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Strategies for assessing and reducing inherent occupational health hazard and risk based on process information

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ABSTRACT

Over the last few decades, the concept of inherent occupational health has gained increasing attention to reduce occupational hazards that may adversely impact workers' health. In order to assess occupational hazards in the chemical process, different inherent occupational health assessment methods have been developed at the early stages of process development and design. The methods in the order of process information availability – ranging from the detailed piping and instrumentation diagrams to a simple sketch of process concepts are the: occupational health index (OHI), health quotient index (HQI) and inherent occupational health index (IOHI). This paper proposes systematic heuristic frameworks to assist process designers and engineers in assessing and reducing inherent occupational health hazards or risks based on process information availability. Strategies for reducing health hazards or risks in the OHI, HQI and IOHI methods based on inherently safer design (ISD) keywords of minimization, substitution, moderation and simplification are included in this study. It is worth mentioning that the proposed frameworks act as guidelines for design engineers in systematically selecting the appropriate index and methodology to assess and reduce health hazards/risks based on the availability of the process information. A case study is solved to illustrate the proposed framework.

1. Introduction

Over the last few decades, the issue of occupational health is gaining increased attention due to increasing number of reported occupational related diseases. In align with the concerns, different health hazard assessment methods have been developed especially for chemical process industries. This is due to the nature of these industries which deal a lot with hazardous operating conditions and harmful chemical substances. The Mond Index is among the earliest methods developed in 1970s (ICI, 1993) which considers toxicity in addition to fire and explosion aspects (a concern of the method developed earlier–the Dow Fire and Explosion Index) when assessing hazards and risks of chemical processes. The Dow Chemical Exposure Index was then proposed to evaluate relative ratings of short-term potential health hazards to people in neighboring plants or communities upon the occurrence of chemical release incidents (Dow Chemicals, 1994). Besides, Tyler et al. (1996) developed a toxicity hazard index to evaluate toxicity hazard, also due to short-term incidents as the previous two methods. They preferred 5 min threshold exposure limit value as the benchmark since it can be expected that within that time a worker would have either escaped from the affected area or donned protective equipment.

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Nomenclature

A	flow cross section area
ALARP	as low as reasonably practicable
$C_{c\text{-}i}$	airborne chemical concentration of carcinogens
$C_{DEL\text{-}i}$	dermal dose limit
$C_{ELc\text{-}i}$	exposure limit of carcinogens (long-term exposure)
$C_{ELeq\text{-}i}$	exposure limit (short-term exposure)
$C_{EL\text{-}i}$	exposure limits data of chemical substance i
$C_{ELnc\text{-}i}$	exposure limit of non-carcinogens (long-term exposure)
$C_{eq\text{-}i}$	equilibrium vapor concentration
C_i	airborne concentration of chemical substance i
$C_{nc\text{-}i}$	airborne chemical concentration of non-carcinogens
$HQ_{a\text{-}i}$	health hazard quotient (short-term exposure)
$HQ_{c\text{-}i}$	health hazard quotient for carcinogens (long-term exposure)
$HQ_{d/e\text{-}i}$	health hazard quotient based on dermal exposure
HQI	health quotient index
HQI_i	health hazard quotient for chemical substance i
HQI_{mix}	health hazard quotient for chemicals mixture
$HQ_{nc\text{-}mix}$	health hazard quotient for non-carcinogens (long-term exposure)
I_C	sub-index of corrosiveness of construction material
I_{EL}	sub-index of exposure limit
I_{HH}	sub-index for health hazards
I_{MS}	sub-index of material phase
IOHI	inherent occupational health index
I_P	sub-index of process pressure
I_{PM}	sub-index of process mode
I_{PPH}	sub-index for physical and process hazards
I_R	sub-index of R-phrase
ISD	inherently safer design
I_T	sub-index of process temperature
I_V	sub-index of volatility
$m_{a\text{-}i}$	dermal exposure rate
$m_{CDI\text{-}i}$	chemical intake rate
$m_{c\text{-}i}$	fugitive emissions of carcinogens
m_i	fugitive emissions of chemical substance i
M_i	molecular weight of chemical substance i
$m_{nc\text{-}i}$	fugitive emissions of non-carcinogens
$m_{SF\text{-}i}$	slope factor
OHI	occupational health index
P&ID	piping and instrumentation diagram
PFD	process flow diagram
p_i	vapor pressure of chemical substance i
R	ideal gas constant
$risk_{c\text{-}i}$	probability of risk for getting cancer
$risk_{d/e}$	dermal/eye exposure risk
T	temperature T
TANKs 4.09D	TANKS Emissions Estimation Software, Version 4.09D
v	wind speed

The assessment methods as described earlier focus on short-term, acute exposures from abnormal incidents; hence they are not really representing occupational health type of events. Occupational health, on the other hand, is dealing more with day-to-day exposures due to normal process operation. The Control of Substances Hazardous to Health Regulations Essentials was developed towards this direction; that is to evaluate the effects of chemicals exposure to employees during process operation (Maidment, 1998). However, the application of this method targets on indoor, small-scale existing processes. Hence the concept of inherent occupational health was introduced with the primary interest of avoiding or reducing the potential occupational health impacts of chemical process design as early as possible (Hassim and Hurme, 2010a).

Methods for inherent occupational health assessment in different stages of process design have been developed to design an occupationally healthier process. In the research and development stage, the availability of process information is still very scarce and uncertain. The inherent occupational health index (IOHI) was proposed by Hassim and Hurme (2010a), which enables health hazard assessment to already be conducted based on information on the reaction chemistries and the chemical properties only. As the design stage progresses, more comprehensive assessment can be performed based on the process information accessible from the process flow diagrams (PFDs). At this preliminary design stage, the health quotient index (HQI) can be applied by determining the fugitive emissions from equipment and piping fittings (Hassim and Hurme, 2010b). Fugitive emissions are the main source of background exposures to workers in chemical processes (Lipton and Lynch, 1994). Once the piping and instrumentation diagrams (P&IDs) are ready during the basic engineering stage, detailed evaluation on the potential health risks can be carried out. For example, besides long-term inhalative exposures due to fugitive emissions, acute effects from normal work procedures and dermal/eye exposures can also be considered, as proposed by the occupational health index (OHI) (Hassim and Hurme, 2010c). These three methods have been summarized into a heuristic framework to assist engineers to select appropriate index method for inherent occupational health assessment (Ng et al., 2014).

As an extension to the efforts made by Hassim and Hurme (2010a,b,c), Hassim et al. (2012) presented the strategies for health hazard and risk reduction (focusing on fugitive emissions) based on the concept of inherently safer design (ISD). The concept of ISD was first introduced by Trevor Kletz following a 1974 hydrocarbon vapor cloud explosion at Flixborough, England (Kletz, 1996). It is a philosophy that focuses on the hazards elimination or reduction rather than relying on the control of these hazards. The Center for Chemical Process Safety has categorized ISD into four main keywords (Center for Chemical Process Safety, 2009): minimize (use small quantities of hazardous material or reduce the size of equipment), substitute (use less hazardous materials, chemistries and processes), moderate (operate at less hazardous condition) and simplify (eliminate unnecessary complexity and human errors). These ISD keywords have been extensively incorporated in designing fundamentally safer chemical production (Gupta and Edward, 2002; Leong and Shariff, 2008; Kidam et al., 2014), pharmaceutical production (Mannan et al., 2012), biofuel production (Gomez et al., 2013), etc.

Several tools have been developed for generating ISD options toward designing a chemical synthesis route with