Study of The Implementation of Semi-Qualitative Risk Based Inspection (RBI) Method Based on API 581 on Gas Dryer Instrument

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Abstract. This research implements Risk Based Inspection (RBI) as an analytical method to perform risk assessment to gas dryer instrument. The risk assessment is performed by determining the probability of failure and consequence of failure from gas dryer instrument. The risk level can be determined by mapping the risk onto risk matrix. The damage factors identified to occur in gas dryer instrument are internal thinning and external corrosion. The probability of failure is found to be 3.51 x 10-6 failure/year, which fall under category 1. While the consequence are of failure was found to be 5,056.88 ft2, which fall under category C. Therefore the risk level posses by gas dryer instrument was found to be 1C. The remaining life of the instrument gas dryer is expected to be 243.5 years. The risk Is expected to reach the risk target after 27 years of operation.

Keywords: API 581, RBI, Semi-Quantitative, PoF, CoF, Risk, Equipment

1 Introduction

The increasing demand for oil is indicated by the opinion of the World Energy Agency (IEA) estimate that until 2030, world energy demand will increase by 1.6% per year. Most or about 80% of the world's energy needs are supplied from fossil fuels. Therefore, various industries engaged in these fields must provide an increase in their production. This can be achieved by conducting intensive exploration so that production also increases [1]. So that one of the actions taken by the company is to increase its production capacity by increasing the production equipment owned.

The tools that are the focus of this research are vertical pressure vessels of the type of gas dryer instrument. However, along with its use, it certainly has a high risk because it is used for a long time, the oil and gas production process involves high pressure and high temperature. In addition, the processed fluid is flammable, so that if a failure occurs in one of the tools used, it will pose a potential hazard. The potential hazards in question include safety risks that can occur such as explosion leaks, fires, and pollution of the surrounding environment [2].

Therefore, an action must be taken in the form of an evaluation of the planning of inspection activities on the tool. A method has been found to schedule inspections called Risk Based

ICO-SEID 2022, November 23-24, Jakarta, Indonesia

DOI 10.4108/eai.23-11-2022.2341979

Inspection (RBI). RBI is a risk-based inspection method used to create an inspection schedule that takes into account the potential failures that may occur in the operation of an equipment [3].

There are three main ways to approach the qualitative, quantitative, and semi-quantitative RBI methods. The qualitative approach method is a way of analysing a situation by looking at the various possibilities and consequences of failure. The semi-quantitative method is a method of transition between qualitative and quantitative, where the results are compared with qualitative but the calculations are not as complicated as the semi-quantitative method. [4].

2 Research Methodology

Risk is defined as the uncertainty of the failure occurrence that can impact to operation process. From this definition, it can be observed that risk constructed of two elements, namely uncertainty of failure occurrence or probability of failure, and impact or consequence of failure. The methodology to perform this research is depicted in **Figure 1**. The procedure is initiated with data and information collection. The purpose of this step is to collect data and information that will be used in conducting RBI analysis. The information collected consist of inspection history, P&ID, operation and maintenance data, Original Equipment Manufacturer (OEM) manual, etc..

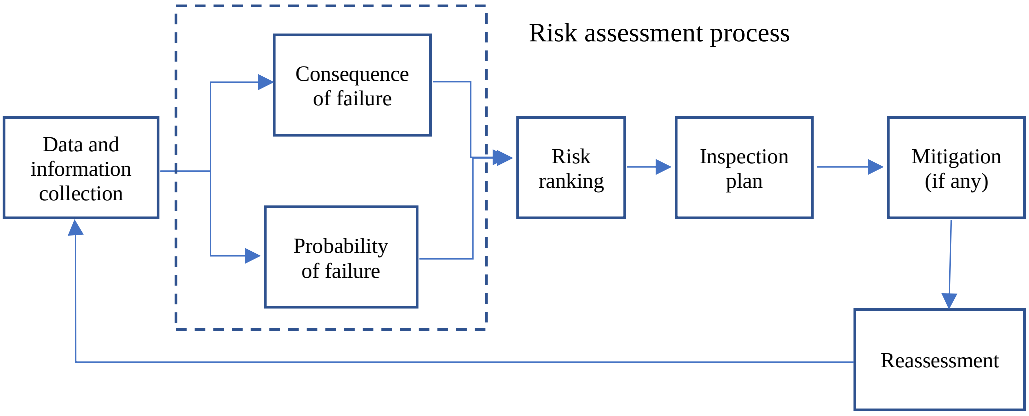

Fig. 1. RBI Planning Process [6]

2.1 Probability of Failure (PoF)

Universal probability of failure is a function of time (s) and increasing gradual breakdown of components that accumulates with time [7]. The probability of failure used in API 581 can be seen in Equation (1).

$$P\,f\,(t) = gff\,.Df(t).F_{MS} \qquad (1)$$

1) Generic Failure Frequency (gff). The gff is the expected failure frequency of any specific failure to happen. The gff is obtained from many failure histories of a tool in many companies or factories around the world and also literature data, then combined to obtain a large value which is a representation of the frequency of failures experienced while the tool is operating until it experiences a decrease in work quality/damage [1]. There is a recommended value that has been provided in API 581 for pressure vessels, namely 0.0000306 failure/year.
2) Factor Management System (FMS) The FMS value was obtained from the results of interviews with field operators.
3) Damage Factor ($Df(t)$). Damage Factor is a factor for statistically evaluating equipment with possible damage conditions in the form of a function of time and effectiveness of inspection activities. Damage factor is an adjustment factor that is applied to the general failure frequency of a component based on the calculation of the damage mechanism that occurs in the component [1]. The estimated damage factor is determined based on the damage mechanism that occurs in the field, namely:

- Thinning – Df^{thin}
  Determining the damage factor based on API 581 is done with a quantitative approach. It takes 2 aspects, namely and beta reliability parameters and posterior probability. Reliability refers to an understanding that the instruments used in research to obtain information used can be trusted as a data collection tool and are able to reveal actual information in the field [8]. To determine the beta reliability parameter, it is necessary to determine the value of the corrosion rate.

$$Corrosion\ Rate\ (CR_{bm}) = max\ [\ CR_{LT}, CR_{ST}] \tag{2}$$

where Long-Term Corrosion Rate (CR_{LT}) is given by:

$$CR_{LT} = \frac{t_{intial} - t_{actual}}{time\ between\ t_{intial} t_{actual}} \tag{3}$$

where Short-Term Corrosion Rate (CR_{ST}) is given by:

$$CR_{ST} = \frac{t_{intial} - t_{actual}}{time\ between\ t_{intial} t_{actual}} \tag{4}$$

The reliability value for the damage factor can be determined using the Equation (5).

$$\beta_1^{Thin} = \frac{1 - D_{S_1}.A_{rt} - SR_P^{Thin}}{{D_{S_1}}^2.{A_{rt}}^2\ .{COV_{\Delta t}}^2 +\ \left(1 - D_{S_1}.A_{rt}\right)^2\ .{COV_{sf}}^2 + \left(SR_P^{Thin}\right)^2.{COV_P}^2} \tag{5}$$

Damage factor thinning value can be determined using the Equation (6) below:

$$D_{fb}^{Thin} = \frac{\left(Po_{p1}^{Thin} \emptyset\left(-\beta_1^{Thin}\right)\right) + \left(Po_{p2}^{Thin} \emptyset\left(-\beta_2^{Thin}\right)\right) + \left(Po_{p3}^{Thin} \emptyset\left(-\beta_3^{Thin}\right)\right)}{1.56\ x\ 10^{-4}} \tag{6}$$

- External Damage - Df^{thin}

To determine the external corrosion damage factor, the same steps were carried out with the similar procedures as thinning damage factor, with a slight difference in the corrosion rate value and the data category. The different is the value used during external corrosion study uses low category based on API 581. Due to this, the beta reliability parameter value is posterior. Therefore, the probability can be determined.

2.2 Consequence of Failure (CoF)

Consequences are defined as the consequences of a failure. In the RBI API, the consequences of failure, are considered no varies with time [9]. The failure consequence analysis described in API 581 consists of 2 parts, namely Level 1 and Level 2. Level 1 is used when the representative fluid in the equipment being evaluated is listed in API 581. On the other hand, Level 2 is used if the representative fluid is not listed in the API 581 document. The procedure to perform consequence of failure is explained as follows:

1) Selection of Release Hole Size. The selection of release hole size is based on the provisions contained in API 581. For pressure vessels, there are 4 sizes of leak holes scenarios which can be used to perform calculations, namely 0.25 inch for small, 1 inch for medium, 4 inch for large, and 10.75 inch for rupture which is diameter of the pressure vessel itself.
2) Vapor release rate (Wn) calculation. The release rate is determined based on the type of fluid flowing in the equipment. So the equation used is for the gas equation. It was found that the operating pressure is greater than the transition pressure so that the equation used is Equation (7).

$$W_n = \frac{C_1}{C_2}.A_n.P_s\sqrt{\left(\frac{k.MW.g_c}{R.T_S}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \tag{7}$$

Where

W_n = release rate (lb/s)
W_n = Discharge coefficient
MW = Release fluid molecular weight (lb/lb-mol)
R = universal gas constant, 8.314 J/(kg-mol-K (1545 ft-lbf/lb-mol K)
T_S = Operating Temperatur (K)
A_n = Hole area related to releasenhole size, mm^2 ($inci^2$)
P_S = Operating pressure (psia)
C_2 = Nilai konversi faktor SI and US Customary

3) Capacity Calculation and Estimated Fluid Available For Release. If leakage is expected to happen on the equipment being evaluated, the fluid available for release shall be considered not only from the fluid contained in the equipment, but also outside the equipment within the components related to equipment under evaluation.
4) Determination of Release Type. Based on API 581 Base Resource Document, there are 2 types of leaks, namely instantaneous and continuous. If the amount of fluid mass that comes out is greater than 10,000 lbs for 3 minutes, then it is falls into category instantaneous type of leak, otherwise it is a continuous type.
5) Determination of the Impact of the Detection and Isolation System on Leaks. This step can be performed by using the information of type of isolation and detection system available for the equipment under evaluation.
6) Determination of Release and Mass Rate. Based on the value of the detection and isolation system factor that has been obtained, it can be used to determine the value of the leakage

rate. the mass of the leak and the actual duration of the leak. Therefore, to determine the value of the leakage rate for each size of the leak hole, Equation (8). is used:

$$Rate_n = W_n \; (1 - fact_{di}) \quad (8)$$

Then the mass of leakage can be determined by Equation (9):

$$mass_n = min \; [\; \{rate_n . ld_n\}, mass_{availl,n}] \quad (9)$$

7) Determining Flammable and Explosive Consequence. To determine the value of the damage consequence areas, the first thing to do is to determine the value of the component damage consequence areas and personnel injury consequence areas for each size of the leak hole. There are two possibilities that must be considered, namely Auto-Ignition Not Likely and Auto-Ignition Not Likely. The consequence area due to fire and explosion is obtained by Equations (10) for component damage and (11) for personnel injury.

$$CA_{imj}^{flam} = \left(\frac{\sum_{n=1}^{4} gff_n . CA_{imj,n}^{flam}}{gff_{total}} \right) \quad (10)$$

$$CA_{imd}^{flam} = \left(\frac{\sum_{n=1}^{4} gff_n . CA_{imd,n}^{flam}}{gff_{total}} \right) \quad (11)$$

8) Determining Toxic Consequence. Equation (12) shows the calculation to determine toxic consequence areas for each release hole sizes.

$$CA_{imj}^{tox} = \left(\frac{\sum_{n=1}^{4} gff_n . CA_{imj}^{tox-CONT/inst}}{gff_{total}} \right) \quad (12)$$

9) Determining the Final Value of Consequences. The final consequence of equipment under assessment can be obtained using Equation (13).

$$CA = max \; [CA_{cmd}, max \; \{CA_{imj}^{flam}, CA_{imd}^{flam}, CA_{imj}^{nfnt} \;\}] \quad (13)$$

2.3 Risk Level

Risk ranking which is designated as a unit of time function with risk distribution for different components can be plotted into a risk matrix, as shown in Fig. 2. After knowing the risk level of the existing equipment, then the determination of the appropriate inspection measures and scheduling of inspection intervals are carried out and then make recommendations for mitigation plant what companies can do. Analysis is required to re-examine actions and timing inspection is appropriate and in accordance with the needs. The higher risk of an asset, the shorter the frequency of inspection; whereas the lower the risk an asset have, it longer the frequency. The remaining life the asset can be determined by using the equation (14) as follows [6]:

$$remainning \; life = \frac{t_{actual} - t_{required}}{Corrosion \; rate} \quad (14)$$

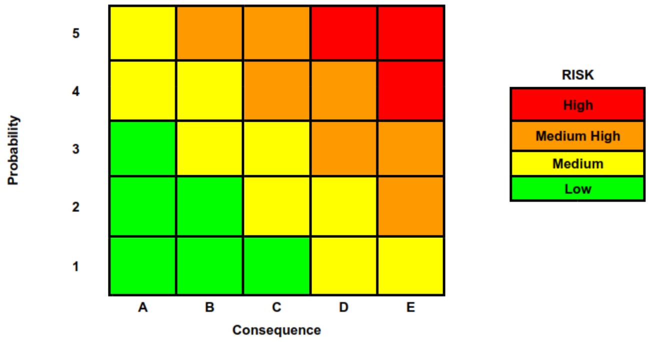

Fig. 2. Balanced Risk Matrix [6]

3 Results and Discussion

In this study, RBI analysis will be carried out on pressure vessel type equipment. This pressure vessel is a vertical type of separator type, namely a gas dryer instrument at PT. XYZ. This instrument gas dryer plays an important role in separating the fluid mixture from steam and condensate. The design and operational data of the gas dryer instrument are shown in Table 1. The data on mechanical properties of materials for each part of the gas dryer instrument is shown in Table 2.

Table 1. Gas Dryer Instrument Design and Operation Data

No.	Data	Value		Unit
1	Equipment Type	Pressure vessel		
2	Design Code	ASME SEC VIII Div. 1		
3	Design Pressure	285		psi
4	Design Temperature	150		ºF
6	Operating Pressure	180		psi
7	Operating Temperature	85		ºF
8	Allowable Stress	20000		psi
9	Joint Efficiency	1		
10	Outside Diameter	273.05		mm
11	Nominal Thickness	9.271		mm
12	Thickness Minimum	Top	1.94	mm
		Shell 1	3.92	mm
		Shell 2	3.92	mm
		Bottom	1.94	mm
13	Corrosion Allowance	3.175		
14	Mass Component	3.636.555		

Table 2. Mechanical Properties of Materials Constructing Gas Dryer

No	Part	Material	Yield Strength	Tensile Strength	Unit
1	Top	SA 105	36000	70000	psi
2	Shell 1	SA 106 - Gr. B	35000	70000	psi
3	Shell 2	SA 106 - Gr. B	35000	70000	psi
4	Bottom	SA 105	36000	70000	psi

The instrument gas dryer at PT. XYZ was installed on May 28, 1982 based on the information obtained. The inspection data of instrument gas dryer is presented in Table 3.

Table 3. Inspection History of Instrument Gas Dryer

No	Part	Previous Thickness	Thickness Minimum	Unit
1	Top	9.11	9.16	mm
2	Shell 1	8.94	8.81	mm
3	Shell 2	8.97	8.69	mm
4	Bottom	10.83	10.67	mm

Based on the inspection, it was found that there are two damage factor occurred on the instrument gas dryer, namely internal thinning and external corrosion. A systematic approach to calculate the damage factor was conducted Table 4 and Table 5 show the damage factor in four different location of internal thinning and external corrosion, respectively. Damage factor thinning value showed 0.1 is the result of adjustment to field conditions. The total damage factor value can be seen in Table 6. Table 7 shows the probability of failure.

Table 4. Thin Damage Factor Value

Point Location in Part	D_{fb}^{Thin}	D_{f}^{Thin}
Top Head	0.01235	0.1
Shell 1	0.00655	0.1
Shell 2	0.00667	0.1
Bottom Head	0.00938	0.1

Table 5. External Corrosion Damage Factor Value

Point Location	D_{f}^{Excorr}
Top Head	0.01486
Shell 1	0.0074
Shell 2	0.00754
Bottom Head	0.01109

Table 6. Damage Factor Total Value

Point Location	Df_{total}
Top Head	0.11486044
Shell 1	0.10739802
Shell 2	0.10754248
Bottom Head	0.11108831

Table 7. Probability of Failure Value

Point Location	$p_f(t)$	Unit
Top Head	$3.51472946 \times 10^{-6}$	Failure/year
Shell 1	$3.28637960 \times 10^{-6}$	Failure/year
Shell 2	$3.29080002 \times 10^{-6}$	Failure/year
Bottom Head	$3.39930238 \times 10^{-6}$	Failure/year

The fluid in the instrument gas dryer is methane gas, which falls into the category of wet gas. Based on Appendix 6 API 581, these fluids fall into the category of fluids C1 – C2 and are included in the gas phase. The properties of the fluid based on the representative fluid are as follows:

- Molecular Weight (MW) : 23 lb-mol
- Density (ρ) : 15. 639 lb/ft3
- NBP : -193 F
- Constant pressure (Cp) : 44,435 J/Kmol-K
- Ideal gas specific heat capacity ratio (k) : 1.230
- Auto Ignition Temperature (AIT) : 1036 F

In order to determine the consequence of failure, four different release hole sizes are used to simulate the fluid release rate, small size with diameter ¼ inch, medium size with diameter ¼ inch to 2 inches, large with diameter 2 - 6 inches, and rupture with diameter greater than 6 inches. Table 8 shows the vapor release rate for each release hole size.

Table 8. Probability of Failure Value

Release hole size	Wn	Unit
(1) Small	0.625	lb/s
(2) Medium	10.003	lb/s
(3) Large	160.041	lb/s
(4) Rupture	1155.921	lb/s

The inventory mass, based on the information data obtained, it is the same as the component mass because in the inventory list there are no other equipment that is directly connected without using a valve, so the mass inventory is the same as the mass component, which is **36.366 x 105 lbs.**

Based on the API 581 Base Resource Document, there are 2 types of leaks, namely instantaneous and continuous. If the amount of fluid mass that comes out is greater than 10,000 lbs for 3 minutes, then it is an instantaneous type of leak, otherwise it is a continuous type. After the calculation, the type of leakage at each size of the leak hole is shown in Table 9.

Table 9. Release Type

Release hole size	t_n (s)	Release type
(1) Small	5995.89	Continuous
(2) Medium	999.7435	Continuous
(3) Large	62.48397	Instantaneous
(4) Rupture	8.651107	Instantaneous

Based on the information obtained by the type of isolation and detection system. The classification value of the detection system for this equipment is **B** while the isolation system is **C**. So from this classification, the Reduction Factor ($fact^{di}$) value is **0.1**. Table 10 shows maximum leak duration (id_{max}) for each hole.

Table 10. Maximum Leak Duration

Release hole size	Id_{max}	Unit
(1) *Small*	3600	Seconds
(2) *Medium*	1800	Seconds
(3) *Large*	1200	Seconds
(4) *Rupture*	0	Seconds

After the leakage rate is obtained, the value of the leakage mass can be calculated for each hole size. The available mass for each leak hole size is 36.366 x 105 lbs. The mass of leakage can be determined by Equation (9). Table 11 and Table 12 show the leakage rate for each leak hole size and release mass, respectively.

The consequence area due to flammable and explosion can also determine, as shown in Table 13. Since the property of methane gas does not exhibit tixicity, therefore, the toxic consequence analysis is not condusted. The final of consequence area is shown in Tabel 14.

Table 11. Maximum Leak Duration

Release hole size	Id_{max}	Unit
(1) *Small*	3600	Seconds
(2) *Medium*	1800	Seconds
(3) *Large*	1200	Seconds
(4) *Rupture*	0	Seconds

Table 12. Release Mass

Release hole size	$mass_n$	Unit
(1) *Small*	2025.519	lb
(2) *Medium*	16204.15	lb
(3) *Large*	172844.32	lb
(4) *Rupture*	36.366 x 10^5	lb

Table 13. Flammable and Explosion Consequence Area

Consequence Area	value	Unit
Component damage	2581.65	ft^2
Personel injury	5056.88	ft^2

Table 14. Consequence Area (Consequence of Failure)

Consequence Area	Value	Unit
CA	**5056.88**	ft^2

Based on the results of the analysis that has been carried out, the PoF and CoF values in the gas dryer instrument are obtained. namely the PoF value of 3.51 x 10^{-6} in the Top Head section; 3.28 x 10^{-6} on the Shell 1; 3.29 x 10^{-6} on the Shell; and 3.39 x 10^{-6} on the Bottom Head. For CoF, the value is 5,056.88 ft2. From the PoF and CoF values, the risk level of the gas dryer instrument can be determined by entering this value into the 5x5 matrix shown in **Figure 3**. The highest PoF value is taken because the highest PoF value can represent a vulnerable failure level of an equipment so as to In this gas dryer instrument, the PoF value used is the Top head section where the 5x5 matrix is in **category 1** and the CoF value is in **category C**. So that the risk level for the gas dryer instrument analysed is **1C (Medium).** The blue lineindicates the risk target of PT. XYZ

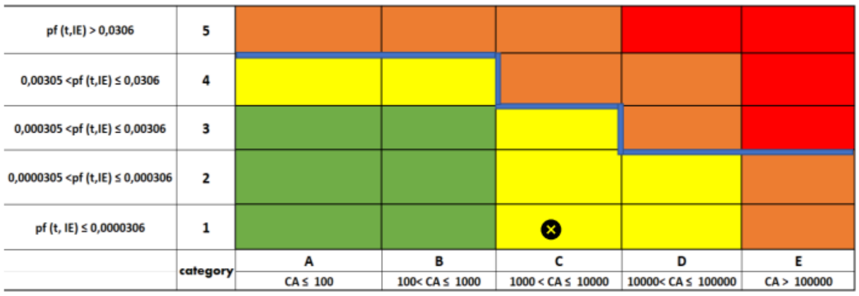

Fig. 3 Risk Matrix on Instrument Gas Dryer

Based on the API 510 pressure vessel inspection code, it is explained that the inspection is carried out for a maximum of 10 years or half of the remaining service life of the tool [6]. The remaining service life of the gas dryer instrument obtained from Equation (14) is 243.5 years.

Based on the risk results obtained on the gas dryer instrument, namely at the medium level, the PoF category is 1 and the CoF is C. Comparison of risk and the risk target shows that the risk is still under the permissible risk limit. An iteration is carried out to determine the time required for the risk to reach the risk target, which expected to be around 27 years.

4 Conclusion

Based on the discussion of the research study, below is some conclusion:

1. The risk level for pressure vessel equipment (instrument gas dryer) is 3.51 x 10^{-6} failure/year for PoF and 5056.88 ft^2 for CoF so that the risk level is in the **1C (medium)** category.
2. The level of risk in an equipment is influenced by several things, based on sensitivity analysis it is found that the corrosion rate. operating pressure and assessment date canaffect the PoF value on the equipment. Fluid type. mass available for release. and detection and isolation systems can affect the CoF value of the equipment.
3. Remaining life for the gas dryer instrument analysed is another 243.5 years. The expected period for the potential risk to reach the risk target is approximately around 27 years.

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