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Corrosion Assessment by Using Risk-Based Inspection Method for Petrochemical Plant - Practical Experience

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Corrosion assessment has a number of uses but the use considered here is as a precursor to Risk-Based Inspection (RBI) planning. Systematic methods consisting of technical modules of RBI program were used to assess the effect of specific corrosion mechanism on the probability of failure in equipments of petrochemical plants. Especially in part of the damage and corrosion assessment, screening step involved evaluating the combinations of process conditions and construction materials for each equipment item in order to determine which damage mechanisms are potentially active. For general internal corrosion, either API 510 or API 570 was applied as the damage rate in the calculation to determine the remaining life and inspection frequency. In some cases, a measured rate of corrosion may not be available. The technical modules of RBI program employ default values for corrosion, typically derived from published data or from experience with similar processes, for use until inspection results are available. This paper describes the case study of corrosion and damage assessment by using RBI methodology in petrochemical plant. Specifically, this paper reports the methodology and the results of its application to the petrochemical units using the KGS-RBI™ program, developed by the Korea Gas Safety Corporation to suit Korean situation in conformity with API 581 Codes.

Keywords *: corrosion assessment, risk-based inspection (RBI), petrochemical.*

1. Introduction

As a part of the Government's heavy chemical industry promotion policy, large scale oil refineries and petrochemical plants began to be built in Ulsan and Yeosoo areas in the latter half of 1960's. These national key industries which have been in operation for forty years are now faced with the problems of potential disaster possibly related to aging facilities. 20 % of all the facilities in domestic key industries is over 20 years old and 50% is over 10 years and the risk of accident due to deteriorated operational functionality, material failure or overheating of equipments is ever increasing. In oil refineries and petrochemical plants, in particular, the advancement of processing technology in refining and chemical production resulted in more diversified and sophisticated facilities using a variety of materials and additives to increase production efficiency, which, in turn, resulted in more facilities exposed to corrosive environment followed by increased cases of reports on small and large accidents and events involving corrosion of aged equipments.[1)-2)] Should any disastrous accident occur in one of the petrochemical plants, its direct effect on economic losses and environmental damage as well as propagating damage in the related industries would be a big blow to the nation's economy. Improvement of the safety and the service life of industrial facilities became rising concerns and people are increasingly aware of the needs for safety enhancement. As an alternative tool for the improvement of safety in industrial sites, the Risk-Based Inspection (RBI) method that allows inspection and timely, effective repair with the consideration of the maintenance state, economy and safety of aged facilities is used widely throughout the world.[3)-8)]

The RBI method uses the probability of risk as the basis in the operation of inspection program and efficiency rating and defines the risk as the multiplication of consequential damage by the likelihood of failure. The likelihood of failure is a variable factor depending on the type of the defect which, in this study, is the speed of deterioration caused by corrosion. The American Petroleum Institute (API) set up API 510[9)] and API 570[10)] for the assessment of generic corrosion damage and remaining life. However, in practical circumstances, these standards require assessment of risk from the calculation of the speed

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of deterioration of equipments or pipes using an inspection program. But the use of inspection program while the plant is in operation is often restricted and, furthermore, the basic values have to be used for those equipments and pipes of which measurement of corrosion speed is not easy. Such limitations call for an alternative method of quantitative assessment.

In this study, we performed RBI using the KGS-RBI™ program, developed by the Korea Gas Safety Corporation based on API 581 Codes at Naphtha Cracking Center (NCC), a major petrochemical plant in Korea, and examined the effect of corrosion on the risk of failure. For the assessment of the corrosion-induced damage rate, the quantified values of damage rate obtained from screen questions and corrosion factors including material information and flow rate were used. The values of damage rate deduced from the result of screen questions were examined to see how they differ in the interpretation of the risk in the NCC plant. Among the equipment in the NCC plant, the heat exchanger tubes were chosen for the evaluation of the efficiency of inspection program and the reliability of risk assessment results through comparative analysis for each method of damage rate assessment using the screen questions in the KGS-RBI™ program.

2. Outline of risk based inspection

RBI method uses the probability of risk as the basis in the operation of inspection program and efficiency rating. Generally, the equipments with higher risk, although they may be fewer, can have greater effect on the overall risk of the plant. Therefore, once an RBI system is set up, it is possible to optimize the inspection program so that the equipments with higher level of risk can be allotted with higher cost of inspection and maintenance whereas those with lower risk are allotted with more moderate cost. One of the benefits of using RBI program is that it can help at least maintain the risk at present level or improve safety whilst improving up-time of equipments. In RBI, assessment of risk is determined by multiplying two independent parameters, LoF (Likelihood of Failure) and CoF (Consequence of Failure) as formula (1).

$$\text{Risk} = \text{LoF} \times \text{CoF} \tag{1}$$

The values obtained from RBI are subject to qualitative, semi-quantitative and quantitative evaluation. The resulting semi-quantitative risk is expressed as a 5x5 matrix where horizontal axis indicates CoF and vertical axis LoF as shown in Fig. 1. Risk is rated in 4 levels as Low Risk, Medium Risk, Medium-High Risk and High Risk and in-

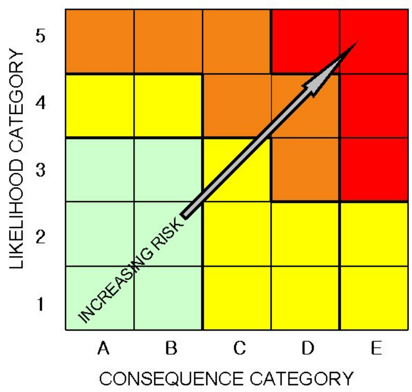


Fig. 1. 5×5 Risk Matrix

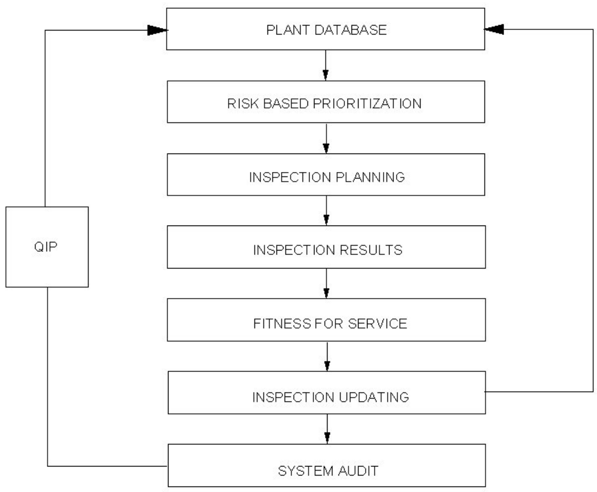


Fig. 2. RBI Program for In-Service Equipment

creases from the bottom left to the top right in the direction of the arrow. Fig. 2 shows RBI method application procedure in which the rating of risk is determined by applying RBI method using failure frequency, consequence of damage and general related data. The results of analysis are used for relief planning including inspection and maintenance services in accordance with risk rating. The results of relief activities are evaluated to update data for the likelihood and consequence of failure and reassessment according to the results of RBI analysis is performed.

Fig. 3. shows data items that must be input at the time of the implementation of RBI system. There are 53 data items in 5 categories; Equipment data includes general data about design and operational requirements of the subject equipment. Equipment information includes the name of the inventory group to which the subject equipment belongs and design-related data. The LoF interpretation data includes major factors influential to the failure of the equipment. CoF interpretation data consists of process in-

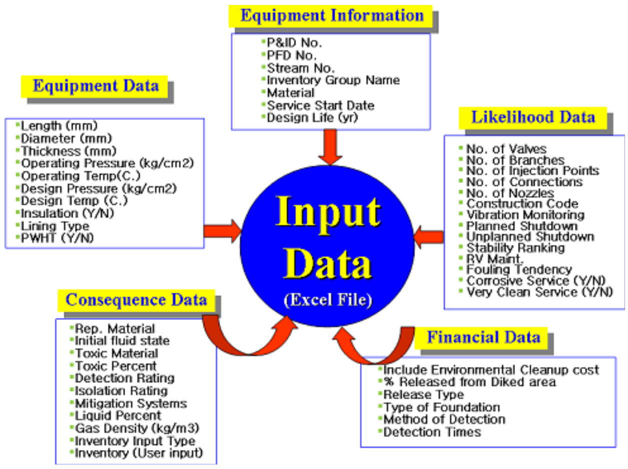


Fig. 3. Input data for Risk Based Inspection

formation pertaining to the operation of the plant including process materials, toxicity data, etc.

3. Assessment results using RBI

3.1 Analysis of the assessment results of the risk in NCC plant

In order to assess the corrosion damage in a petrochemical plant, the assessment using RBI method was performed on a number items: 1,258 pipes and the stationary equipments including 122 drums, 468 exchangers, 32 filters, 13 reactors, 48 columns, 10 heaters and 6 tanks in the NCC plant. The RBI assessment program used was KGS-RBI™ v2.6[12] developed by Korea Gas Safety Corporation. The results of assessment are shown in Fig. 4. In the case of column, assessment was performed separately for top and bottom. As indicated in Fig. 4(a), "Low" rated risk were found in 16% of all the items in the plant, "Medium" in 30%, "Medium High" in 39% and "High" in 15%. Fig. 4(b) and (c) shows the same statistics for stationary equipments and pipes respectively where "Medium High" and "High" ratings consist 28% in stationary equipments and 65% in pipes.

3.2 The effect of damage modification factor on stationary equipments and pipes

The Likelihood of Failure (LoF) is analyzed based on the Frequency$_{generic}$ (Generic Failure Frequency) data for each different physical type of the equipment and is calculated by setting F_E (Equipment Modification Factor) and F_M (Management Systems Evaluation Factor) and using them to compensate the generic failure frequency values based on API 581 Code. Fig. 5 shows the details of Equipment Modification Factor that is an important factor

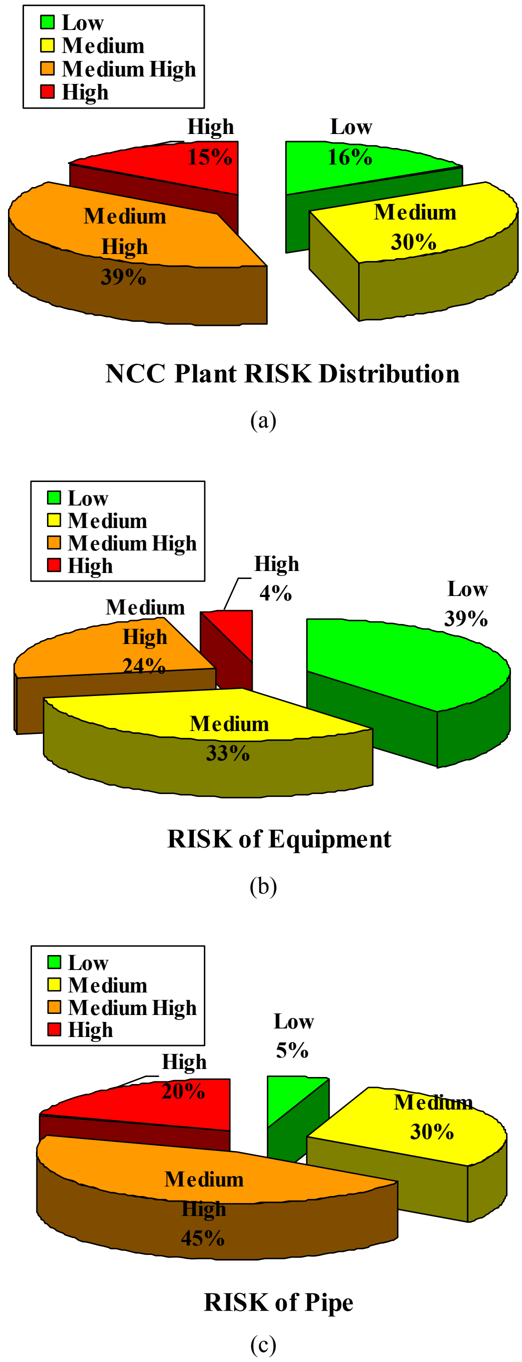


Fig. 4. Risk distribution of stationary equipments and pipes for NCC plant

in the interpretation of LoF. It includes TMSF (Technical Module SubFactor), the data necessary for the evaluation of the effect of specific equipment on the determination of likelihood of failure. In order to identify TMSF, operating conditions should be investigated and damage rate should be estimated to check for the existence of damaged equipment. It is structured for the systematic calculation

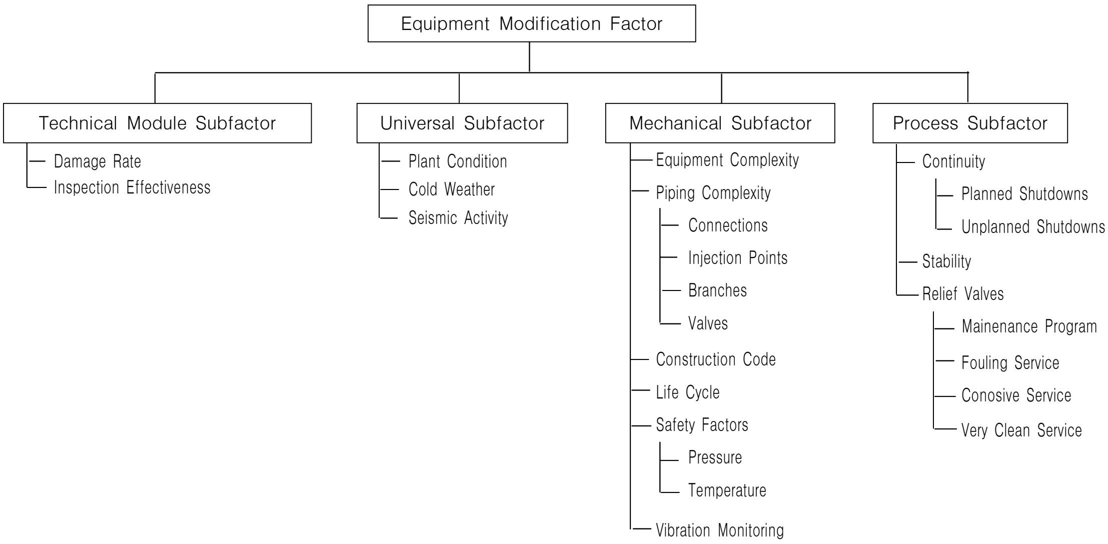


Fig. 5. Overview of Equipment Modification Factor[11)]

of damage modification factor which is used to quantify the inspection program and applied to the $\text{Frequency}_{\text{generic}}$. The effect of damage modification factor should be considered when comparing failure frequency expected as the result of the level of damage with the generic failure frequency of the equipment types. The damage modification factor is calculated by multiplying the probability of failure according to the generic failure frequency with the probability for the damage level. The resulting value is used as an indicator of how much more often the subject equipment will fail compared with the generic probability of failure for that particular equipment as a result of damage. This value is multiplied by another factor value which is determined for the subject level of damage based on the efficiency evaluated from the inspection history. The complex damage compensation factor is calculated based on the damage factors in progress in the equipment. The damage factors are classified into the mechanisms of thinning, stress corrosion cracking (SCC), high temperature hydrogen attack (HTHA), furnace tube, piping fatigue, brittle fracture, lining, external damage, etc. Among those damage factors, thinning, SCC, HTHA, brittle fracture and external damage mechanisms were found to influence the probability of damage in the subject NCC plant and corrosion was only influenced by thinning, SCC and external damage mechanisms, of which the results of analysis is shown in Figs. 6~8.

Fig. 6 shows the respective effects of thinning, SCC, HTHA, brittle fracture and external damage mechanisms on pipes and stationary equipments where thinning is shown to be most frequent and external damage is highly

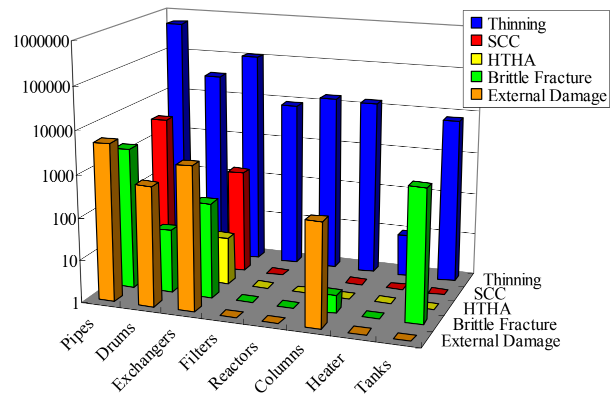


Fig. 6. Distribution of TMSF by damage mechanism

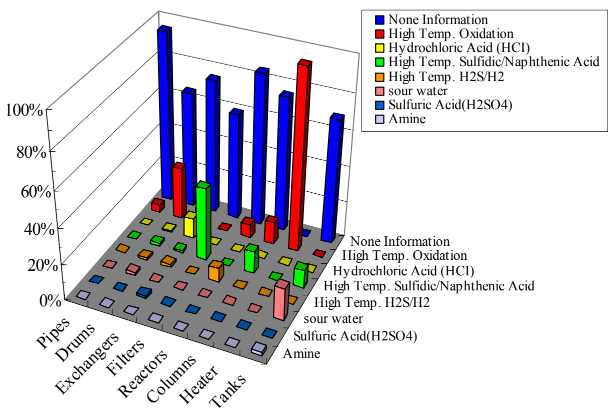


Fig. 7. Distribution of percentage by thinning mechanism

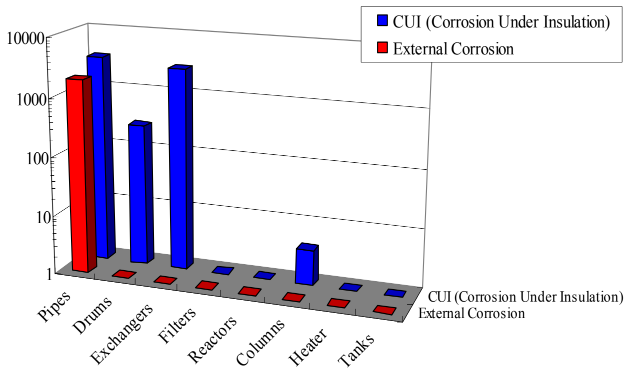


Fig. 8. Distribution of percentage by external damage mechanism

common in pipes, drums, exchangers, columns and tanks. Pipes are found to be more severe than stationary equipments to thinning, SCC, brittle fracture and external damage mechanisms and the exchangers, among other stationary equipment, is affected by all damage factors. On the other hand, filters, reactors, heaters and tanks are only affected by thinning and are hardly affected by SCC and external damage mechanisms. Figs. 7~9 are the diagrams for thinning, external damage and SCC mechanisms respectively showing the effects in more detail. As shown in Fig. 7, "High Tem. Oxidation" factor and "High Temp. Sulfidic/Naphthenic Acid" factor have more effect on both pipes and stationary equipments than other damage factors, particularly on drums, filters and columns. The factors of which precise information is not available were classified as "Non Information" factor which is also included by setting the base value in the program to obtain conservative overall result. Fig. 8 shows the comparative effects of two external damage mechanisms, CUI (corrosion under insulation) and external corrosion. Pipes, drums, exchangers and columns are found to be generally affected by CUI whereas external corrosion appears only in pipes. SCC was found only in 57 items. They were mostly affected by "HIC/SOHIC-H_2S" factor. The effects of Carbonate, Caustic and PTA also regularly existed at different degrees in each item.

3.3 Determination of re-inspection interval

Fig. 9 and Table 1 show the results of re-inspection interval (internal open test) for NCC plant according to the RBI assessment. This result was established based on the risk matrix specified in API 581 with more weight on the effects of LoF on the risk than that of CoF and the criterion of Korea Gas Safety Corporation which is regulatory body for petrochemical plant in Korea. The results showed that, of all the items, 262 (approx. 13%) were found to be at highest risk specified with "1 yr" interval

Table 1. Result of re-inspection interval for NCC plant

Re-Inspection Interval (yr)	Total	Percentage (%)
1 yr	262	13.1%
4 yr	593	29.65%
6 yr	827	41.35%
8 yr	318	15.90%
Summation	2000	100.00%

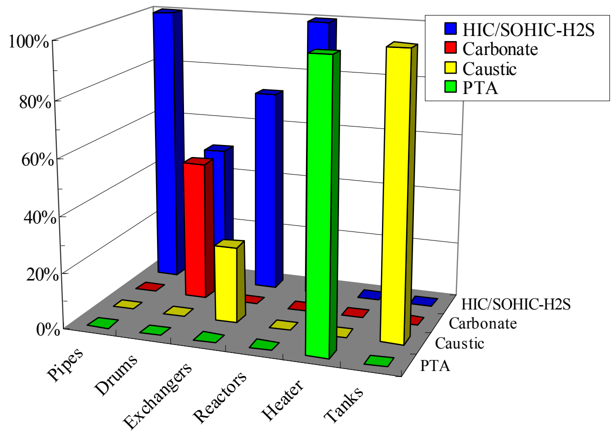
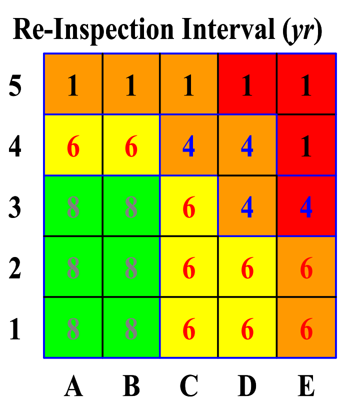
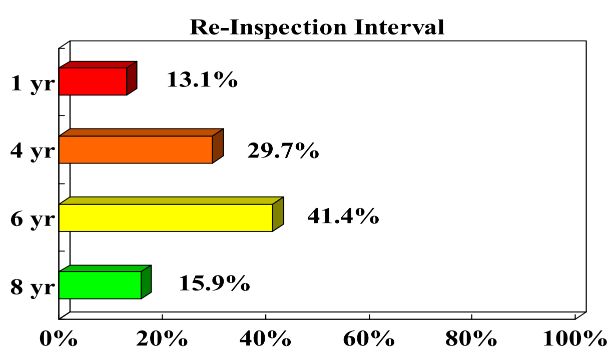


Fig. 9. Distribution of percentage by SCC mechanism



(a)



(b)

Fig. 10. Re-inspection interval for NCC plant

and 593 (approx. 30%) were specified with "4 yr". The number of items specified with "6 yr" was 827, the largest group taking up approx. 41%. The number of items with the lowest risk specified with "8 yr" was 318 (approx. 16%). These results showed that most of the items were specified with longer interval than legal requirement of "4 yr".

3.4 Reliability assessment of thinning by screen questions based on API 581 codes

The measurement using inspection program usually does not produce substantial values as far as heat exchanger tubes are concerned due to their conditions. Therefore, the assessment of damage rate for the interpretation of failure frequency in RBI is done by comparative evaluation of the results from screen questions on damage state, the thinning damage data obtained from the similar equipments and the average thinning damage data specified in API 581 Codes. There were total 60 heat exchanger tubes that could be used as the subject of comparison for the ascertainment of reliability of this study. 10 tubes of EA101A-TS ~ EA110A-TS were chosen from the dissolution process of the NCC plant as shown in Table 2. Of these tubes, detail inspection record was available with EA101A-TS and its thinning damage rate was found to be 3.09 mpy. The thinning damage rate for the other 9 heat exchanger tubes for which no records of inspection are available was estimated as 6.03 mpy and 1.86 mpy. The results of the assessment of thinning damage rate for the selected tubes are shown in Table 2 and Fig. 11. In the assessment using screen questions based on API 581 code, the highest corrosion rate was expected in the pipes in "High Temperature H_2S/H_2 Corrosion" condition where H_2S/H_2 corrosion occurs. Corrosion rate of 50 mpy was expected mainly due to the corrosion agent containing sulfuric component. The resulting calculation showed very high probability of damage with TMSF value of 2,500. Such high probability of damage led to the change of risk rating from Medium Risk to High Risk for EA101A-TS and form Medium High Risk to High Risk for EA109A-TS and EA110A-TS indicating that the pipes that were considered to be at moderate risk were at potentially higher risk. Although EA102A-TS ~ EA107A-TS maintained their original rating of Medium High Risk, their probability of failure was changed from Class 4 to Class 5 indicating that they are the equipment at potentially high risk. The thinning rate so far estimated from the screen questions suggested that the same value can be obtained for the same type of equipment if material information is known and that it can be used as the method of evaluating the level of risk and comparing the reliability or consistency of the equipment.

Table 2. Corrosion Rate vs Screening Questions Result

No.	Sort	Damage	TMSF	Ranking	Note
EA 101A-TS	Corrosion Rate	3.09 mpy	1	2D	2D→5D
	Screen Question	50 mpy	2500	5D	
EA 102A-TS	Corrosion Rate	6.03 mpy	325	4C	4C→5C
	Screen Question	50 mpy	2500	5C	
EA 103A-TS	Corrosion Rate	6.03 mpy	325	4C	4C→5C
	Screen Question	50 mpy	2500	5C	
EA 104A-TS	Corrosion Rate	6.03 mpy	325	4C	4C→5C
	Screen Question	50 mpy	2500	5C	
EA 105A-TS	Corrosion Rate	6.03 mpy	325	4C	4C→5C
	Screen Question	50 mpy	2500	5C	
EA 106A-TS	Corrosion Rate	6.03 mpy	325	4C	4C→5C
	Screen Question	50 mpy	2500	5C	
EA 107A-TS	Corrosion Rate	6.03 mpy	325	4C	4C→5C
	Screen Question	50 mpy	2500	5C	
EA 108A-TS	Corrosion Rate	6.03 mpy	325	4D	4C→5C
	Screen Question	50 mpy	2500	5D	
EA 109A-TS	Corrosion Rate	1.86 mpy	1	2E	2E→5E
	Screen Question	50 mpy	2500	5E	
EA 110A-TS	Corrosion Rate	1.86 mpy	1	2E	2E→5E
	Screen Question	50 mpy	2500	5E	

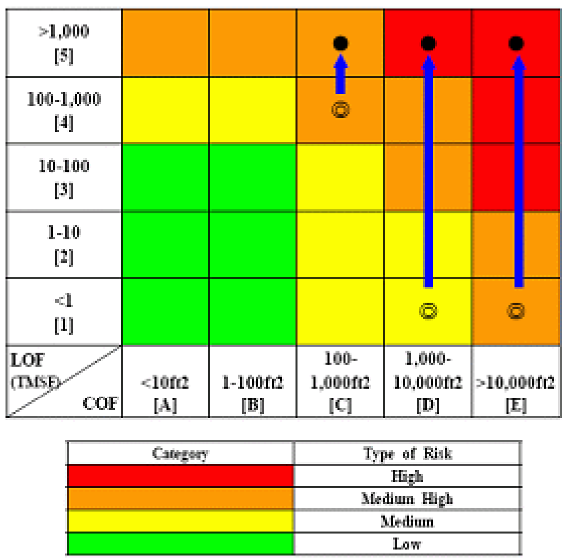


Fig. 11. Risk Matrix Result

4. Conclusions

In this study, we set up an RBI system for an NCC plant, a type of petrochemical production facilities, and investigated the effects of corrosion damage caused by corrosion mechanism specified in the RBI method, of which conclusion is summarized as follows:

1) Assessment of Corrosion Damage in an NCC plant was performed using Risk-Based Inspection method and the distribution of corrosion damage factors including thinning, SCC, external damage, etc for stationary equipments and pipes was analyzed.

2) In the case of Thinning, "High Temp. Oxidation" factor was found to be the most influential factor in the whole corrosion damage mechanisms in both stationary equipments and pipes and conservative assessment results were obtained by applying "None Information" factor for those items whose accurate information on corrosion damage factor was not available.

3) In the case of SCC, occurrence was observed in 57 items among all the items studied and the effect of "HIC/SOHIC-H_2S" factor was found to be the highest whilst each item was commonly affected by carbonate, caustic, PTA, etc..

4) In the case of External Damage, effect of CUI was noted in pipes, drums, exchangers and columns whereas, in the case of External Corrosion, effects were noted in a part of pipes only.

5) Re-inspection interval for each subject item was determined resulting in the specification of less than 1 year for 13.1% of the subject items, 4 years for 29.7%, 6 years for 41.4% and 8 years for 15.9%.

6) From the above results, we believe that it is possible to develop a method to reduce risk, enhance safety, save additional cost for inspection and ascertain reliability; that the assessment of risk using RBI in petrochemical plant should be carried out by a group of experienced specialists; and, particularly, that the maintenance of historical data on on-site inspections should be improved for better assessment results.

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