CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

A reliable and robust mathematical tool for establishing a risk-based inspection program can be viewed as a valuable asset for operating and maintaining a plant. Such quantitative means can assist a corrosion/inspection/maintenance engineer to reduce costs arising from frequent inspections and unnecessary plant shutdowns as well as to take preventive maintenance action before an accident actually occurs. Unfortunately, the calculation of risk requires knowledge about the probability and the consequence of failure where both are difficult to estimate quantitatively mainly due to the availability of data involved. In particular, complexities in assessing quantitatively the probability of failure for piping systems subject to CUI arise in modeling the rate of corrosion and running the available mathematical/statistical models due to lack of field failure data as well as the wall thickness data typically collected during inspection periods to assess the integrity of the corroded pipe. Looking at this scenario, this study aims to find the possible method to assess quantitatively the probability of failure for piping systems subject to CUI based on the types of data available.

It was identified that CUI data that is available in practice is mainly from the inspection and maintenance report. The data can be classified as qualitative and quantitative. Qualitative data can be treated as binary data (0 = CUI is not found, 1 = CUI is found) and quantitative data is the wall thickness data measured. Four models have been identified that can go along with the data available which are logistic regression model, degradation analysis, structural reliability analysis and continuous-time Markov model. The four models have been studied, developed, tested and validated.

Logistic regression model was proposed to be used for prediction of the probability of CUI occurrence where the data can be interpreted as a binary data (0 = CUI was not found and 1 = CUI was found). Logistic regression, expressed as a probability, describes the relationship between the binary response variables and one or more independent variables. In this study, the independent variables are age of pipes, operating temperature and insulation type. In other words, using logistic regression model, the relationship between the binary outcomes and the factors contributed to CUI was modeled mathematically. This study demonstrated that without the wall thickness data typically used to analyze corrosion problem, the probability of CUI occurrence can still be generated. However, the results do not tell the severity of CUI in term of depth of corrosion. For that reason, the results generated cannot be employed in the current quantitative risk assessment. The model can only be a guideline for inspection planning purpose i.e. which insulated pipe to be checked based on given age, operating temperature and insulation type.

Another model proposed was degradation analysis where the model requires the wall thickness data measured at several TMLs during each inspection period. Rather than just developing a degradation model of corrosion as normally being practiced, the model also seeks the resulting lifetime model. This model has linked a practitioner's selected degradation model and the resulting lifetime model with the objective to predict quantitatively the failure probability. This study demonstrated the usefulness of degradation analysis where using this approach, the future corrosion rate is not necessary in order to predict the reliability of the piping systems. The study revealed that assuming the degradation follows a linear model; the probability of failure for piping systems subject to CUI followed well either the lognormal or the Weibull distribution.

However, to have abundance of wall thickness data was not always the case for most of the insulated pipes. Therefore, a method using structural reliability analysis approach was proposed to assess the failure probability since this approach requires the design and operational data which are readily available. The use of this probabilistic approach was found to a useful tool for predicting the probability of failure in a more quantitative means. This study also showed that structural reliability analysis is a useful quantitative approach to assess the failure probability if the failure data and wall thickness data are not available or very limited.

All the above models assumed only two states which are either success (working properly) or fail. However, in actual condition, CUI progresses into several states before the actual failure occur. Thus, this study also demonstrated the usefulness of Markov analysis procedure developed by Fleming (2004). A probability-based Markov-chain model is proposed to model the degradation where Markov-chain model explicitly modeled the interactions between the degradation mechanism and the inspection, detection, and repair strategies being performed to reduce the failure probability. It was shown in this study that Markov models are useful for this purpose, when combined with structural reliability analysis in order to determine the transition rates.

The followings are the results of the study:

- ✓ A good quantitative model that can be applied with the current available data is the structural reliability analysis model where the reliability calculation is based on the design and operating data as well as the wall thickness data to estimate the corrosion rate. However, in the case where the wall thickness data is abundant, the degradation analysis is proposed to be used.
- ✓ The Markov model seems to be a potential model in the future. To adopt and apply it successfully, then several steps have to be put in place such as:
    - The number of states and the definition of each state have to be developed properly by having consensus from experts/plant experience because these two factors give a big impact to the probability of failure calculation.
    - The method to estimate the transition rates should be established. It will be more realistic if the actual data can be collected. The transition rate estimated for the Markov model developed in this study was based on the design data, not from the actual plant data.

In summary, a careful consideration of the data type associated with deterioration is important for a credible model to assess the failure probability and its effectiveness application to RBI analysis. Although applying the quantitative method in assessing the failure probability is not required in the current RBI analysis, a quantitative risk evaluation is, in fact, now a required element of the maintenance optimization methodology. The approach was necessary to make the process truly risk informed.

6.2 Significance of the Project

The significant for this study is to provide alternative method in predicting the probability of failure due to CUI. It has been mentioned previously that the assessment of CUI is rather qualitative in RBI analysis. Therefore, the research work aims in establishing a more quantitative way by evaluating several quantitative models in order to predict CUI occurrence. This project is aligned with the PETRONAS Risk-Based Inspection System (PRBI) that is currently applied in most PETRONAS subsidiary companies as a tool to plan inspection activities, to collect inspection, to update and subsequently improve the system. Thus, CUI cases can be handled in a more effective means and thus, minimize the maintenance budget. The model can be utilized in identifying the pipes with at higher risk so that possible inspection can be conducted and therefore, eliminating the randomness often associated with this inspection activity.

6.3 Future Works

This thesis focuses on using the inspection data point that considered after the insulation was being removed. The external visual inspection data (without insulation removal) that are typically available were not being considered. The external visual inspection data are the data on any susceptible sign for CUI where the inspection is done by qualified inspectors. The insulated system's condition is being inspected based on several defined criteria such as the insulation and cladding quality (punctured, dislodged, missing or dented), or whether there is any sign of water ingress etc. Decision whether or not to open the insulation for further inspection will be based on this inspection result which can be translated to a form of discrete state or condition rating. This result can be further used to develop a deterioration model for insulated systems. Another model that typically represents the discrete condition ratings in infrastructure deterioration is a discrete time Markov model. This model should be explored and compared to the results generated by the continuous time Markov model.

Until today, no standard condition rating system or rating scale for insulated system is developed. Only approximations and expert opinions are used to determine the insulated system condition. A standardized condition rating system is required to generate a more robust deterioration model. Currently, each plant uses a different condition rating system for the insulated systems. The use of different condition rating systems prevents objective comparison of the effects of inspections/maintenance regarding condition assessment among plants.

The structural reliability used in this study assumed that independence of variables. Therefore, future work should consider the correlation among variables.