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

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Literature Review on Integrity Management of Subsea Pipelines Operating Beyond Design Life

Abstract

Subsea pipelines are an important means of offshore oil and gas transportation. Subsea pipelines that operate beyond their design life can experience reduced performance and integrity due to factors such as corrosion, leaks, cracking, buckling, and scour. Subsea pipeline integrity management aims to ensure that subsea pipelines can operate safely and efficiently throughout their life cycle. This article reviews literature related to integrity management of subsea pipelines operating beyond their design life, including concepts, methods, technology, and challenges faced. The results of the review show that integrity management of subsea pipelines operating beyond their design life requires a comprehensive, integrated, and adaptive approach, considering technical, economic, environmental, and social aspects. This article also provides recommendations for further research and development in this area.

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1. Introduction

Subsea pipelines are pipes installed on the seabed to transport fluids, such as oil, gas, water, or chemicals, from one location to another [1]. Subsea pipelines have a very important role in the offshore oil and gas industry because they can connect undersea oil and gas resources with production and distribution systems on land [2]. Subsea pipelines also have advantages compared to other transportation methods, such as tankers, trains, or trucks, because they are safer, more efficient, more reliable, and more environmentally friendly [3]. Subsea pipelines are usually designed to operate for a certain period, which is called design life. The design life of a subsea pipeline is determined by various factors, such as environmental conditions, technical specifications, quality standards, legal requirements, and availability of funds [4]. Generally, the design life of a subsea pipeline ranges from 20 to 50 years, depending on the type and function of the pipe [5].

However, in practice, many undersea pipelines are still operating beyond their design life, for several reasons, such as: (1) increasing demand for oil and gas, (2) decreasing oil and gas reserves on land, (3) advances in exploration technology and offshore production, (4) limited resources and costs to replace old pipelines, and (5) uncertainty regarding the future of offshore oil and gas projects. According to data from Oil & Gas UK, around 45% of subsea pipelines in the North Sea were operating beyond their design life in 2019, and this is expected to increase to 80% by 2030.

2. Method

a. Research object. The research object is scientific literature relating to the integrity management of subsea pipelines operating beyond their design life. The scientific literature in question includes journals, conferences, books, reports, and standards published within the last 10 years (2014-2024).
b. Treatment of research objects. The fixed variable of this research is the theme of integrity management of subsea pipelines that operate beyond their design life. The changing variables of this research are sub-themes which include concepts, methods, technology, and challenges related to the integrity management of subsea pipelines operating beyond their design life. The variation carried out in this research is the selection, filtering, and grouping of scientific literature based on these subthemes.
c. Solving methods/methods and procedures used for research. The method/solving method used for research is the content analysis method, namely the method for identifying, classifying, and summarizing the contents of selected scientific literature. The procedure used for research is as follows:

- Conduct scientific literature searches using web search engines, such as Google Scholar, Scopus, Web of Science, etc., using relevant keywords, such as "subsea pipeline", "integrity management", "design life", "corrosion", "leakage", "crack", "buckling", "scour", and combinations of these keywords.
- Filter the scientific literature obtained based on inclusion and exclusion criteria. Inclusion criteria are scientific literature in English, published within the last 10 years (2014-2024), and related to the integrity management of subsea pipelines operating beyond their design life. Exclusion criteria are scientific literature that does not meet the inclusion criteria, is duplicated, cannot be fully accessed, or is not relevant to the research objectives.
- Grouping filtered scientific literature based on predetermined subthemes, namely concepts, methods, technology, and challenges related to the integrity management of subsea pipelines operating beyond their design life.
- Analyze the contents of scientific literature belonging to each subtheme, by identifying, classifying, and summarizing important and relevant information, such as definitions, characteristics, advantages, disadvantages, developments, applications, and problems faced.
- Present the results of the content analysis in the form of a descriptive narrative, accompanied by tables, figures, or graphs if necessary, to provide a clear and comprehensive picture of the integrity management of subsea pipelines operating beyond their design life.

The systematic literature review method used in this article has been widely used in the field of science and technology because it can provide an objective, transparent, and reproducible review of a research topic. The advantage of this method is that it can provide a broad and in-depth overview of the latest developments in knowledge and practice in the field of integrity management of subsea pipelines operating beyond their design life. The disadvantage of this method is that it requires quite a lot of time and resources to search, filter, group, and analyze relevant scientific literature.

3. Results and Discussion

Subsea pipelines that operate beyond their design life can face various challenges and risks, which can affect the performance and integrity of the subsea pipeline. Subsea pipeline performance is the ability of a subsea pipeline to fulfill its function and purpose effectively and efficiently. The integrity of a subsea pipeline is the physical condition and structure of a subsea pipeline that meets established safety and quality standards [8]. Several factors that can cause a decrease in the performance and integrity of subsea pipelines that operate beyond their design life are as follows:

a. Corrosion. Corrosion is the process of material degradation due to chemical or electrochemical reactions with the surrounding environment. Corrosion can cause thinning of pipe wall thickness, decrease in pipe mechanical strength, and the formation of holes or cracks on the pipe surface. Corrosion can be influenced by various factors, such as the quality of the pipe material, the composition of the flowing fluid, operating temperature and pressure, flow speed, seawater salinity, biological activity, and cathodic protection.
b. Leaks. Leak is the unwanted loss of fluid from inside a pipe to the surrounding environment. Leaks can be caused by various factors, such as damage to pipe connections, failure of valves or flu, cracks or holes in pipe walls, or leaks in additional equipment, such as risers or manifolds. Leaks can cause economic losses, environmental pollution, and fire or explosion hazards.
c. Cracked. Cracks are the separation of pipe material into two or more parts due to mechanical stress that exceeds the elastic limit of the material. Cracks can be caused by various factors, such as external loads, internal loads, thermal loads, cyclic loads, dynamic loads, earthquake loads, explosion loads, or accidental loads. Cracks can cause a decrease in pipe strength and stiffness, increased leakage, and an increased risk of structural failure.
d. Buckling. Buckling is a large deformation of a pipe due to an axial load that exceeds the pipe's critical limit. Buckling can be caused by various factors, such as changes in temperature and pressure, ground movement, hydrodynamic forces, hydrostatic forces, gravity forces, or friction forces. Buckling can cause a decrease in pipe carrying capacity, increased pipe stress, increased leakage, and increased risk of structural failure.
e. Scour. Scour is erosion of the seabed due to water flows carrying sediment. Scour can be caused by various factors, such as flow speed, water depth, sediment size and shape, pipe size and shape, and pipe distance from the seabed. Scour can cause decreased seabed support, increased pipe loading, increased pipe deformation, and increased risk of structural failure.

To overcome the challenges and risks faced by subsea pipelines that operate beyond their design life, a systematic and structured process is needed to ensure that subsea pipelines can operate safely and efficiently throughout their life cycle. This process is referred to as subsea pipeline integrity management. Subsea pipeline integrity management is a concept based on three main principles, namely: (1) identifying and assessing risks associated with underwater pipelines, (2) implementing and monitoring risk prevention and mitigation measures, and (3) reviewing and improving the performance of subsea pipeline integrity management.

Figure 1. Subsea Pipeline Inspection

The results and discussion of this article are divided into four parts, namely concepts, methods, technology, and challenges related to the integrity management of subsea pipelines operating beyond their design life. Here is a summary of each section:

a. Draft. The concept of subsea pipeline integrity management is a systematic and structured process to ensure that subsea pipelines can operate safely and efficiently throughout their life cycle, taking into account technical, economic, environmental, and social aspects [1]. This concept is based on three main principles, namely: (1) identifying and assessing risks associated with undersea pipelines, (2) implementing and monitoring risk prevention and mitigation measures, and (3) reviewing and improving the performance of undersea pipeline integrity management [2]. The concept of integrity management for subsea pipelines operating beyond their design life is an adaptation of the integrity management concept for subsea pipelines in general, taking into account the special conditions faced by subsea pipelines operating beyond their design life, such as reduced performance and integrity due to factors such as corrosion, leakage, cracking, buckling, and scour [3]. This concept requires a comprehensive, integrated, and adaptive approach, involving all relevant stakeholders, such as operators, regulators, contractors, and the community [4].
b. Method. The underwater pipeline integrity management method is a method or tool for implementing the concept of underwater pipeline integrity management. These methods can be divided into two categories, namely: (1) methods for identifying and assessing risks, and (2) methods for implementing and monitoring risk prevention and mitigation measures. Methods for identifying and assessing risks include methods for collecting and analyzing data about the condition and performance of subsea pipelines, such as inspection, testing, modeling, and simulation [5]. This method also includes methods for measuring and classifying the level of risk associated with underwater pipelines, such as failure analysis, and reliability analysis.

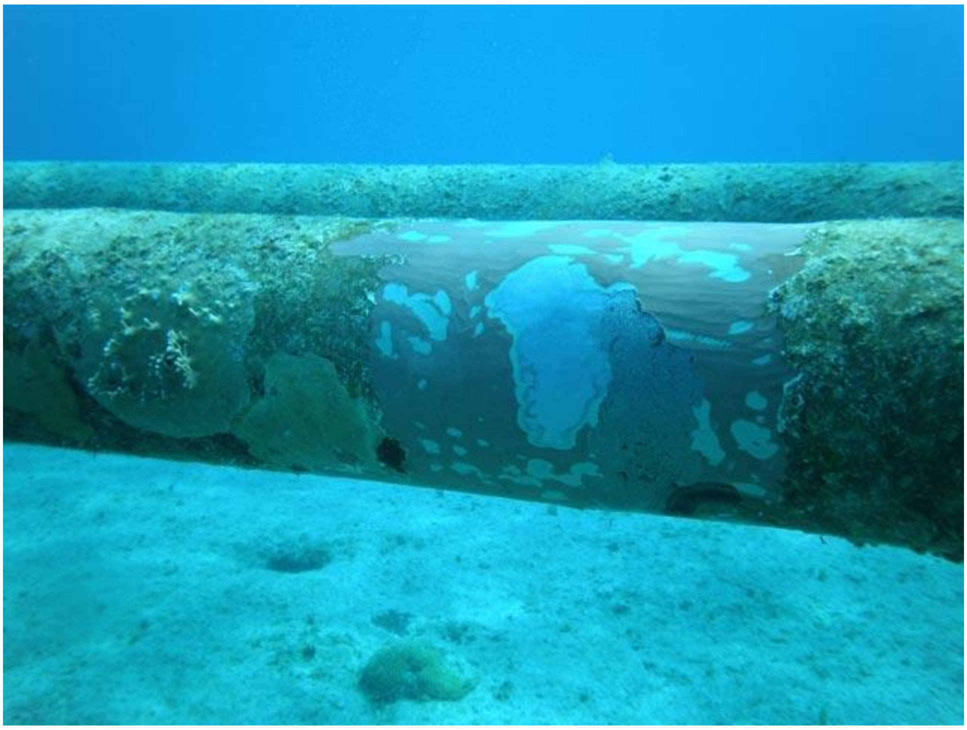

Figure 2. Subsea Pipeline Corrosion

- Subsea pipelines that operate beyond their design life require special attention in terms of risk management because they can have negative impacts on safety, the environment, and business.
- Factors that influence the risk of undersea pipelines must be understood and analyzed comprehensively, so that risk sources, risk levels, and possible risk impacts can be identified.
- The methods used in this literature review have their respective advantages and disadvantages, so they need to be adapted to the specific conditions and needs of the underwater pipeline being reviewed.
- Bayesian Network is a flexible method and can accommodate various variables and causal relationships involved in undersea pipeline risk, but requires sufficient and valid data to build and validate the model.
- DNV RP F107 is a practical standard and can provide technical guidance for designing, building, and operating subsea pipelines, but it cannot address dynamic and unpredictable risks.

4. References

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