THE EFFECT OF CORROSION DEFECTS ON BURST PRESSURE OF PIPELINES

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ABSTRACT

The predictions of pipeline burst pressure in the early stage are very importance in order to provide assessment for future inspection, repair and replacement activities. The failure of oil and gas pipelines contribute to economic implications and also constitute a serious hazards to the environment due to leakage. This thesis deals with the study on the effect of corrosion defect on the burst pressure of pipelines for API 5L X42 steel. The objectives for this project are to determine the burst pressure of corroded pipelines using Finite Element Analysis (FEA) and to compare the results with the available pipelines design code. This project implicates analysis of the API X42 steel by using MSC Patran 2008 r1 software as pre-processor and MSC Marc 2008 r1 software as a solver. A quarter of pipe was simulated by fully applying the symmetrical condition. The pipe is modeled in 3-D with outer diameter of 60 mm, wall thickness of 6 mm and different defect parameters. In this analysis, stress modified critical strain used as failure criterion to predict the failure of defective pipe. Result shows that the burst pressure decreases when both defect depth and length increases. The defect depth appear as a most influence parameter that affect the burst pressure. The circumferential extent has a less influence on the burst pressure. The results have been compared to available design codes for corroded pipelines such as ASME B31G, Modified ASME B31G and DNV RP F101. Comparison with available design codes have shown that FEA burst pressure gives higher values compare to codes. From the results, ASME B31G gives the lowest values than other codes.

ABSTRAK

Ramalan-ramalan tekanan letus saluran paip di peringkat awal adalah sangat penting untuk menyediakan penilaian bagi pemeriksaan pada masa akan datang, aktiviti pembaikan dan penggantian. Kegagalan saluran paip minyak dan gas menyumbang kepada implikasi ekonomi dan juga merupakan suatu bahaya yang serius kepada alam sekitar yang berpunca daripada kebocoran. Tesis ini berkaitan dengan kajian pada kesan kecacatan kakisan pada tekanan pecah saluran paip untuk API 5L keluli X42. Objektif bagi projek ini adalah untuk menentukan tekanan pecah paip berkarat yang menggunakan Analisis Unsur Terhingga (FEA) dan membandingkan keputusan dengan kod saluran paip reka bentuk yang ada. Projek ini aib analisis keluli API X42 dengan menggunakan MSC Patran 2008 r1 perisian sebagai pra-pemproses dan MSC Marc 2008 perisian r1 sebagai penyelesai. Satu perempat daripada paip adalah simulasi dengan menggunakan sepenuhnya keadaan simetri. Paip model 3-D dengan diameter luar 60 mm, ketebalan dinding 6 mm dan parameter kecacatan yang berbeza. Dalam analisis ini, menekankan tarikan kritikal yang diubahsuai digunakan sebagai kriteria kegagalan untuk meramalkan kegagalan paip rosak. Keputusan menunjukkan bahawa tekanan yang pecah berkurangan apabila kedua-dua kedalaman kecacatan dan panjang bertambah. Kedalaman kecacatan muncul sebagai satu parameter pengaruh yang paling yang memberi kesan kepada tekanan pecah. Sejauh lilitan mempunyai pengaruh yang kurang pada tekanan pecah. Keputusan telah berbanding kod reka bentuk tersedia untuk saluran paip berkarat seperti ASME B31G, Modified ASME B31G dan DNV RP F101. Perbandingan dengan kod reka bentuk yang ada telah menunjukkan bahawa tekanan letus FEA memberikan nilai yang lebih tinggi berbanding dengan kod. Daripada keputusan, ASME B31G memberikan nilai yang terendah daripada kod lain.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2-D	Two Dimension
3-D	Three Dimension
ASTM	American Society for Testing and Materials
ASME	American Society of Mechanical Engineers
API	American Petroleum Institute
ANSI	American National Standards Institute
DNV	Det Norske Veritas
FEA	Finite Element Analysis
FEM	Finite Element Method
HIC	Hydrogen Induced Cracking
RP	Recommended Practice
SCC	Stress Corrosion Cracking
SOHIC	Stress-Oriented Hydrogen Induced Cracking
SSC	Sulfide Stress Cracking
MSS	Maximum Shear Stress

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

A pipeline is all parts of the physical facility where liquids or gases such as crude oil and natural gas are transported usually over long distances between a producing region and a local distribution system. Offshore pipeline systems are vital to transport the raw oil products and gas from the oil platform to the onshore terminal. Such pipelines are necessary because the locations of oil/gas production sites tend to be far away from the refineries, processing plants and end user (Khan and Islam, 2007).

Offshore pipeline transport enormous quantities of oil and gas vital to the economic of virtually all nations. Therefore the exploration and production of oil and gases form adverse or hostile environments and from marginal field is becoming increasing important to ensure a continuous and independent energy supply. Production of oil and gas from sea bottoms,performed from stationary platform has gained wide development. Most of the sub sea oil and gas fields that been developed,or are under development, are marginal with a production life time between 5 and 15years (Martinussen, E. 1995).

As a pipeline ages, it can be affected by a range of corrosion mechanisms, which may lead to a reduction in its structural integrity and eventual failure. The economic consequences of a reduced operating pressure, loss of production due to downtime, repairs, or replacement can be severe and, in some cases, not affordable.

There are lots of methods (codes) in the engineering practice to determine the burst pressure of corroded pipes depending on the loadings and the scopes of the pipelines. These semi-empirical methods based on measurement data (ASME B31G, Modified ASME B31G, DNV RP F101,) consider only the length and depth dimensions of the simple, 3D geometrical shapes which are used to approximate the real corrosion failures. They are based on limit analysis of defective pipelines, however, one part of them over- or underestimate the burst pressures considering their geometrical models or semi-empirical factors. The transmission steel pipelines are usually made from ductile steel, but the majority of codes consider only elastic and perfectly plastic material behaviour. A fairly severe disadvantage of them is that they consider internal loads only. Because of these enumerated properties they can be called conservative.

1.2 PROJECT BACKGROUND

Predicting the failure of damaged oil and gas pipeline has become an essential art for the determination of design tolerance. A pipeline may experience significant internal and external corrosion defects by chemical and environmental effects that reduce its strength and resistance to fatigue, local buckling, leakage and bursting. Finite Element Modeling has become a reliable method for a prediction technique. The technique developed recently has enabled the reliable and accurate location and sizing of pipeline wall corrosion. The burst pressures of pipes with corrosion defects on their outer surfaces were determined with the help of FEA, where the calculated burst pressure values were called as ultimate pressures.

The main goal of the simulations was to determine how the depth, width, and length of the corrosion defects influence the burst pressures. The material use for this analysis is API 5L X42 steel. In order to determine stress triaxiality and equivalent strain, model with different parameter defects will be simulated in finite element software. For this purpose, MSC Patran/Marc 2008 r1 were applied. The main reasons for using MSC Patran/Marc for failure prediction is to reduce cost by replacing physical testing with less expensive digital simulation. True stress-strain data for API 5L X42 steel was used as input data in the finite element analysis.

Throughout this project, ASME B31G, Modified ASME B31G, and DNV-RP-F101 are the standards followed in order to standardize the results obtained. The limitations of this study are subjected to previously mentioned codes and standard. The data from the analysis will be compared with the available design code for pipelines.

1.3 PROBLEM STATEMENT

Nowadays, the investigation of the crude oil- and natural gas transmission steel pipelines applied in the pipeline industry has generally revealed that the primary reason for their failure is corrosion. Wall thinning caused by corrosion failure on the inner or outer surfaces of the pipelines will generate stress concentration on the pipe wall. The highest stress and strain value will occur at the deepest point of the corrosion defect, therefore the failure of the pipelines are usually expected at this location. Including dimensions (length, width, depth) of the corrosion defects influence the stress concentration to a different extent. (Length of the defect refers to the longitudinal, the width of the defect refers to the circumferential directions of the pipelines.)

Integrity assessment of corroded pipeline is very vital in oil and gas industry. Better understanding is required to reduce the conservatism involved in the current assessment method. Previous research has found out that finite element analysis has become a reliable engineering approach towards achieving actual results. Many Consultant Company realize that it is difficult to have a finite element modeling of the offshore corroded pipeline as the modeling need further understanding and detail research on each data. In this research, finite element analysis will be implemented comparing with the available codes as it is a higher demand in the oil and gas industry. This research will be a start and guidance in helping industries towards achieving accurate prediction of failure on corroded pipelines.

1.4 OBJECTIVES

For this project, two main objectives are listed:

i. To determine the burst pressure of corroded pipelines using Finite Element Analysis (FEA)
ii. To compare the FE burst pressure results with available design code for corroded pipelines.

1.5 SCOPE OF STUDY

The scope of study of this project is failure predictions which include the study of remaining strength of corroded offshore pipeline by using finite element analysis software. The scope of the research are :

a) API 5L X42 steel is used in this analysis.
b) MSC Patran is used as pre-processor and MSC Marc is used as solver.
c) Finite element analysis (FEA) condition:
   - 3-D model.
   - Homogeneous material model.
   - Elastic-plastic.
   - Reduced integration.
   - Non-linear.

d) True stress-strain data for API 5L X42 steel was used as input data in the finite element analysis.
e) Stress modified critical strain model is the failure criterion used to predict the burst pressure.
f) Finally, finite element results will be compared with the available design code that are ASME B31G, Modified ASME B31G, and DNV-RP-F101.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will briefly explain about the properties, material , design, failure and cause of failure in pipeline. The sources are taking from journals, articles, and books. Besides, the information about the software that will be used also included in this chapter. Literature review is done to provide information about previous research and that can help to smoothly run this project. All this information is important before furthering to the analysis and study later.

2.2 OIL EXPLORATION REVIEW IN MALAYSIA

The first oil well discovered in Malaysia was by Shell Company, in 1910 in Miri, Sarawak. Thereafter, the same company constructed Malaysia's first refinery in 1914, which undertakes the whole manufacturing of petroleum products. At present, Malaysia's oil company, PETRONAS undertakes the exploration and production of the oil and gas in Malaysia whilst Shell and other oil companies operate as a contractor to PETRONAS under Production Sharing Contracts.

Malaysia's oil and gas fields can be found mainly offshore of Peninsula Malaysia as well as the east coast. At present, Malaysia has 37 producing oil fields and 11 producing gas fields whilst several others are under development. The main five oil fields that produce high quality blends of crude can be found in the east of Peninsula Malaysia mainly, Tapis, Labuan, Miri, Bintulu and Dulang. It has been estimated that Malaysia has been producing 630,000 barrels of oils and five billion cubic feet of gas per day. Such an amount produced has made Malaysia one of the niche players in the oil and gas industry.

Malaysia has uncovered an estimated 214 gas field and most of these fields are under some development. As at 1 January, 2000, Malaysia has about 3.4 billion barrels of crude oil reserves and about 84.2 trillion standard cubic feet of gas reserves. This reserve has successfully placed the country at 27th and 12th places respectively in terms of world ranking. PETRONAS has the licensing authority for all upstream activities: exploration, production and transportation of oil in Malaysia. Most of the country's oil fields contain 10 low sulphur, high quality crude, with gravities in the 35-50 API range. Over half of the country's oil production comes from the Tapis field, which contains 44 API oil with low sulphur content (EIA, 2000; PETRONAS, 1999). Esso Production Malaysia Inc. (EPMI) is the largest crude oil producer in Peninsular Malaysia, accounting for nearly half of Malaysia's crude oil production. EPMI operates seven fields near the peninsular, and one-third of its production comes from the Seligi field. (EIA, 2000).

Currently, Terengganu produce more than half of Malaysia's total oil output with daily production totalling 380,000 barrels (EIA, 2000). Proven reserves off Terengganu total 2.4 billion barrels from 18 oil fields. Besides PETRONAS Carigali (PCSB), five other companies are also involved in the oil and gas exploration off Terengganu coast in PSC agreement. They are International Petroleum Ltd, USA; Esso Production Malaysia; Western Mining Corporation, Australia; Texaco and Penyu International Inc. The others major oil companies operating in Sabah and Sarawak are Shell, Sarawak Shell Berhad, Sarawak Shell/PETRONAS Carigali, and Amoco (PETRONAS, 2001). Figure 2.1 shows Malaysia`s oil production and consumption in 1990 until 2009.

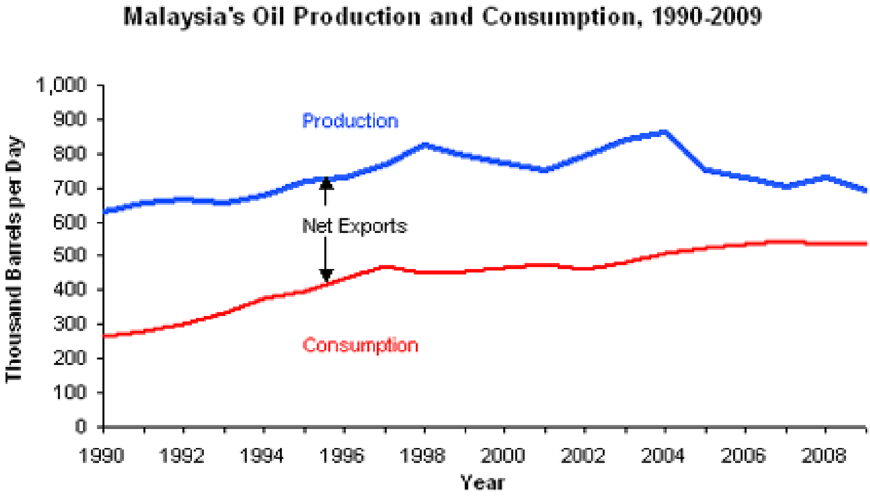

Figure 2.1: Malaysia`s oil production and consumption

Source: Petronas (2001)

PETRONAS is concern in the area of safety regulations and enforcement. Among the tools for ensuring pipeline integrity, one of the most successful is risk management and RBI (Reid, 1998). PETRONAS has been successful in implementing RBI for platform structures and for mechanical piping. Number of planned comprehensive inspection for platform structures have been reduced from 117 to only 59 after the implementation of RBI procedure (Goh, 2000). Now, PETRONAS is moving ahead in implementing the same procedure for offshore pipelines.

2.3 THEORY OF CORRODED PIPELINE

Corroded pipeline are referring to the pipeline that undergo the chemical reaction between a metal or alloy and its environment. A pipeline may experience significant internal and external corrosion defects that will reduce its strength and resistance to fatigue, local buckling, leakage and bursting. Corrosion mechanisms include electrochemical corrosion, chemical corrosion, and stress-promoted corrosion.

The strength of old pipelines declines because of a number of reasons, with corrosion being the major one. This is especially true when the pipeline is not well corrosion–protected. The study of increasing corrosion resistance is essential to reduce the maintaining cost. The factors that most influence the behaviour of the stainless steel, in rough order of importance to corrosion, are as follow:

1. Presence of oxidizing species which aids reformation of the oxide film
2. Chloride ion concentration because chloride hinders oxide film repair
3. Conductivity of the electrolyte, which affects the cathode/anode ration
4. Crevices that can initiate corrosion
5. Sediments that prevent reformation of the oxide film
6. Scales and deposits that prevent reformation of the oxide film
7. Chlorinating practice that alters the chlorine content of the environment
8. Surface condition of the stainless steel
9. pH(if below 5) that increase the cathodic reactions
10. Temperature that alters the relative rates of oxide film breakdown, corrosion processes and oxide film reformation rate.

The reaction that occurs when steel is immersed in sea water or corrosive liquid environment can be written as followed (Craig, 1993):

$$\text{Oxidation: } Fe \rightarrow Fe^{2+} + 2e^{-} \tag{2.1}$$

$$\text{Reduction: } O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-} \tag{2.2}$$

The overall reaction will be written as (Khan and Islam, 2007):

$$2Fe + 2H_2O + O_2 \rightarrow 2Fe^{2+} + 4OH^- \qquad (2.3)$$

Or

$$2Fe + 2H_2O + O_2 \rightarrow 2Fe(OH)_2 \qquad (2.4)$$

However, ferrous hydroxide (corrosion products) reacts with salt to form ferrous chloride:

$$Fe(OH)_2 + 2NaCl \rightarrow FeCl_2 + 2NaOH \qquad (2.5)$$

In the later stage of corrosion, ferrous chloride reacts with water to form hydrochloric acid:

$$FeCl_2 + 2H_2O \rightarrow Fe(OH)_2 + 2HCl \qquad (2.6)$$

2.4 TYPES OF CORROSION

Corrosion can be categorized in various ways which are (Craig, 1993):

2.4.1 Uniform corrosion

Uniform corrosion represents the ideal case in which the metal is uniformly corroded away at some constant rate. Figure 2.2 shows uniform corrosion of pipe. This type of corrosion attack is the basis for most design. Corrosion often very localized and failure occurs long before failure by general thinning of metal. This form of corrosion is observed on metal structures exposed to the atmosphere such as offshore platforms.

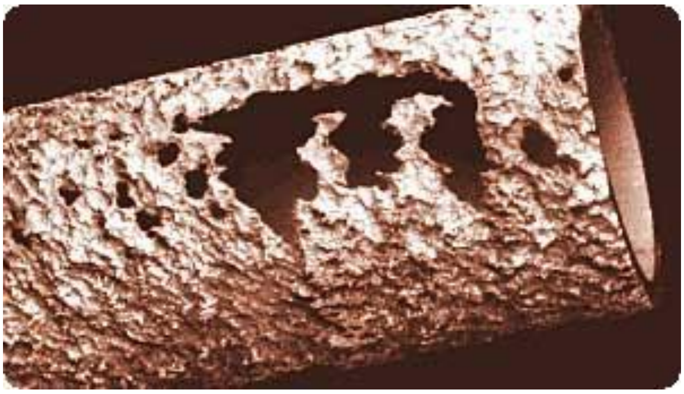

Figure 2.2: Uniform corrosion

Source : Craig (1993)

2.4.2 Pitting corrosion

Pitting attack is one of the most frequent forms of corrosion encountered. It shows a very localized attack in a few weeks or months while the remaining area of metal is relatively uncorroded. The shape of pits depends on the particular pitting environment. Once pitting is initiated, the remaining unpitted surface area becomes cathodic to the pits. As pits progress, pH of solution in the bottom of pit is reduced often to a pH of 1. With the reduction in pH together with anodic character of the pit, it drives the corrosion process until the metal is perforated. During perforation of metal, some pits will initiate and then stop growing while others propagate to various depths and stop or continue to grow until failure. While pitting can be catastrophic and difficult to predict, it is necessary to understand the environments which induce pitting. Figure 2.3 shows pitting corrosion of pipe.

Figure 2.3: Pitting corrosion

Source : Craig (1993)

2.4.3 Dealloying corrosion

Dealloying or selective leaching is the selective corrosion of one element in an alloy. Figure 2.4 shows dealloying corrosion of pipe. Dezincification is an example of dealloying whereby zinc is selectively attacked and removed from brass alloys, leaving only copper behind. Another form of cast irons attack is called graphitization is whereby the iron matrix of gray cast iron is being corroded leaving behind a layer of graphite. For instance, gray cast-iron butterfly valves and water pumps used in petroleum industry are most susceptible to this type of corrosion.