorr}}{\sqrt{D_{s3}^2 A_{rt}^2 COV_{\Delta t}^2 + (1-D_{s3} \times A_{rt})^2 \times COV_{sf}^2 + (SR_P^{extcorr})^2 \times COV_P^2}} \tag{15}$$

Where

$$D_{s1} = 1 \ , \ D_{s2} = 2 \ , \quad D_{s3} = 4 \quad , \quad COV_{\Delta t} = 0.2 \quad , \quad COV_{sf} = 0.2 \quad , \quad COV_P = 0.05$$

STEP 16- Calculate the damage factor $D_f^{extcorr}$

$$D_f^{extcorr} = \frac{\left[\left(Po_{p1}^{extcorr}\varphi(-\beta_1^{extcorr})\right)+\left(Po_{p2}^{extcorr}\varphi(-\beta_2^{extcorr})\right)+\left(Po_{p3}^{extcorr}\varphi(-\beta_3^{extcorr})\right)\right]}{1.56\times10^{-4}} \qquad (16)$$

where φ is the standard normal cumulative distribution function (API, 2020).

2.4 Consequence of failure CoF

The consequence of failure (CoF) is defined as the result of a failure, which can be expressed in terms of safety for personnel, economic loss or environmental damage.

2.5 Presentation of the OBRA method

OBRA is an assessment of the risks to the occupants of a building in the event of a major accident. The location and design of occupied buildings can have a significant impact on the chances of survival of the occupants in the event of a major accident.
OBRA uses a set of damage models to assess the extent of areas where pressure waves capable of damaging buildings could develop.
For each occupied building, the risk is determined by taking into account the number of people who may be present in the building and the likelihood of the event resulting in fatal injury.
According to OBRA:

- Windows are expected to be damaged at 3 kPa.
- Light buildings with steel framing and cladding at 5 kPa.
- Brick or block buildings at 10 kPa.

All such structures in these areas that are occupied are considered at risk of damage.
In our study we will adopt the damage assessment using the TNT model:

$$Q_{PV} = V^* \, P_B \left[(\ln\left(\frac{P_B}{P_A}\right) + \frac{P_A}{P_B} - 1\right] \qquad (17)$$

With:

V^*: The volume of the building

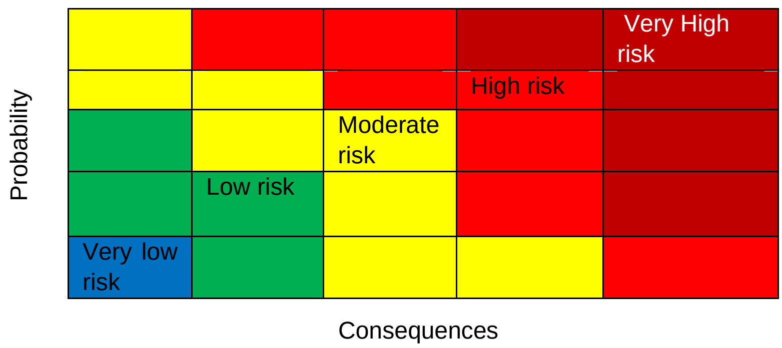
P_B, P_A : Burst pressure and atmospheric pressure respectively.

The burst pressure P_B is provided by the OBRA method.
The Sadowsky formula is then used to calculate the blast wave of the TNT explosion at the earth's surface under normal atmospheric conditions; (API, API RP 752 Management of Hazards Associated With Location of Process Plant Permanent Buildings, 2009)

$$\Delta p_1 = 0.95\,\frac{\sqrt[3]{m}}{r} + 3.9\,\frac{\sqrt[3]{m^2}}{r^2} + 13\,\frac{m}{r^3} \qquad (18)$$

2.6 Risk calculation

The risk R is determined by plotting the probability and consequences on a risk matrix, the presentation of the results in a risk matrix is a very effective way of communicating the distribution of risk throughout a plant.
R=P_f ×C and the risk matrix used in the RBI procedure is a 5 x 5 matrix with probability categories ranging from very low risk to very high risk.



2.7 Elaboration of the inspection plan

The results of the RBI assessment are used to develop an overall inspection strategy, which is used in conjunction with mitigation plans to ensure acceptable risk. RBI team members should consider risk levels, inspection schedules and remaining life in their strategy

The level of risk reduction achieved by inspection will depend on the failure mode of the damage mechanism, the interval between the onset of damage and failure i.e. the rate of damage, the detection capability of the inspection technique; the scope of the inspection and the frequency of inspections.

3. Results

In this study, the application of the RBI approach on a natural gas pipeline, gave us a probability of failure calculated according to API 581 Pof= 2.1835 x 10^{-5} with

$$gff = 3{,}06 \times 10^{-5}$$

$$D_f(t) = 5{,}9366$$

$$F_{MS} = 0{,}12$$

The consequence of failure (Cof) due to a gas explosion in boilerhouse Brick/Block with a Burst pressure of 20kPa and a volume of 250m3

By using the TNT model and the The Sadowsky formula an over pressure ΔP = 24 kpa at a distance of 5m

The vulnerability of building occupants to the overpressure can be determined from building vulnerability curves (CIA, 2020)

Taking the example of an office building located 20metres from the boilerhouse.

The overpressure experienced is 4.75kPa.

The vulnerability taken from the CIA Vulnerability curves is 0.02 (i.e. 2%).

The occupancy of the office is 100 people.

The persons vulnerable is therefore 100 x 0.02 = 2 people.

This is therefore classed as Severity S4 according to the OBRA method is a severe level.

The projection of these data on criticality the matrix gives us a high-risk level.

This result allows to elaborate an adequate inspection plan in order to ensure the integrity of the asset and to reduce the risk.

4. Conclusion

Asset integrity is a pillar of process safety. It is far more effective to maintain equipment on a preventive basis, rather than allowing it to become worn to the point of breakdown, and so an effective preventive system is essential for any plant.

In this study a quantitative RBI approach was applied, the probability of failure was determined according to API 581 and the estimation of the severity of consequences by using the OBRA method.

This quantitative approach gave us precise results on the level of risk which will be the basis for the elaboration of an optimal inspection plan in order to reduce the risk, reduce the inspection costs and improve production up-time.

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