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Application of Markov modelling and Monte Carlo simulation technique in failure probability estimation — A consideration of corrosion defects of internally corroded pipelines

Chinedu I. Ossai *, Brian Boswell, Ian J. Davies

Department of Mechanical Engineering, Curtin University, GPO Box U1987, Perth, WA 6845, Australia

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ABSTRACT

For effective integrity management, the reliabilities at times of exposure of pipelines to corrosive environment need to be understood. This paper described the procedure for using Markov modelling and Monte Carlo simulation to determine the reliabilities of internally corroded pipelines. The corrosion wastage of the pipeline was classified with Pipeline Corrosivity Indexes (PCIs), which were expressed as functions of retained pipe-wall thickness at exposure times. The model was tested on X52 grade pipeline that was monitored by Magnetic Flux Leakage (MFL) In-Line-Inspection (ILI) technique and the failure probabilities were determined for different failure scenarios such as small leakage, bursting and rupture. It was observed that, as the time of exposure of the pipeline to corrosive condition increased, there was a slight variation of the reliability of the pipeline that failed by bursting and rupture. The result also indicated a very high likelihood of small leakage of the pipeline than bursting and rupture. Since the failure probability of the corroded pipeline increases with increased time of exposure, it is expected that this model will be viability for the integrity management of internally corroded pipelines.

1. Introduction

Managing oil and gas pipelines entails the oversight of the corrosion problems, which degrade these assets over time in operation. Numerous research has pointed to corrosion as the major problem associated with pipelines used for oil and gas transportation [1–3], due to the enormity of downtime it contributes to the entire production process [4–5]. Hence, concerted efforts have been made by relevant stakeholders to predict the rate of corrosion and estimate the remaining useful life of corroded oil and gas pipelines. The work of researchers on the probabilistic estimate of pipeline corrosion using different techniques highlights the importance of this study area. Singh and Markeset [6] provided a hybrid approach for calculating the likelihood of failure of corroded pipelines under internal pressure by using a 2D fussy Monte Carlo simulation approach. Teixeira et al. [7] used the First Order Reliability Method (FORM) and Monte Carlo simulation in estimating the reliability of corroded pipeline subjected to corrosion whilst Qian et al. [8] depended on FITNET FFS procedure and Monte Carlo simulation for correlating the effects of corrosion defects on pipeline failure probability. Other researchers such as Pandey [9], utilized in-line inspection data obtained from a magnetic flux leakage technique for establishing the future time of pipeline inspection in consideration of the probability of failure of corroded pipeline whereas Ahmmed [10] adopted failure model that was based on fracture mechanics. Zhang et al. [11] utilized Monte Carlo simulation in the work, which focused on deterministic approach for corroded pipeline failure probability estimation. Keshtega and Miri [12] applied average shear stress criterion in their own probability estimation of corroded pipelines whereas

* Corresponding author.

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Breton et al. [13] and Bisaggio and Netto [14] used Bayesian probability approach to estimate the probability risk of corroded pipelines.

Other researchers such as Paik and Kim [15] determined the effect of corrosion on the burst strength of a pipeline elbow by numerically analysing the effects of the internal and external pressure of the corroded elbow on its failure strength using finite element analysis. Other authors [16] used the scatter of corrosion wastage at exposure times to formulate an empirical model that was based on the Weibull function for estimating the future corrosion defect of steel structures exposure to salt water environment.

Although numerous research works have been carried out on pipeline corrosion estimation and probability analysis, there is limited information on failure probability estimation of corroded pipelines using Pipeline Corrosivity Index (PCI). Hence, this work aims to predict the failure probability and estimate the reliability of corroded pipelines in consideration of the retained pipe-wall thickness of corroded pipeline at a given time. The research will use Markov modelling and Monte Carlo simulation for predicting the survival probability of corroded pipelines at a given time for different corrosion wastage rates whilst using Weibull probability function to calculate the time lapse for pipeline leakage. Markov modelling and Monte Carlo simulation was used for the model developed in this paper because it has been used for estimating the failure probability of corrosion defect growth of corroded pipelines and other structures by numerous researchers [9–13]. Again, given the successful use of these techniques in different research areas for abstraction from reality, it is will be a useful tool for the prediction of future corrosion defect growth and reliability of pipeline corrosion in consideration of the internal operating pressure of the corroded pipeline. The failure probability of a corroded pipeline that is expected to fail by small leakage, burst and rupture will be determined for different corrosion wastage rates that will be measured with Poisson arrival rate. It is expected that the model developed in this research will be a viable tool for managing the integrity of corroded ageing pipelines.

2. Damage estimation model of corrosion wastage

Corrosion defect depth of internal corroded pipeline can change with time of exposure of the pipeline to a corrosive environment. This time dependent phenomenon is most predominant between 8 O'clock and 4 O'clock zone of the pipeline because the flow of oil in the pipeline is concentrated in the region. By estimating the corrosion defect depth and length at different time intervals, the wastage rate of the corrosion defects of the pipeline can be determined for a given time according to Eq. (1). The corroded defect depth and length of a pipeline used for the damage estimation model is shown in Fig. 1.

$$C_W(t) = \begin{cases} \sum_{i=1}^{t} d_i \\ \sum_{i=1}^{t} L_i \end{cases}_{i=1,2,\ldots,t} \tag{1}$$

where $C_W(t)$, d and L represents total corrosion wastage at time t, corrosion defect depth and corrosion defect length respectively.

It is expected that the corrosion defect depth of the pipeline will increase cumulatively with the increase in the duration of exposure of the pipeline to the corrosive environment. This increase in the corrosion defect depth varies from year to year due to the random nature of corrosion depth growth that is necessitated by the variability in the operational condition of the pipeline [18], which influences the corrosive condition.

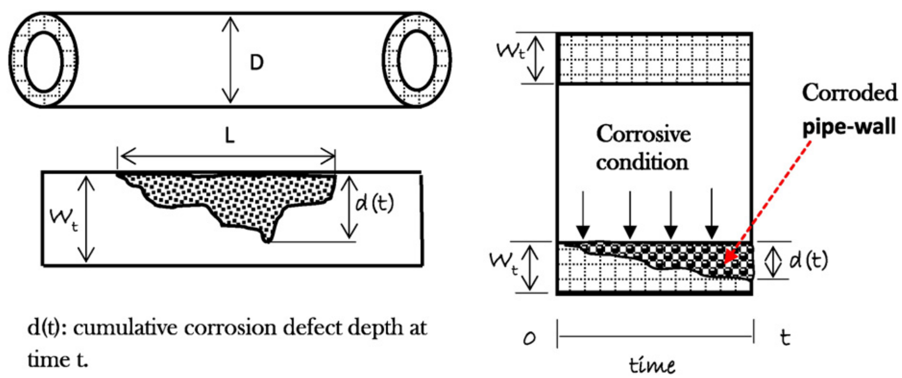

Fig. 1. Corrosion wastage model for damage estimation.