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Available Prediction Methods for Corrosion under Insulation (CUI): A Review

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Abstract. Corrosion under insulation (CUI) is an increasingly important issue for the piping in industries especially petrochemical and chemical plants due to its unexpected catastrophic disaster. Therefore, attention towards the maintenance and prediction of CUI occurrence, particularly in the corrosion rates, has grown in recent years. In this study, a literature review in determining the corrosion rates by using various prediction models and method of the corrosion occurrence between the external surface piping and its insulation was carried out. The results, prediction models and methods available were presented for future research references. However, most of the prediction methods available are based on each local industrial data only which might be different based on the plant location, environment, temperature and many other factors which may contribute to the difference and reliability of the model developed. Thus, it is more reliable if those models or method supported by laboratory testing or simulation which includes the factors promoting CUI such as environment temperature, insulation types, operating temperatures, and other factors.

1 Introduction

Corrosion under insulation (CUI) is commonly localized corrosion occurring at the interface of metal between the metal surface and its insulation. Insulation usually applied to maintain process temperatures which reduce energy loss and associate costs including precaution for safety issues. CUI is typically difficult to identify because it lies hidden under insulation material until it becomes a serious problem, especially in chemical or petrochemical plants that have been operating for decades [1]. These failures can be catastrophic in nature or at least have an adverse economic effect in terms of downtime and repairs.

In 2001, a study commissioned by US Congress reported the direct cost of corrosion to be $276 billion per year, with that number potentially doubling when indirect costs are also considered [2]. Other than that, in 2003 Exxon Mobile Chemical presented to the European Federation of Corrosion indicated that the highest incidence of leaks in the refining and chemical industries is due to CUI. The piping maintenance costs are between 40% and 60% for CUI detection, and a cure for occurrence [3]. Later in 2008, National Association of Corrosion Engineers (NACE) completes a survey, out of 30 facilities, 17 experiences CUI as a first place challenge they have to encounter. More, NACE

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Corrosion Costs Study in 2011 specifies that corrosion costs in the US are approaching $1 trillion annually, and will likely exceed that unfortunate milestone in 2012.

2 Introduction to Inspection, Detection, Prevention and Prediction of CUI

To avoid those problems, it is important to inspect for or repair by any technical method or non-destructive method such as radiography, ultrasonic or other forms of inspection. However, those methods involve high cost and most cases requires removal of the insulation system which require specific time and planning for the removal, evacuate, cure and other related works for the inspection [4,5].

Although alternatively the methods to detect CUI without the need of insulation removal are now available, such as X-ray tomography, optical fiber Doppler sensors, usage of corrosion inhibitor, it is critical because the expected remaining life of the pipes still not discovered [6,7,8]. In latest study for CUI detection, Francois et al comes out with integrated sensor network using Wi-Fi which monitor, reduce cost and as strategy to extend life of piping. However, the creation of this sensor is not an easy task due to the need of a large number of interconnected sensors to have a good estimation of CUI growth. [8]

Other than that, researches are now growth in discovery for prevention of CUI such as new materials and types of protective coating and insulations including pipeline design [9,10,11,12]. However, new invention is always risky. An example case of the use of the new highly publicized, Foamed in Place Polyurethane (FIPP). It was believed that FIPP would be immune to atmospheric weathering and sunlight exposure for thermal insulation. It was used in Germany and Holland directly to uncoated steel with no top coat. Within three years, massive failures resulted and aggressive corrosion had taken place. As an example, one large refinery insulated approximately 150 heated storage tanks by 1973 with FIPP. Within four years, 50% of those tanks required repair because of CUI [13].

Thus, to overcome this problem alternatively, researchers come out with CUI prediction method. CUI prediction method is an estimation life time of piping for CUI potential. There are two types of prediction which are the save and dangerous prediction. The save prediction is the prediction of CUI occurrence earlier than the maximum time expected while the dangerous prediction will specify the maximum life of CUI occurrence. However both predictions will have their own advantages and risks especially in terms of safety and cost. For example, the dangerous prediction will save budget but might be very dangerous thus may cause higher cost to cure.

The importance of CUI prediction model is to ensure the effectiveness of asset integrity management and better predictability of corrosion growth under insulation. Recently, most study estimates and predicts the CUI potential based on calculation of corrosion rates or failure probability of the systems. In this paper, the studies related to the available CUI prediction methods or models were compared and presented.

3 Available Corrosion under Insulation Prediction

There are very limited studies on this CUI prediction and still require a lot of improvement. Most study estimates and predicts the CUI potential based on calculation of corrosion rates or failure probability of the systems.

Tateno et al attempt several methods to predict CUI occurrence based on actual corrosion cases data from thirteen petrochemical plants in Japan. In 2009 [14,15], he estimates the corrosion occurrence by using the database modelling method and continue using k-NN (k-Nearest Neighbour) which calculate a distance from a demanded point to their historical data. This k-NN (k-Nearest Neighbor) method can increase the accuracy of the estimation, however sometimes the problems exist such as a possibility of prediction decrease. In the case that a possibility of prediction is low, it is difficult to combine each plant case database. Thus, in 2010 [16], he then groups the corrosion cases into several groups based on each proper standard such as continuous or discrete conditions and later compile the input data into diversity and consistency cases. By averaging the similar records corrosion rates, this Group numbering method tends to reduce its prediction range. However, the accuracy of prediction is still insufficient and in some cases, corrosion rates cannot be predicted.

Then in 2012 [17], Tateno et al. use IGR (Information Gain Reliability) method consists of 2698 cases from 20 actual plants in Japan, which is actually estimates corrosion ratio using condition based. This method can estimate corrosion rates in all cases by setting proper thresholds, which selected from the correlation between the predicted corrosion rates and actual corrosion rates. This method added in reliability factor in order to calculate corrosion rates with better accuracy. This method increases estimation hitting rate of around 40% compared to his works before.

Other available CUI prediction works are done by Ainul et al, using failure function which is the ability of a material to resist failure, based on the difference between the material resistance and the applied stress. The failure probability assessment models based on structural reliability analysis is then developed, applied and compared to the real case. Other than that, Markov model, which calculate the reliability index and failure probability also have been used. [18,19].

For Kurihara et al, the analysis which based on actual plant data in Japan resulted that the trend of CUI follows Gumbel distribution, and CUI are controlled by types of equipment, temperature and structure design. Thus, the modification of CUI technical module was established for the more accurate prediction and estimation of CUI in Japan [20].

The largest bare steel pipeline in oil fields on the North Slope of Alaska which insulated with polyurethane foam with a galvanized steel jacket have been operated for nearly three decades, transporting crude oil, water and gas. Insulation is applied due to harsh arctic condition and process requirements. CUI growth of this complex network of 800 miles (1280 km) is predicted using Weibull analysis by correlating history and inspection data of 73 miles (117 km) pipeline with the total number of CUI repairs and refurbishments done each year. Specifically, the total number of CUI-susceptible locations that were refurbished each year was divided by the total number of CUI-susceptible locations on the pipeline to yield the total fraction refurbished by year. This accumulated damage distribution over time fit to Weibull curves. The model can be further used as input to risk assessments to support maintenance strategies, and as background rationale for budgeting and manpower optimization for inspection, repair and refurbishment activities in this environment. [21] However, this model is developed based on data from the North Slope of Alaska with known harsh arctic environment. Thus, prediction model with suit others condition should be generated.

Summary of the literature review are compiled in Table 1. However, all of the prediction methods available are based on each local industrial data only. And, local industrial data might be different based on the plant location, environment, temperature and many other factors which may contribute to the difference and reliability of the model developed. Thus, it is more reliable if those models or method supported by laboratory testing or simulation. Factors affecting the CUI rate such as environment temperature and meteorological conditions, insulation types, operating temperatures, and other factors can be control and tests effectively [23,24,25,26].

Table 1. Summary of the studies related to CUI prediction.

Year	Paper	Prediction Method	Place	How/detail of method
2009	Shigeyuki Tateno et al. [14]	Database modeling method.	Japan	Uses historical data which is similar to a demanded point.
2009	Shigeyuki Tateno et al. [15]	k-NN (k-Nearest Neighbor)	Japan	Calculating a distance from a demanded point to each historical data

2010	Shigeyuki Tateno et al. [16]	Group numbering of continuous conditions	Japan	Divition of Input data into several groups based on each proper standard.
2010	T. Kurihara, R. Miyake, N. Oshima, and M. Nakahara [20]	Modification of CUI Technical Module published by API	Japan	The modification of CUI Technical Module published by API is examined based on historical data
2010	Tobias H. Erickson et al. [21]	Weibull Statistical Analysis	North Slope of Alaska	Application of available historical data to Weibull Analysis
2011	Ainul Akhmar Mokhtar and Mokhtar Che Ismail [18]	First Order Realibility method (FORM)	Malaysia	Calculation of reliability index and failure probability. Failure probability assessment model based on structural reliability analysis
2012	Shigeyuki Tateno et al. [17]	Information Gain Ratio	Japan	Selection of support system which estimate corrosion rates with high accuracy using information gain ratio and reliability

4 Summary

In the last decade, a significant increase in the number of studies on corrosion under insulation has been observed, which aim to reduce costs, ensure the effectiveness of asset integrity management and better predictability of corrosion growth under insulation. However, the number of studies is still very limited, especially on prediction method for CUI occurrence. This study presented a literature review on the prediction of corrosion under insulation, and focused especially on the determination of prediction model. The prediction methods and model in the literature were compiled and presented. This study could be a useful resource for researchers since it includes a review of available corrosion under insulation prediction model and methods. Due to limited study available in this area, it is hope that this study can be an initiator for more reliable prediction method in industries. However, in future, to ensure the prediction of CUI growth and occurrence is reliable and accurate, factors promoting CUI such as environment temperature, insulation types, operating temperatures, and other factors must be consider and included in the method if possible.

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