# INHERENT OCCUPATIONAL HEALTH ASSESSMENT FOR CHEMICAL BATCH PROCESSES

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# INHERENT OCCUPATIONAL HEALTH ASSESSMENT FOR CHEMICAL BATCH PROCESSES

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*This entire research is dedicated with deepest love to my dearest parents, sisters, brothers, late grandfather and family.*

*Thank you for the never ending love, trust, understanding, support, and motivation.*

*May Allah give you the best reward and may the blessings of Allah be upon you.*

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## ABSTRACT

The purpose of this study is to develop the methodology to assess inherent occupational health hazards for chemical batch process. Evaluation of potential hazards during the early stage of process design is critical so that the hazards can be tackled earlier before the process is constructed. Besides, the cost associated with any conceptual modification at this stage is so much lower compared to the later stages of the project lifecycle. Nowadays, batch process is favoured in many chemical industries especially pharmaceutical and specialty chemical. Since batch operation involves more manual handlings compared to continuous processes, it is important to assess occupational health hazards as a result of workplace exposure among workers especially to harmful substances. Most of the available methods for hazard assessment in batch processes were developed for safety rather than health hazard. In this study, an assessment method is proposed based on index-based approach to evaluate potential hazards in batch chemical process during the conceptual design stage. The parameters from the process, either due to chemical properties, process conditions or the operation of the unit operations that may cause occupational health hazards to the exposed workers were included in the index. The index was demonstrated on a real case of *Eurycoma Longifolia* (Tongkat Ali) water extraction. From the case study, the potential hazards of each unit operation can be evaluated through the index calculated. Comparison of exposure (hazards) for each unit operation in the process is able to highlight the critical parameters or conditions that need to be adjusted, so that the process can be less hazardous especially from the occupational health point of view. Based on the index calculated, the process can be designed to be less hazardous during the early design phase in the process development.

# ABSTRAK

Tujuan kajian ini adalah untuk menghasilkan kaedah untuk menilai bahaya yang wujud dalam pekerjaan dari aspek kesihatan untuk proses kimia berkelompok. Penilaian bahaya yang mungkin timbul pada peringkat awal reka bentuk proses adalah kritikal supaya bahaya boleh ditangani awal sebelum proses disiapkan sepenuhnya. Selain itu, kos yang berkaitan dengan apa-apa pengubahsuaian konsep pada peringkat ini begitu jauh lebih rendah berbanding dengan peringkat akhir kitar hayat projek. Pada masa kini, proses kimia berkelompok disukai dalam banyak industri kimia terutamanya farmaseutikal dan bahan kimia khusus. Oleh kerana operasi berkelompok melibatkan lebih aktiviti mengendali dalam manual berbanding dengan proses yang berterusan, adalah penting untuk menilai bahaya kesihatan pekerjaan akibat daripada pendedahan di tempat kerja di kalangan pekerja terutama untuk bahan-bahan berbahaya. Kebanyakan kaedah yang ada bagi penilaian bahaya dalam proses berkelompok telah dibangunkan untuk keselamatan dan bukan bahaya kesihatan. Dalam kajian ini, kaedah penilaian adalah dicadangkan berdasarkan pendekatan berasaskan indeks untuk menilai bahaya yang mungkin timbul dalam proses kimia berkelompok semasa peringkat reka bentuk konsep. Parameter dari proses tersebut, sama ada disebabkan oleh sifat-sifat kimia, keadaan proses atau operasi unit operasi yang boleh menyebabkan bahaya kesihatan pekerjaan kepada pekerja terdedah dimasukkan dalam indeks. Indeks ini diaplikasikan pada kes sebenar pengekstrakan *Eurycoma Longifolia* (Tongkat Ali) menggunakan air. Dari kajian kes, potensi bahaya setiap unit operasi boleh dinilai melalui indeks yang dikira. Perbandingan bahaya pendedahan bagi setiap unit operasi dalam proses itu dapat menunjukkan parameter atau syarat-syarat yang kritikal untuk diselaraskan, supaya proses itu boleh menjadi kurang berbahaya dari segi kesihatan. Berdasarkan indeks yang dikira, proses boleh direka menjadi kurang berbahaya semasa fasa reka bentuk awal dalam proses pembangunan.

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| | | |
|---|---|---|
| ACH | - | Acetone cyanohydrin based route |
| AHI | - | Atmospheric Hazard Index |
| C2/MP | - | Ethylene via methyl propionate based route |
| C2/PA | - | Ethylene via propionaldehyde based route |
| C3 | - | Propylene based route |
| EHI | - | Environmental Hazard Index |
| EL | - | Exposure limit |
| FEs | - | Fugitive emissions |
| HAZOP | - | Hazard and Operability Study |
| HHF | - | Health Harm Factor |
| HQI | - | Health Quotient Index |
| i-C4 | - | Isobutylene based route |
| IETH | - | Inherent Environmental Toxicity Hazard |
| ISHE | - | Inherent Safety Health and Environment |
| I2SI | - | Integrated Inherent Safety Index |
| ISI | - | Inherent Safety Index |
| IOHI | - | Inherent Occupational Health Index |
| LF | - | Leak Factor |
| MMA | - | Methyl Methacrylate |
| MSDS | - | Material Safety Data Sheet |
| OEL | - | Occupational Exposure Limits |
| OHHI | - | Occupational Health Hazards Index |
| OHI | - | Occupational Health Index |
| PFD | - | Process Flow Diagrams |
| P&ID | - | Piping and Instrumentations diagrams |
| PIIS | - | Prototype Index for Inherent Safety |
| PRI | - | Process Route Index |

| | | |
|---|---|---|
| PRHI | - | Process Route Healthiness Index |
| PSD | - | Process Sequence Diagram |
| R&D | - | Research and Development |
| SHE | - | Safety, Health and Environment |
| SWeHI | - | Safety Weighted Hazard Index |
| TBA | - | Tertiary butyl alcohol based route |
| WAR | - | Waste Reduction Algorithm |

# NOMENCLATURE

| | | |
|---|---|---|
| $I_C$ | - | Corrosiveness sub index |
| $I_{EL}$ | - | Exposure limit sub index |
| $I_{HH}$ | - | Index for Health Hazards |
| $I_{MS}$ | - | Material state sub index |
| $I_P$ | - | Pressure sub index |
| $I_{PM}$ | - | Process mode sub index |
| $I_{PPH}$ | - | Index for Physical and Process Hazards |
| $I_R$ | - | R-phrases sub index |
| $I_T$ | - | Temperature sub index |
| $I_V$ | - | Volatility sub index |
| $I_{OHBP}$ | - | Index for Occupational Health Batch Process |
| $I_{PH}$ | - | Index for Process Hazards |
| $I_{BH}$ | - | Index for Batch Hazards |
| $I_H$ | - | H statement sub index |
| $I_{UO}$ | - | Unit operation sub index |
| $I_{CT}$ | - | Cycle time sub index |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Research Background

Sustainability is now essential to any process industry. Sustainability can be defined as 'meeting the needs of the present without compromising the ability of future generations to meet their own needs' (Anon, 1987). It can be divided into economic, environmental, and social sustainability. These aspects are covered under corporate responsibility from company point of view where health and safety are the critical elements that need to be addressed.

Due to the increasing awareness on sustainability especially after the introduction of Responsible Care in 1988 (Hook, 1996), safety, health and environmental (SHE) evaluations are nowadays become mandatory in new process development and design. The whole concept of early process hazard assessment actually originates from the idea of inherent safety. The concept of inherent safety was first introduced in 1970s as an idea of improving process safety through the elimination or reduction of hazards (Kletz, 1984). The concept professes that hazards that might arise in a process should be identified earlier, that is when the plant is still 'on paper'.

In principle, inherent safety can be applied throughout a process lifecycle (Hurme and Rahman, 2005). However the assessment should be conducted earlier starting from the process development to avoid potential negative consequences at the later stages of process lificycle e.g. higher risk, higher costs, longer development time, etc. Early hazards assessment is critical since oppurtunities and costs for making process modifications are more appealing during process development and design. Despite the benefits of early assessment, the data and process information required for the assessment is mostly unavailable and uncertain at early stages. This has made early hazards assessment a challenge, which later receives quite a lot of attentions from researchers through the introduction of methods and indexes for inherent safety assessment of chemical process design.

The fundamental concept of process design is the selection of best technology option to achieve a particular product specification and to minimize operational cost and/or maximize profits as its sole objective function (Adu *et al.*, 2008). Formerly, issues such as safety, workers' health and environmental impacts are considered as not an essential part of a systematic decision making during process development and design stage. But they are usually considered only at the final design as design criteria, or in some cases, only after the plant is operated. Increasing number of accidents in chemical industries and the rising awareness of SHE impacts have demanded industries to start considering SHE assessment much earlier before even progressing to the design phase. Consideration of process hazards during early in the process conceptual phases is critical to have a fundamentally more benign (safer, healthier and environmentally friendlier) process. This has led people in industry and academia to enhance efforts in considering hazards during early design which include the assessment of inherent hazards of the proposed process concepts and this is what the concept of inherent safety is all about.

The idea of inherent safety is to eliminate or reduce hazards rather than to control or manage them. The rationale of inherent safety makes it interesting for adoption in other criteria as well. Following the introduction in 1970s, the concept has later been adopted by the environmental criteria in 1980s. Since then massive works have been done related to inherent environmental friendliness. Adoption to occupational health started much later in year 2001. Among the notable methods for inherent safety, inherent environmental friendliness and inherent occupational health assessment are mentioned in the next chapter.

Compared to safety and environment, occupational health has received less attention due to its complex nature. Supposed health is given as much as, if not more, focus because millions of workers throughout the world are subjected to a wide range of health and physical hazards at their workplace. Yearly, over two million people worldwide die of occupational injuries and work related diseases (Eijkemans, 2005). Health is differing from safety in terms of the time for the effect to appear. For health, it takes some time before the effects on people's health can be recognized (long-term events) and the impact might persist over a long time (Hassim, 2010). Meanwhile, safety deals with acute, serious short-term events. Besides, health assessment requires a lot of worker exposure related data, hence increasing the complicatedness of the assessment in comparison to safety and environment assessment.

Despite the limiting works done on inherent occupational health, there are still several existing methods available for evaluations in process development and design. However, most of the works published are dedicated to continuous process. Hazard assessments in batch processes, on the other hands, have not been widely discussed especially occupational health aspect. In reality batch is a more regular mode of operation in chemical industries especially in 'low-volume high value' chemical production. Nowadays, production flexibility is becoming a priority in almost all kinds of production facilities. Due to its inherent flexibility in market changes and small production volumes, batch plants seem to be preference in new market environment. This plant can be easily rearranged to allow for production modifications and/or to cover a wide range of operating conditions within the same plant configuration (Barbosa-P´ovoa, 2007). From health perspective batch processes pose greater hazards compared to continuous operations since the former involve more manual operations and higher number of workers (Hassim, 2010). Besides regular start-ups and shut downs may cause extra equipment strain and more frequent maintenance works. Hence, systematic assessment of health hazards in batch chemical processes is highly needed.

## 1.2 Problem Statements

Health and safety are an important part of the corporate responsibility in social responsibility. An increased in production volumes and higher knowledge about the potentials danger of chemical substances and processes have brought up safety and environmental issues to the attention of publics, industries and regulatory authorities focus starting from the 1960s. Major disastrous events involving chemical plant industries have witnessed the introduction of inherent safety ideology to embed inherently safer design features when developing a new process (Kletz, 1985). Such idea has been extended to environmental aspect through the concept of clean technology (Ashford, 1997), but not in occupational health aspect. Active work on occupational health assessment has been done governing medical point of view but very poorly in the design of chemical plants. Because of its complex nature, occupational health has received much less attention compared to process safety and environmental assessment by chemical engineers. As a matter of fact, health hazard is more critical as it poses higher potential of direct impacts to human compared to safety and environmental hazards. Therefore, occupational health aspect should be considered at the early design phases of chemical plant industry.

Batch processing is a regular operation mode in the “low-volume high-value” chemical production, e.g. specialty chemicals, agricultural products, pharmaceutical. Batch production requires common facilities where various of products are manufactured by sharing the available resources e.g. equipment, manpower, utilities etc. Batch processes have more wide applications due to its small production volumes. Also this mode of operation is able to flexibly manage fluctuate demands due to frequent market changes (Biegler *et al*., 1997; Simon *et al*., 2008). Despite being a widely employed process mode in the industries, hazard assessments specifically occupational health hazards in batch process design are still very much limited. Therefore the aim of this study is to assess inherent occupational health hazards in batch processes. This work proposes a new study of inherent occupational health of batch process in the early stage of process conceptual design. Such studies which exclusively focusing on inherent occupational health hazards assessment for conceptual batch process design have never been reported so far since the early works were focusing on continuous processes only.

## 1.3 Objectives of the Study

The main objective of this study is to develop a systematic method for assessing inherent occupational health hazards in chemical batch processes during conceptual design phase.

The other objectives of this study are:

1. To identify the potential health hazard in chemical batch processes at the early stage of design which is during the conceptual design.

2. To develop an index-based method for assessing inherent occupational health hazards in chemical batch processes during conceptual design stage.

3. To demonstrate the developed method on a case study for method validation.

## 1.4 Scopes of the Study

In order to achieve the above objectives, this research is extended into more specified scope.

1. Comprehensive literature study on hazards assessment for batch processes by previous researchers.

2. Extensive review on inherent occupational health assessment methods

3. The boundary of the assessment covers the early conceptual design only (before process flowsheeting).

4. The occupational health hazards considered include those caused by chemical substances, operating conditions and unit operations.

5. The method is applied on Tongkat Ali water extraction case study for demonstration.

## 1.5 Significance of the Study

Nowadays, health aspect has becoming important aspect of sustainability that receives more attention from industries especially greater today than ever before. The study on occupational health hazards from the chemical design point of view has been poorly researched and still very much lacking especially for batch operation. Therefore, this study is critically important to address the gap in this subject matter. From this study a new methodology is proposed for evaluating inherent occupational health hazards of chemical batch processes in conceptual design phase. Based on the proposed index, the potential health hazards in chemical batch processes can already be identified and assessed early starting from the process conceptual design phase. This will provide great opportunities for designers and engineers to apply process modifications for reducing, if not eliminating, the hazards at relatively so much lower cost compared to the later lifecycle stages. The proposed index may contribute significantly in providing systematic method which allows health hazards to be already evaluated in much earlier point of process lifecycle than before. This will indirectly encourage designers and engineers to start considering health aspect earlier when developing a new process. A healthier workplace is a key to everything as it contributes to workers' satisfaction, higher productivity, less compensation and better company images.

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