Journal of Loss Prevention in the Process Industries 37 (2015) 101–109

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: www.elsevier.com/locate/jlp

Risk assessment of offshore crude oil pipeline failure

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ARTICLE INFO

Article history:
Received 26 May 2015
Received in revised form
12 July 2015
Accepted 12 July 2015
Available online 15 July 2015

Keywords:
Leak detection systems
Offshore pipelines
Risk-based assessment
Probability of failure

ABSTRACT

Failure of Leak Detection System (LDS) to detect pipeline leakages or ruptures may result in drastic consequences that could lead to excessive financial losses. To minimize the occurrence of such failure, the functionality of the LDS and the integrity of the pipeline should be assessed on a priority basis. This paper presents an integrated risk-based assessment scheme to predict the failure and the failure consequences of offshore crude oil pipelines. To estimate risk, two important quantities have to be determined, the joint probability of failure of the pipeline and its LDS and the consequences of failure. Consequences incorporate the financial losses associated with environmental damage, oil spill cleanup and lost production. The assessment provides an estimate of the risk in monetary value and determines whether the estimated risk exceeds a predefined target risk. Moreover, the critical year for the asset can be determined. In essence, the outcome of the assessment facilitates an informed decision-making about the future of the asset.

1. Introduction

Pipeline rupture or leakage that has been miss-detected by LDS exposes public, or the environment to safety and health hazards. Moreover, it decreases oil and gas production and in the worst cases scenario causes a partial or complete shutdown of the production facility. According to the UK Health and Safety Executive (HSE UK, 2011) there were about 1978 incidents involving offshore hydrocarbon releases between 2001 and 2011 in the UK continental shelf. As per the US Pipeline & Hazardous Materials Safety Administration (PHMSA, 2014), there were about 306 offshore pipeline incidents in the U.S in the past 10 years. Out of these incidents, 71 involved hydrocarbon releases. Any failure involving the release of hydrocarbons may end up in a catastrophic incidents resulting in fatalities, damage to the environment and may threaten the corporate economy. The worst impact of all is the exposure of the public to danger in areas where the pipelines are close to shorelines or residential areas.

In light of the above, assessing the pipeline and its LDS integrity to ensure that they do not present any safety or operational risks is highly recommended. Such assessment should take into consideration the pipelines degradation mechanisms and their growth rate. Moreover, the assessment should be comprehensive and takes into consideration the likelihood and consequences of failure of the pipeline and the LDS. To address these issues, a risk-based assessment method should be applied to determine the level of risk expressed in dollar value. Having such information will enable operators to determine when and where to take the appropriate action to mitigate risk.

Several authors have contributed to the subject of risk-based assessment for maintenance planning, optimum replacement of the degraded components or risk assessment and its impact on safety and the environment. Risk-based assessment methods have been used to determine the optimal replacement of offshore process components, based on the likelihood and consequence of failure caused by time-dependent degradation mechanisms (Thodi et al., 2013). Bayesian theory along with risk-based assessments have been applied to update the probabilistic pipelines deterioration (Khan et al., 2006; Straub and Faber, 2005; Tang, 1973) and to determine the optimal inspection plans (Straub and Faber, 2005). Moreover, risk based methodology has been used in conjunction with other techniques such as fuzzy logic to address subjectivity and uncertainty. Risk-based assessment methodology based on fuzzy logic has been used to perform risk-based assessment for

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http://dx.doi.org/10.1016/j.jlp.2015.07.004
0950-4230/

Nomenclature

C	capacity
C_a	discharge coefficient is equal to 0.61 (DNV – RP – G101,2010)
C_P	price of oil – $/Barrel
Cof	consequences of failure
$Cost_{failure}$	cost of failure
CoV	coefficient of variance
D	diameter of the pipeline – mm
$d(T)$	corrosion depth measured at time T
d_C	critical corrosion depth
d_o	initial defect depth – mm
ΔT	time interval
$L(T)$	estimated corrosion length at time T
L_O	initial defect length – mm
EC	environmental consequences
FV	future value
i	nominal interest rate
i^*	real interest rate
IC	inspection cost
LDS	leak detection system
LPC	lost product cost
LSF	limit state function
M	Folias factor
N	number of simulation trials
N_f	number of simulation trials that violate the LSF
P_f	failure pressure
P_o	operating pressure of the pipeline segment – MPa
P_s	external pressure surrounding the leaking spot – MPa
PFA	probability of false alarm
PL	pipeline
Pof	probability of failure
Pof_{Target}	target probability of failure
PMD	probability of missed detection
Q_B	leak rate – (Barrels per hour)
Q_h	leak rate – kg/h
RC	segment replacement cost
$Risk_{Target}$	target risk
SNR	signal to noise ratio
T	time
t	pipe wall thickness-mm
T_{lp}	period of time where the production was lost due to spill (hours)
T_{dp}	period of time where the production was lost due to the shutdown of the pipeline for repair
V_{cr}	corrosion annual growth rate (mm/year)
Xth	threshold – °C
$Y_{B-failure}$	critical failure year due to burst
Y_{B-risk}	critical risk year due to burst
Y_C	critical year
$Y_{L-failure}$	critical failure year due to leakage
Y_{L-risk}	critical risk year due to leakage
Z	performance function
β	reliability index
μ_Z	mean of the LSF
ρ	liquid density – kg/m^3
σ_U	ultimate tensile strength –MPa
σ_Z	standard deviation of the LSF

pipelines (Singh and Markeset, 2009). Likewise, risk-based methodology has been used in conjunction with Analytical Hierarchy Process (AHP) to select a maintenance strategy (Bevilacqua and Braglia, 2000; Zhaoyang et al., 2011). Multi attributes decision making techniques have been used to improve risk assessment methodology to analyze risk and to provide a maintenance model for oil and gas process components, (Khan et al., 2004).

The cost associated with the offshore or subsea facilities is much higher than that of the onshore facility (Rangel-Ramirez and Sorensena, 2012). For the offshore cases, the unplanned inspection, repair or replacement work requires mobilization of equipment and personnel transported by boats or by a helicopter, and in some cases may require the deployment of Remotely Operated Vehicles (ROVs). In addition, the extensive coordination effort and logistics are very difficult to undertake.

As per the reviewed literature, the subsea pipeline was not specifically addressed in the risk based integrity assessment as a distinct component; all what had been indicated is a general case scenario for either a whole plant or other assets associated with the processing facility. The risk-based assessment should take into account the degradation mechanisms, their growth rate and should determine the likelihood and consequences of failure.

The objective of this paper is to provide a risk-based methodology for assessing offshore crude oil pipeline leakage and burst failures. The calculated risk is the expected financial losses that an operating company may incur as a result of the joint failure of the pipeline and the LDS. Essentially, the assessment helps decision makers to determine when and which component of the asset requires an immediate remedial action.

Section 2 provides an overview and background information; Section 3 summaries pipeline risk assessment; Section 4 outlines the methodology to assess the pipeline risk; Section 5 presents a case study; Section 6 presents the results and provides a discussion about the results and finally Section 7 provides a summary and concluding remarks.

2. Overview and background information

The key elements of risk assessment are the estimation of the probability of failure and assessment of its consequences. Pipeline degradation takes place as a result of corrosion, cracks or any other anomalies that grow over time. If the anomalies are overlooked or ignored and left without being repaired or the affected assets are not replaced, they may grow randomly over time. Hence, the pipeline probability of failure, which can be calculated by limit state approach, can be estimated by stochastic modeling of the degradation mechanisms. For the corrosion, the limit state function defines the difference between the measured and the critical corrosion flaw depth, and for the collapse pressure, it defines the difference between the operating and failure pressures. The LDS probability of failure is the probability of missed detection that can be expressed in terms of the signal to noise ratio and the probability of false alarm (Aljaroudi et al., 2014b). The consequence of failure is estimated as the cost of failure, which comprises the cost of pipeline replacement, environmental damage repair, and financial losses associated with lost production.

3. Pipeline risk assessment

The assessments starts by determining the damage mechanisms and the rate of their growth over time and the likely failure events (leakage or burst). The limit state approach is used to estimate the