Dow Fire and Explosion Index

General

The safety and loss prevention guide developed by the Dow Chemical Company, and published by the American Institute of Chemical Engineers, Dow (1980), gives a method for evaluating the potential hazards of a process and assessing the safety and loss prevention measures needed. A numerical “Fire and Explosion Index” is calculated, based on the nature of the process and properties of the materials. The larger the value of the index, the more hazardous is the process. When used to evaluate the design of a new plant the index is normally calculated after the Piping and Instrumentation diagrams and equipment layout have been prepared, and is used as a guide to the selection and design of the preventive and protection equipment needed for safe plant operation. It may be calculated at an early stage in the process design, after the preliminary flow-sheets have been prepared, and will indicate whether alternative, less hazardous, processes should be considered.

The Dow index applies only to the main process units; it does not cover process auxiliaries, such as, warehouses, tank farms, utilities and control rooms. Only the fire and explosion hazard is considered; toxicity and corrosion hazards are not covered. Nor does it deal with the special requirements of plants manufacturing explosives.

Only a brief discussion of the Dow Safety and Loss Prevention Guide will be given in this section; sufficient to show how the Fire and Explosion Index is calculated and used. The full guide should be studied before applying the technique to a particular process design.

Calculation of the Dow F & E index

The basis of the F & E index is a material factor (MF), which is normally determined from the heat of combustion of the main process material. This primary material factor is multiplied by factors to allow for special material hazards; and for general and special process hazards.

The process is divided into units and the index calculated for each unit. A unit is defined as a part of the process that can be considered as a separate entity. It may be a section that is separated from the remainder of the plant by a physical barrier, or by distance; or it may be a section of the plant in which a particular hazard occurs.
• Material factor

The material factor is a number from 0 to 60 that indicates the magnitude of the energy released in a fire or explosion. For non-combustible materials the factor is zero; examples: water, carbon tetrachloride. For combustible materials the factor is calculated from the following equation:

\[
MF = -\Delta H_r \times 10^{-3}
\]

where \(-\Delta H_r\) = heat of combustion, Btu/lb.
Converted to SI units:

\[
MF = -\Delta H^\circ \times \frac{4.3 \times 10^4}{\text{mol wt}}
\]

where \(-\Delta H^\circ\) is now the standard heat of combustion at 25°C, kJ/kmol.

The Dow guide includes a list of the material factors for commonly used chemicals. The material factor should be evaluated for all process materials present in the unit in sufficient quantity to constitute a hazard, to decide the dominant material.
IS A SAFETY STUDY REQUIRED? (cont/d)

ICI Mond/Dow Index

Calculate the Following Indices

1 Material Factor (ie Flammability, Reactivity)

2 General Process Hazards
   (eg Exothermic Reactions, Dust Explosions)

3 Special Process Hazards
   (eg Operating Conditions, Proximity to Flammable Areas)

4 Quantity Factor

5 Layout Considerations

6 Toxicity Considerations
• Special material hazards

These factors are included to take account of any special hazards associated with the materials present in the unit. The primary material factor is increased by a percentage for each of the hazards listed in the Table, if applicable to any material present in a significant quantity in the unit. The percentage shown in the Table are given as a guide; the values to be used will depend on judgement: the designer's assessment of the hazard.

• General process hazards

These factors are intended to allow for the general process hazards associated with the unit being considered. The material factor, after adjustment for the special material factors, is increased by a percentage for each of the hazards listed below that are applicable to the process. The values given in the Table are used.

• Special process hazards

These factors allow for any of the special process hazards given below. The percentages shown in the table are used as a guide; the percentage to be used depending on the magnitude of the hazard.
Selection of preventive and protective measures

In the Dow Safety and Loss Prevention Guide, the F & E index is used as an aid to determining the equipment and facilities needed to control hazards and reduce the losses from any incident that may occur, the preventive and protective measures (P & P). The preventive and protective measures to be taken are divided into three categories:

1. The basic P & P features, which must be provided for all processes, regardless of the F & E index.
2. The recommended minimum features, which depend on the value of the F & E index.
3. Specific preventive features; measures that provide specific protection for the hazards considered in evaluating the index.
### ICI MOND/DOW INDEX

**Assessment of Hazard**

<table>
<thead>
<tr>
<th>Degree of Hazard</th>
<th>Index Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>0 – 20</td>
</tr>
<tr>
<td>Light</td>
<td>20 – 40</td>
</tr>
<tr>
<td>Moderate</td>
<td>40 – 60</td>
</tr>
<tr>
<td>Moderately Heavy</td>
<td>60 – 75</td>
</tr>
<tr>
<td>Heavy</td>
<td>75 – 90</td>
</tr>
<tr>
<td>Extreme</td>
<td>&gt; 90</td>
</tr>
</tbody>
</table>
Mond-Dow Index

The principles and general approach used in the Dow method of hazard evaluation have been further developed by ICI Mond Division. Their revised, Mond, fire, explosion and toxicity index is discussed in a series of papers by Lewis (1979). The main developments made to the Dow index in the Mond index are:

1. It covers a wider range of process and storage installations.
2. It covers the processing of chemicals with explosive properties.
3. A calculation procedure is included for the evaluation of a toxicity hazards index.
4. A procedure is included to allow for the off-setting effects of good design, and control and safety instrumentation.
5. The procedure has been extended to cover plant layout.
6. Separate indices are calculated to assess the hazards of fire, internal explosion and aerial explosion.

The procedure followed in calculating the Mond method is, briefly:

1. An initial assessment of the hazards of each unit, in a similar manner to that used for the Dow index. At this stage no account is taken of the off-setting effect of any protective and preventive features.
2. An analysis of the different types of potential hazard: fire, explosion and toxicity. Comparison of these hazard levels with standards of acceptable risk.
3. Review of the hazard factors used in the assessment; for example, the general and special process hazards, to see if the risks can be reduced by design changes.
4. Application of the appropriate off-setting factors to allow for the preventive features included in the design; calculation of the final hazard indices.

The Mond technique of hazard evaluation is fully explained in the paper by Lewis (1979), which includes a Technical Manual setting out the calculation procedures. The calculations are made on a calculation sheet similar to that given in the Table extended to include the additional features in the Mond index.

Summary

The Dow and Mond indexes are useful techniques, which can be used in the early stages of a project design to evaluate the hazards and risks of the proposed process. Calculation of the indexes for the various sections of the process will highlight any particularly hazardous sections and indicate where a detailed study is needed to reduce the hazards.

Example

Evaluate the Dow fire and explosion index for the nitric acid plant.
Solution

The calculation is set out on the special form shown in the Table. Notes on the decisions taken and the factors used are given below:
Unit: consider the total plant, there are no separate areas.
Material factor: main combustible material is ammonia and the factor is calculated from the heat of combustion for the reaction:

\[ \text{NH}_3(g) + \frac{5}{2} \text{O}_2(g) \rightarrow \text{NO}(g) + \frac{3}{2} \text{H}_2\text{O}(g), \Delta H = -226,334 \text{kJ} \text{ / kmol} \]

From equation

\[ \text{Material factor} = \frac{4.3 \times 10^{-4}}{17} \times 226,334 = 5.7 \]

Note: Hydrogen is present, and has a large material factor (51.6), but the concentration is too small for it to be considered the dominant material.

Special material hazards: none.

General process hazards
B. oxidation reaction: 50 per cent.

Special process hazards
B. Operation near explosive range, relies on instrumentation to prevent an explosive mixture entering the reactor: 100 per cent.
C. Low temperature storage of NH: 15 per cent

The index works out at 18.5: classified as "Mild". Ammonia would not normally be considered a dangerously flammable material; the danger of an internal explosion in the reactor is the main process hazard. The toxicity of ammonia and the corrosiveness of nitric acid would also need to be considered in a full hazard evaluation.
# Is a Safety Study Required?

**Evaluation of Dow Fire and Explosion (F&E) Index Plant for a Nitric Acid**

<table>
<thead>
<tr>
<th>Fire and Explosion Index Calculation Sheet</th>
<th>UNIT: Complete Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Factor For: Ammonia</td>
<td>→ → → → → 5.7</td>
</tr>
</tbody>
</table>

## Special Material Hazards

<table>
<thead>
<tr>
<th>Hazard Description</th>
<th>% Factor Suggested</th>
<th>% Factor Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidising Materials</td>
<td>0 - 20</td>
<td></td>
</tr>
<tr>
<td>Reacts with Water to produce a combustible gas</td>
<td>0 - 30</td>
<td></td>
</tr>
<tr>
<td>Subject to Spontaneous Heating</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Subject to rapid spontaneous polymerisation</td>
<td>50 - 75</td>
<td></td>
</tr>
<tr>
<td>Subject to explosive decomposition</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>Subject to detonation</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>0 - 150</td>
<td></td>
</tr>
</tbody>
</table>

Add Percentages A-Q for special material hazard (S.M.H)  

\[
\text{TOTAL} = (100 + \text{S.M.H. Total})/100 \times \text{(Material Factor)} = \text{Sub-Total No. 2} = 5.7
\]

## General Process Hazards

<table>
<thead>
<tr>
<th>Hazard Description</th>
<th>% Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handling and Physical Changes Only</td>
<td>0 - 50</td>
</tr>
<tr>
<td>Continuous Reactions</td>
<td>25 - 50</td>
</tr>
<tr>
<td>Batch Reactions</td>
<td>25 - 60</td>
</tr>
<tr>
<td>Multiplicity of Reactions in same</td>
<td>0 - 50</td>
</tr>
</tbody>
</table>

Add Percentages A-D for general process (G.P.H)  

\[
\text{TOTAL} = (100 + \text{G.P.H. TOTAL})/100 \times \text{(Sub-Total No. 2)} = \text{Sub Total No. 3} = 50
\]

## Special Process Hazards

<table>
<thead>
<tr>
<th>Hazard Description</th>
<th>% Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Pressure (below 1 bar)</td>
<td>0 - 100</td>
</tr>
<tr>
<td>Operation in or near explosion range</td>
<td>0 - 150</td>
</tr>
<tr>
<td>Low Temperature 1. (Carbon Steels 10 to 30°C)</td>
<td>15</td>
</tr>
<tr>
<td>2. (Below - 30°C)</td>
<td>25</td>
</tr>
<tr>
<td>High Temperature (use one only)</td>
<td></td>
</tr>
<tr>
<td>1. (Above Flash Point)</td>
<td>10 - 20</td>
</tr>
<tr>
<td>2. (Above Boiling Point)</td>
<td>25</td>
</tr>
<tr>
<td>3. (Above Autoignition Point)</td>
<td>35</td>
</tr>
<tr>
<td>High Pressure 1. (15-200 Bar)</td>
<td>30</td>
</tr>
<tr>
<td>2. (Above 200 Bar)</td>
<td>60</td>
</tr>
<tr>
<td>Processes or reaction difficult to control</td>
<td>50 - 100</td>
</tr>
<tr>
<td>Dust or Mist Hazard</td>
<td>30 - 60</td>
</tr>
<tr>
<td>Greater than average explosion hazard</td>
<td>60 - 100</td>
</tr>
<tr>
<td>Large quantities of combustible liquids</td>
<td></td>
</tr>
<tr>
<td>(Use one only)</td>
<td></td>
</tr>
<tr>
<td>1. 10-25 m³</td>
<td>40 - 55</td>
</tr>
<tr>
<td>2. 25-75 m³</td>
<td>55 - 75</td>
</tr>
<tr>
<td>3. 75-200 m³</td>
<td>75 - 100</td>
</tr>
<tr>
<td>4. Above 200 m³</td>
<td>100+</td>
</tr>
</tbody>
</table>

Add Percentages A-J for special process (S.P.H.)  

\[
\text{TOTAL} = (100 + \text{S.P.H. Total})/100 \times \text{(Sub-total No. 3)} = \text{Fire & Explosion Index} = 115
\]

\[
\text{Fire & Explosion Index} = 115 \times 5.7 = 18.5
\]
Other Indices

There are a number if other indices available but not in wide use. The Dow Fire and Explosion Index and the Mond-Dow Index, both described, in the previous section are by far the most widely used. However, to obtain the Index requires a significant amount of calculating.

Other Indices and methods using Indices are being developed in an attempt to simplify the calculations and also introduce the use of computers to facilitate the calculations.

The attached paper demonstrates one such recent development at the test stage.
### Consequence Analysis

Consequence analysis starts with a review of the facilities and activities, within the scope of the Process Hazards Analysis for the area being studied, to select an initial range of accidental event scenarios. Most of the events having potential impact will involve the release of a toxic, flammable, or environmentally-damaging material. Frequently, a set of release scenarios has been identified in previous process hazards analysis. Otherwise, the first step is to identify and survey the hazards present to select hazardous events with the potential for consequences beyond the immediate hazard location, e.g., 100 feet or greater away. Evaluation of events with major impact is usually an iterative process. It alternates between the activities of identifying hazardous events and estimating the resultant harm from these events.

Hazardous consequences include injuries, substantial property damages, or major harm to the environment from episodic events. An initial range of accidental release scenarios should be selected that extends from a major event, thought to be a candidate for worst-case consequences to an event thought to result in only minor consequence. To help identify releases that could impact off-site locations, it is useful to identify a "de-minimus" release. This is defined as a release that just causes minor consequences at the closest off-site locations. Events producing smaller releases will not have any direct off-site impact that exceeds the selected consequence criterion.

For efficient use of resources, an appropriate consequence analysis strategy is to initially use conservative, simplifying approximations for consequence analysis. The worst-case scenario is developed by evaluating the following probabilities for each material with potential adverse consequences beyond the immediate, local release area:

- Catastrophic vessel(s) or container failure(s) resulting in instantaneous loss of all of a regulated substance in the process.
- Catastrophic line or hose failure (flow from both ends) including the largest lines and hoses.
- Exposure of vessels and equipment to fire if fires can occur, or if flammable or combustible substances are handled or stored nearby.
- Venting or pressure relief devices at the relief system design basis.
The above scenarios should include consequences such as explosions and/or thermal radiation. All the scenarios studied and the logic for selection of the worst-case scenario should be documented. For accident scenarios involving prolonged toxic or flammables releases, typically the scenario with the greatest rate of vapour and aerosol generation will produce the largest consequences. There are also events where the worst consequence comes from the largest quantity released, such as a short duration "puff" of toxic vapour, or an unconfined spill of evaporating liquid.

Conservative approximations tend to overestimate either the magnitude of the event, the extent of the consequences, or both. When a more complex analysis of consequences is required, software programs are available for this analysis and will be discussed later.

Consequence estimates should always be prepared in a manner that can be substantiated and so that one can easily follow the logic in the documentation.

This means that they should be technically consistent with established methods that are widely accepted by experts and are on the conservative side by over-predicting consequences. However, gross overestimates must be guarded against, since they could yield unrealistic public concern or unwarranted, and possible unsafe, large-scale evacuation planning. A range of models are available to predict dispersion scenarios and are frequently in consequence analysis.

The OSHA Standard 1910.119e(3)vii requires a qualitative evaluation of a range of the possible safety and health effects of failure of controls on employees in the workplace.

**Fault Tree Analysis**

**General**

The fault tree analysis is a Hazard Analysis technique and gives guidance to the likelihood of an event occurring. Incidents usually occur through the coincident failure of two or more items; failure of equipment, control systems and instruments, and mis-operation. This graphical representation and analysis of a system portrays sequences of failure events leading to an ultimate undesired Top Event, and yields the combinations of component failures that may lead to this Top Event.
Procedure

The fault tree schematic is shown in the block diagram.

Fault Tree Schematic

```
Identify
Top Event

Construct
Fault Tree

Qualitative
& Quantitative

Make
Decision

Acceptance

Develop
Improvements
```

The undesired event is usually based on the results of previous Process Hazard Reviews such as What If/Checklist, FMEA or HAZOP. Often the symbols may be formalised in a fault tree analysis, for example:

- Event or Subevent
- Basic Cause
- System Cause
- Normal Cause
- Transfer
In the construction of a Fault tree, the Subevents leading to the Top Event are shown as branches of a tree in reverse chronological order. An AND symbol is used where coincident events are necessary before the system fails and the OR symbol where the failure of any input by itself, would cause failure of the system.

**AND Gate**          **OR Gate**

A fault tree is analogous to the type of logic diagram used to represent computer operations, and the symbols are analogous to logic AND and OR gates.

The construction is as follows:

```
Select Top Event         Step 1
↓
List All Causes         Step 2
↓
Select Gate Type        Step 3
↓
Connect Causes         Step 4
↓
Repeat Steps 2 - 4     Step 5
```

Fault trees are used to make a quantitative assessment of the likelihood of failure of a system, using data on the reliability of the individual components of the system.

Consider the following system which shows a chlorine vaporiser, which supplies chlorine at 2bar to a chlorination reactor. The vaporiser is heated by condensing steam.
The sequence of events which can lead to flooding of the chlorine vaporiser are shown.

**Fig.** Chlorine vaporiser instrumentation

**Fig.** Simple fault chart (logic diagram)
If the following figures represent an estimate of the probability of events happening, the probability of failure of the total system by this route can be calculated.

<table>
<thead>
<tr>
<th>Component</th>
<th>Failure rate, times per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam trap</td>
<td>1</td>
</tr>
<tr>
<td>Flow control valve</td>
<td>0.1</td>
</tr>
<tr>
<td>Level control, sub-system</td>
<td>0.5</td>
</tr>
<tr>
<td>High level shut-down, sub-system</td>
<td>0.04</td>
</tr>
</tbody>
</table>

The failure rates are added for Or gates, and multiplied for And gates; so the probability of flooding the vaporiser is given by:

\[
(1 + 0.1 + 0.5) \times 0.04 = 0.06 \text{ times per year}
\]

or, once in \(1/0.06 = 17\) years

The data on failure rates given in this example are for illustration only, and do not represent actual data for those components. Some quantitative data on the reliability of instruments and control systems is given by Lees (1976). Several data banks have been established, for example, OREDA and HARIOS.