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Chemical Reactivity Hazards Assessment in Downstream Chemical Industries in Indonesia

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Abstract: This paper was based on research that have been conducted at three different downstream chemical industries located in Indonesia, as follows; the paint and resin industry (PT XYZ), the cosmetics industry (PT PQR) and the herbicide industry (PT CDF). The methodology of research starting from (1) assessment of chemical hazards based on *NFPA 704*, (2) study of CRH using *CRW 2 software programs from NOAA*, (3) identification of potential CRH in production processes, (4) develop a CRH worst-case scenarios and (5) assessment of CRH worst-case scenario with the *KJ Analysis.* Result: CRH Risk Index (RI) for PT XYZ = 0.67 (high risk), PT CDF = 2.0 (very high risk) and PT PQR = 0.71 (high risk). CRH Remaining Hazard Index (RHI) for PT XYZ = 1.46 (very high hazard), PT CDF = 0.06 (low hazard) and PT PQR = 0.46 (moderate hazards). CRH Remaining Risk Index (RRI) for PT XYZ = 0.31 (moderate risk), PT CDF = 0.06 (low risk) and PT PQR = 0.06 (low risk). It was concluded that the Safety Management System Factor (SMSF), Workers Factor (WF) and Safety Technology Factor (STF) decreased Hazards Index (HI) and Risk Index (RI) of CRH in DCI higher than Shah *et al.* model which only includes STF. WF provides the greatest contribution (44.6%) compared SMSF (32.5%) and STF (22.9%).

Key words: Hazards Index · Risk Index · Standard Management System · Worst-case Scenario · Workforce Factors · Safety Management Factors · Safety Technology Factors

INTRODUCTION

Chemical reactivity hazards is the situation whereas the potential for uncontrolled chemical reaction that can result in accidents and directly or indirectly cause harm to workers, lost companies and environmental asset. Uncontrolled reaction can be accompanied by a rise in temperature and pressure, then release of gas or energy [1]. Chemical reactivity hazards is a complex concept, until now there has been no single single parameter that can be developed which fully characterize all aspects of chemical reactivity [2]. As a result of uncontrolled chemical reactions is the release of energy, heat and gas in large quantities, which in turn can lead to explosions, fires and toxic gas release [3]. Reactivity hazards arise due to the tendency of chemicals to react or decompose. There are four ways of reactivity hazards can occure: (1) Exothermic reaction with air, (2). The reaction with water, (3) Mixed with other chemicals and (4) Selfreaction or decompose [4].

National Oceanic and Atmospheric Administration (NOAA) released worksheet software CRW 2 to conduct a study of chemicals incompatibility. From this worksheet we can predict the likelihood of potential consequences of the interaction of mixed materials such as heat, pressure, gas released and so forth. The study of chemical reactivity hazards begins with collecting physical and chemical properties data of chemicals, also need to learn the function of each chemical in a process. Then we need to study the type, rate, pressure and temperature of reaction. The data obtained is transformed into the form of the potential hazards that can occur; poisoning, power flame, explosion, reactivity and reaction conditions [5].

The potential of Chemical Reactivity Hazards (CRH) for downstream chemical industry (DCI) in Indonesia is still considerably high. In general, DCI in Indonesia still uses conventional technology with limited human resources capability, while have to handle numerous types of chemicals. Most of them

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use a system of batch and semi-batch process, where the production process is done in small-scale vessel and raw materials entered manually into the vessels or reactors. They also have very limited production facility to produce numerous types of products so that the process cycle of product in one reactor or vessel is very high. These allow for the occurrence of errors in the process or the occurrence of contamination of one product with another product that can lead to chemical reactivity accident.

The general objectives of this research is to identify potential reactivity hazards, to identifiy the factors that influence the potential accidents of chemical reactivity hazards from the aspects of environment, management and workforce and know the level of remain hazards and risk indexs of chemical reactivity. This research was done in three different downstream chemical companies which have different stage implementation of international standard management system.

Research Methodology: The state of the art of this research is combining quantitative and qualitative method. The first two stages is quantitative research to find the hazards index of chemical reactivity and the last two stages is qualitative research to find the factors that influence reactivity hazards. The stages of the research are as follows:

- Hazard assessment of chemicals based on NFPA 704.
- Study the chemical reactivity hazards.
- Develop worst-case scenarios of chemical reactivity hazards.
- Study of chemical reactivity hazards worst scenario with KJ Analysis method.

Hazard Assessment of Chemicals: The initial phase of this research is to study individual chemical hazards of all chemicals used. The chemicals are categorized based on hazard index (HI) as listed in Table 1. There are four categories of HI in this study namely [6];

- Very high (HI> / = 0.75-1)
- High (HI> / = 0.5-.75)
- Medium (HI> / = 0.25 to 0.5)
- Low (HI: <0.25).

HI grouping refers to a study conducted by Shah *et al.* [6].

Only chemicals that have a hazard index> / = 0.5 which will be included in subsequent studies.

Chemical Reactivity Hazards (CRH) Assessment: The next step is to evaluate the chemical reactivity hazards of chemicals that have a hazard index (HI)> / = 0.5 (a medium hazard level). The study of chemical reactivity hazards was done by using software programs CRW 2 is issued by NOAA (National Oceanic Atmospheric Association). All chemicals incorporated into this program one by one to see the chemical incompatibility with other chemicals. The output of this review is a chemical incompatibility matrix. Chemical reactivity hazards output was given as a worksheet that can be grouped by hazard index as in tables 2. This matrix will be used to design a worst-case scenario of chemical reactivity hazards in the next stage.

Table 1: Chemical Hazards Index Indeks

Parameters	Indicators	Hazards Index (0-1)	Hazards Clasification
Flammabilty Rating NRFA 704	1	0,5	Moderate
	2	0,75	High
	3, 4	1	Very High
Health Rating NRFA 704	1	0,5	Moderate
	2	0,75	High
	3, 4	1	Very High
Water Reactive (NWRFA 704)	1	0,5	Moderate
	2	0,75	High
	3, 4	1	Very High
LD 50 (Mouth)	> 25 or < 200 mgKg BW	0,5	Moderate
LD 50 (Skin)	> 25 or < 400 mgKg BW	0,5	Moderate
LC 50	> 0.5 mg/l and 2 mg/l	0,5	Moderate
LD 50 (Mouth)	25 mgKg BW	1	Very High
LD 50 (Skin)	25 mgKg BW	1	Very High
LC 50	0.5 mg/l	1	Very High
Flash Point (Flammable Liquid)	> 21 C and < 55 C pd 1 atm	0,5	Moderate
	< 21 C and boiling point >20 C at 1 atm	1	Very High
Boiling Point (Flammable Gas)	< 20 C at 1 atm	1	Very High

Tabel 2: Indeks Bahaya Reaktifitas Kimia CRW 2

Bahaya Reaktifitas	Kode (CRW 2)	Indeks Bahaya (0-1)
Risk of explosion by shock, friction, fire or other sources of ignition	A2	1
May form unstable explosive metal	A3	1
May form explosive peroxides	A5	1
Reaction proceeds with explosive violence and / or forms explosive products	A6	1
Exploide if mix with flammable chemicals	A8	1
Heat generated from chemical reaction may initiate explosion	A9	0,75
May become highly flammable or may initiate a fire, especially if other combustible materials are present	B1	0,75
Spontaneous ignition of reactants or products due to reaction heat	B4	0,75
Combination liberates gaseous products, at least one of which is flammable.	B5	1
Combination liberates gasesous products, including both flammable and toxic gases. May cause pressurization.	B6	1
Exothemic reaction. May generate heat and/or cause pressurization	C	0,75
Exothermic, potentially violent polymerization. May cause pressurization	D1	1
Combine liberates gaseous products, at least one of which is toxic. May cause pressurization	D3	1
Combination liberates nonflammable, nontoxic gas. May cause pressurization	D4	0,75
Combination liberates combustion-enhancing gas (e.g., oxygen). May cause pressurization	D5	0,75
Exothermic, generation of toxic and corrosive fumes	D6	1
Generation of corrosive liquid	D7	0,75
Generate water soluble products	E	1
Reaction may be intense or violent	G	0,75
May be hazardous but unknown	F	1
Highly Flammable	101	1
Strong oxidation agent	104	1
Form peroxide compound	111	1
No Reaction	NR	0

Development of CRH Worst Scenario: Rasmussen [7] found four main trigers of accidents are caused by the hazards of chemical reactivity based on a study of 190 accidents in chemical reactivity, namely (1) impurity, (2) mixing error, (3) error process conditions and (4) of imperfect mixing. Those four factors were used to develop worst-case scenario in this study to know the possible root cause of CRH accident in downstream chemical industry in Indonesia. The worst case scenario must be designed in accordance with the conditions of the process in a particular industry.

Worst Scenario Impurities: The worst scenario is designed based on the likelihood of contamination on raw materials and processes. Selected impurities are impurities that allow for unwanted chemical reactions that can cause CRH with HI> / = 0.5.

Worst Scenario Mixing Error: The worst scenario is designed based on the error of the mixing process of raw material in production. Raw materials and process chosen is a possibility of unwanted chemical reactions that can cause CRH with HI> / = 0.5.

Worst Scenario Process Condition Error: The worst scenario is designed based on the risk of error in the process of production, such as temperature, pressure, flow rate of raw materials and others. Error is the selected process conditions which allow for unwanted chemical reactions that can cause CRH with HI> / = 0.5.

Worst Scenario Imperfect Mixing: The worst scenario is designed based on the possibility of imperfect mixing raw materials in production, such as errors in the sequence of mixing, lack or excess of one or more raw materials, lack one or more raw materials and imperfect steering. Imperfect mixing selected is a possibility of unwanted chemical reactions that can cause CRH with HI> / = 0.5.

After having ideas of the most likely worst case scenario for each industry, then we proceed with designing the worst case scenario of chemical reactivity hazards. The processes of designing the worst case scenario are as follows:

- Identify the composition of raw materials for every product manufactured and looks at the possibility of unwanted reactions based on matrix of chemical incompabitibity.
- Studying the production process to look at the possibility of potential causes of chemical reactivity hazards.
- Discuss with the production team in designing the worst scenario that may occur.

Table 3: Calculation Results of Weight for Management System Reduction Factors (FSMK)

No	Management System Reduction Factors (MSRF)	ISRS Element	ISRS Score	% Score	MSRF Weigth
1	Management commitment	Leadership and Administratiom	1310	24%	0.08
2	Hazards identification process	Off-the-job safety	240	4%	0.01
3	Accident analysis process	Accident/incident investigation	605	11%	0.04
4	New product development procedure	Engineering and change management	670	12%	0.04
5	Review/audit system	System evaluation	700	13%	0.04
6	Emergency response	Emergency preparedness	700	13%	0.04
7	Raw materials management	Materials and service management	615	11%	0.04
8	Production working standard and procedure	Critical task analysis and procedure	650	12%	0.04
	Total MSRF		5490	100%	0.33

Note: Total value of MSRF is 0.33

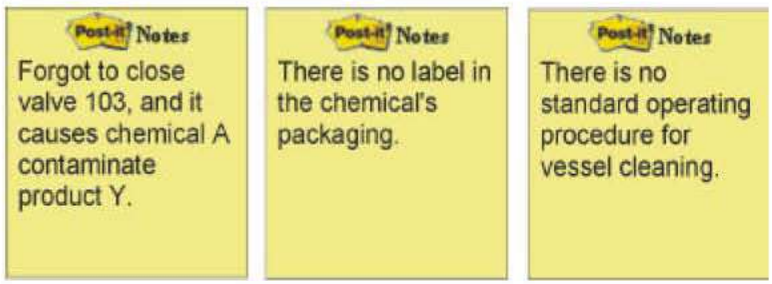

Fig. 1: Example of KJ Analysis input from participants in the Post-it Note

All worst cases scenarios of chemical reactivity hazards to be tested must have a hazard index (HI) at least 0.5 refers to table 2 and 3. Each company included in this study will have at least 3 worst case scenarios, thus the total scenario will be at least 9 worst-case scenarios from 3 companies included in this study.

Worst Case Scenario Assessment Using KJ Analysis Method: The worst case scenario of chemical reactivity hazards is analysed deeply to find the factors that could potentially lead to the occurrence of chemical reactivity hazards. The study was conducted in a group brainstroming involving various departments like production, QC, R and D, engineering, safety and warehouse by using the method of KJ analysis. KJ analysis is the most common way of building the diagram. It is also useful as a way of organising the results of a brainstorm, where we start with a problem and generate number of possible solution around it.

The process of KJ analysis is as follows:

- Form a brainstorming group (10-20 people) with the approval of the management company, with participants following criteria:
    - Department: Production, QC, R and D, Maintenance Engineering, K3 and Warehouse.
    - Position: Operators, Foremen, Supervisors and Managers.
    - Working Experience: minimum 2 years.
- Determining the schedule and make invitations for participants.
- Conducting KJ analysis (3-4 hours) for each scenario, the stages as follows:
    - Explain the purpose and procedure KJ analysis method.
    - Explain the worst case scenario of chemical reactivity hazards that will be discussed.
    - Each participant was asked to give the input by writing (on the prepared Post-it Note) the factors that may lead to chemical reactivity. Three factors became the main concern namely: work environment factors, factor management systems and worker factors. One idea/cause was written on each sheet Post-it Note and participants are given the freedom to write as much as they want. Figure 1 is an example of writing input with KJ method of analysis.
    - Then participants were asked to attach Post-it Note that has been provided by category of work envRIonment factors, management systems factors and worker factors.
    - Then all participants were asked to look at and read all the input on the paperboard and they were grouped into the same categories.

RESULTS

Hazard Assessment of Chemicals: 881 of chemicals were included in this study 881 that come from three companies, namely PT XYZ (501 chemicals), PT PQR (355 chemicals) and PT CDF (25 chemicals). The number of chemicals with very high hazard index (HI = 1.0) in PT XYZ was 7.39% (37 chemicals), PT PQR was 1.13% (4 chemicals) and PT CDF eas 28% (7 chemicals). While the number of chemicals with high hazard index (HI = 0.75) in PT XYZ was 4.19% (21 chemicals), PT PQR was 20.56% (73 chemicals) and PT CDF was 28% (7 chemicals). The number of chemicals with medium hazard index (HI = 0.5) in PT XYZ was 9.18% (46 chemicals), PT PQR was 48.17% (171 chemicals) and PT CDF was 24% (6 chemicals). While the number of chemicals with low hazard index (HI <0.25) in PT XYZ was 2.4% (12 chemicals), PT PQR was 13.24% (47 chemicals) and PT CDF was 16% (4 chemicals). The number of unknown chemical hazards index in PT XYZ index was 76.85% (385 chemicals), PT PQR was 16.9% (60 chemicals) and PT CDF was 0%. Here, numerous number of chemical hazard indexes can not be determined due to the lack of information on the properties of those chemicals. This is caused by unavailability of Material Safety Datasheet (MSDS) and Tedchnical Data Sheet (TDS), or can also be caused by trade secret from the manufacturers.

Reactivity Hazards Assessment of Raw Materials: The number of chemicals included in this study was 492 from three chemicals companies, PT XYZ was 112 chemicals, PT PQR was 355 chemicals and PT CDF was 25 chemicals. Total chemical pairs of the processed data using CRW 2 for PT XYZ was 6328 pairs, PT PQR was 63190 pairs and PT CDF was 300 pairs. The number of mixtures who have interactions or chemical reactions in PT XYZ was 9.72% (615 pairs of chemicals), PT PQR was 0.74% (470 pairs of chemicals) and PT CDF was 4% (12 pairs of chemicals). The number of mixed pairs that have no interaction or chemical reaction in PT XYZ was 9.72% (615 pairs of chemicals), PT PQR was 0.68% (427 pairs of chemicals) and PT CDF was 5.33% (16 pairs chemicals). The level of potential reactivity hazards occur with very high hazard index (HI = 1.0) in PT XYZ was 5.64% (356 pairs of chemicals), PT PQR was 0.48% (304 pairs of chemicals) and PT CDF was 1,67% (5 pairs of chemicals). The level of potential reactivity hazards occur with a high hazard index (HI = 0.75) in PT XYZ was 3.22% (203 pairs of chemicals), PT PQR was 0.26% (166 pairs of chemicals) and PT CDF was 2,33% (7 pairs of chemicals). While the level of potential reactivity hazards occur with medium hazard index (HI = 0.5) and low (HI <0.25) was not found (0) in all three companies. From the results of this study can be concluded that there are potential dangers of chemical reactivity of materials used with very high hazard index (HI = 1) and high hazard index (HI = 0.75) in all three types of industry in this study.

Reactivity Hazards Assessment of Finished Products: Chemical analysis using software CRW 2 had shown that 111 products (32%) had the potential interaction / reaction of raw materials in their formula. Eventhough there was no chemical reaction within the production, some raw materials might react with each other if the conditions of chemical reaction were fulfilled. Number of interaction pair of chemical reactions with HI = 1.0 in the final product was 72 (21%) and HI = 0.75 was 39 (11%). These data shows that CRH can potentially occur in all three types of industries. However, the paint industry (PT XYZ) and herbicides (PT CDF) showed a higher hazard level than the cosmetics industry (PT PQR), where PT XYZ has HI = 1.0 was 47%, PT CDF was 100%, while PT PQR was only 9%.

Products that potentially interact / react when mixed were 295 products out of 351 with detail as follows: PT XYZ was 89 products (87%), PT PQR was 204 products (83%) and PT CDF was 2 products (100%). Those three companies showed very high potential for CRH, where most of intermediates and final products (> 80%) can react when being mixed if the reaction conditions are fulfill. Number of product pair that interact / react with HI = 1.0 was 2706 pairs (18%) and HI = 0.75 was 4850 pairs (32%) and there was no pair with hazard index of 0.5. While the number of pairs that have unknown hazards index was 7486 pairs (50%). High number of unknown HI was caused by many raw materials that are not available in the CRW 2 database and lack of clarity about the name and properties of chemical used.

The results from CRH studies of the final products shown that there was a potential for chemical reactivity hazards from the raw material and also there was potential of chemical reactivity hazards for some intermediates or final products.

Results of KJ Analysis: There were 16 CRH worst-case scenario included in this KJ analysis for three companies; 7 scenarios for PT XYZ (2 contamination scenario, 1 mixing errors scenario, 2 process conditions error scenarios, 1 imperfect mixing scenario and 1 general safety

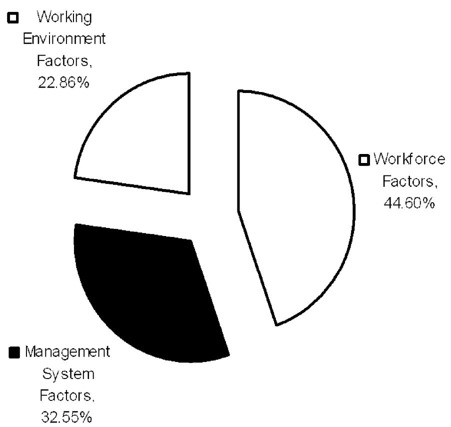

Fig. 2: Three Main Factors of CRH Accident Causation Based on KJ Analysis of Worst-Case Scenario

accident scenario), 4 scenarios for PT PQR (1 contamination scenario, 1mixing error scenario, 1 process condition error scenarion and 1 mixing imperfections scenario), 5 scenarios for PT CDF (2 contamination scenarios, 2 process condition error scenario and 1 general safety accident scenario). All CRH worst-case scenario above except a general safety accident scenario have HI = 1.0 (very high hazards). Actually, several worst case scenario of chemical reactivity hazards were a real cases based on each company history, ie, 2 cases in PT XYZ, 1 case of PT PQR and 1 case of PT CDF. General safety accident scenario was proposed by the management of company to find out the cause of accidents in general, that is believed happened due to the chemical reactivity hazards.

There were 805 input of the root causes of CRH accident in the study of worst-case scenarios with a KJ analysis for this three companies, consist of 366 inputs from PT XYZ, 211 inputs from PT PQR and 228 inputs from PT CDF. Numerous number of inputs that have obtained, indicate the seriousness and desire of participants to seek an appropriate solution of the problems raised. Of the 805 input can be grouped into 3 main factors that are considered the most dominant as the cause of the safety accident, namely Human factor (44.6%), Management System factors (32.55%) and Working Environment factors (22.86%). The figure 2 shows the three main factors of CRH accident.

DISCUSSION

Various types of chemicals in the downstream chemical industry in Indonesia related to numerous chemical reactivity hazards. Despite the scale of the impact, it can be significant or even bigger if a domino effect occured. The need of safety technology needed to handle small quantity of chemicals in downstream chemical industry of course not the same as safety technology on the upstream chemical industry with large quantity of chemicals. In general, upstream chemical industry implements very high standard safety technology, but for the downstream chemical industry do not have to apply high safety technology. Based on the data from chemical hazard assessment, author has hypotized that to manage many types of chemicals in small quantities can be done by applying a good chemical management system and safety technology with minimum requirement. Chemical management system referred here is the system that regulates the flow of chemicals from a supplier, storage system and condition, delivery system and production control in accordance with the request (Bill of Material), the handling of chemical residual, controlling intermediate products and delivery and storage of final product. Each stage must be properly and systematically arranged in a standard operation procedure (SOP) and good control systems. The most important things are to know types of chemical hazards and the ways of handling it at every stage of the process.

Chemical hazard control system focused on chemicals in moderate to very high hazard index. Shah *et al.* [6] proposed an equation that shows the level of remaining primary hazard index (RPHI) after deducting the factor of safety technology implementation, as follows:

$$RPHI = PHI - \sum STRF$$

Where,

RPHI = Remaining Primary Hazard Index
PHI = Primary Hazard Index
∑ STRF = Safety Technology Reduction Factor

Refering to the equation developed by Shah *et al.* [6], author proposed a new equation with additional reduction factors of workforce factor and management system factor in calculating the remaining hazard index (RHI) of CRH. The equation is as follows.

$$RHI = HI - (\sum MSRF_{n-k} + \sum WRF_{n-k} + \sum STRF_{n-k})$$

Where,

RHI = Remaining Hazards Index
HI = Hazard Indexs
∑MSRF = Management System Reduction Factors
∑ WRF = Workforce Reduction Factors
∑ STRF = Safery Technology Reduction Factors

Table 4: Calculation Results of Weight for Workforce Reduction Factors (WRF)

No	Workforce Reduction Factors (WRF)	ISRS Element	ISRS Score	% Score	WRF Weight
1	Human resources allocation	Hiring and placement	405	21%	0.09
2	Workforce safety involvement	Personal Communication	490	25%	0.11
3	Training and communication	Knowlegde and skill training	700	35%	0.16
4	Personal protective equipment utilization	Personal Protective Equipment	380	19%	0.08
	Total WRF		1975	100%	0.44

Note: Total value of WRF is 0.44

Table 5: Calculation Results of Weight for Safety Technology Reduction Factors (STRF)

No	Safety Technology Reduction Factors (STRF)	ISRS Element	ISRS Score	% Score	STRF Weight
1	Safety technology for Volatile chemicals	Health and hygine control	700	20%	0.046
2	Safety technology for Flammable chemicals	Health and hygine control	700	20%	0.046
3	Safety technology for Toxic chemicals	Health and hygine control	700	20%	0.046
4	Safety technology for mitigation from CRH	Health and hygine control	700	20%	0.046
5	Working environment/Equipment	Planned inspection and maintenance	690	20%	0.045
	Total STRF		3490	100%	0.230

Note: Total value of STRF is 0.23

Management systems reduction factors (MSRF), workforce reduction factors (WRF) and safety technology reduction factors (STRF) were proposed as listed in Table 3, 4 and 5. Tables show the element of each factors refer to the checklist that is used for field audit and observation of CRH safety management system. Based in KJ analysis result, ratio of the causes of accident between working environment, management system and workforce factors is 0.23: 0.33: 0.44 (Figure 1). This ratio is used as the basic for developing values of MSRF, WRF and STRF as reduction factors of hazard index value.

The total value of the proposed MSRF is 0.33 or 33% can reduce the hazards of chemical and chemical reactivity in the downstream chemical industry. The total value of the proposed WRF is 0.44 or 44% can reduce the hazards of chemical and chemical reactivity in the downstream chemical industry. The total value of the proposed STRF is 0.23 or 23% can reduce the hazards of chemical and chemical reactivity in the downstream chemical industry. As described before, downstream chemical industry in Indonesia mostly still use conventional technology with limited human resources competency, while handling various chemicals and products that being used. Therefore, implementing safety technology (STRF) was not enough to reduce hazard index and we have to consider other factor. Here, the results of KJ analysis proofed that the workforce factors (WRF) and management system factors (MSRF) were more dominant in causing the CRH accident.

The weighing for MSRF, WRF and STRF that being used refers to the weighing of the International Safety Rating System (ISRS) which are used for audit developed by DNV Management System (1994). Percentage of ISRS score for each element in MSRF, WRF and STRF are multiplied by the total value of MSRF, WRF and STRF obtained from KJ analysis.

Weight MSRF = % ISRS score x 0.33
Weight WRF =% ISRS score x 0.44
Weight STRF =%ISRS score x 0.23

Tables 3, 4 and 5 also show the results of weight calculations for each element of MSRF, WRF and STRF. The weight value of MSRF, WRF and STRF are used to calculate the actual value of MSRF, WRF and STRF on all three companies where research was done.

To calculate the value of MSRF, WRF and STRF of each company, authors used the formula as follows:

MSRF =% Compliance x Weight MSRF
WRF =% Compliance x Weight WRF
STRF =% Compliance x Weight STRF

Percentage of compliance obtained from the system management audit and field observations using a checklist. Percentage of compliance reflects the degree of compliance to the implementation of management standards. Hence, the value MSRF, WRF and STRF is a

Table 6: Calculation Results of MSRF, WRF and STRF: PT XYZ, PQR PT and PT CDF

	PT XYZ	PT PQR	PT CDF
∑MSRF	0.231	0.270	0.330
∑WRF	0.195	0.346	0.409
∑STRF	0.084	0.152	0.230

Table 7: Calculation Results of RHI, RI and RRI of PT XYZ, PQR PT and PT CDF

	PT XYZ	PT PQR	PT CDF
RHI Raw Materials	0.720	0.232	0.031
RHI CRH	1.460	0.464	0.062
Total RI CRH	0.670	0.710	2.000
RRI CRH	0.313	0.067	0.062

multiplication of the weights of each of these factors is multiplied by % the level of implementation of the standards or requirements set for each of these factors.

Table 6 shows the calculation results of the actual value MSRF, WRF and STRF for those three companies. Total actual value of MSRF for PT XYZ was 0.231, PT CDF was 0.330 and PT PQR was 0.270. MSRF value indicates that PT CDF has a better management system compared with PT PQR and PT XYZ. Likewise, the PT PQR has a better management system than PT XYZ. The total actual value of WRF for PT XYZ was 0.195, while PT CDF was 0.409 and PT PQR was 0.346. WRF value indicates that PT CDF also has better human resources capability, especially in terms of competency and competency development systems and also the involvement of workers in safety program compared with two other companies. Total actual value of STRF for PT XYZ was 0.084, while PT CDF was 0.230 and PT PQR was 0.152. STRF value indicates that PT CDF has a better safety technology system compared with PT XYZ and PT PQR. The total value MSRF, WRF and STRF was used to calculate the remaining hazard index (RHI) for those three companies.

Referring to the calculation method of semi-quantitative risk level that is widely used in the analysis and risk management, where [8]:

Risk = Likelihood x Severity

or Risk = Likelihood x Exposure x Hazards

By using the same principle, the value of risk index (RI) and remaining of risk index of CRH for all three companies can be calculated by using the following equation:

CRH Risk Index (RI) = CRH Probability x CRH Hazards Index

CRH Remaining Risk Index (RRI) = CRH Probability x Remaining Hazard Index

CRH probability value is taken from the value pair interaction percentage (incompatibility matrixs) of products or chemicals that potentially caused CRH. According to Cross [8], the probability of the likelihood accidents is proportional to the probability value of the accident. CRH hazard index value is comparable to the severity level caused by the CRH. The proposed Risk Index value equal to the value of HI that refers to a study conducted by Shah *et al.* [6], where:

RI:>/= 0.75 to 1.00 is very high risk,
RI:>/= 0.50 to 0.75 is high risk,
RI:>/= 0.25 to 0.50 is moderate risk
RI:<0.25 is low risk.

The calculation result of CRH remaining hazard index (RHI), CRH risk index (RI) and CRH remaining risk index (RRI) for those three companies were given in Table 5. The total value of CRH RHI for PT XYZ was 1.460 (very high), PT CDF was 0.062 (very low) and PT PQR was 0.464 (moderate). For the CRH RI at PT XYZ was 0.670 (high), PT CDF was 2.00 (very high) and PT PQR was 0.710 (high). CRH RRI value after application of MSRF, WRF and STRF to PT XYZ was 0.313 (medium), PT CDF was 0.062 (very low) and PT PQR was 0.067 (very low).

RHI and RRI proved that the CRH potential risk of downstream chemical industry in Indonesia was quite high, but the CRH potential risk can be reduced by applying safety management systems, safety technology and increasing the competency of workers in the area of chemical safety. The CRH potential risk of PT CDF can be reduced from total RI = 2.0 to 0.062 (97%) by applying various management systems, such as OHSAS 18001, ISO 9001, ISO 14000, PSM, BS 8800 and SMK3 (Indonesia Safety Management System). Here, PT XYZ has total RI = 0.670, which was quite high but still much lower than the PT CDF as PT XYZ does not perform any chemical reactions in their production process.

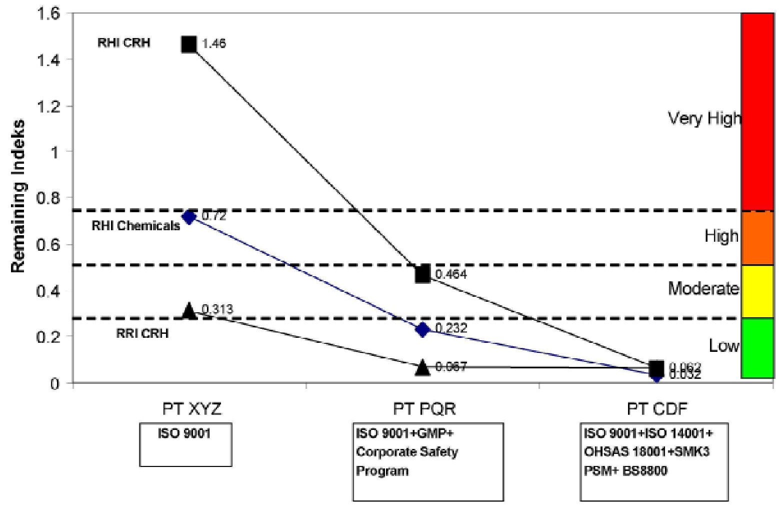

Fig. 3: The trend of declining of HI and RI by Implemantation of Quality (ISO9001), Safety (OHSAS 18001) and Environment (ISO 14000) Management System

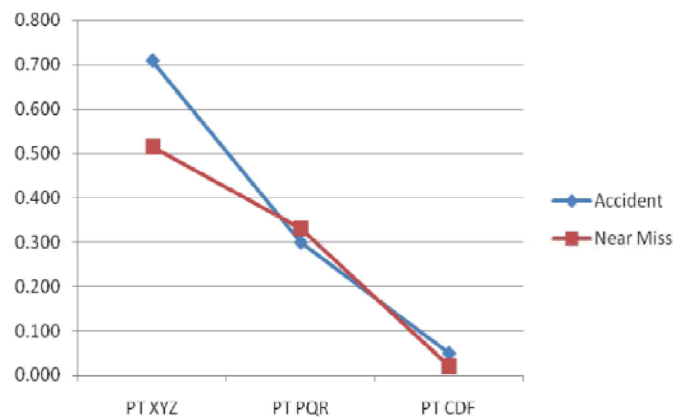

Fig. 4: The actual average accident and near miss for those three chemical industries

All processes that were carried out by PT XYZ are simply mixing process. RRI of PT XYZ was in moderate level (0.313). Application of quality management system (ISO 9001) can reduce CRH potential risk by 47% at this company. Improvements to the existing management system, like applying SMK3 or OHSAS 18001 are needed to improve chemical hazard control systems and chemical reactivity hazard, or by applying the elements required in controlling the CRH. Improvement of safety technology systems will also be able to reduce the CRH potential risk to lower level. The CRH potential risk of PT PQR was also quite high, even higher than the PT XYZ (RI = 0.710) as both companies run mixing processes without chemical reactions nor exothermic chemical reaction. The value of RI can be reduced significantly from 0.710 to 0.067 (90%) with the application of quality management system ISO 9001 and Industrial Hygine and Safety Management System as their parent company. PT PQR which is a Multinational Company has an considerably good internal system for industrial hygiene and safety programs. Figure 3 shows the trend of declining hazard and risk index by the application of quality, safety and environment management system.

HI and RI declining for those three industries has similar trend with actual chemical accident and near miss. Figure 4 shows the chemical accident and near miss for those three industries. This result proved that the proposed equation for Remaining Hazards Index (RHI) that contain Management systems reduction factors (MSRF), workforce reduction factors (WRF) and safety technology reduction factors (STRF) is more appropriate or applicable for downstream chemicals industry than Shah *et al*. [6] equation.

Conclusion that can be drawn from this study can answer the research hypothesis and research objectives as follows:

- The potential hazards of chemical reactivity in downstream chemical industry in Indonesia are considerably very high.
- Conditions of downstream chemical industry in Indonesia, which generally still using conventional technology and low labor competency caused a rising CRH potential risk.
- The results of CRH KJ analysis from worst-case scenario showed that workforce factors (WRF) can reduce CRH potential risk by 44%, the management system factors (MSRF) can reduce CRH potential risk by 33% and the safety technology factors (STRF) can reduce CRH potential risk by 23%.
- WRF and MSRF are more dominant in controlling the potential chemical hazards than the safety technology factors (STRF) in the downstream chemical industry, as downstream chemical industry use various chemicals but in small to medium scale of quantity. Therefore, need more complicated chemical safety management system than the upstream chemical industry that has few chemicals but large scale of quantity.
- Quality, safety and environmental management system can significantly reduce the CRH potential risk.
- KJ analysis method developed by Jiro Kawakita can be used to analyze and identify the causes of an accident scenario through brainstorming involving workers from the lowest level (Operator) to the management level (Director)

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