DEVELOPMENT OF AN EFFECTIVE INSPECTION PLAN FOR PRESSURE VESSELS ACCORDING RISK-BASED INSPECTION TECHNOLOGY FOR POLYETHYLENE PLANT

SAW PING LIH

A project report submitted in partial fulfilment of the requirements for the award of the degree of Master of Engineering (Industrial Engineering)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

To my mother and father

To my Lotte Chemical Titan Colleagues

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Mr. Affandi Bin Mohd Zainal, for encouragements, guidance, criticism and friendship. Without his continued support and interest, this thesis would not have been the same as presented here.

I am also indebted to Universiti Teknologi Malaysia (UTM) and MyBrain 15 for funding my postgraduate study.

My fellow postgraduate students should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members.

ABSTRACT

In order to ensure the asset integrity, all unfired pressure vessels (UPVs) should be examined at the intervals recommended in inspection codes or risk-based inspection (RBI) assessment. RBI assessment may allow previous inspection intervals to be extended and the inspection method may be reselected. In this paper, RBI study performed on 114 unfired pressure vessels components for Unipol Polyethylene Plant. Risk assessment performed and determines the risk ranking. Inspection plan developed base on the risk assessment result. The risk-based inspection plan compared with conventional inspection plan i.e. API 510's inspection intervals. This thesis will summarize the fundamental steps for API 580 Risk-Based Inspection methodology, i.e. the risk calculation and assessment, evaluated the damage mechanism via the corrosion loops, and the inspection technologies.

ABSTRAK

Demi menjaminkan keintegritian aset, semua pengandung tekanan tidak berapi (PTTB) perlu diperiksa dalam tempoh masa yang disyorkan dalam kod pemeriksaan atau penilaian pemeriksaan berdasar risiko (RBI). Penilaian RBI boleh membenarkan tempoh pemeriksaan yang disyorkan dalam kod pemeriksaan lama dilanjutkan dan cara pemeriksaan akan dicadang semula. Dalam kajian ini, penilaian RBI akan dilaksanakan atas 114 PTTB dan komponentnya untuk kilang proses polyethylene. Penilaian risiko akan dijalankan dan menentukan tahap risiko untuk semua PTTB. Pelan pemeriksaan akan dibentukan berdasarkan keputusan risiko. Pelan pemeriksaan RBI akan dibandingkan dengan pelan pemeriksaan yang berdasarkan cara konvensional terutamanya tempoh pemeriksaan. Dalam kajian ini akan merumuskan langkah asas untuk API 580 RBI, iaitu cara penilaian risiko dan penilaian, penentuan cara kemerosotan berdasarkan corrosion loops dan teknologi pemeriksaan.

TABLE OF CONTENTS

| CHAPTER | TITLE | PAGE |
|---------|--------------------------------------|------|
| | DECLARATION | ii |
| | DEDICATION | iii |
| | ACKNOWLEDGEMENT | iv |
| | ABSTRACT | v |
| | ABSTRAK | vi |
| | TABLE OF CONTENTS | vii |
| | LIST OF TABLES | X |
| | LIST OF FIGURES | xii |
| | LIST OF SYMBOLS | xiv |
| | LIST OF APPENDICES | XV |
| | | |
| 1 | INTRODUCTION | 1 |
| | 1.1 Background | 2 |
| | 1.1.1 Global RBI Activities | 2 |
| | 1.1.2 RBI Implementation in Malaysia | 3 |

| | 1.2 | Research | n Problem | 6 |
|---|-----|----------|------------------------------------|----|
| | 1.3 | Research | a Scope and Objectives | 6 |
| 2 | LIT | ERATUR | E REVIEW | 7 |
| | 2.1 | Maintena | ance Philosophy | 7 |
| | 2.2 | Risk Bas | sed Inspection (API 580/581) | 8 |
| | | 2.2.1 | Introduction | 8 |
| | | 2.2.2 | Probability of Failure, POF | 12 |
| | | 2 | .2.2.1 Generic Failure Frequency | 12 |
| | | 2 | 2.2.2.2 Management System | |
| | | | Factor | 13 |
| | | 2 | 2.2.2.3 Damage factor | 13 |
| | | 2.2.3 | Consequence of Failure, COF | 14 |
| | | 2.2.4 | Risk Assessment | 15 |
| | | 2.2.5 | Risk Analysis | 16 |
| | | 2.2.6 | Risk Matrix | 17 |
| | | 2.2.7 | Effective Inspection Plan Based on | |
| | | F | Risk Assessment | 19 |
| | | 2.2.8 | Corrosion Loop for RBI | 20 |
| | 2.3 | Previous | Case Study | 21 |
| | | | | |
| 3 | RES | EARCH 1 | METHODOLOGY | 24 |

| | 3.1 | Corrosion Loop Development | 25 |
|---|-----|--|----|
| | 3.2 | Risk-Based Inspection Development and Risk Assessment | 26 |
| | 3.3 | Develop Inspection Activities and Risk Management | 32 |
| 4 | RES | SULT AND DISCUSSION | 34 |
| | 4.1 | Potential Damage Mechanism & Materials | 34 |
| | 4.2 | Risk Analysis Result | 36 |
| | 4.3 | Risk Based Inspection Planning | 43 |
| | 4.4 | API 510 Inspection Planning | 46 |
| | 4.5 | Comparison of API 580 Inspection Intervals and API 510 Inspection Intervals | 47 |
| | 4.6 | Cost Comparison between Conventional Method vs RBI Method | 49 |
| 5 | CO | NCLUSION | 54 |
| | 5.1 | Contribution to Knowledge | 54 |
| | 5.2 | Contribution to Practice | 55 |
| | 5.3 | Limitation of Research | 55 |
| | 5.4 | Suggestion to Future Work | 55 |
| | 5.5 | Overall Conclusion | 56 |

| REFERENCE | 57 |
|----------------|----------|
| Appendices A-D | 59 – 111 |

LIST OF TABLES

| TABLE NO. | TITLE | PAGE |
|-----------|---|------|
| 2.1 | Numerical values associated with Probability Of Failure | 18 |
| 2.2 | Numerical values associated with Consequence Of Failure | 18 |
| 2.3 | Article studies summary | 21 |
| 3.1 | Calculated corrosion factors based on fractional wall | |
| | loss and number of confidence of inspection | 27 |
| 3.2 | Probability category | 28 |
| 3.3 | Combined POF | 29 |
| 3.4 | Consequence category | 30 |
| 3.5 | POF & COF compilation table | 31 |
| 3.6 | Combined criticality rating for external visual | |
| | inspection | 33 |
| 4.1 | Thinning damage factors selection for UPV "Plan- | |
| | 7353 Reservoir 3 Gallon Capacity" | 38 |
| 4.2 | Possibility category for "Plan-7353 Reservoir 3 | |

| | Gallon Capacity" | 38 |
|------|--|----|
| 4.3 | Combined POF for "Plan-7353 Reservoir 3 Gallon Capacity" | 39 |
| 4.4 | POF & COF result for "Plan-7353 Reservoir 3 Gallon Capacity" | 42 |
| 4.5 | Inspection strategies for external visual inspection for medium high UPV | 45 |
| 4.6 | Inspection strategies for internal visual inspection for medium high UPV | 46 |
| 4.7 | Inspection planning in 15 years for API 580 | 48 |
| 4.8 | Inspection planning in 15 years for API 510 | 48 |
| 4.9 | Average inspection cost | 49 |
| 4.10 | Inspection priority range | 50 |
| 4.11 | Temperature range | 50 |
| 4.12 | Grouping for UPVs by CUI inspection | 50 |
| 4.13 | Cost comparison table between conventional method and risk-based inspection method | 52 |
| | | |

LIST OF FIGURES

| FIGURE NO. | TITLE | PAGE |
|------------|--|------|
| 1.1 | Flow sequence for CF extension application | 4 |
| 1.2 | COF _{RBI} Validity | 5 |
| 2.1 | Risk management by using RBI | 10 |
| 2.2 | Risk plot | 11 |
| 2.3 | Superposition principle for the calculation of risk in API 580 | 16 |
| 2.4 | 5X5 Risk matrix | 17 |
| 2.5 | Corrosion loop for piping and fixed equipment | 20 |
| 2.6 | Schematic example of corrosion loop | 21 |
| 3.1 | Risk-based inspection frameworks | 25 |
| 3.2 | Corrosion study interface in RBMI software | 26 |
| 3.3 | External corrosion study interface in RBMI software | 29 |
| 3.4 | Consequence analysis interface in RBMI software | 31 |
| 3.5 | Inspection priority categories | 32 |
| 4.1 | Material of construction for 114 UPVs | 35 |
| 4.2 | Potential internal damage mechanisms for 114 UPVs | 35 |

| 4.3 | Potential external damage mechanisms for 114 UPVs | 36 |
|------|--|----|
| 4.4 | Risk distribution percentage for 114 UPVs | 37 |
| 4.5 | "Plan-7353 Reservoir 3 Gallon Capacity" data | 40 |
| 4.6 | "Plan-7353 Reservoir 3 Gallon Capacity" corrosion study | 40 |
| 4.7 | "Plan-7353 Reservoir 3 Gallon Capacity" internal corrosion study | 41 |
| 4.8 | "Plan-7353 Reservoir 3 Gallon Capacity" internal corrosion study | 41 |
| 4.9 | "Plan-7353 Reservoir 3 Gallon Capacity" consequence analysis | 42 |
| 4.10 | "Plan-7353 Reservoir 3 Gallon Capacity" risk rating | 43 |
| 4.11 | Recommended inspection method based on risk analysis | 44 |
| 4.12 | Recommended inspection frequency based on risk analysis | 44 |
| 4.13 | Recommended inspection frequency based on API 510 | 47 |
| 4.14 | Comparison between API 510 and API 580 in time frame 5 years, 10 years, 15 years | 48 |

LIST OF SYMBOLS

 $P_f(t)$ - Probability of Failure

gff - Generic failure frequency

 $D_f(t)$ - Damage factor

 F_{MS} - Management systems factor

LIST OF APPENDICES

| APPENDIX | TITLE | PAGE |
|----------|--------------------|----------|
| | | |
| A | Corrosion Loop | 59 – 70 |
| В | Risk Distribution | 71 – 79 |
| C | POF & COF Analysis | 80 – 87 |
| D | Inspection Plan | 88 – 111 |

CHAPTER 1

INTRODUCTION

Petrochemical plants and refineries consist of hundred pieces of pressure vessels, heat exchangers, towers and other unit operation which operate under various operating condition. They tend to deteriorate due to corrosion, aging, wear, and etc. In addition, process safety for a petrochemical process relies among other things, on the adopted management criteria. It will affect the plant life-cycle, production activity, until the possibility to dismantle. If the consequence of failure is low, the number of maintenance activity will be low at the time of failure. However, if the failure consequence is high, the deterioration of equipment will lead to unplanned shutdowns, production losses, high maintenance cost and severe safety, health and environment issues. If the plant equipment or pressure vessel deterioration condition can be modelled, it is possible to predict the time for failure, and suitable inspection activities can be planned on the basis of the service age and the anticipated failure time. A risk-based inspection not only extends the interval between shutdowns but also produces millions of dollars in savings. (Hameed & Khan, 2014)

1.1 Background

1.1.1 Global RBI Activities

The objective for the study is to show how to implement risk based inspection method for piping system in naphtha cracking unit. Their scope of focus was to provide inspection personnel with optimal planning tools for piping inspection and predict the potential piping risk effectively. API 581 was used as the analyst tools to understand the potential risk. In addition, applied risk based inspection for process piping in refinery plant (Chang, Chang, Shu, & Lin, 2005). The outcome of the study is the risk ranking distribution but no inspection plan.

Besides piping inspection, risk analysis for low density polyethylene equipment was conducted at Sinopec Shengli Oilfield. (Wang, Yan, Zhang, Zhao, & Chen, 2011)Their focus in the study is to identify the risk for high pressure polyethylene ethylene devices. Qualitative analysis was conducted to determine the risk and danger zone. Study on maintenance strategy optimization for ethylene oxide production facilities was conducted (Khan & Haddara, 2004). Their objective is to determine the maintenance interval by risk level and fault tree analysis.

A comparison of API 510 and API 581 was conducted for Abadan Oil Refining Company (AORC) and Esfahan Oil Refining Company (EORC) (Shishesaz, Bajestani, Hashemi, & Shekari, 2013). The calculated inspection intervals reveal that in both units there exists some equipment with inspection intervals less than current overhaul (turnaround) intervals, and also lots of items with inspection interval much longer than current overhaul interval. Based on RBI analysis results, RBI permits the shift of inspection and maintenance resources to provide a higher level of coverage (inspection plans with higher effectiveness) on the high-risk items and an appropriate effort (inspection plans with less effectiveness) on lower risk equipment during plant turnarounds.

In addition, the components with inspection intervals longer than twice the adjusted overhaul interval can be eliminated from future overhaul plan, leading to shorter outage time while keeping plant risk within acceptable range.

Having compared the RBI recommended inspection intervals with intervals calculated based on API 510, it can be concluded that, for components in which thinning is the only active damage mechanism, API 510 calculation procedure is much more conservative API 581. Generally, the RBI recommended inspection intervals are usually as long as twice the API 510 inspection intervals. It is also concluded that API 581 calculations can be used for determination of a more exact value for RSF_a in FFS calculations. (American Petroleum Institute, API 510 Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair and Alteration, 2008)

1.1.2 RBI Implementation in Malaysia

In Malaysia, based on jurisdictional requirement, i.e. Factories and Machinery Act 1967 P.U. (A) 43/70, Factories and Machinery (Notification, Certification of Fitness and Inspection) Regulation, 1970, all unfired pressure vessel (UPV), steam boiler or hoisting machine other than a hoisting machine driven by manual power shall hold a valid certificate of fitness (CF) in respect thereof so long as such machinery remains in service. The period of validity of every certificate of fitness shall ordinary be fifteen calendar month from the date of inspection or such longer period not exceeding three years as the chief inspection in his discretion may consider appropriate: (Malaysia, Factories And Machinery (Notification, Certificate Of Fitness And Inspection) Regulations, 1970, 1970)

Provided where any steam boiler, unfired pressure vessel or hoisting machine is out of service for a long period immediately subsequent to an inspection by reason of dismantling or repair of any defect the Inspector may issue a certificate effective from the date when such machinery is replaced in service.

In order to renew the certificate of fitness, the respective machines must stop and open for internal inspection after 15 months period of operation. Industries can apply for extension of CF due to various reasons, but normally based on:

- Economic reasons, such as loss of competitiveness, orders from clients and etc.
- Technical reasons, such as machine integrity maintenance and etc.
- Safety reason.

Hence, certificate of fitness can be apply for extension up to 72 months and with approval from chief inspectors and minister approval. Each extension process, the UPV's owner must submit the application to authorities 6 months before the current certificate expires. 4 different application processes is require to extent the CF to 72 months. Figure 1.1 shows the flow sequence for extension application:

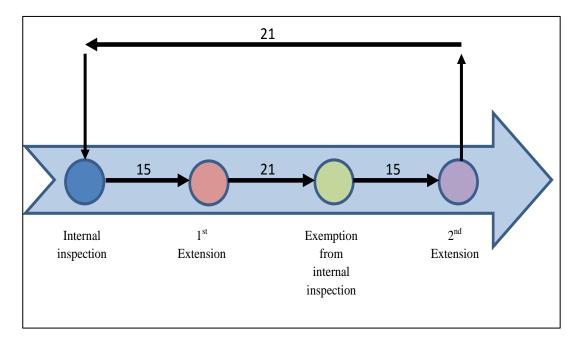


Figure 1.1 Flow sequence for CF extension application

The principle for this CF is time-based inspection. The equipment's risk and safety in rely on inspector findings during internal inspection, hence the responsibilities on machines safety is not on owners. This method will affect owners' plant productivities and equipment safety is merely relying on inspectors' findings. The authorities aware the gap for this and regulation amendment had been make

during April 2014 and come into operation on 1st June 2014 (Department of Occupational Safety and Health, Malaysia, 2014).

The new regulation had been introduce as Factories and Machinery (Special Scheme of Inspection) (Risk-Based Inspection) Regulation 2014. The principle of this scheme is to shift the responsibilities to machines' owners to ensure the equipment safety. In addition, the inspection period and type will be based on the risk taken by each machines. The validity for this scheme is 150 months and along this scheme only 2 internal inspections is required after the internal inspection during new scheme application. Compared with previous regulation, the validity for this CF had increase from 72 months to 75 months and only required 1 application process instead of 4 applications. This implementation will help to reduce the numbers of shutdown for internal inspection without compromise the safety and risk in the plant. (Malaysia, Factories and Machinery (Special Scheme of Inspection) (Risk-Based Inspection) Regulations 2014, 2014)

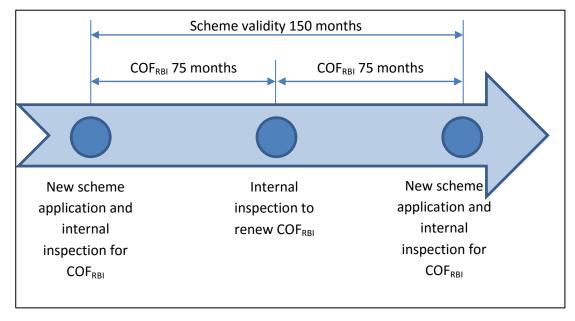


Figure 1.2 COF_{RBI} Validity

1.2 Research Problem

In Malaysia, due to the regulation is newly implemented and most of the petrochemical and chemical processes industries not aware the benefits and advantages for risk-based inspection and risk-based inspection planning. In addition, no specific guidelines for plants' owners to follow when implement RBI to replace the traditional maintenance method.

1.3 Research Scope and Objectives

In this study, the scope will focus will on a Unipol Polyethylene Plant which located in Pasir Gudang, Johor in service since 1992.

- The objectives for this research can be introduced into 3 objectives:
- To develop corrosion loop for unfired pressure vessels in polyethylene plant and determine the potential damage mechanism.
- To identify unfired pressure vessels risk criticality based on Risk Based Inspection (API 580).
- To propose an effective inspection plan for unfired pressure vessels based on Risk Based Inspection for aging plant.

REFERENCES

- American Petroleum Institute. (2002). API Recommended Practice 580: Risk-based Inspection. Washington, D.C.: API Publishing Services.
- American Petroleum Institute. (2008). API 510 Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair and Alteration. Washington, D.C.: API Publishing Services.
- American Petroleum Institute. (2008). API Recommended Practice 581: Risk-Based Inspection Technology. Washington, D.C.: API Publishing Services.
- Arunraj, N., & Maiti, J. (2007). Risk-based maintenance Techniques and applications. *Journal of Hazardous Materials* 142, 653-661.
- Batsaris, P., Naris, A., & Gaidajis, G. (2009). A risk-based inspection (RBI) preventitive maintenance programme: A case study. *Proceeding of the 4th World Congress on Engineering Asset Management*, (pp. 902-911). Athens, Greece.
- Bertolini, M., Bevilacqua, M., Ciarapica, F., & Giacchetta, G. (2009). Development of Risk-based Inspection and Maintenance procedures for an oil refinery. *Journal of Loss Prevention in the Process Industries*, 244-253.
- Chang, M.-K., Chang, R.-R., Shu, C.-M., & Lin, K.-N. (2005). Application of risk based inspection in refinery and processing piping. *Journal of Loss Prevention in the Process Industries* 18, 397-402.
- Department of Occupational Safety and Health, Malaysia. (2014). Factories and Machinery (Special Scheme of Inspection) (Risk-Based Inspection) Regulation 2014. Putrajaya: DOSH Malaysia.
- Garcia, E. (2012). Risk Based Approach to Turnaround Planning. 2012 LR Energy Conference (p. 37). Houston: Lloyd's Register Energy Americas, Inc.

- Hameed, A., & Khan, F. (2014). A framework to estimate the risk-based shutdown interval for a processing plant. *Journal of Loss Prevention in the Process Industries*, 18-29.
- Khan, F. I., & Haddara, M. R. (2004). Risk-based maintenance of ethylene oxide production facilities. *Journal of Hazardous Materials A108*, 147-159.
- Malaysia. (1970). Factories And Machinery (Notification, Certificate Of Fitness And Inspection) Regulations, 1970. Malaysia: By Authority.
- Malaysia. (2014). Factories and Machinery (Special Scheme of Inspection) (Risk-Based Inspection) Regulations 2014. Malaysia: By Authority.
- Mei, S., & YingZhi, W. (2012). Risk Analysis Methodology and On-line inspection using acoustic emission technology on pressure equipment in chemical installation. *Advances in Technology and Management*, 847-855.
- Shishesaz, M. R., Bajestani, M. N., Hashemi, S. J., & Shekari, E. (2013).
 Comparison fo API 510 pressure vessel inspection planning with API 581
 risk-based inspection planning approaches. *International Journal of Pressure Vessels and Piping*, 202-208.
- Tien, S.-W., Hwang, W.-T., & Tsai, C.-H. (2007). Study of a risk-based piping inspection guideline system. *ISA Transaction*, 119-126.
- Wang, G., Yan, T., Zhang, J., Zhao, L., & Chen, J. (2011). Risk Based Inspection on the equipment of low density polyethylene. *Procedia Engineering*, 1145-1148.
- Zhaoyang, T., Jianfeng, L., Zongzhi, W., Jianhu, Z., & Weifeng, H. (2011). An evaluation of maintenance strategy using risk-based inspection. *Safety Science* 49, 852-860.