INHERENT OCCUPATIONAL HEALTH CONCEPT FOR CHEMICAL PROCESSES: A NEW PERSPECTIVE

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ABSTRACT

The concept of inherent safety was known since the last few decades. The idea was quickly spread from the origin UK to the USA and later, to the other parts of the world. The idea was then extended to environment and subsequently health aspects. Various works have been done related to inherent safety and environmental friendliness in chemical process industries. Such works on occupational health however, are lacking. Unlike the other aspects, the term inherent occupational health has never been defined in literatures. This paper proposes a definition of the inherent occupational health concept as well as the background of inherent health studies, which was designed for chemical processes. The definition, which was carefully developed based on deep understanding and extensive works in this research area will have a huge impact on the chemical process industry (CPI) especially related to their efforts in considering occupational health aspect early in process development and design.

Keywords: *Definition; Inherent Occupational Health; Inherent Safety; Chemical Process Industry; Terminology*

1.0 INTRODUCTION

Inherent safety initiatives in the chemical process industry (CPI) are known since 30 years ago. The idea has been thought up after enormous efforts to improve chemical process safety have failed to stop or reduce catastrophic plant disasters from occurring. History has witnessed hundreds and thousands of deaths and higher number of injuries due to major accidents even though the most updated add-on protective equipment were installed and the best safety managements were practiced. Among the accidents and the reported number of deaths are: Flixborough in 1974 (28), Bhopal in 1984 (2 000 to 8 000), Piper Alpha in 1987 (167), Mexico City in 1984 (650), and Pasadena in 1989 (23). These aftermaths show the need for CPI to shift from conventional safety approaches to inherent safety.

The concept of inherent safety was first introduced to enhance process safety in chemical industries and oil and gas refineries. It is widely accepted as it put forward ideas and principles that are making sense and back-to-basic. Trevor Kletz [1], the father of inherent safety, proposed that the concept applies also to the prevention of pollution (environment) and the avoidance of small continuous leaks into the atmosphere of the workplace (industrial hygiene/health), but he did not evolve it further. The concept has later been extended to environmental and subsequently health aspects. This agrees with the idea of sustainability which incorporates safety, health, and environmental besides economic and technical criteria when developing a new process.

Various researches have been conducted in the area of inherent safety, inherent environmental friendliness as well as integrated inherent safety, health, and environmental friendliness (ISHE) in chemical process design. However inherent occupational health aspect has not been widely researched in the design of chemical plants, but active work has been done dominantly from medical point of view. Being the earliest and the most researched subject, the concept of inherent safety is well defined and discussed. Even though research studies on inherent environmental friendliness and ISHE are also active, not much attention has been put on defining the terms. The definitions however, are still available. As for inherent occupational health, no definition has been found; even the use of the terminology in CPI-related studies is rare. In this paper, inherent occupational health is defined from the perspective of CPI. This is very important since there is an increasing demand to evaluate the health impacts of substances used in the process industries. For example an European Community Regulation on chemicals and

their safe use called the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) which has been enforced on 1 June 2007 requires anyone manufacturing or importing a chemical substance to be placed on the market in the European Union countries, in quantities above 1 tonne per year, to register that substances for the uses to which it will be put. The hazardous effects of these chemicals also need to be reported.

In order to conduct a comprehensive health hazard and risk assessment of chemical process design, definitions of the related terms itself are important. A properly designed definition of inherent occupational health could bring a huge impact to the CPI because it somehow describes the objective and scope of inherent occupational health assessment of a chemical process, besides indirectly provides means for preventing health hazards and making process changes as early as in the development and design phases. For better appreciation of the subject matter, brief discussions on the background of inherent safety, inherent environmental friendliness, and ISHE as well as their definition are also given.

2.0 INHERENT SAFETY

Inherent safety ideology started to develop in 1970's. Professor Trevor Kletz was the first to propose the concept in 1971 [2]. The idea was thought up when he was a member of the organizing committee for the symposium on 'Loss Prevention in the Process Industries' held in Newcastle, UK, in 1971. A paper presented on the manufacture of nitroglycerin [3] and temperature control of methanol vaporizer [4] had led to a remark made by T. A. Kantyka, who is the chairman of the committee, that it was far better to avoid the need for complex safety or control systems than to install them. Kantyka's remark had the effect on Kletz on his earliest idea of inherent safety.

The idea however, remained latent until the explosion at Flixborough four years later. At the 1975 loss prevention symposium, Kletz [5] delivered the idea on the inventory reduction to avoid Flixborough type of explosions, but the words 'inherently safer' was not used. The inherent safety principles were then formalised [6]. In 1977, Kletz gave an annual Jubilee lecture 'What you don't have, can't leak' to the Society of Chemical Industry in London, which devoted entirely to inherently safer design.

2.1 Definition

Before discussing the definition of inherent safety, it is important to first, understanding the related terms. *Safety* is the prevention of accidents [7] through hazards identification and their elimination. *Accident* is defined as any unplanned event that results in injury or ill health of people or loss to property, plant, materials, or the environment or a loss of a business opportunity [8]. *Occupational safety* is the protection of people from physical injury from accidents at work [9]. An *occupational injury* is any personal injury, disease, or death resulting from an occupational accident [10] *e.g.* instantenous exposure in the working environment [11]. *Process safety* is the prevention of accidents through the use of appropriate technologies to identify and eliminate the hazards of a chemical plant [7]. Figure 1 summarises the concept of safety. When introducing the inherent safety concept, Kletz's focus was on process and not occupational safety. Therefore inherent safety discussion in this paper will be revolved around process safety subject. However for better understanding, the difference between occupational health, process safety, and occupational safety will be discussed in Section 5.1.

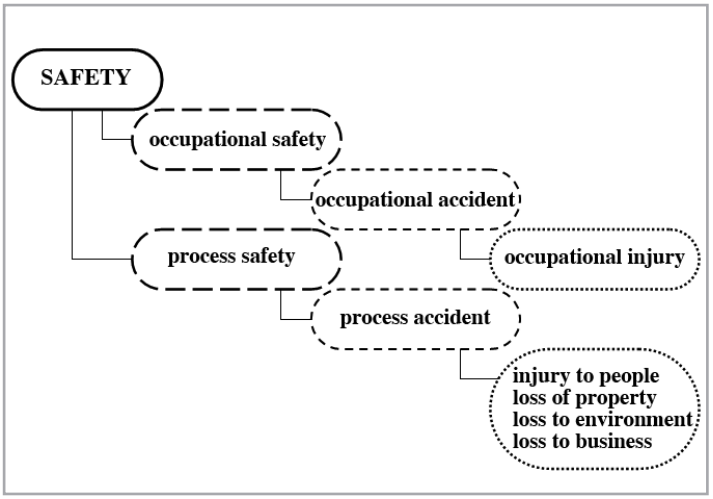

Figure 1: Safety concepts

The topic of safety is closely related to hazard and risk; therefore definition of these terms worth the attention. The definition of hazard is widely available in various publications [*e.g.* 7-8; 12-15]. Basically, hazard is a chemical or physical condition that has a potential to cause damage. A safety hazard alone is something that has the potential to cause an injury. Specific definitions of environmental and health hazards will be given in subsequent sections.

Like hazard, the definition of risk can be easily found not only for CPI, but also for other fields [*e.g.* 7-8; 12-13; 15-16]. In general, risk is a measure concerning both the likelihood and magnitude of loss. Inherent safety was introduced as a new measure of risk reduction through hazards elimination or minimisation.

Inherent means that which is intrinsic to something. American College Dictionary [17] defines inherent as existing in something as a permanent and inseparable element, quality, or attribute. Compared to extrinsic safety that relies on add-on engineered safety systems and procedural controls [18-19], inherent safety associates with the intrinsic properties of the process itself. If add-on safety relates to prevention of risk of accidents (prevention of likelihood and magnitude), inherent safety concerns with prevention of hazards (prevention of hazard potential in a system) through the use of more benign chemicals and technologies. The idea of inherent safety is to avoid problems by solving them at their roots rather than to manage the consequences [20].

The terminology of inherent safety varies somewhat throughout the process safety community [2]. Based on the

discussions of the term by several researches in this area inherent safety is commonly defined as a proactive approach to loss prevention that tries to avoid or eliminate hazards, or reduce their magnitude, severity, or likelihood of occurrence by careful attention to the fundamental design and layout [1; 2; 12; 18-19; 21-28].

2.2 Related Research Efforts

Since the introduction of the concept in 1970s, researches on inherent safety have been very dynamic and continuously growing. The researches cover wide range of areas, but major efforts have been put on inherent safety assessment during process design, which involve the development of various tools and methodologies. Among research groups that actively work in this field and some of their members are; Loughborough University (D. W. Edwards, T. A. Kletz, F. P. Lees), Aalto University School of Science and Technology (M. Hurme, A.-M. Heikkilä, M. Rahman), Indian Institute of Technology, Kanpur (J. P. Gupta), Swiss Federal Institute of Technology (ETH) (K. Hungerbühler, G. Koller, S. Shah, U. Fischer), Memorial University of Newfoundland (F. I. Khan), Dalhousie University (P. R. Amyotte, C. B. Etowa), Pondicherry University (S. A. Abbasi), The Mary Kay O'Connor Process Safety Centre at Texas A&M University (M. S. Mannan, M. Gentile, W. J. Rogers), National University of Singapore (C. Palaniappan, R. Srinivasan. R. Tan), Universiti Teknologi Petronas (Azmi M. Shariff), The Dow Chemical Company (T. Overton), Rohm and Haas Company (D. C. Hendershot, K. Study), and National Research Council of Canada (R. Sadiq). The list is endless as process safety awareness among industries, academia, and regulators around the world is everyday improving and the concept of inherent safety is rapidly propagating.

3.0 INHERENT SAFETY, HEALTH AND ENVIRONMENTAL FRIENDLINESS (SHE)

A review of the status of inherently safer process design in UK conducted by Health and Safety Executive (HSE) stressed the need for methodologies that address safety, health, and environmental issues in an integrated manner [29]. Among the established publications on the SHE evaluation during process design are as follows [28; 30-35]. However, no definition of inherent SHE terminology was given. Srinivasan and Nhan [35] used the term inherent benign to describe a process which is inherently less hazardous in all the SHE aspects, but no proper definition was provided. In the early 1990s the European Union started the INSIDE Project to promote inherent safety, health, and environmental protection within the European industries. A toolkit was developed to enhance to enhance the use of inherent SHE approaches to process plant development and design [30]; however no definition of inherent SHE was given.

The definition of the terminology was finally found in a pharmaceutical book [16]. Inherent SHE is defined as the elimination of hazards by suitable process design so that processes are, by their very nature, safe, healthy, environmentally friendly, unaffected by change and stable [36]. Upon our knowledge, this is the only inherent SHE definition formally published up till now.

4.0 INHERENT ENVIRONMENTAL FRIENDLINESS

Despite the advantages of integrating all the SHE aspects, aggregating disparate indexes into one meaningful integrated index is difficult and fraught with the danger of being unrepresentative, subjective, and user-dependent [25; 37]. Some of these drawbacks can be overcome by considering the SHE aspects separately. A survey [26] conducted to cross-section of chemical engineering professionals from 11 countries found that some of the respondents suggested different indices for each of the safety, health and environment elements rather than a composite one to help in decision-making. Most of the methods that assess all the SHE criteria do not fairly addressing the aspects in balance. Usually they focus more on the inherent safety, waste minimization, and green chemistry concepts; with health aspect is often assessed very minimum. Some examples of such methods are given in Section 5.2.

Various studies have been conducted on environmentally conscious chemical process design, which include the assessment of environmental hazards of a design concept and substances [*e.g.* 27; 38-44]. An environmental hazard is a potential to cause harm to the environment [45]. However, none used the term inherent environmental friendliness or related terms in their publications, moreover defined it. A group in Loughborough University was the first to introduce the terminology formally and also defined it [45-47]. They suggested that an inherently environmentally friendly chemical plant would have small levels of actual and potential environmental impacts - the impacts encompass those due to a catastrophic failure, its emissions due to normal operational activities and also the small-scale accidental emissions during the life of the plant.

5.0 INHERENT OCCUPATIONAL HEALTH

Before inherent occupational health is defined, the associated terms are first discussed. *Health* in general is defined as a state of physical and mental well-being (as an opposite to illness) [48]. *Occupational health* is the protection of the bodies and minds of people from illness resulting from materials, processes, or procedures used in the workplace [9] and its aim is the promotion and maintenance of the highest degree of physical, mental, and social well-being of workers in all occupations by preventing departures from health, controlling risks, and the adaptation of work to people and people to their jobs [49]. OSHA [50] defines an *occupational disease* or *illness* as any abnormal condition or disorder, other than one resulting from an occupational injury, caused by exposure to factors associated with employment. *Occupational diseases* concern with a disease contracted as a result of an exposure over a period of time to risk factors arising from work activity. Figure 2 summarizes the concept of health.

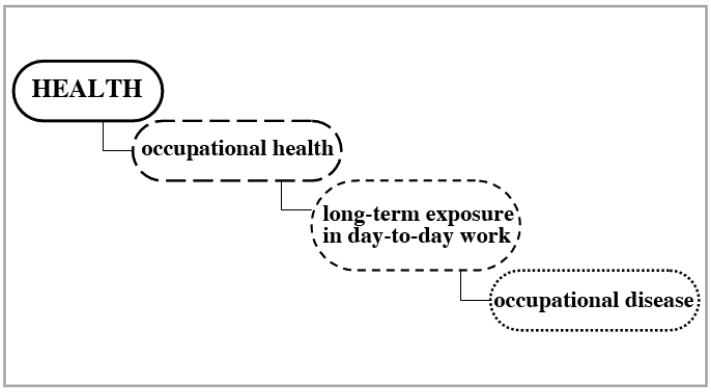

Figure 2: Health concept

Based on the earlier discussions on occupational safety (Section 2.1) and health (in this section), *occupational safety and health* is the discipline dealing with the prevention of injuries and diseases of workers resulting from the materials, processes, or procedures used in the workplace [9; 51]. The two words are normally used together and the borderline between health and safety is ill defined [20]. This is further discussed in the next section.

5.1 Related Research Efforts

Occupational health differs from occupational safety and process safety in terms of several criteria; the exposure pattern, duration of event, exposure scenario, and process state. The details about the differences are summarised in Table 1.

From Table 1, occupational health is related to normal everyday work activities and long-term exposure to chemicals. Occupational safety also is concerned with normal activity, but short-term accident due to physical hazards. Meanwhile process safety refers to major accidents, loss prevention, and acute short-term exposure in abnormal situations. The occupational health and safety hazards directly affect human's life only compared to process safety hazards, which also have interest on the plant, property, and cost. The nature of risk is also different; since airborne toxic substances are harmful at much lower concentrations than merely corrosive and flammable ones, their effects extend to much greater distances. These imply that although the occurrence of occupational health effect is long-term and less dramatic, the impact could be more serious in the long run than the occurrence of safety-related events. The insidious nature of occupational disease is the reason for it rarely reaches the news and is not well publicised as the industrial accident cases.

Health effects can be divided into acute and chronic effects due to short-term and prolonged exposures, respectively. Occupational health mainly deals with chronic exposure as a result of regular operations and day-to-day (routine) working activities. In large-scale process industry, chronic exposure is mainly contributed by fugitive emissions. Acute exposure may also occur in large-scale process industry primarily due to periodic emissions, which are mainly from occasional but acceptable working practices *e.g.* manual operations. Occupational health assessment should cover both chronic and acute occupational exposures as presented in Figure 3.

Table 1: Occupational health vs. occupational/process safety criteria

Criteria	Occupational health	Occupational safety	Process safety
Exposure pattern	Chronic (repeated)	Acute (single)	Acute (single)
Event duration	Long-term	Short-term	Short-term
Exposure scenario	Routine activity	Accident, routine activity	Accident,loss of containment
Process state	Normal	Normal	Abnormal

5.2 Occupational Health Studies in Chemical Process Industries

Unlike safety and environment, studies on occupational health aspect in CPI are very limited, but often being evaluated alongside the other two aspects, with health always being the least analyzed criteria. There are several methods available for health hazard assessment in chemical process. The methods however, are more diversified due to the complicated underlying principle of the aspect itself. Even though they have been developed for the purpose of health assessment; the scope, approach, and considered aspects vary. The review of 51 chemical ranking and scoring systems demonstrates that there was no consensus regarding an appropriate framework for evaluating adverse impacts to human health from exposure to chemicals [52].

The two basic types of health studies are the substance and process-type indices. Majority of the methods developed earlier are chemical substance-based and they are widely known as hazard indices. Hazard indices aim to rank substances in a process by their hazard potential. They take into account the volatility and the toxicity of a substance. As for process-based assessment, the methods are more disparate. Basically, the methods can be classified into those which:

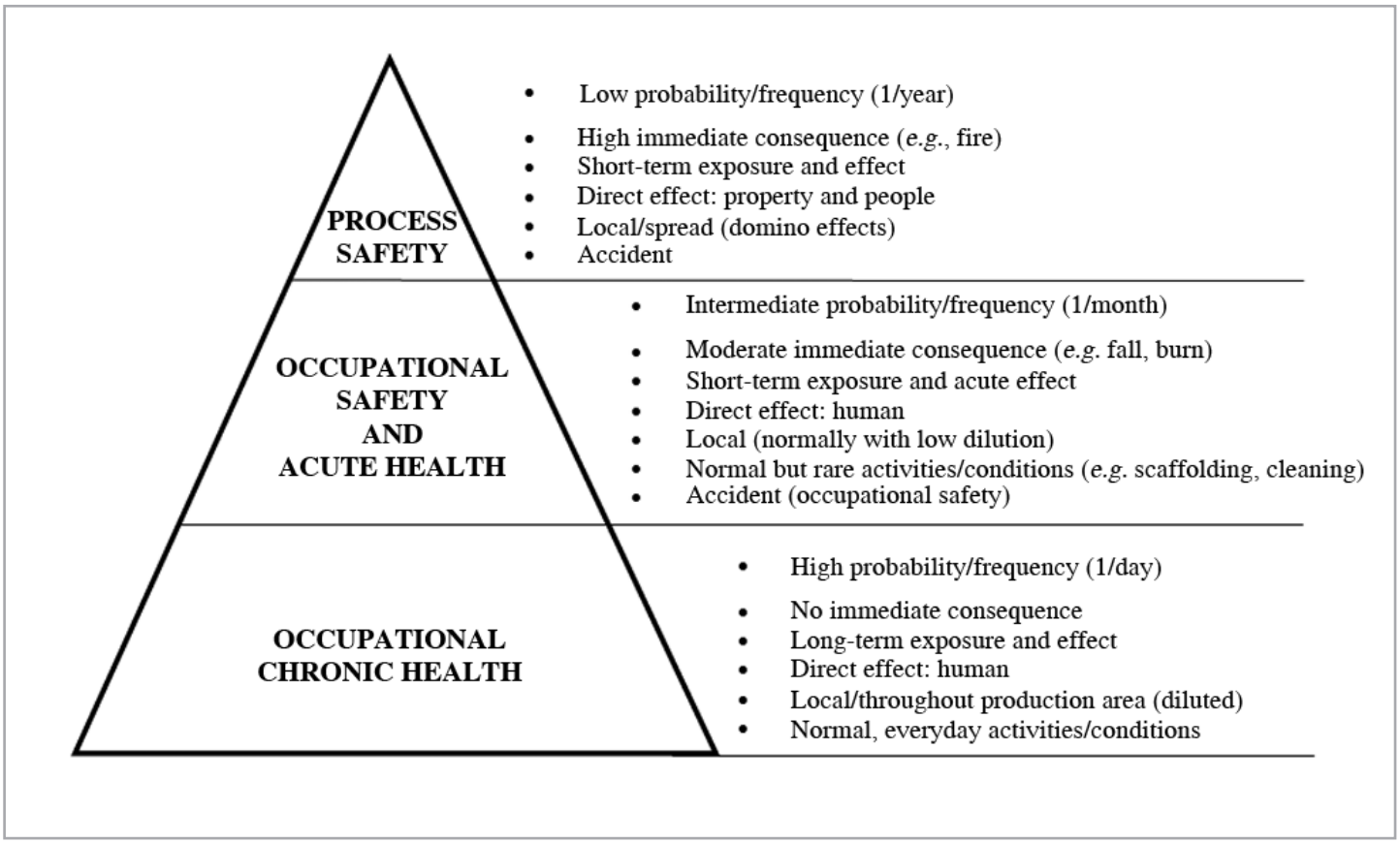

Figure 3: Occupational health vs. occupational/process safety [20]

Category 1 – health aspect is addressed only as minor part of the safety and/or environmental assessments [*e.g*. 28; 31-32; 35; 53].

Category 2 – health is not being evaluated from the occupational context. For example, some of them focus only on the acute hazards due to accidental chemical release, some concern with the effects on public community, and some address the environmental health impacts [*e.g*. 54-55].

Category 3 – occupational health assessment is not suitable for process screening during the early design stage, but is intended for process operation [*e.g*. 56]. Inherent occupational health studies have the largest benefits on process design stage.

Category 4 – health impacts are adapted in an existing Life-Cycle Assessment (LCA) method [*e.g*. 55].

Category 5 – inherent occupational health assessment is feasible during the design stage of chemical processes [*e.g*. 57-64].

The methods in Category 1 intend to cover all the SHE aspects, however health is often not as well assessed as the other two. In the INSET Toolkit [53], health hazards are assessed simply based on R-phrases and brief scoring system called Leak Factor to estimate the fugitive release rate in the process. In the EHS [32] and Inherent Benign-ness Indicator (IBI) [35] methods, only chemical health effects are assessed (based on *e.g*. exposure limit values and National Fire Protection Association (NFPA) ranking) without considering the chemical exposure aspect. However a proper risk assessment requires both the chemical exposure and the effect to be evaluated [65].

5.3 Concept and Definition

Health hazard refers to damaging potential of substance, activity, or process, which is described by the inherent health properties [20]. Hazards that might affect workers' health can be divided into five major categories of physical, chemical, biological, ergonomic/mechanical, and psychosocial [66-67]. During chemical process design, the major focus is the chemical and some physical hazards. The other categories cannot be evaluated due to the limited data available in the early stages of design. At the early design stage *e.g*. R&D, chemical health hazards can be evaluated from toxicity properties of materials whereas physical health hazards are based on process conditions *e.g*. operating temperature that may cause burn.

Health risk can be defined as the probability that an individual exposed to a chemical substance may experience an adverse health effect subsequent to the exposure [68]. The effect can be either acute or chronic depending on the duration of exposure; short-term or long-term, respectively. The level of health risk in chemical plant is determined by: a) the potential for harm and b) the potential for exposure. The potential for harm is a function of the toxicity characteristics of chemicals present in

the workplace. In principle chemicals will only be a risk to health once human are exposed to them. The exposure is determined by materials' physical properties (*e.g.* volatility), operating and workplace conditions, leaking tendency of equipment, working activities (duration and frequency), and human behavior.

In order to design the definition of inherent occupational health, it is vital to first understand the levels of inherent health studies in chemical process design. The study of inherent health can be made in three levels (see Figure 4):

i) Inherent health hazard potential

Inherent health hazard potential includes hazards of materials in a process that are potentially harmful to health. However, leak or exposure aspect is not yet considered. Therefore the focus of the very early assessment is typically on material's toxicity.

ii) Inherent leak hazard potential

In petrochemical plants, process materials may escape from the system through flanges, valves etc. through fugitive emissions. In this case the materials (hazard) are no longer contained but they are released into air. The inherent release rate depends on the complexity of process, the types of equipment involved, and physical properties of fluids. No specific protection layers are considered; therefore the evaluation of material release sources (leak potential) is still a hazard and not a risk-level study.

iii) Inherent exposure potential and risk

Chemical exposure assessment requires information on chemical concentration (a function of leak rate and dilution), exposure (a function of frequency and duration of exposure), protective equipment, and type of work procedure (*e.g.* manual operation close to the emission source). From inherent stand point, protective equipment should not be considered in order to give the worst-case scenario. Only at this level, some protective layers and human aspect start to get involved, thus allowing health risk to be quantified.

Inherent occupational health is a prevention of occupational health hazards (*i.e.* chemical or physical condition) that have the potential to cause health damage to workers by trying to eliminate the use of hazardous chemicals, process conditions, and operating procedures that may cause occupational hazards to the employees. Here inherent occupational health hazards can be defined as a condition, inherent to the operation or use of material in a particular occupation or environment, that can cause death, injury, acute or chronic illness, disability, or reduced job performance of personnel by an acute or chronic exposure.

There are twofold aims of inherent occupational health: Firstly to reduce the hazards from inherent properties of chemicals (such as toxicity and high vapor pressure) by using friendlier chemicals or the chemicals in safer physical condition (such as lower temperature) to eliminate the exposure. Secondly to reduce such process steps or procedures which involve inherent danger of exposure to the chemicals. Examples of such operations are some manual operations where the worker is in close contact with the material, such as the manual handling and dosing of chemical, emptying, and cleaning of the equipment etc. For reducing the occupational hazards, evaluation methods are of prime importance. With the establishment of the inherent occupational health definition, the associated assessment methods can be developed more easily and systematically.

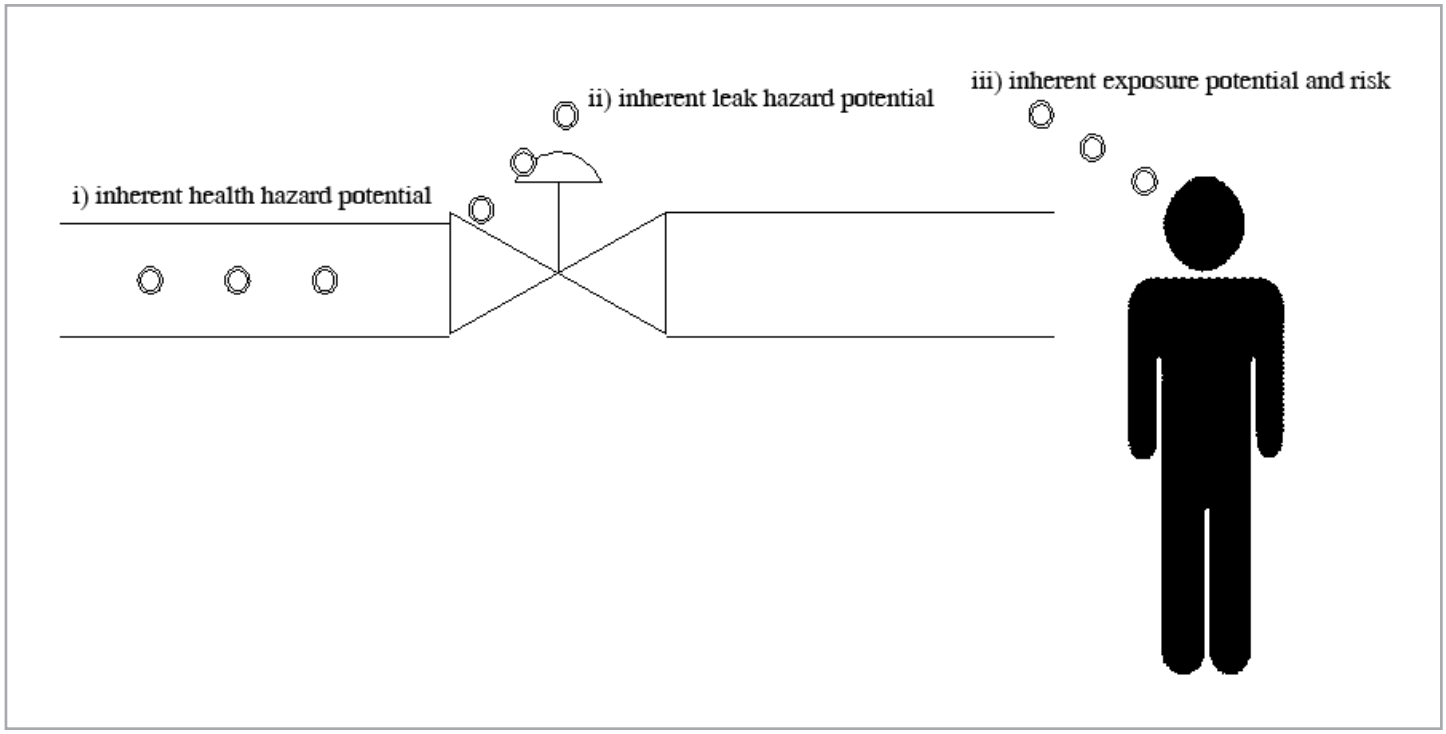

Figure 4: Levels of inherent health study

6.0 CONCLUSION

Occupational health is an important part of sustainability together with process safety and environmental issues. Each year, more people die from work-related diseases than are killed in industrial accidents. Every year new chemicals and technologies are being introduced which present new and often unknown hazards to workers. Therefore occupational health issue has been gradually gaining attentions especially from chemical process industries (CPI).

This paper introduces a new concept of inherent occupational health. Inherent occupational health is a prevention of occupational health hazards that have the potential to cause health damage to workers by trying to eliminate the use of hazardous chemicals, process conditions, and operating procedures that may cause occupational hazards to the employees. The paper also discusses the existing methods for assessing occupational health of chemical processes. Majority of the methods are not appropriate because they either evaluate health minorly as part of safety and environmental assessments, they focus on acute toxicity (process safety related) or environmental health impacts but not occupational health, and they are intended for process operation which receives less benefits from inherent level-related studies.

The introduction of the inherent occupational health concept as well as the establishment of its definition will have a significant impact on the appreciation and understanding of this subject matter especially in the CPI. Based on the definition, the objective and scope of occupational health assessment in CPI especially in the design stage become more certain. It also gives initial ideas on how health hazards can be eliminated early and process can be designed towards becoming inherently healthier. ■

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PROFILES

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