# Inherent Health Consideration for Workers’ Protection in Chemical Plants

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A new index-based method for assessing inherent occupational health hazards is presented for the R&D stage. The index results can be viewed in three perspectives; additive-type, average-type, and worst case-type calculations. The method enables the alternative chemical process routes to be ranked based on their health characteristics of the level of occupational health hazards to be determined for a single process. A phenol process case study is given to illustrate the approach.

## 1. Introduction

The United Nation’s International Labor Office reported that yearly over two million people worldwide die of occupational injuries and work-related diseases (Eijkemans, 2005). The figure can be reduced if hazards inherent in workplaces are assessed during the process development. Careful selection of the chemical synthesis route is critical because it fixes the chemicals and the operating conditions to be used throughout the process. As a process proceeds through its lifecycle, the opportunities to implement inherently healthier design features become less and the cost is higher.

Inherent occupational health, which is based on the idea of inherent safety, strives to eliminate or reduce the occupational health hazards by trying to avoid the use of hazardous chemicals, process conditions, and operating procedures that may cause hazards to the employees (Hassim and Hurme, 2009).

Various methods have been developed for assessing the inherent safety and environmental friendliness of chemical processes in the R&D stage, but such methods for occupational health are still lacking. Health methods are highly in need because each year more people die from diseases caused by work than are killed in industrial accidents.

## 2. Existing Health Assessment Methods

There are several existing methods available addressing toxicity and health hazards aspect, but the number is much lower than the safety and environmental methods. Earlier methods such as the Dow Chemical Exposure Index; CEI (Dow Chemicals, 1998), Toxicity Hazard Index (Tyler et al., 1996), and HIRA-TDI (Khan and Abbasi, 1998) are more likely referred as safety-type assessment methods, because they only deal with acute toxicity from chemical release incidents rather than the overall aspect of health hazards. The later generation methods, e.g. the EHS method (Koller et al., 2000), INSET Toolkit (INSIDE Project, 2001), Occupational Health Hazard Index; OHHI (Johnson, 2001), and Process Route Healthiness Index; PRHI (Hassim and Edwards, 2006) fit the occupational health definition better, with the aim to protect workers' health from routine workplace exposures. The methods however, are either too brief because health is minorly assessed as part of safety and environmental aspects or too complicated for the R&D stage.

## 3. Development of the Assessment Methodology

The aim of this study is to develop a method for screening chemistry pathways based on the health risk level of several process routes during the R&D stage. Only chemicals' properties and reaction conditions data are used because of their availability at this stage.

Two factors considered in determining the level of health hazards are 1) the potential for harm, which depends on types and amounts of chemicals present and conditions in the working environment and 2) the potential for exposure, which is influenced by physical properties of materials, operating conditions, human behavior, and work activities.

Here a method called the Inherent Occupational Health Index (IOHI) is proposed. It comprises of two indexes; Index for Physical and Process Hazards ($I_{PPH}$) that represents the possibility for workers being exposed to chemicals and Index for Health Hazards ($I_{HH}$) that characterizes the impacts on health due to the exposure. The IOHI for each process route is calculated as a sum of the two indexes:

$$I_{IOHI} = I_{PPH} + I_{HH} \qquad (1)$$

In the $I_{PPH}$, factors with the ability to increase risks of injuries or health effects, either directly or indirectly, are identified. The factors considered are process mode ($I_{PM}$), pressure ($I_P$), and temperature ($I_T$), materials' phase ($I_{MS}$), boiling point ($I_V$), and corrosiveness ($I_C$). For the $I_{HH}$, two factors are included; exposure limit ($I_{EL}$) that gives information on the chronic hazards of the chemicals in the working air and R-phrase ($I_R$), which describes the type of health effect that might be caused by the chemicals. Summary of the subindexes and their penalties for the $I_{PPH}$ and $I_{HH}$ are given in Tables 1 and 2.

## 4. Case Study on Phenol Process

The IOHI is demonstrated by applying the method to compare four alternative process routes for phenol production. The routes are cumene oxidation based route (CO), toluene oxidation based route (TO), direct benzene oxidation in liquid phase based route (DBL), and direct benzene oxidation in gas phase based route (DBG).

### 4.1 Calculation of the index

Each subprocess of the phenol alternative routes is assessed using the IOHI parameters and the penalties assigned to the steps are summarized in Table 3. The assessment results can be viewed in three perspectives; additive-type, average-type, and worst case-type calculations.

*Table 1 Physical and process hazards ($I_{PPH}$) subindexes*

| factor | score formation | penalty |
|---|---|---|
| Mode of process, $I_{PM}$ | continuous | 1 |
| | semi-continuous/semi-batch | 2 |
| | batch | 3 |
| Material phase, $I_{MS}$ | gas | 1 |
| | liquid | 2 |
| | solid | 3 |
| Volatility, $I_V$ | *liquid and gas* | |
| | very low volatility (boiling point > 150 °C) | 0 |
| | low (150 °C ≥ boiling point > 50 °C) | 1 |
| | medium (50 °C ≥ boiling point > 0 °C) | 2 |
| | high (boiling point ≤ 0 °C) | 3 |
| | *solid* | |
| | non-dusty solids | 0 |
| | pellet-like, non-friable solids | 1 |
| | crystalline, granular solids | 2 |
| | fine, light powders | 3 |
| Pressure, $I_P$ (bar) | 0.5 – 5 | 0 |
| | 5 – 50 | 1 |
| | 50 – 200 | 2 |
| | > 200 | 3 |
| Corrosiveness, $I_C$ – based on construction material | carbon steel | 0 |
| | stainless steel | 1 |
| | better material | 2 |
| Temperature, $I_T$ (°C) | < 70 | 0 |
| | 70 – 150 | 1 |
| | 150 – 200 | 2 |
| | > 200 | 3 |

### 4.2 Results and discussions

The results of the assessment based on different types of calculations are summarized in Table 4 and the routes ranking is presented in Fig. 1. The additive based calculation sums up the subprocess indexes. Obviously, the approach indicates the CO route as the most health hazardous option due to its largest number of subprocess (three). This is followed by the TO route, which consists of two steps. Both the DBL and DBG processes have only one route, but the DBG receives a higher index value because it operates under a much higher operating temperature than the DBL process (DBG: 377-427 °C vs. DBL: 20-60 °C) and the DBG route contains highly volatile material.

The average of the IOHI can be calculated for each route to eliminate the influence of the number of subprocess on the final index value. Now the results are almost opposite from the additive based approach; CO and TO are the most favorable alternatives followed by the DBL and DBG. The CO has the lowest $I_{PPH}$ value – indicating it as the process with the lowest potential exposure hazard. Among the four alternatives, the CO process operates under the mildest operating temperature range of 35-120 °C. The TO route has the lowest $I_{HH}$ index due to the absence of very harmful substances such as benzene that presents in all the other three routes.

In the worst case-type approach, the highest penalty of each subindex is taken to represent the worst potential hazard of a process. This is to avoid the same ‘worst chemical’ in different subprocess to be penalized repeatedly. Like in the average-type approach, the DBG is regarded as the most harmful route followed by the CO, TO, and DBL processes. The CO, DBL, and DBG have the highest $I_{HH}$ index values of 9, followed by TO route of 6. For the $I_{PPH}$, the processes have an opposite outcome with the TO and DBG have the highest index value of 12, followed by CO of 11 and DBL of 8. The reason for these results is as already described in the average based approach.

## 5. Standard Setting for the Index

The index presented above cannot be used to determine the level of the inherent occupational health hazard of the individual process because the index value is meaningless as an absolute number. Therefore an IOHI standard is created, which have four categories of safe, moderately safe, moderately hazardous, and hazardous.

*Table 2 Health hazards ($I_{HH}$) subindexes*

| factor | score formation | penalty |
|---|---|---|
| Exposure limit, $I_{EL}$ | *solid (mg/m³)* | |
| | $OEL > 10$ | 0 |
| | $OEL \leq 10$ | 1 |
| | $OEL \leq 1$ | 2 |
| | $OEL \leq 0.1$ | 3 |
| | $OEL \leq 0.01$ | 4 |
| | *vapor (ppm)* | |
| | $OEL > 1000$ | 0 |
| | $OEL \leq 1000$ | 1 |
| | $OEL \leq 100$ | 2 |
| | $OEL \leq 10$ | 3 |
| | $OEL \leq 1$ | 4 |
| R-phrase, $I_R$ | *acute* | |
| | no acute toxicity effect | 0 |
| | R36, R37, R38, R67 | 1 |
| | R20, R21, R22, R65 | 2 |
| | R23, R24, R25, R29, R31, R41, R42, R43 | 3 |
| | R26, R27, R28, R32, R34, R35 | 4 |
| | *chronic* | |
| | no chronic toxicity effect | 0 |
| | R66 | 1 |
| | R33, R68/20/21/22 | 2 |
| | R62, R63, R39/23/24/25, R48/20/21/22 | 3 |
| | R40, R60, R61, R64, R39/26/27/28, R48/23/24/25 | 4 |
| | R45, R46, R49 | 5 |

*Table 3 Summary of IOHI calculations for phenol subprocess*

| | $I_{PPH}$ | | | | | | $I_{HH}$ | | $I_{IOHI}$ |
|---|---|---|---|---|---|---|---|---|---|
| route/step | $I_{PM}$ | $I_T$ | $I_P$ | $I_{MS}$ | $I_V$ | $I_C$ | $I_R$ | $I_{EL}$ | |
| CO | | | | | | | | | |
| 1 | 1 | 0 | 1 | 2 | 3 | 0 | 5 | 4 | 15 |
| 2 | | 1 | 1 | 2 | 1 | 0 | 4 | 3 | 12 |
| 3 | | 1 | 0 | 3 | 1 | 2 | 4 | 1 | 12 |
| TO | 1 | 1 | 0 | 3 | 1 | 0 | 3 | 2 | 10 |
| 1 | | 3 | 0 | 3 | 3 | 2 | 4 | 1 | 16 |
| 2 | | | | | | | | | |
| DBL | 1 | 0 | 1 | 3 | 1 | 2 | 5 | 4 | 16 |
| 1 | | | | | | | | | |
| DBG | 1 | 3 | 0 | 3 | 3 | 2 | 5 | 4 | 20 |
| 1 | | | | | | | | | |

*Table 4 The IOHI values for phenol routes*

| route | additive | | | average | | | worst case | | |
|---|---|---|---|---|---|---|---|---|---|
| | $I_{PPH}$ | $I_{HH}$ | $I_{IOHI}$ | $I_{PPH}$ | $I_{HH}$ | $I_{IOHI}$ | $I_{PPH}$ | $I_{HH}$ | $I_{IOHI}$ |
| CO | 19 | 21 | 40 | 6.3 | 7 | 13.3 | 11 | 9 | 20 |
| TO | 17 | 10 | 27 | 8.5 | 5 | 13.5 | 12 | 6 | 18 |
| DBL | 8 | 9 | 17 | 8 | 9 | 17 | 8 | 9 | 17 |
| DBG | 12 | 9 | 21 | 12 | 9 | 21 | 12 | 9 | 21 |

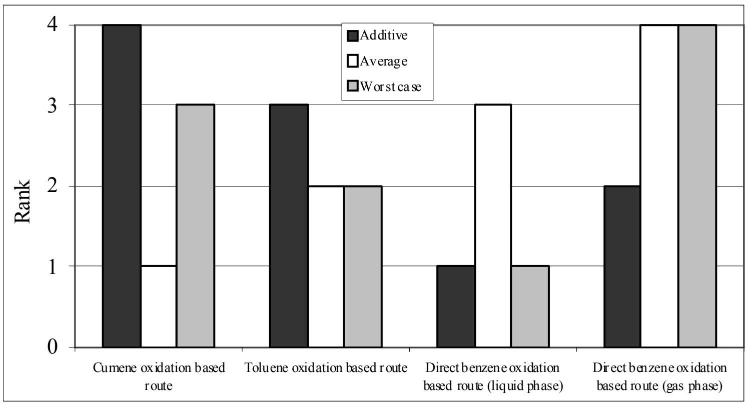

*Figure 1 The ranking order for phenol routes (rank 4 indicates worst route)*

*Table 5 IOHI standards*

| category | $I_{IOHI}$ scales[a] |
|---|---|
| Safe | 0 - 7 |
| Moderately safe | 8 - 11 |
| Moderately hazardous | 12 - 15 |
| Hazardous | 16 - 26 |

[a] per reaction step

The standard is set up based on the penalty of the subindexes – a higher penalty represents a higher degree of hazard or probability for exposure. The scales of each hazard category are shown in Table 5 and they are readily used with the index values from the average-type or worst case-type calculations. The standard is applied on the same case study. The results show that the CO and TO routes can be categorized on average as moderately hazardous to health. Meanwhile, the DBL and DBG routes are in hazardous category. Analysis of the subprocesses finds the TO first route as the only one that can be classified as moderately safe, but none is categorized as safe.

## 6. Conclusions

An index is proposed for assessing inherent occupational health hazards of chemical processes during the R&D stage. The method evaluates both the potential for workers exposure and the potential for harm as a result of exposure based on material properties and reaction chemistries data. The method can be used either for comparing alternative processes by their health properties or for determining the health hazard level of a single process. The introduction of the index enables health performance of process concepts to be quantified swiftly under the constraint of a limited data.

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