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Fire and Explosion Index calculation method incorporating classified safety measure credits

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ABSTRACT

Based on an analysis of two methods for the modification of the F&EI for the DOW Guide, it is found that the effects of safety measures are not classified. Moreover, the efficiency of the measures is magnified to various degrees, as the positive impact of the loss reduction measures are applied to the rate reduction of the intrinsic hazard in the evaluated unit. For this reason, a modification method using classified safety measures is proposed, in which safety measures are classified into process protection measures and loss reduction measures. The calculation of the modified F&EI involves the credit factors of process protection measures, whereas the determination of the maximum probable property damage incorporates the loss reduction measures. This method could provide more reasonable reference data for hazard units because of its more objective and reasonable evaluation results.

1. Introduction

The Dow Fire and Explosion Index (F&EI) was developed by the American Dow Chemical Company in 1964 and is currently in its 7th edition. This index is widely applied in the hazard evaluation or inherently safer design of chemical processes, including the production, storage, and processing of flammable, explosive, and active materials, as well as in water (gas) supply or drainage systems, sewage treatment systems, distribution systems, and some facilities for boilers, power plants, and potentially dangerous devices (American Institute of Chemical Engineers (AIChE), 1994, Etowa, Amyotte, Pegg & Khan, 2002, Gupta, 1997, Krewer, Liauw, Ramakrishna, Babu & Raghavan, 2002, Mannan, Suardin & El-Halwagi, 2007). Based on statistical accident data, the potential energy of the material, and existing safety measures, the potential fire, explosion, and reaction hazard can be evaluated quantitatively. The main aims of this evaluation are to quantify the anticipated loss caused by fire, explosion, and reaction accidents, to determine the facilities that may cause or amplify events, and to communicate the risk to management in such a way that management may take appropriate actions to reduce the risk.

The F&EI method estimates the hazards of a single unit based on the chemical properties of the materials in its inventory and then uses the plant construction cost or replacement cost to estimate the potential risk in dollars (Jensen & Jørgensen, 2007).

Though semi-quantitative the Dow Fire and Explosion Index is, this method is widely used in the hazard evaluation of chemical and industrial processes. It is necessary to modify the method based on its initial principle to make its results more correct and realistic. According to the general procedure for using the F&EI guide, it is implied that the positive effect of the safety measures are only represented by the reduction of the maximum probable property damage (MPPD) and not by the F&EI, which reflects the inherent hazard of the unit. Thus, the area of exposure is relatively large. For this reason, scholars have proposed some methods to modify the F&EI, radius of exposure, and area of exposure by considering safety measure credit factors. Based on an examination of the literature, the modification methods can be classified into two categories: direct modification methods, in which the initial F&EI is directly multiplied by the credit factor and the modified F&EI is then used to determine the radius of exposure and area of exposure; and square methods, in which the initial F&EI is multiplied by the square root of the credit factor and the modified F&EI is then used to calculate the radius of exposure and area of exposure (Gupta, Khemani & Mannan, 2003; Ning, Zhou, Li & Zhang, 2011; Song, Li & Li, 2008; Wang & Wang, 2012; Xu, 2009; Yu, Shi & Chen, 2008; Zhang & Wang, 2011).

Both modification methods can reduce system costs and insurance premiums and improve the accuracy of the inherent hazard

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rate of the evaluated unit. However, neither method classifies the safety measures based on their effects, which leads to unreasonable results. Following an analysis of the existing modification methods, this paper proposes a calculation method that incorporates the classification of safety measures and then compares the results calculated by a different method in a case study.

2. The concept of the classified effects of the safety measures

The level of risk is the most important concern in the safety evaluation of a unit or enterprise. With regard to the risk, two aspects should be considered simultaneously: the degree of the damage or the quantity of the loss and the potential possibility to cause an expected loss or damage (Wu, Gao & Wei, 2011). The risk can be defined using equation (1):

$$\text{Risk} = \text{Unreliability} \times \text{Damage} \quad (1)$$

Usually, in the Dow Guide, the F&EI and MPPD are used to express a unit's fire and explosion hazards. The F&EI reflects the inherent hazard of the unit, or the possibility of a fire and/or explosion; hence, it corresponds to the *unreliability* in equation (1). The MPPD, which incorporates the loss caused by the fire and explosion, corresponds to the *damage* in equation (1).

There are three categories of loss control features: the Process Control Credit Factor (C_1), Material Isolation Credit Factor (C_2), and Fire Protection Credit Factor (C_3). According to this classification, it is reasonable to use the product of these three factors to calculate the Actual MPPD. However, using the product of the three factors to modify the F&EI, without considering the different effects caused by different measures, would lead to incorrect results.

In the practical application of the Dow Guide, to represent the influence of the safety measures objectively, safety measures should be classified on the basis of their effects. For this reason, the measures are classified into process protection measures and loss reduction measures, whose definitions are as follows:

(1) Process protection measures

Process protection measures are those measures that can reduce the possibility of fire and explosion incidents or improve the reliability of the unit. The positive effects of these measures decrease the F&EI. Examples of process protection measures include incorporating emergency power in the process control measures and interlock in the material isolation measures.

(2) Loss reduction measures

Loss reduction measures are those measures that can control the further spread of accidents and decrease the loss or damage once a fire or explosion has occurred. The positive effects of these measures decrease the MPPD. Examples of loss reduction measures include the use of explosion control in the process control measures, remote control valves in the material isolation measures, and all fire protection measures.

Based on the effects of the measures, the classifications of the measures mentioned in the Dow Guide are shown in Table 1.

Because the F&EI reflects the inherent hazard of the unit, when using the credit factors to modify it, only the process protection measures, which reduce the possibility of fire and explosion, should be taken into account, rather than the loss reduction measures, which control the loss or damage caused by an accident. Correspondingly, when calculating the Actual MPPD using the modified F&EI, only the loss reduction measures should be considered, not the process protection measures. Therefore, this method can avoid the underestimation of fire and explosion hazard.

3. Analysis of the existing methods for the modification of the F&EI in the Dow Guide

3.1. Direct multiplication of the initial F&EI by the credit factor

Directly multiplying the initial F&EI by the credit factor is a popular modification method. This method is referred to as the direct modification method here, and it has many advantages, such as simplicity, intuitiveness, and ability to fully reflect the important effects of the safety measures on hazard rate reduction. However, this method suffers from two issues that may lead to incorrect modification results:

(1) In this method, all safety measure credits are multiplied, and the product is used to modify the initial F&EI without considering the variable effects of different measures. That is, the effects of the loss reduction measures are also incorporated into the F&EI, which corresponds to the intrinsic hazard of the unit. Thus, the modified value of the F&EI will be lower than the actual value, preventing the objective estimation of the hazard unit.
(2) In the Dow Guide, the effect of the safety measures is incorporated to calculate the actual MPPD. Using the modified F&EI,

Table 1
Classifications of measures based on their effects.

Feature	Classification	Corresponding parameter	Feature	Classification	Corresponding parameter
1. Process control measures					
(1) Emergency power	Process protection	F&EI	(6) Inert gas	Process protection	F&EI
(2) Cooling	Process protection	F&EI	(7) Operating instructions/procedures	Process protection	F&EI
(3) Explosion control	Loss reduction	MPPD	(8) Reactive chemical review	Process protection	F&EI
(4) Emergency shutdown	Loss reduction	MPPD	(9) Other process hazard analysis	Process protection	F&EI
(5) Computer control	Loss reduction	MPPD			
2. Material isolation measures					
(1) Remote control valves	Loss reduction	MPPD	(3) Drainage	Loss reduction	MPPD
(2) Dump/blowdown	Loss reduction	MPPD	(4) Interlock	Process protection	F&EI
3. Fire protection measures					
(1) Leak Detection	Loss reduction	MPPD	(6) Water curtains	Loss reduction	MPPD
(2) Structural steel	Loss reduction	MPPD	(7) Foam	Loss reduction	MPPD
(3) Fire water supply	Loss reduction	MPPD	(8) Hand extinguisher/monitors	Loss reduction	MPPD
(4) Special systems	Loss reduction	MPPD	(9) Cable protection	Loss reduction	MPPD
(5) Sprinkler systems	Loss reduction	MPPD			