Risk Analysis Using the Risk-Based Inspection (RBI) Method for a Pressure Vessel at Offshore Platform

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Abstract. Energy sources that can be utilized by humans are oil and natural gas. However, in exploration activities, there are problems regarding the risk level determination of equipment in offshore platforms. The equipment that has an important function for the processing of oil and gas is a pressure vessel. In the contents of the hydrocarbon flow produced by the production well, it consists of various mixtures (gas, crude oil, and water). Therefore, it is necessary to have a separation process between the three fluid phases by using a device, namely a separator (pressure vessel). If the process of separating the three-phase from the hydrocarbon flow fails, it will result in product failure and also threaten the workers and the surrounding environment.

So, this study will use the risk-based inspection (RBI) method to determine the level of risk from a pressure vessel. The risk-based inspection (RBI) method was chosen because the oil and gas processing industry have a high level of risk so that safety for business management and environmental conditions is the main consideration. Another advantage of using the risk-based inspection (RBI) method is the reduced shutdown time and the number of equipment inspections.

1. Introduction

Energy is the main requirement used to meet various human needs. Therefore, it requires a large number of energy sources to meet human needs in various fields of life. One of the energy sources that can be used by humans is oil and gas. In this century, oil and gas exploration has been widely available in the high sea, because many oil and gas reserves are found in the depths of the seabed. For this reason, companies engaged in oil and gas mining are competing to build offshore platforms, which are useful for mining oil and gas from the bowels of the earth in the depths of the sea. An offshore platform is a building that operates in the open seas around an oil and gas source to carry out mining activities [1]. Many offshore structures are now widely used [2]: Shallow Water Complex, GBS (Gravity Base Structure), Compliant Towers, FPSO (Floating Production, Storage and Offloading), TLP (Tension Leg Platform), Semi-submersible Platforms, and SPAR.

However, in oil and gas exploration activities, many problems are encountered regarding how to determine the appropriate maintenance strategy for equipment in offshore platforms. So that the authorities in various countries issue regulations regarding the safety of installations and equipment in oil and gas business activities. For this reason, all existing equipment must be guaranteed reliability so as not to cause harm to both workers and the environment. One of the types of equipment that have an important function for the processing of oil and gas is a pressure vessel (separator) that functions to separate the three fluid phases (gas, liquid hydrocarbons/crude oil, and air) [3].

So that this research will explain about the risk-based inspection (RBI) method so that it can predict the criticality level of the pressure vessel. The risk-based inspection (RBI) method was chosen because the oil and gas processing industry have high and dangerous level of risk so that work safety for oil
and gas workers is a major consideration along with environmental conditions. Another advantage of using the risk-based inspection method (RBI) is the reduced plant shutdown time (because the RBI has a 3-5 year period of inspection or maintenance according to the type of equipment), a reduction in the number of inspection equipment (because RBI prioritizes units or equipment that have a risk criticality high/high risk), and reduced inspection and maintenance costs (because the RBI has a 3-5 year inspection or maintenance period according to the type of equipment, only the initial investment is slightly more expensive) [4].

2. Oil and Gas
Since ancient times, the use of petroleum has been widely used by humans around 5000 years ago by the Sumerians, Mesopotamians, and Egyptians [5]. Then in 1859, Colonel Edwin Drake drilled an oil well located in north western Pennsylvania [2]. Colonel Edwin Drake's success led to the start of the search for and mining of oil and natural gas internationally for industrial purposes.

![Drake Well](Figure 1. Drake Well [2].)

3. Offshore Platform
An offshore platform is a building that operates in the open seas around an oil and gas source to carry out mining activities [1]. According to ABB, there are several types of offshore platforms that are currently widely used. First, there is a shallow water complex, which is a combination of several platforms that have different functions and are connected by a gangway bridge as a connecting bridge between platforms (see Figure 2) [2]. Second, the gravity base structure (GBS) is a platform supported by a large concrete structure embedded in the seafloor (see Figure 3) [2]. Third, compliant towers are platforms that are supported by a relatively flexible foundation structure, so that this platform is suitable for placement in deep waters up to 1000 meters because it can absorb a lot of pressure [2]. Floating production, storage, and offloading or FPSO is a platform that is shaped like a large tanker and is a conversion from the VLCC or ULCC type tankers (see Figure 4) [2]. Tension Leg Platform or TLP is a platform equipped with vertical tendons that are connected to the seabed which is useful as a buffer (see Figure 5) [2]. The semi-submersible platform is a platform similar to the TLP, but without having a tight tie like a tendon (see Figure 5) [2]. Lastly, SPAR is a platform consisting of a single floating cylinder hull that has the function of stabilizing the platform while in the water and allows motion to stabilize the position in case of storms and support the deck platform [2]. However, the cylindrical hull does not extend directly to the seabed but is anchored under the sea by a series of steel cables or the like (see Figure 6).
Figure 2. Shallow Water Complex [2].

Figure 3. Gravity Base Structure [2].

Figure 4. Floating Production, Storage and Offloading [2].

Figure 5. Tension Leg Platform and Semi-submersible Platform [2].

Figure 6. SPAR [2].
4. Pressure Vessel

Equipment that has an important function for oil and gas processing are pressure vessels. Pressure vessels serve to separate the content contained in the hydrocarbon flow produced by production wells that consist of various mixtures, including gas, liquid hydrocarbons (crude oil), and water [3]. Based on its use, there are several types of separators commonly used in the oil and gas processing process, namely: vertical separator (see figure 7 and figure 8), horizontal single tube (see figure 9 and figure 10), horizontal double tube, and spherical [3].

Figure 7. Vertical Low-Pressure Oil and Gas Separator Mechanical Controls [3].

Figure 8. Vertical HP or LP Oil Gas Water Separation Pneumatic Controls [3].

Figure 9. Horizontal HP or LP Oil Gas Separator Pneumatic Controls [3].

Figure 10. Horizontal HP or LP Oil Gas Water Separator Pneumatic Controls [3].
5. Regulation for Processing Oil and Gas

Indonesia is one of the countries that issued regulations regarding safety in oil and gas processing, as follows:

- Regulation No. 1 Year 1970
- Government Regulation No. 11 Year 1979
- Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia No. 38 Year 2017

This regulation intends to take preventive measures against system failures that can affect human safety, the environment, and the product itself. The preventive action meant here is to inspect the equipment used to support activities based on the time-based method or the results of risk analysis to ensure success in production and to minimize the occurrence of failures.
6. Risk-Based Inspection (RBI)

Risk-based inspection (RBI) is a risk-based approach to prioritizing and planning inspections, especially in the oil and gas industry because it has high risks [6]. The purpose of the RBI is to identify the damage or defect that could have caused a large-scale accident before it occurred. Also, it can identify incidents that will occur (consequences) when equipment is damaged and how often (probability) these incidents occur [7].

In the RBI, the risk is defined as the product of the probability of an event occurring and the consequences of that event. It can be written systematically as follows [7][12][13]:

\[
\text{Risk} = \text{Probability} \times \text{Consequence} \tag{1}
\]

Risk assessment is a process to identify sources of hazards, so that they can estimate risks and evaluate them. This risk assessment process will answer the following questions [8]:

- What caused the problem?
- How often the problem can occur?
- What are the consequences of the problem?

According to API RP 581, risk can be written in the form of a 5 x 5 risk matrix which shows the level of risk into 4 categories, namely:

- Low Risk
- Medium Risk
- Medium High Risk
- High Risk

![Balance Risk Matrix](image)

Figure 14. Balance Risk Matrix [9]
7. Risk-Based Inspection (RBI) for Pressure Vessel

A pressure vessel is an equipment that has a temperature and pressure that is different from its environmental conditions [10]. Based on the applicable regulatory requirements, all equipment that uses pressure must be inspected following the inspection code used and is still valid. This inspection activity aims to maintain the appropriateness of the pressure vessel equipment to continue its function. One method that can be used to inspect pressure vessels is risk-based inspection (RBI). In API RP 581, it has been explained that the vessel is divided into 8 component types, namely: KODRUM, COLB TM, FINFAN, FILTER, DRUM, REACTOR, COLTOP, COLMID which must be adjusted to the type of vessel to be analyzed [9]. After that, data related to equipment/components, operating conditions, damage mechanisms, inspection history, and so on will be searched (data and information collection). After the data is obtained, calculations will be carried out related to the probability of failure (PoF) and the consequences of failure (CoF) (risk assessment process). So that the risk level is obtained and can make an inspection plan.

Data and Information Collection

Probability of Failure Analysis (PoF)

Consequence of Failure Analysis (PoF)

Risk Ranking

Inspection Plan

Figure 15. RBI Flowchart [7]

7.1 Data and Information Collection

At this step, data collection related to pressure vessels, such as operating conditions, damage mechanisms, inspection history, chemical compositions of fluid, volume inventory, mass inventory, and so on will be searched related pressure vessel.

7.2 Probability of Failure (PoF) for Pressure Vessel

For the steps in calculating the probability of failure (PoF) for a pressure vessel are as follows [11]:

- Calculates the generic failure frequencies (gffs)
- Determine and calculate the damage factors that occur, such as thinning damage factors, cracking damage factors, and so on.
- Calculate the total damage factor ($D_f(t)$)
- Calculate the probability of failure ($P_f(t)$)
7.3 Consequence of Failure (CoF) for Pressure Vessel

In accordance with the existing problem boundaries above, that the RBI analysis used is level 1 analysis, so the calculation of the consequences of failure (CoF) can be seen as follows [11]:

- Determine representative fluid and fluid properties
- Calculating the release hole size selection, which includes the following steps:
  - Calculate the hole size area \( (A_n) \)
  - Computes generic failure frequencies \( (gff_n) \)
- Calculate the release rate
  - Determine the release phase
  - Calculate the liquid release rate \( (W_n) \)
- Estimating fluid inventory available for release
  - Calculate the mass of component \( (mass_{comp}) \)
  - Calculate mass inventory \( (mass_{inv}) \)
  - Calculating mass available for release \( (mass_{avail}) \)
- Estimating the release type \( (t_n) \)
- Determine the release rate and mass
  - Determine the continuous release rate \( (rate_n) \)
  - Determine the length of leak duration \( (ld_n) \)
  - Determine the instantaneous release mass \( (mass_n) \)
- Determining the flammable and explosive consequences
  - Calculating the energy efficiency adjustment factor \( (eneff_n) \)
  - Calculate consequence areas for the equipment damage
  - Calculate consequence areas for personnel injuries
  - Determine factors for blending
  - Calculate blended consequence areas
  - Determine the final weighted consequence of the area
- Determining the toxic consequences
  - Calculate the toxic release rate and release mass
  - Determine toxic leak duration
  - Determine the area of toxic consequence
  - Calculate the weighted toxic consequence for the area
- Determine the non-flammable non-toxic consequences
- Determine component damage and personal injury consequence area
- Financial Consequences
  - Calculate component damage cost
  - Calculate damage costs to surrounding equipment in the affected area
  - Calculate accounts for the time lost in production while the failed equipment is offline
  - Calculate the resulting outage from damage to surrounding equipment
  - Calculate business interruption costs
  - Calculate the potential injury cost
  - Calculate the environmental clean-up cost
  - Calculating the total financial cost and toxic financial cost
- Risk analysis
  - Calculate the area risk
  - Calculate the financial risk


7.4 Risk Ranking

For plotting the values of probability and consequence into a graphic, two ways can be used, namely by using a risk matrix. To determine risk by area, the relationship between probability of failure and area-based consequence of failure can be used to form a risk level according to the risk matrix. And to determine risk by financial, it is possible to use the relationship between probability of failure and financial-based consequence of failure, which can be used to form a risk level according to the risk matrix.

| Tabel 1. Numerical Values Associated with PoF and Area-Based CoF Categories [7] |
|---------------------------------|---------------------------------|
| Probability Category | PoF Category \( P_f (t, I_E) \) |
| Category | Range \( \leq 3.06 \times 10^{-5} \) |
| 1 | \( 3.06 \times 10^{-5} < P_f (t, I_E) \leq 3.06 \times 10^{-4} \) |
| 3 | \( 3.06 \times 10^{-4} < P_f (t, I_E) \leq 3.06 \times 10^{-3} \) |
| 4 | \( 3.06 \times 10^{-3} < P_f (t, I_E) \leq 3.06 \times 10^{-2} \) |
| 5 | \( P_f (t, I_E) > 3.06 \times 10^{-2} \) |
| Consequence Category | Range \( (m^2) \) |
| Category | Area \( CA \) |
| A | \( \leq 9.29 \) |
| B | \( 9.29 < CA \leq 92.9 \) |
| C | \( 9.29 < CA \leq 929 \) |
| D | \( 929 < CA \leq 9,290 \) |
| E | \( CA > 9,290 \) |

| Tabel 2. Numerical Values Associated with PoF and Financial-Based CoF Categories [7] |
|---------------------------------|---------------------------------|
| Probability Category | PoF Category \( P_f (t, I_E) \) |
| Category | Range \( \leq 3.06 \times 10^{-5} \) |
| 1 | \( 3.06 \times 10^{-5} < P_f (t, I_E) \leq 3.06 \times 10^{-4} \) |
| 3 | \( 3.06 \times 10^{-4} < P_f (t, I_E) \leq 3.06 \times 10^{-3} \) |
| 4 | \( 3.06 \times 10^{-3} < P_f (t, I_E) \leq 3.06 \times 10^{-2} \) |
| 5 | \( P_f (t, I_E) > 3.06 \times 10^{-2} \) |
| Consequence Category | Range \( (m^2) \) |
| Category | Financial \( FC \) |
| A | \( \leq 10,000 \) |
| B | \( 10,000 < FC \leq 100,000 \) |
| C | \( 100,000 < FC \leq 1,000,000 \) |
| D | \( 1,000,000 < FC \leq 10,000,000 \) |
| E | \( FC > 10,000,000 \) |

7.5 Inspection Plan

The inspection plan is based on the risk level of a pressure vessel at the time the RBI analysis is carried out. If this inspection is carried out, it will not directly impact on reducing the risk of a pressure vessel. However, at least carrying out an inspection is expected to get actual information from a pressure vessel. The accuracy of this information is used to update the condition of a pressure vessel to reduce uncertainty in the analysis of the probability of failure.

The inspection plan is designed to detect and measure specific types of corrosion that may occur (such as local corrosion and general corrosion), cracking, or other types of damage. Each type of damage has its method of detection and measurement. So that the inspection plan is effective if the inspection method and the area of the inspected can represent the types of damage that may occur.
Tabel 3. Inspection Effectiveness Category [7]

| Inspection Effectiveness Category | Description                                                                 |
|-----------------------------------|-----------------------------------------------------------------------------|
| A                                 | Highly Effective: The inspection methods will correctly identify the true damage state in nearly every case (or 80-100% confidence). |
| B                                 | Usually Effective: The inspection methods will correctly identify the true damage state most of the time (or 60-80% confidence). |
| C                                 | Fairly Effective: The inspection methods will correctly identify the true damage state about half of the time (or 40-60% confidence). |
| D                                 | Poorly Effective: The inspection methods will provide little information to correctly identify the true damage state (or 20-40% confidence). The inspection method will provide no or almost no information that will correctly identify the true damage state and are considered ineffective for detecting the specific damage mechanism (less than 20% confidence). |
| E                                 | Ineffective: The inspection method will provide no or almost no information that will correctly identify the true damage state and are considered ineffective for detecting the specific damage mechanism (less than 20% confidence). |

8. Conclusion

From this explanation, it can be concluded that a pressure vessel is an equipment that has an important function in terms of processing oil and natural gas. The function of the pressure vessel is to separate the flow of hydrocarbons into 3 types of fluid (gas, oil, and water) for further processing. However, several factors cause failure in this activity. So that several authorities in various countries issued regulations regarding the safety inspection of installations and equipment in the oil and gas industry. Several authorities in various countries have also issued regulations regarding the safety inspection of installations and equipment in the oil and gas industry. For this reason, all existing equipment must be guaranteed reliability so as not to cause harm to workers and the environment. The risk-based inspection (RBI) method was chosen because the oil and gas processing industry have a high and dangerous level of risk. RBI is a method that is considered complex because it can determine and predict the current and future risk levels for pressure vessels.

References

[1] Putra, F. M. A., 2016. ANALISA TEKNIK DAN EKONOMIS PEMBANGUNAN INDUSTRI MANUFAKTUR BANGUNAN LEPAS PANTAI DI JAWA TIMUR. Surabaya: Repository ITS.

[2] ABB, 2013. Oil and gas production handbook an introduction to oil and gas production, transport, refining and petrochemical industry. Oslo: ABB Oil and Gas.

[3] Sivalls, C. R., 2009. Oil and Gas Separation Design Manual. Odessa: Sivalls, INC.

[4] Seo, J. K. et al., 2015. A risk-based inspection planning method for corroded subsea pipelines. ELSEVIER, 109(Ocean Engineering), pp. 539-552.

[5] Hassan, D. A., 2013. Review of The Global Oil And Gas Industry: A Concise Journey From Ancient Time to Modern World. Petroleum Technology Development Journal, Volume 3, pp. 123-141.

[6] Zhaoyang, T. et al., 2011. An evaluation of maintenance strategy using risk based inspection. ELSEVIER, 49(Safety Science), pp. 852-860.

[7] API, 2016. API RECOMMENDED PRACTICE 580-RISK BASED INSPECTION. 3th ed. Washington DC: API Publishing Services.

[8] Saifulloh, M., 2018. ANALISIS PENJADWALAN PROGRAM INSPEKSI PRESSURE RELIEF DEVICE (PRD) DENGAN METODE RISK BASED INSPECTION API 581 PADA CENTRAL PROCESSING PLANT SISTEM PRODUCTION GAS SEPARATOR. Surabaya: s.n.
[9] API, 2016. API RECOMMENDED PRACTICE 581-RISK-BASED INSPECTION METHODOLOGY. 3th ed. Washington DC: API Publishing Services.

[10] Al Qathafi, A. Q. & Sulistijono, 2015. Studi Aplikasi Metode Risk Based Inspection (RBI) Semi-Kuantitatif API 581 pada Production Separator. JURNAL TEKNIK ITS, Volume 4, pp. 89-94.

[11] Leta, J. & Mekker, J., n.d. Example Problems Manual For API RP 581. s.l.:The Equity Engineering Group, Inc..

[12] Siswantoro, N., Priyanta, D., Zaman, M.B., Semin, 2020. Failure Mode and Effect Criticality Analysis (FMECA) Fuzzy to Evaluate Critical Level on Main Engine Supporting System. IOP Conference Series: Earth and Environmental Science, 557, pp. 1-13.

[13] Siswantoro, N., Semin, Zaman, M.B., 2020. Criticality assessment for marine diesel engine using failure mode and effect criticality analysis (Fmeca) approach: Case study on lubricating oil system. International Review of Mechanical Engineering, 14, pp. 258-263.