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Review of Chemical Hazard Based Occupational Health Assessment Methods for Chemical Processes

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Hazard and risks are two terms that are often used interchangeably, but in reality, they are used in different context. In simple terms, hazard is basically something that exists all the time which is likely to cause damage whereas risks only appeared when there are exposures to the hazard. In chemical process industry, the occupational hazard caused by exposure to chemicals is quite difficult to detect, because some chemicals exist in a form which cannot be seen and are odourless. As a result, the workers who work in chemical process industry tend to have higher risk exposure to hazardous chemicals than in other industries. The reported cases of work-related diseases have been increasing yearly – this indicates that there is an urgent need to take into account the occupational health impact on worker's health when developing, designing and operating a chemical process. Several occupational health assessment methods are available on the literature review to assess occupational health hazards generated from chemical processes. Several regulations such as OSHA 1970 (United States) and OSHA 1994 (Malaysia) have been gazetted to ensure safe and healthy working conditions for the workers. This indicates that occupational health issues in the chemical industries have drawn much attention from public, business companies and policy makers. With growing concern over the issue of chemical exposure among workers in chemical industries, it is expected that there will be more methods to be introduced in the near future. This could give rise to the difficulties faced by users in selecting the most appropriate method that cam meet their needs and are within their constraints. As for current practice, upon interested in applying any of the available methods, the users need to put additional effort to first conduct a literature review and analyse each of the said methods in order to find the most suitable one that can be used for their process. The result of this research is to produce an occupational health assessment framework, which aims to provide a systematic guideline on how to select the most appropriate and reliable method from all the options available. However, the result presented in the paper only covers the finding from literature review. The future work of this study will be developed an occupational health assessment framework by combining all the existing occupational health assessment methods into a single framework.

1. Introduction

Over the last few decades, the main factors that need to be considered when designing any chemical process are the process productivity, capital cost, environmental impact and the safety of the process. Recently, occupational health is one of the new factors that need to be considered during chemical process development stage. The concept of occupational health is gaining increasing public awareness because health hazard is difficult to detect and can result in the inherent development of the disease. In the early stages, the disease may be relatively minute and cannot be easily detected, but the severity of the disease can cause permanent disability realised after working for a few years. According to Wenham (2002), there are more people who died due to work-related disease than death from industrial accidents. Occupational health hazard need to be assessed in the initial process design stage, where modifications can still be implemented at lower costs (Kletz and Chemist, 1991). The ideal way to improve workers' protection is to totally remove the

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occupational health hazard. Some hazards cannot be removed, so a more practical way is to control or managed the risks that the hazards posed (Workplace Hazard, 2013). The term risk can be defined as a combination of hazard and probability of hazard occurrence by Khan and Abbasi (1998). For example, chemicals are regarded hazardous at all times, but chemicals will only be a health risk if workers are constantly exposed to them in their workplace (Hellweg et al., 2005). Risk assessment is strongly needed especially in chemical process industries. It can be used to identify health risk which is the underlying root cause contributing to work-related diseases by using engineering control methods to reduce it.

2. Risk Assessment

A risk assessment is a common tool which is normally used to identify sensible measures to control the risks in the workplace. Risk assessment process can be divided into four (4) distinct stages, which are known as hazard identification, effect assessment, exposure assessment as well as the risk characterization (van Leeuwen and Vermeire, 2007). Among these four stages, exposure assessment is considered as the most critical stage, because it is aimed to quantify the level of chemicals to which human population and individuals are exposed, in terms of magnitude, duration and frequency (RATSC, 1999). According to Koller et al. (2000), detailed information about the actual workplace (e.g., ventilation, layout, handling of substances) are needed in conducting exposure assessment. This information is not available in the early stages of the design phase, so SHE methods that was developed by Koller et al. (2000) does not covered exposure assessment, it only covered the effect assessment. Exposure assessment is growing concern in chemical industry, so a variety of different methods for quantifying human exposure have been developed by researchers and academicians. Some of the methods can also be applied in the early process design stage. The details of each approach will be discussed in the following section.

3. Existing Occupational Health Assessment Approaches

The earliest comprehensive method of assessing health hazards in chemical industry is known as Dow Chemical Exposure Index, CEI (Marshall and Mundt, 1995) which was developed by Dow Chemicals Company. For CEI, it is used to quantify the acute health risk to people as a result of the loss of containments. CEI cannot be categorised under occupational hazard assessment because it does not cover the long-term health effects on workers from normal operating condition. There are several occupational health assessment methods have been developed, but they are mainly used to assess safety and environmental aspects. These methods are known as Waste Reduction (WAR) Algorithm (Young and Cabezas, 1999), Environmental, Health and Safety (EHS) method (Koller et al., 2000), Inherent Safety, Health and Environmental Evaluation Tool (INSET) Toolkit (INSIDE Project, 2001), Substance, Reactivity, Equipment and Safety Technology (SREST) (Shah et al., 2003) and Inherent Benign-ness Indicator, IBI (Srinivasan and Nhan, 2007). Overall, these methods (e.g., WAR, EHS and SREST) only covered the health effects of chemical substance, they do not consider the risk of exposure to hazardous chemical.

A practical occupational health assessment needs to consider both the chemical exposure and health effects of chemicals when assessing health hazards encountered in the workplace (Tielemans et al., 2002). INSET Toolkit, (INSIDE Project, 2001) can be considered as the earliest method that have been developed to assess occupational health hazards. In the INSET Toolkit, health hazards are assessed based on R-phrases and leak factor was used to estimate the fugitive release rate in the process (INSIDE Project, 2001). The limitations of INSET Toolkit were complexity and required detailed information which are unavailable during the early process design stage.

The earliest methods developed specifically to assess health hazards from occupational health point of view were known as Occupational Health Hazard Index (Johnson, 2001) and Process Route Healthiness Index (Hassim and Edwards, 2006). Both these methods were used to rank alternative reaction chemistry pathways based on the inherent health hazard level. Although these methods were developed for process research and development stage, they still required some information beyond the desired stage. Based on the shortcomings of previous methods, Hassim and Hurme (2010) have developed a series of manual inherent occupational health assessments which are applicable for different process design stages. The Inherent Occupational Health Index (IOHI) method for the research and development stage (Hassim and Hurme, 2010a), the Health Quotient Index (HQI) method for the preliminary design stage (Hassim and Hurme, 2010b) and lastly the Occupational Health Index (OHI) method for the basic engineering stage (Hassim and Hurme, 2010c). Currently, industries prefer a simpler and faster method to conduct hazard assessment, so IOHI method has been further extended to become graphical-based method Hassim et al. (2013) and computer-aided tools. For example, Abbaszadeh et al. (2012) formulated the IOHI code using MATLAB presented in the Graphical User

Interface (GUI); Pandian et al. (2013) developed a comprehensive electronic chemical properties database and adopted logical functions in Microsoft Office Excel to calculate the IOHI value.

Although the proposed occupational health assessment methods are well developed, there is still no guideline to assist engineers to select the suitable method to assess the health hazards of chemical process. Without a proper guideline, users will require time and effort to conduct literature review in order to find a suitable method. Ng et al. (2014) have summarised all the three methods (e.g., IOHI, HQI and OHI) into a single framework, which aims to help users to select an appropriate method based on the availability of process information. Recently, Ng and Hassim (2015) have further extended the framework to adopt the inherently safer design (ISD) keywords (e.g., minimisation, substitution, moderation and simplification) in order to reduce health hazard or risk in chemical process. The framework developed by Ng et al. (2014) only focused on three (3) inherent occupational health assessment methods. In fact, there are quite a number of other existing methods which are not categorised under the inherent based method. But these methods are also able to address health issues and health hazards. The main objective of this work is to review the existing occupational health assessment methods that have been developed to assess chemical hazards in chemical industry. This review only covers the exposure and the effect of all chemical substances under normal operating conditions.

In this paper, the methodology and the findings from literature review will be explained in the following section. This paper ends with conclusion and recommendation are given in order to further improve this study.

4. The literature finding

In this paper, the literature finding is presented with respect to current practices in risk assessment. The primary goals of the existing assessment methods are to (1) identify health hazards of a chemical process or specifically a process unit that needs to be considered during process design and development, (2) estimate the concentration of the chemical in the workplace, (3) identify the health effect of the chemical substance present in the workplace, (4) quantify the health risk of the chemical to workers' health. In this section, the methodology used to compile the finding from literature review (see Figure 1) will be explained as follows:

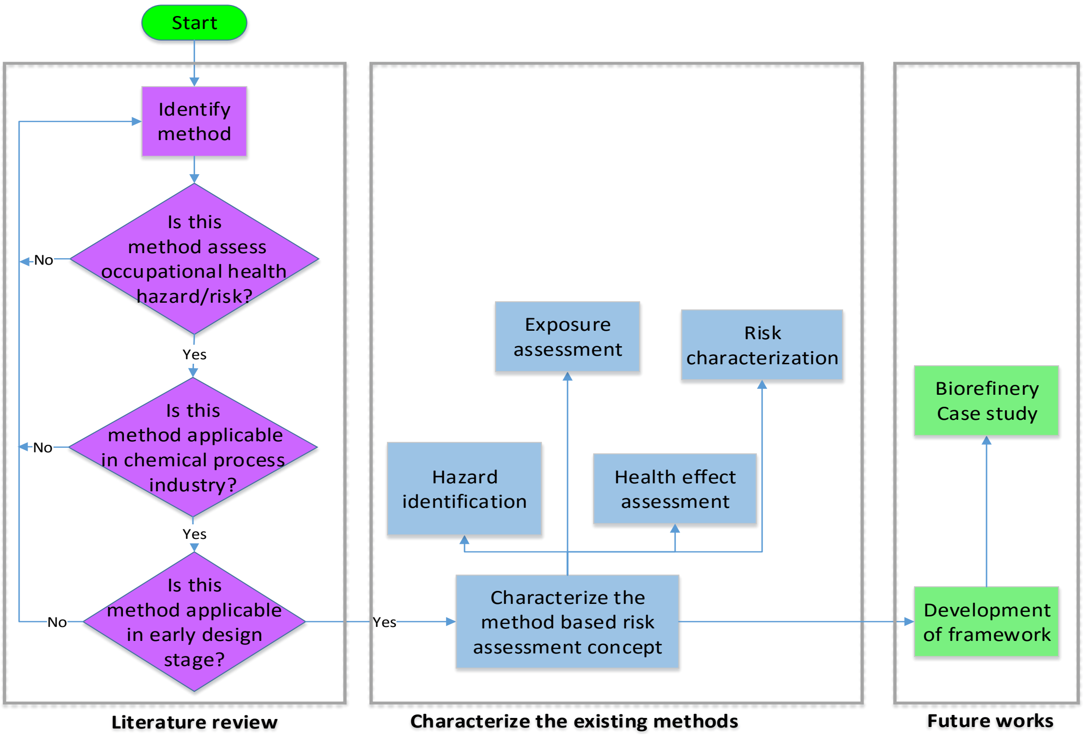

Figure 1: Methodology of This Study

4.1 Assessment method identification

The first task in this study is to conduct an extensive literature review on the existing occupational health assessment methods, which also includes inherent occupational health assessment methods. This boundary of this study only focus on the methods developed to assess health hazards during the process design and development stage of chemical process, especially in the early design stage (e.g., R&D stage, preliminary stage and basic engineering stage) as shown in Figure 1. From the literature review stage, there are a total of twenty-one (21) methods that have been identified and will be analysed in this study. Overall, most of the methods (e.g., SHE method, WAR algorithm) are focused on the chemical substances that can cause health effects, whereas only limited methods (e.g., HQI and OHI) cover the exposure assessment. In this study, the most relevant and specific methods that have be compiled in the finding as shown in Figure 2 are WAR algorithm, SHE method, HQI and OHI.

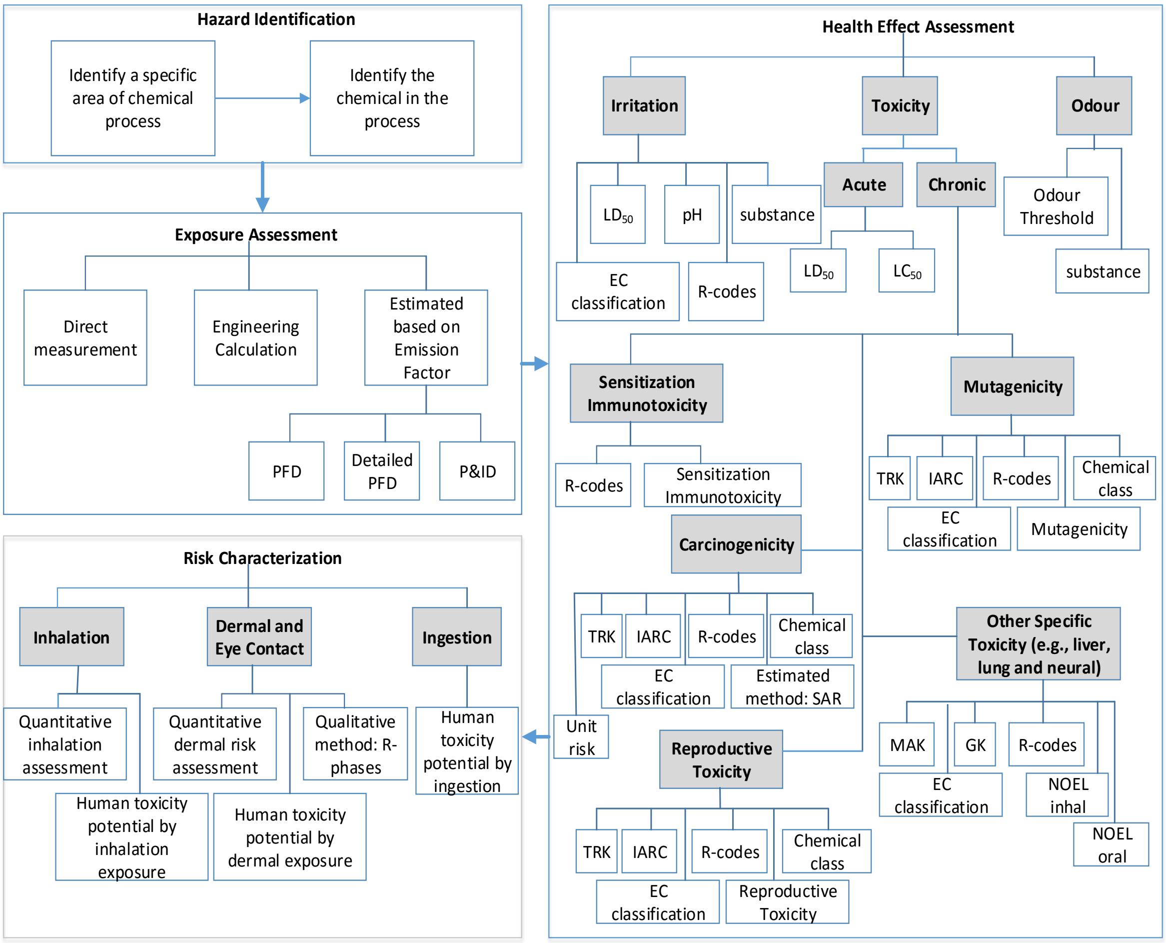

Figure 2: Literature Review Finding from Existing Occupational Health Assessment Methods.

4.2 Characterisation of the assessment methods

After the methods have been selected, the methods will be compiled according to the 4 main steps of risk assessment. In this literature finding, the most reliable method is located at the left side while the method on the right side is less reliable and less accurate. The box with grey colour indicates the subdivided group whereas the box with white colour indicates the methods that are available and can be selected within them.

The first step in most of the existing methods is hazard identification. It is used to identify where the chemical health hazards come from in the chemical processes. The purpose for this step is to identify the boundary of assessment (e.g., the area of the assessment such as process unit) and what are the hazardous chemicals that can caused health hazards. This is one of the critical steps, because it establishes the base of the occupational health assessment.

The next step is the exposure assessment, which aims to estimate the amount of hazardous chemical to which workers may be exposed, depending on different pathways (oral, dermal and inhalation). Within the exposure assessment, the definition of the condition is very critical under which the chemical is used. In fact, the condition will be directly influenced the levels of exposure. Exposure assessment is very difficult to conduct in the early design phase because it requires comprehensive data such as ventilation and handling of chemicals. These data are not available in the early design stage. From the literature review, the most accurate method to quantify fugitive emissions is through the direct measurement at the site. However, this can only be applicable for actual industrial plant. Besides direct measurement method, another method which is known as engineering calculation or specifically Emission Model of Industrial Sources (EMIS) program, was developed by Wolfe (2007), which aims to estimate fugitive emissions at the process design stage. This method requires information such as piping equipment configuration and operating conditions which is only available at the detailed design stage. This limits the application of EMIS at the early design phase. Within all the methods in the literature review, only two assessment methods have considered exposure assessment, which are known as HQI and OHI. For both methods, they only focused on inhalation exposure from fugitive emissions, because they assumed that this is the only exposure source in large-scale continuous plants with few manual operations (Hassim and Hurme, 2010b). The main source of fugitive emissions from chemical processes are leaking from piping equipment and fittings. Hassim and Hurme (2010) have developed three methods to estimate fugitive emissions at different design stage such as process flow diagram (PFD), detailed PFD and piping and instrumentation diagram (PID). From Figure 2, it can be observed that the method to cover chemical hazard from other phases (solid and liquid) is still missing, so researches can also develop some exposure assessment methods to assess chemical hazard generated from liquid and solid phases.

The third step of risk assessment is the effect assessment, or specifically known as dose-response assessment. In this step, it is used to estimate the relationship between dose or level of exposure to a chemical, and the incidence and severity of an effect (van Leeuwen and Vermeire, 2007). The idea of this step is adopted from Koller et al. (2000) works, but the difference is odour which grouped under chronic toxicity properties will be regrouped under itself, because highly smelly substance or strong odour does not mean that the substance is very harmful. The effect assessment in this work is known as health effect assessment. It will be subdivided into three dangerous properties: irritation, toxicity and odour. Irritation effects include chemical causing eye and skin irritation. They can be assessed on the basic of the classification scheme of the European Community. As second priority, dermal toxicity data or the acidity of the substance can be used. The toxicity effects can be classified into long-term (known as chronic toxicity effect) or short-term (known as acute toxicity effect) exposure duration. The primary route for a chemical to enter the body at the workplace is through inhalation. However, the chemical may also enter the body through absorption and ingestion pathway. Hence, the lethal–concentration, LC_{50} is used to assess the acute toxicity focus on inhalation exposure, whereas lethal dose, LD_{50} is used for ingestion exposure (Honma and Suda, 1998). For chronic toxicity, it comprises a variety of effects such as carcinogenicity, mutagenicity, developmental toxicity, sensitization and other specific toxicity. Within this method, the assessment is mainly based on the legal system, i.e., the threshold value defined for workers (TLV, MAK value), a quantitative estimation of the cancer probability or a qualitative classification of the evidence of carcinogenicity to humans. Substances that have not been classified can be analyzed using chronic toxicity data (“no observed effect levels”) or checked for the existence of groups indicating a cancer potential (e.g., nitroso groups, epoxides). Another subgroup is known as odour effect. It can be assessed based on odour threshold. If odour threshold data is not available, the odour effect can be estimated based on chemical or physical data of the chemical substance.

The last step of risk assessment is the risk characterisation. The risk is quantified by comparing the actual or estimated exposure values to the threshold exposure limits by hazard quotient (Roach, 1994). The hazard quotient can be applied to individual chemical as well as chemicals mixture (Hassim and Hurme, 2010b). Based on the literature review, the risk characterisation can be divided into three categories which is based on the pathway of how chemical can enter the workers’ body (e.g., inhalation, ingestion and dermal contact). The first priority method to identify the health risk is based on the quantitative risk assessment, then followed by the second priority method, where the potential of health risk can be estimated based on WAR.

5. Conclusion

In this work, the literature review has been conducted on existing occupational health assessment methods for assessing health risk in chemical process design. The result from this review is developed by combining different existing assessment methods and compiled them into the concepts of risk assessment. From this findings, it is noted that most of the occupational health assessment methods are considering the health effects aspect. On the other hand, the existing methods in exposure assessment are quite limited as compared to the methods available in health effect assessment. This is due to exposure assessment method required more information such as the details of the actual workplace, but this data is not available at early design stage, so researchers can focus to develop several useful exposure assessment methods. One of the contribution of this work is that all the methods available in each assessment have been arranged from the most reliable (left side) to the least reliable (right side), so that readers can easily identify the reliable method. Lastly, the occupational health assessment framework will be developed and presented in the future works based on the finding from this work.

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