

Dow's fire and explosion index: a case-study in the process unit of an oil extraction factoryZeynab Sadat Nezamodini¹, Zahra Rezvani², Kumars Kian³

¹ M.Sc. of Occupational Health and Safety, Senior Lecturer and Faculty Member, Department of Occupational Health, Faculty of Health, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran

² Ph.D. Candidate of Safety Science, VTI Department, Faculty of Technology, Policy and Management, Delft University of Technology, Delft, Netherlands

³ B.S. of Occupational Health and Safety, HSE Manager, Tehran, Iran

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Abstract

Introduction: The incidence of fires and explosions have led to severe damage in many industries, primarily in industries' financial losses. This study was conducted to estimate losses due to fire and explosion and the impact of control measures on the number of losses applying Dow's Fire and Explosion Index.

Methods: This is a case study conducted in one of the process units of an oil extraction factory. Dow's Fire and Explosion Index Hazard classification guide, 7th edition, issued by the American Institute of Chemical Engineers was applied. Data were obtained mainly through interviews and consultation with experts, as well as reported operating parameters and process documents.

Results: The Dow Index of the processing unit was estimated to be 243.68, and the most probable base damage was approximately \$4.15 million in 2008. The actual damages were estimated to be \$2,863,500, and the number of lost work days to be 64.56 days. The interruption losses were estimated to be \$15,817,200 and the total losses to the system to be \$18.67 million. These results demonstrated that losses resulting from production interruptions are greater than losses due to the destruction of equipment. A series of corrections was then proposed and risk analysis was performed again to examine the effects of reforms. The comparison shows that by applying reforms the FEI can change to 86.62 and the total loss can reduce to \$9.03 million.

Conclusion: This study shows that Dow's Index is a systematic tool to examine the impact of control measures. It also enhances resource management considering an optimal insurance contract. Considering the priority of reducing damage factors, several correction actions were suggested, such as modifying the drainage system, installation of hexane detectors, an automatic sprinkler system, fire detectors on the cable tray, and finally, using the water spray washing on the tanks.

Keywords: Fire, Explosion, Cost, Losses, DOW Index

1. Introduction

Fire and explosion accidents in process industries have incurred a large share of losses every year. These accidents are, respectively, the first and second major risks in the process industries (1) that cause financial, human, and ecological losses. Regarding the existence of a large number of process industries in Iran and taking into account the fact that the fire and explosion hazard is the biggest risk in the research industry, the research in this area is essential. Different methods of assessing fire risks have been applied to reduce fire and explosion risks. They include classical qualitative methods such as Hazard and Operability (HAZOP), Failure Mode Effect Analysis (FMEA), and new quantitative tools like Dow's Fire and Explosion Index (FEI), Mond's Fire Explosion and Toxicity Index (FETI), the Instantaneous Fractional Annual Loss (IFAL) Index, and the Safety Weighted Hazard Index (SWEHI). In this study, the Dow Index is used for the following reasons: First, Dow's Index is the most widely used method (2, 3) which has been applied in process industries where flammable, combustible or reactable agents are stored, transported, or

Corresponding author:

Zahra Rezvani, VTI Department, Faculty of Technology, Policy and Management, Delft University of Technology, Delft, Netherlands. Tel: +31.687042596, Email: z.rezvani@tudelft.nl

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processed. Second, fire and explosion losses can be estimated economically and efficiently by using this index. Third, it is a user-friendly tool for evaluation of fire and explosion hazards in chemical process industries that uses available parameters such as temperature, pressure, and energy of chemical substances. Finally, it is a useful tool for inherent safety evaluation and safer design (4). Dow's Index is a quantitative risk analysis method that has been used for hazard identification at plant level. This method was introduced by the Dow Chemical Company for fire and explosion hazard analysis. The potential occurrence of fire and explosion can be estimated by using the Dow Index. Management priorities can be identified as well (5-7). The losses estimated by this method can serve as a basis for determining the insurance costs of the explosion and fire. The primary objective of safety management in this factory was to find out whether it was performing at an acceptable safety level. Therefore, the classical method, which is a qualitative risk assessment method based on expert judgment, was applied. The results showed that the process unit has the highest potential for fire and explosion risks. Consequently, the current study was performed to determine the expected losses more accurately and to encourage management to invest in control systems and to improve current fire and explosion control measures based on their priorities. It was also used to calculate insurance rates for an optimal insurance contract.

2. Material and Methods

This is a case study conducted in 2012 in one of the process units of an oil extraction factory in Iran's Khuzestan province. The objective of the method was to examine the FEI index in an operation industry which involves different processes. Dow's Fire and Explosion Index Hazard classification guide, 7th edition, issued by the American Institute of Chemical Engineers was applied (8). Data were obtained mainly through interviews and consultation with experts, as well as reported operating parameters and process documents. This study was conducted in three distinct stages as follows:

2.1. Calculation of Fire and Explosion Index

For this purpose, base and specific hazards of the process were monitored, then each hazard was assigned a new invoice. The penalty factors, base hazard factor, and special hazard factor were calculated. The product of two of these factors was the process unit hazard factor (F_3). Meanwhile, the degree of flammability and reactivity of Hexane, which is the main hazardous material in this unit, were determined to calculate material factor (MF). Then temperature correction was carried out according to the thermal conditions of the study. The DOW Index was calculated by multiplying F_3 and MF. Then the radius of exposure and the area at risk were calculated.

2.2. Estimation of potential losses caused by fire and explosion

In the next step, the equipment values were estimated through replacement value in the contact area and damage factor (DF), which represents the sum of the damage of fire and explosion and degradation of energy of the process unit. By using a material factor (MF) and process unit hazards factor (F_3) and referring to the manual diagrams, DF was determined. The most probable base damage that is the damage without any safety and control measures in place was calculated by multiplying the value of the equipment and the damage factor.

2.3. Assessment of safety and control measures

It is essential to consider the series of existing protective and control measures, including those that might be inadequate, to more accurately estimate the amount of compensation in the event of fire and explosion. Thus, loss control credit factor was calculated by multiplying three measures - process control (C_1), separation of materials (C_2), and fire protection (C_3). The credit factor is a number between 0 and 1. Number 1 is allocated when there is not any control measure. Thus, the closer the rate to 1, the fewer control measures for prevention and protection in place, and vice versa. By multiplying the most probable base damage and loss control credit factor, the most probable actual damage was calculated. Fire and explosion would probably cause interruption to production for several days. Therefore, it is necessary to estimate the loss of working days or days out of service. Since a fire or explosion has not yet occurred in this industry, this information does not exist. Therefore, these days were calculated by following equations based on the most probable actual damages and considering the parameters that influence the cost of interruptions in production:

- 1) Top level: $\log y = 1.550233 + 0.59841 (\log x)$
- 2) Normal: $\log y = 1.325132 + 0.592471 (\log x)$
- 3) Lower level: $\log y = 1.045515 + 0.610426 (\log x)$

Where:

- X: Most probable actual damages
- Y: Number of lost working days

Since spare parts existed in stock for equipment replacement, the most probable lost working days (MPDO) was predicted based on the normal equation in FEI graphs. Finally, the total loss of the unit was calculated by summing the most probable actual damages and the calculated interruption loss.

3. Results

The extraction unit was selected by taking into account several factors such as flammability and reactivity of materials, operating pressure, temperature, and the amount of material. Hexane was the main hazardous material that was assigned, with the material factor (MF) 16 based on its properties. DOW's Fire and Explosion Index was calculated to be 243.68. The extraction unit was, therefore, categorized as a severe risk and consequently, requiring correction measures. Radius of exposure, damage factor and total loss were calculated to be 62.38 m, 0.83 and \$18,680,700. Other parameters such as loss control credit factor, process control factor, separation of materials factor and fire protection factor were calculated, which are shown in Table 1. The results of calculating the DOW index showed that there were deficiencies and shortcomings in the existing control strategies. As a result, a series of changes and corrections was proposed such as modification of the drainage system, preparing the water supply for fire protection, establishing a sprinkler system, using water curtains, using the foam extinguisher, installing a leak detection system, establishing a cooling system, using cable protection devices, and implementing inert gas. Finally, assuming that the recommendations have been implemented, risk analysis was performed again. As presented in Table 2, by carrying out a series of changes and corrections, the risk index found a considerable number of changes. For instance, the Fire and Explosion Index changed from 243.68 to 86.62 and the total loss of \$18.6 million was reduced to \$9.03 million.

Table 1. Loss control credit factor

Calculating the loss control credit factor						
Process control factor (C ₁ =0.79)	Features	Loss control credit factor range	Credit factor	Features	Loss control credit factor range	Credit factor
	Emergency propulsion	0.98	1	Neutral gas	0.94-0.98	1
	Cooling system	0.97-0.99	1	Operating instructions	0.91-0.99	0.91
	Explosion control	0.84-0.98	0.98	Review of chemical reactions	0.91-0.98	1
	Emergency shut down	0.96-0.99	0.98	Other methods of analysis process	0.91-0.98	0.98
	Computer control	0.93-0.99	0.93			
	Separation of materials factor (C ₂ =0.92)	Remote control valves	0.96-0.98	0.98	Drainage	0.91-0.97
Vacate- Vent		0.96-0.98	0.98	Interlocks		0.98
Fire protection factor (C ₃ = 0.96)	Leak detection	0.94- 0.98	1	Water curtains	0.97- 0.98	1
	Steel structure	0.95- 0.98	0.98	Foam resistant	0.92- 0.97	1
	Water supply for fire suppression	0.94- 0.97	1	Manual extinguisher/ monitors	0.93- 0.98	0.98
	Specific system	0.91	1	Cable protection	0.94- 0.98	1
	Sprinkler systems	0.74- 0.97	1			

Loss control credit factor= C₁.C₂.C₃= 0.69

Table 2. Comparison of results before and after the supposed reforms

Parameter	Results before hypothetical improvement	Results after hypothetical improvement
Fire and explosion index (FEI)	243.68	86.62
Radius of exposure (m)	62.38	22.17
Exposure area (m ²)	12,218.57	1,543.34
Value of equipment in contact area (\$)	5000000	5000000
Damage factor	0.83	0.83
Most probable base damage (\$)	4,150,000	4,150,000
Loss control credit factor	0.69	0.23
Most probable actual damages (\$)	2,863,500	954,500
Most likely lost working days	64.56	33
Interruption losses (\$)	15,817,200	8,085,000
Total damage (\$)	18,680,700	9,039,500

4. Discussion

The Fire and Explosion Index at the extraction unit was calculated as 243.68, which is classified as a severe and unacceptable risk. This rate is higher than the Fire and Explosion Index for methyl isocyanate in the Bhopal event (FEI = 238), that caused widespread financial and physical damage (7). The cause of high fire and explosion risk in this case study might be as a result of several risk factors, such as an improper drainage system, lack of neutral gas, corrosion and excessive wear, hexane toxicity, and working within flammability range. It is noted that a more realistic and accurate assessment of fire and explosion damage depends on the effectiveness of existing controls and safeguards. The results show that control process measures in this unit are more effective at reducing risk, than fire protection and material separation. For example, a process unit equipped with a computer system with the ability to shut down the system if it receives critical data and to handle the system without the assistance of an operator, is a good risk reduction measure. Performing regular risk assessment procedures in units is another effective measure in reducing risks in this company. On the other hand, numerous deficiencies and pitfalls can be observed in fire protection systems in this company, which increases the loss control credit factor. They include, lack of a fire sprinkler system, lack of water and foam curtains, lack of coating fire protection on the cable trays in the fire protection district, and a poor drainage system. The current drainage system is not capable of evacuating all liquids spilled during fire extinguishing. Therefore, it increases the possibility of a large pool of hydrocarbon liquids forming around the process unit and consequently, the risk of fire and explosion (9). According to the calculated damage factor (83%) and the value of the equipment in the contact area, the base damage was estimated as \$4,150,000. But since each process unit is equipped with a series of control measures ($C=0.69$), the actual damage was estimated at less than base damage. Fire and explosion can lead to the destruction of equipment and interruption in the work process. Damages resulting from interruption in production were estimated by the most likely amount of lost working days due to a fire and explosion accident. There are three levels given in the Fire and Explosion index guide—upper, normal and lower. Given the conditions in the process unit, the normal level was used to calculate lost workdays, yielding 64.56 lost workdays. Interruption losses were allocated as 84.7% of total damage (\$15.81 million), which is a large share of damage. Only 15.3% of the damage (\$18.67 million) was caused by the equipment. It is apparent that by undertaking a series of corrective measures in the process unit, the amount of damages will be far less (9). Implementation of corrective measures in areas such as drainage systems, flammable liquid storage tanks, corrosion, erosion and leakage prevention can reduce the Fire and Explosion Index from 243.68 to 86.62 and the radius of exposure from 62.38 to 22.17 meters. This obviously reduces the area at risk and consequently, will reduce the damage. The study by Etowah et al. evaluating the inherent safety of chemical processes by applying the Dow Fire and Explosion Index to the use of a methyl isocyanate storage tank, also suggested that reducing the amount and pressure of hazardous materials reduced the index value (1). On the other hand, in this case study, the loss control credit factor due to the current state is 0.69. Merely by properly improving the drainage system, this factor will reduce from 0.69 to 0.64 and the most probable actual damage will reduce from \$2,863,500 to \$2,656,000 and lost work days will reduce from 64.56 to 60. Then, the total loss will be reduced to less than half of the current loss. Although the Dow index is not appropriate for process plants handling highly toxic substances, it is useful in this case where the major hazardous substance is Hexane with high flammability but low toxicity.

5. Conclusions

In summary, the findings showed the Dow Fire and Explosion Index is a suitable technique for measuring inconsistencies and it is also a criterion for measurement of the total hazards of a plant or of a part of the provided services. Functional significance of these findings is that, this criterion can provide guidelines for required changes or extend the protective equipment with respect to their effects in reducing the damage. The results of this method in the determination of losses, may also be considered as a basis for determining insurance coverage. Since the risk of fire and explosion in the process unit of this study was estimated to be unacceptable, considering the priority of reducing damage factors, several corrections were offered, such as modifying the drainage system, using an amber glass eye view, installation of hexane detectors, an automatic sprinkler system, fire detectors on the cable tray, and finally, using the water spray washing on the tanks. It might be more challenging to perform such a study in similar industries or in more complex industries where the amount of flammable materials is not accurately determined or where a large variety of material exists.

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Conflict of Interest:

There is no conflict of interest to be declared.

Authors' contributions:

All authors contributed to this project and article equally. All authors read and approved the final manuscript.

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