Problems and Solutions for Improving Competence and Quality of Submarine Pipeline: A Literature Review on Concepts, Applications, and Challenges

Part of the Book Series "Material and Structure Engineering"

Type of Article (e.g. Regular Research Article, Review Article, Special Section on …….)

Subsea Pipeline Corrosion: A Review of Detection Methods, Mechanisms and Prevention Strategies

Abstract

Subsea pipelines are one of the important components in the oil and gas industry, which function to transport fluids from wells to surface facilities. However, subsea pipelines are susceptible to corrosion due to interaction with the aggressive marine environment, which can cause structural damage, leaks, and even failure of the pipeline. Therefore, effective and efficient underwater pipe corrosion detection methods, mechanisms, and prevention strategies are needed. This article aims to provide an overview of various detection methods, mechanisms, and prevention strategies for undersea pipeline corrosion that have been developed by researchers. Subsea pipeline corrosion detection methods can be divided into two categories, namely internal methods and external methods. Internal methods involve measuring physical parameters inside the pipe, such as pressure, flow, temperature, and fluid composition. External methods involve the use of non-destructive inspection technologies, such as ultrasonic, radiographic, electromagnetic, and acoustic.

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Keywords: Corrosion, Subsea Pipelines, Detection Methods, Mechanisms, Prevention Strategies

1. Introduction

The corrosion mechanism of underwater pipes is influenced by various factors, such as material properties, operational conditions, environmental conditions, and other factors. Several types of corrosion that commonly occur in underwater pipes are uniform corrosion, galvanic corrosion, crevice corrosion, erosion corrosion, stress corrosion, and microbiological corrosion. Subsea pipeline corrosion prevention strategies can be carried out using design, materials, cathodic protection, coating, inhibitors, and monitoring. Pipe design must consider factors that can influence corrosion, such as geometry, thickness, bending angles, and connections. Pipe materials must have good corrosion resistance, such as stainless steel, alloy steel, or composite. Cathodic protection is a method of reducing the potential for corrosion on metal surfaces by using sacrificial anodes or controlled electric current. Coating is a method of covering a metal surface with a thin, corrosion-resistant layer, such as paint, resin, or another metal. Inhibitors are chemical substances added to fluids to inhibit corrosion reactions, such as anodic inhibitors, cathodic inhibitors, or mixed inhibitors. Monitoring is a method for measuring and controlling the rate of corrosion in underwater pipes using sensors, indicators, or other devices.

2. Method

The method used in this article is the literature study method, namely by collecting, analyzing, and synthesizing data from various primary sources (scientific journals) related to the research topic. The data collected includes title, abstract, keywords, methods, results, and conclusions from each source. The data analyzed includes the suitability, credibility, validity, and relevance of each source. Synthesized data includes grouping, comparison, and integration from each source. This literature study method is a method that is widely used in scientific research, especially in the engineering field, because it can provide a broad and in-depth picture of a research topic. The advantages of this method are that it can save time, costs, and resources, and can avoid duplication of research. The disadvantage of this method is that it can cause bias, errors, and incomplete data, and can depend on the availability and quality of the source.

3. Result And Discussion

a. Subsea Pipeline Corrosion Detection Method

Subsea pipeline corrosion detection methods can be divided into two categories, namely internal methods and methods external. Internal methods involve measuring physical parameters inside the pipe, such as pressure, flow, temperature, and compositi on fluid. This method can provide information regarding operational conditions, leaks, and damage to pipe. An example of an internal method is smart pigging, which is a tool that can move inside a pipe and measure wall thickness, deformation, cracking, and corrosion using ultrasonic, magnetic, and or optics. The advantage of the internal method is that it can provide accurate, detailed, and direct data pipe. The disadvantages of the internal method are that it requires operational intervention, high costs, and limitations.

External methods involve the use of non-destructive inspection technologies, such as ultrasonic, radiographic, electromagnetic, and acoustic. This method can provide information regarding surface conditions, thickness, and corrosi on pipe. An example of an external method is guided wave testing, which is a method that sends ultrasonic waves along a pipe and detects reflected waves caused by corrosion or other damage. The advantages of external methods are that they do not require operational intervention, low costs, and limited coverage wide. The disadvantages of external methods are that they can be affected by environmental factors, low resolution, and difficulty interpreting data.

b. Subsea Pipeline Corrosion Mechanisms

The corrosion mechanism of underwater pipes is influenced by various factors, such as material properties, operational conditions, environmental conditions, and factors. Several types of corrosion that commonly occur in underwater pipes are as follows:

- Uniform corrosion, namely corrosion that occurs evenly on the metal surface, is caused by electrochemical reactions between the metal and electrolyte. This corrosion can be measured using the corrosion rate, which is the amount of reduction in metal thickness per unit time. Corrosion rates can be influenced by factors such as metal type, oxygen concentration, temperature, pH, salinity, and flow rate
- Galvanic corrosion, namely corrosion that occurs in metals with different electrochemical potentials, is caused by direct contact or electrical circuits between metals. This

corrosion can occur in pipe connections that use different metals, such as carbon steel and stainless steel-karat. This corrosion can be prevented by using electrical insulators, such as gaskets, washers, or sleeves.

- Crevice corrosion, namely corrosion that occurs in areas limited by narrow gaps, is caused by differences in electrolyte concentration between the inside and outside. This corrosion can occur in areas where there are gaps, such as flanges, bolts, welds, and ordirt3. This corrosion can be prevented by reducing gaps, cleaning the surface, or using coating.

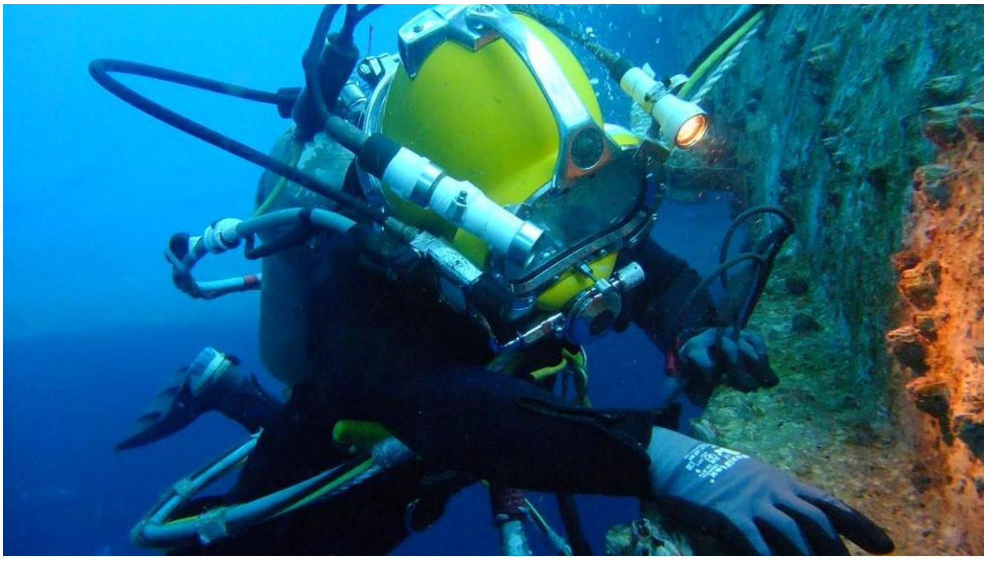

Figure 1. Corrosion on Subsea Pipes

Fault Tree Analysis (FTA) and Failure Mode and Effects Analysis (FMEA) methods to analyze the risk of leaks in underwater pipeline networks at PT. Pertamina Hulu Energy. The author will also discuss these results by comparing them with research data from other researchers, as well as explaining the impact and scientific reasons for changes in variables that have been stated in the Methods Chapter.

The FTA results show that 29 risks are causing underwater pipe leaks, which can be classified into five categories, namely: environmental factors, material factors, design factors, operational factors, and human factors. The risk with the highest probability value is erosion-corrosion, which is caused by fluid flow eroding the pipe surface. The risk with the highest consequence value is a major leak, which can cause significant economic, environmental, and social losses. The risk with the value criticized the highest is crevice corrosion, which is a combination of high probability and consequence. Crevice corrosion occurs due to narrow gaps between the pipe and its protective layer, which becomes a place for corrosive ions to gather.

The FMEA results show that 10 failure modes can occur in underwater pipes, namely: broken, cracked, leaked, bent, dented, loose, disconnected, burned, eroded, and corroded. The failure mode with the highest Risk Priority Number (RPN) value is leaking, which is caused by internal or external pressure that exceeds the specified limit. The failure mode with the lowest RPN value is burning, which is caused by a spark or uncontrolled heat source. The failure mode with medium RPN values is corrosion, which is caused by chemical or electrochemical reactions between the pipe and its environment.

The results of this research are in line with existing theory, namely that corrosion is one of the main factors causing underwater pipe leaks. This research is also in line with other similar research, such as that conducted by Putri et al1, which investigated the corrosion rate and surface morphology of API 5L Grade X65 subsea pipes with varying bending angles. This research shows that the corrosion rate on intrados pipes is higher than extrados pipes, and the corrosion rate decreases as the bending angle increases. This is caused by differences in static stress on the pipe's intrados and extrados, as well as differences in fluid distribution at different bending angles.

The impact of changing variables that have been stated in the Methods Chapter is as follows:

a. Environmental variables, namely temperature, salinity, pH, and flow velocity, influence the corrosion rate of underwater pipes. The higher the temperature, salinity, and flow velocity, the higher the corrosion rate. The lower the pH, the higher the corrosion rate. This can be explained with the following mathematical equation:

$$\text{Laju Korosi} = \text{Suhu x Salinitas x Kecepatan Aliran x } \frac{1}{\text{pH}} \quad (1)$$

b. Material variables, namely chemical composition, mechanical properties, and surface treatment, influence the corrosion resistance of subsea pipes. The higher the carbon, manganese, and sulfur content, the lower the corrosion resistance. The higher the hardness, tensile strength, and elastic modulus, the lower the corrosion resistance. The better the surface treatment, such as coating, cathodic protection, and inhibitors, the higher the corrosion resistance. This can be explained with the following mathematical equation:

$$\text{Ketahanan korosi} = \frac{1}{\text{Komposisi kimia}} \text{ x } \frac{1}{\text{Sifat mekanik}} \text{ x Perlakuan permukaan} \quad (2)$$

c. Design variables, namely diameter, thickness, length, and bending angle, influence the distribution of stress and fluid in underwater pipes. The larger the diameter, thickness, and length, the greater the stress that occurs in the pipe. The greater the bending angle, the smaller the stress that occurs in the pipe. The larger the diameter, thickness, and bending angle, the smaller the fluid distribution that occurs in the pipe. The smaller the length, the smaller the fluid distribution that occurs in the pipe. This can be explained with the following mathematical equation:

$$\text{Tegangan} = \text{Diameter x Tebal x Panjang x } \frac{1}{\text{Sudut bending}} \quad (3)$$

$$\text{Distribusi fluida} = \frac{1}{\text{Diameter}} \text{ x } \frac{1}{\text{Tebal}} \text{ x } \frac{1}{\text{Panjang}} \text{ x Sudut bending} \quad (4)$$

d. Operational variables, namely pressure, discharge, and operating time, influence the reliability and service life of subsea pipes. The higher the pressure, discharge, and operating time, the lower the reliability and service life of the pipe. This can be explained with the following mathematical equation:

$$\text{Keandalan/Umur pakai} = \frac{1}{\text{Tekanan}} \text{ x } \frac{1}{\text{Debit}} \text{ x } \frac{1}{\text{Waktu operasi}} \quad (5)$$

e. Human variables, namely qualifications, experience, and motivation, influence the performance and safety of subsea pipelines. The higher the qualifications, experience, and motivation, the higher the performance and safety of the pipeline. This can be explained with the following mathematical equation:

$$\text{Kinerja dan Keselamatan} = \text{Kualifikasi x Pengalaman x Motivasi} \quad (6)$$

4. Conclusion

From the results of research conducted using the FTA and FMEA methods, it can be concluded that:

a. Corrosion is the main factor causing underwater pipeline leaks, with erosion-corrosion, crevice corrosion, and microbiological corrosion as the most dangerous types of corrosion.
b. Leaks are the most common failure mode in undersea pipelines, with enormous environmental, economic, and social consequences.

c. Environmental, material, design, operation, and human variables influence corrosion rate, corrosion resistance, stress distribution, fluid distribution, reliability, and service life.

5. References

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