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The Implementation of Risk-Based Inspection for the Refinery Plant

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Recently, regulatory bodies quite often encourage to adopt risk-based inspection (RBI) and management programs because they can enhance safety simultaneously with deregulation in Korea. RBI is an integrated methodology that factors risk into inspection and maintenance decision making. This paper describes an example of how to use known risk assessment codes (API 580, API 581 BRD) to address such safety analysis requirements for risk management in the refining industry. Specifically, this paper reports the methodology and the results of implementation to the Crude Distillation Unit(CDU) plant of refinery units using the KGS-RBI™ program, developed by the Korea Gas Safety Corporation in reference of API Codes and ASME PC (Post Construction) with a suitable consideration of Korean situation. The results of the risk and reliability assessment using KGS-RBI™ program are useful in determining whether the detected defects are tolerable or required to be repaired. The subsequent decisions are to manage the future inspection, repair and maintenance planning in the risk reduction control.

Keywords *: risk, risk-based inspection(RBI), refinery, reliability, inspection interval*

1. Introduction

The concept of risk analysis has long been used in refinery and petrochemical units. In particular, the method of risk-based inspection (RBI) estimates a grade or degree of risk for each equipment, and then prioritizes inspection processes and establishes a necessary inspection method, interval, and schedule, in order to provide a comprehensive and systematic inspection.[1] Due to such wide applicability of the RBI methodology, many heavy chemical industries, gas businesses and steam-power institutions in Korea have already attempted to introduce or develop their own programs. To comply with such an attempt, the Korea Gas Safety Corporation (KGS), a governmental inspection and regulatory body in refinery and petrochemical fields working under the control of the Ministry of Knowledge Economy (MKE), developed KGS-RBI™ software, the Korean-style RBI program, on the basis of API 580 and API 581 BRD Code in order to present an assessment method to reduce costs for repair and maintenance of refinery plants and ensure safety of equipments.

This study includes description of algorithm and implementation of the RBI assessment methodology in the KGS-RBI™ program. The crude distillation units (CDU) system in refinery plants to which risk-based inspection was applied in this study has been operated for 35 years since 1968, it also uses the program to assess 725 pieces of pressure equipment (including all piping circuits) for risk, and describes an analysis of the results.

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2. Industrial loss

According to the report of the 170 major losses in the hydrocarbon-chemical industry during the last 30 years, more than half of those losses have been caused by mechanical failure of equipment. Over 80% of the equipment failure category have been caused by the failure of pressurized equipments, such as pipings, vessels, columns, reactors, tanks, pumps and exchangers.[2] The risk-based inspection methodology is focused on such a pressure envelop, including the potential for pump seal failure.[3] In case of failure to consider efficiency of inspection expenses in the field as well as accident management costs, it may require great expenses. RBI provides a tool that can prioritize the inspection processes to prepare thorough safety supervision. The prioritization based on the risk level of all the equipments is an epoch-making assessment technique that can allocate inspection capacities to provide the basis for frequent intensive inspection of high-risk parts, thereby reducing expenses that will be involved in an industrial field.[4)]

3. Methodology

Given the RBI definition for risk as the product of both likelihood of failure (LOF) and the consequence of failure (COF), in the traditional mathematical terms, the risk for a scenario is (1).

$$Risk_s = C_s \times F_s \quad (1)$$

where,

S = scenario number (Hole Size)
C_s = consequence (area in ft^2 or \$) for scenario,^{s}
F_s = failure frequency (per year) for scenario,^{s}

The algorithm of KGS-RBI developed by this study has been invoked on the basis of the assessment procedure presented in the appendices of API 581 BRD Code; those parts presented by the procedure with less certainty were constructed in reference of the text of the code and literature cited. The algorithm can be divided largely into three modules as qualitative, semi-quantitative, and quantitative RBI.

The algorithm constructed presently to support risk calculation and apply the results is as follows:

1) Plant data management algorithm
2) Group inventory calculation algorithm
3) Inspection effectiveness/Inspection planning algorithm

Calculating sub-algorithms belonging to the main algorithm category includes continuous release time, release speed, inspection efficiency, corrosion rate, damage mechanism, inspection plan, consequence calculation, risk estimation, financial risk calculation algorithms, and so on. Fig. 1 illustrates the general flow of RBI algorithm based on API 581 BRD Code.

4. Qualitative RBI

Qualitative RBI Assessment calculates likelihood, damage consequence, and health consequence categories and presents the results in the 5×5 risk matrix. Likelihood category is composed of equipment, damage, inspection, condition, process, and design factors, which are indicated in grade 1, 2, 3, 4, or 5. The consequence category is composed of chemical, quantity, auto-ignition, credit, state, and pressure factors while the health consequence category toxic quantity, dispersibility, credit and population factors, each of which is indicated in grade A, B, C, D, or E.

5. Semi-Quantitative RBI

The semi-quantitative RBI procedure is almost identical to quantitative one; contrary to the latter, however, the former doesn't demand accurate data on the terms of the inventory group and makes a calculation in the same way with quantitative RBI considering flammable and toxic

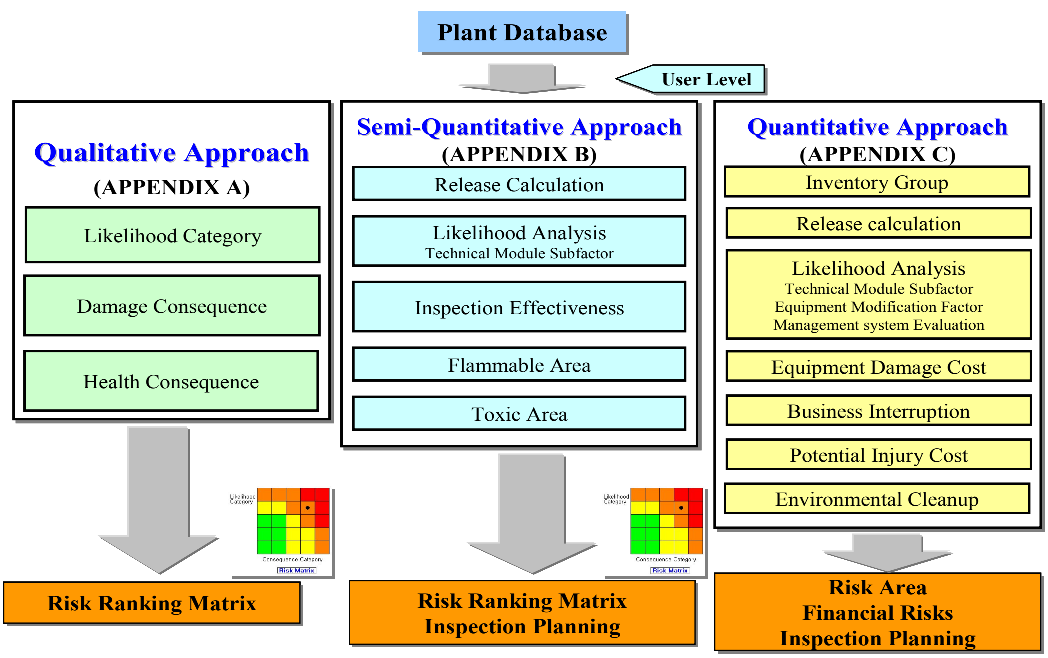

Fig. 1. Flowchart of the KGS-RBI™ software developed based on the API 581 BRD Code.

consequence areas alone. It considers no financial risk. Generic equipment failure frequency is reflected in each of the consequence areas calculated, and the following equation is used to calculate a likelihood weighted average area and to determine a consequence category by the resulting values.

$$Likelihood\,Weighted\;Average\,Area = \sum_{n=1}^{n=4} \times \frac{Frequency_n}{\sum_{n=1}^{n=4} Frequency_n} \qquad (2)$$

For likelihood analysis, those subfactors with relatively small value are disregarded among many necessary subfactors while only technical module subfactors are considered to determine the likelihood category.

6. Quantitative RBI

The quantitative analysis looks not only at the inspection records and equipment design and maintenance records, but also at numerous process safety management issues and all other significant issues that can affect the overall mechanical integrity and safety of a process unit.[5)]

The likelihood analysis by quantitative RBI considered even universal, mechanical, and process subfactors of the equipment modification factor not considered by semi-quantitative RBI. In addition, the likelihood analysis begins with a database of generic failure frequencies for the specific equipment types. These generic frequencies are then modified by two terms, the equipment modification factor (F_E) and the management system factor (F_M). An adjusted failure frequency is calculated by multiplying the generic failure frequency by the two modification factors.[1)] The following equation demonstrates the likelihood analysis:

$$Frequency_{adjusted} = Frequency_{generic} \times F_E \times F_M \qquad (3)$$

In entering the actual inventory of equipment, quantitative RBI enters relatively accurate values, considering not only the inventory of the equipment but that of other related equipment types. Contrary to semi-quantitative RBI, the consequence assessment considers financial risks including equipment damage, business interruption, and potential injury/fatality, and environment cleanup costs as well as the flammable/toxic consequence area. While semi-quantitative RBI simply prioritizes risk levels of equipments, quantitative RBI is more effective in that it can estimates damage area and amount when a release accident actually occurs.

Table 1. List of the equipment items in the CDU system

EQUIPMENT TYPE	UNIT / EQUIPMENT COUNT
Column	6
Drum	17
Heat Exchanger	90
Fin/Fan Cooler	17
Compressor	3
Heater	2
Pump	43
Related Pipe	547
Total	725

7. Implementation of risk-based inspection on the CDU system in refinery plant

As a conventional risk assessment method, ASME Risk-Based Inspection guidelines have been used frequently.[6)] However, this study divided it into seven steps to implement RBI of CDU system. The following steps were undertaken to accomplish our risk-based inspection of CDU system using the KGS-RBI™ software in the refinery. Table 1 shows the classification of equipments in the CDU system under investigation.

Step 1 - Prerequisites
Step 2 - Scope Definitions
Step 3 - RBI Team Constitution
Step 4 - Data Collection and Input
Step 5 - Data Analysis and Evaluation by the Experts using the KGS-RBI™ Software
Step 6 - Inspection Planning
Step 7 - Inspection Plan Execution

8. Results and discussion

Fig. 2 shows the results of RBI implementation for 725 equipments using the KGS-RBI program and quantitative RBI for all the equipments by the consequence of failure (COF) and the likelihood of failure (LOF) in the risk matrix. These results were ranked by four grades (High, Medium High, Medium and Low) by risk. Table 2 shows the percentage of all the equipments ranked into each grade. As shown in Table 2, the equipments in the High-Risk grade were 3.69 percent that in the Medium-High-Risk grade 35.3 percent. Thus, the combination of the two categories reached to 39 percent. This result is different from that of the general 80/20 version, for the following reason:[3)]

The equipment ranked High-Risk means that the risk of the equipment is so high that it requires intensive management, which could provide data required by assessment with available detailed information on design data, inspection history, and measure record. However, these ranked Medium High seemingly generated conservative assessment and results due to insufficient input data and absence of information on risk mitigation though they weren't indeed very dangerous, exclusive of several items.

In other words, there is high likelihood that those records will be omitted on any possible repair or replacement and it is evident that RBI using these data will produce conservative results, which is a significant example of how important it is to manage history data. Table 3 prioritizes equipments ranked High Risk through quantitative RBI in terms of risk and shows operation terms, representative materials, LOF, and COF for each equipment. The following describes the cause analysis of several equipments that rank high. Since risk is calculated by the likelihood and consequence, the results will be analyzed along with the description of mitigation in relation to likelihood and consequence.

The FIN/FAN that ranks the first in Table 3 is a cooler that has been operated for 35 years since 1968. Technical Module Subfactor (TMSF) was dominant in the likelihood analysis. TMSF in API 581 BRD means the ratio of the frequency of failure due to the generic failure frequency to the likelihood that the damage level presents general corrosion. With remarkably high corrosion rate of 24.4 mpy measured as general corrosion, there was great risk factors due to thinning. However, its internal part went through only one highly effective inspection for about 30 years with no inspection of external damage. It is therefore natural that it had high likelihood of failure. Here, the

Table 2. Results of quantitative risk assessment using the KGS-RBI program for the CDU system

RISK RANK	NUMBER	PERCENTAGE(%)
HIGH	26	3.69
MEDIUM HIGH	256	35.31
MEDIUM	344	47.45
LOW	99	13.66
TOTAL	725	100.00

Likelihood Category	A	B	C	D	E
5	19	6	31	8	0
4	50	19	86	51	8
3	30	30	93	58	10
2	27	10	93	86	5
1	2	0	0	3	0

Consequence Category

Fig. 2. Quantitative Risk-Based Ranking Matrix.

Table 3. List of the high risk ranking with respect to the equipment types

Rank	Equipment Type	RR	Service Start Date	Material	Op. Temp (℃)	Op. Pressure (kg/cm^2)	Insulation	Rep. Material	Likelihood Of Failure	Consequence of Failure (m^3/yr)	Risk (m^3/yr)
1	FIN/FAN	5D	1968-10-01	Carbon Steel	59	9.5	No	C6-C8	23.10880	38.78933	896.38
2	FIN/FAN	5D	1968-10-01	Carbon Steel	150	9.5	No	C6-C8	11.60845	38.78565	450.24
3	COLUMN-BTM	4E	1968-09-01	Carbon Steel	345	2.4	Yes	C25+	0.15453	1168.07425	180.50
4	FIN/FAN	4E	1991-05-01	Carbon Steel	154	20.5	No	C9-C12	2.51167	41.954664	105.38
5	EXCHANGER	5D	1991-05-01	Carbon Steel	280	20	No	C25+	0.10842	804.10816	87.18
6	EXCHANGER	4E	1991-05-01	Carbon Steel	306	20	No	C9-C12	0.06973	568.91566	39.67
7	DRUM	4E	1991-08-01	Carbon Steel	43	21.1	No	C9-C12	0.06739	507.30890	34.19

"highly effective inspection" means the detection of over 90 percent of damage expected during operation in almost all cases. The consequence analysis shows very high risk because of the amount of inventory due to instantaneous release of liquid. This equipment in practice had low accident occurrence rate but high consequence of failure if an accident occurs; however, it ranked as equipment with the highest generic risk that induced a high value of LOF because of usual failure to provide proper management of damage caused by corrosion. To mitigate risk of this equipment, the following activities were taken. Accurate causes of corrosion were found and the corrosion handbook was used to predict the corrosion rate and estimate the remaining life. The results demonstrated that it satisfied the minimum required thickness and had the remaining life of about ten-years.

The following is analysis of the bottom of column that ranks the third in Table 3. For the column, API 581 BRD Code recommends that RBI should be accomplished for top and bottom parts separately because of phase flowing in the inner part. The column is also exposed to severely corrosive environment with the corrosion rate of 19.7 mpy measured relatively higher than other equipments. The cause of rise in the corrosion rate seems to be the combination of high-temperature operation, sulfide acid, and naphthenic acid. Consequence analysis revealed that it had the greatest amount of equipment inventory generated during the continuous release mainly due to liquefied C_{25+}(residuum, heavy crude), the representative material, and increased in the value of COF, thereby showing high risk. To reduce the risk of this equipment, it is necessary to implement safety management systems and special mitigation activities such as assessment of remaining life and continuous monitoring of corrosion rate by the nondestructive inspection within column during the period of preventive maintenance. The risk analysis for heat exchangers is also shown in Table 3. As pressure vessel composed of shell and internal tube, a heat exchanger has high tendency to be damaged by corrosion of the tube. According to RBI assessment in this study, there were a relatively great number of heat exchangers belonging to "3E" among High Risk and Medium High Risk, which means that a heat exchanger could have greater COF than LOF if damage occurred.

The following shows the results of risk assessment of "4E" drum that ranks the seventh in Table 3. Likelihood analysis shows that mechanical subfactor is in the B grade of construction code: "The code for this type of equipment has been significantly modified since the time of fabrication." This means that vessel was modified after the time of fabrication and that it is unknown whether an appropriate code is satisfied. The vessel exposed to corrosive environment was selected as a process sub-factor. Technical Module Subfactor has brittle fracture as a main fracture mechanism along with internal/external thickness thinning. Thinning is caused by localized corrosion. The inspection history showed no inspection or "ineffective" in inspection. Here, "ineffective" means that it has very low (33%) identification of actual damage. Such a high rank in risk is largely due to failure to select an appropriate inspection method for thinning or failure to carry out it. On the ground of these results, the following inspection plans can be recommended. Inspection activities and methods include "implementation of inspection by raising the inspection level for pressure vessel like drum" and "requests for corrosion experts' advice on inspection intervals and methods."

9. Conclusion

After applying the risk-based inspection program (KGS-RBI) developed by the Korea Gas Safety Corporation to the CDU system on the refinery plant in Korea, there was a proper management of high-risk equipments; the equipments expected to have of low risk increase in their risk; and RBI is very effective and efficient of the inspection techniques. It served to identify damage mechanism in a damaged part for each equipment to be reflected in inspection planning in order to reflect necessary things in next turnaround. In particular, it will be found how to apply both inspection interval as a result of RBI implementation and re-inspection interval of pressurized equipment defined by the High Pressure Safety Management Law in Korea[7] and it is expected that an RBI method applicable to refinery plant will be provided to establish more effective safety management.

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