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Original

Improving the Results of Fire and Explosion Risk Assessment Method Using Fuzzy Logic in a Gas Refinery

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Abstract

Background: The occurrence of fire and explosion accidents in the process industries is accompanied by the gradual release of large amounts of energy. The DOW Index is one of the methods of evaluating fire and explosion in the process industries. The present study used the fuzzy logic method to improve the results of the fire and explosion risk analysis method and reduce their uncertainty (error in achieving the correct result). **Methods:** In the present cross-sectional study, having analyzed the gas separation process, the DOW index was applied to study high-risk equipment. Then, to optimize the behavior of the parameters affecting the DOW index, each weight parameter was assigned to between 0 and 1, and the membership functions of each degree of risk were determined based on the fuzzy rules classification system. The five selected linguistic variables based on membership functions were used to assess the risk level. **Results:** Considering butane, the level of fire and explosion risk was 231.3, which was less risky than the fuzzy logic result of 248.6. Methane risk was calculated according to the fire and explosion index of 262.1 while using fuzzy logic that was 265.6. The lowest risk difference was observed between the two methods for ethane (258.9 conventional method and 259.1 fuzzy method results). The risk level calculated by DOW for propane was 243.6, and the risk level was 255.1 while using fuzzy logic. **Conclusion:** Although both methods yielded a high degree of risk, fuzzy logic results indicated higher numerical values comparing to the conventional DOW method. Compared to the conventional DOW method, fuzzy logic results are closer to reality with higher confidence levels.

Keywords: Fire and explosion index; Risk assessment; DOW; Fuzzy logic; Process unit

Introduction

Although there are many benefits to producing basic and by-products in chemical processes, it also has some disadvantages, such as fire and explosion occurrence. The incidence of fire and explosion events in these processes is accompanied by the release of large amounts of energy gradually and suddenly.[1] Besides, fire and explosion hazards are the first and second significant hazards in process industries, respectively.[2] Process industry accidents occur due to leakage of flammable materials, mixing of chemicals with air and formation of flammable vapors (VCE), and vapor cloud access to the source of fire and explosion in process units.[3, 4] For instance, the oil explosion in Pasadena, Texas, happened in 1989, resulted in the death of 23 people and the wounding of more than 300 individuals.[5] In October 2005, in Mexico, a cloud of vapor created by a car collision with a pressurized pipeline at Formosa Plastic

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Manufacturing Company that killed and injured many people.[6] Failure to evaluate such risks can result in human casualties and losses in industrial and environmental units.[7, 8] To maintain the safety of the process industries, various methods of identifying, assessing, and controlling risks, that the DOW risk assessment index is one of them, were used.

This method uses risk factors concerning different materials and processes to determine the risk of fire and explosion step by step. The contribution of each component to the risk factors (as a penalty factor) of fire and explosion is calculated. Therefore, the DOW method is one of the high precision methods compared to other fire risk assessment method .[6, 8, 9] One of the previous studies with the DOW index conducted on fire and explosion risk assessment was done by Etawad et al. to determine the level of fire and explosion risk for methyl isocyanate storage tanks in Bhopal, India.[10] Gupta et al. also modified the effect of damage control factor on the ammonia reactor production unit to reduce the DOW explosion index using fire and explosion index guidance. The fire and explosion index of 0.8 was calculated with extreme and unacceptable risk.[11] Zarei carried out a study to assess the risk of fire and explosion at the ISO refinery unit of Tehran Refinery with the DOW fire and explosion index method and examined the effectiveness of control measures. In this study, high and low-pressure separator containers, catalytic converter reactor, distillation unit furnace, distillery feed warehouse, and distillation tower were at the high-risk, and the baking tower was at the medium-risk level.[12] Jafari et al.

used the latest version of the DOW fire and explosion index in 2008 to evaluate and calculate the fire and explosion of the ISO-Max process unit of an oil refinery. They identified essential subunits using parameters such as process pressure, temperature, and amount of material and then estimated the parameters that influenced the outcome of the fire and explosion. In the present study, it is concluded that the separator container had a higher risk comparing to other subunits due to the high pressure.[13] To reduce the uncertainty in conventional risk assessment methods such as DOW, fuzzy logic was proposed. Fuzzy logic is a theory of acting in uncertainty, and it can provide the basis for reasoning, inferencing, controlling, and decision making in uncertain situations.[14] The present study aimed to improve the fire and explosion risk assessment method using the fuzzy logic system in a gas refinery.

Methods

A cross-sectional study of a gas refinery was carried out in 2018. Gas refining includes desalination, dehydration, methane separation from liquefied natural gas (NGL), and methane compression for domestic use. Also, this process comprises the separation of ethane from NGL for petrochemical purposes, the separation of propane, and butane from NGL and their refining, in addition to gas condensate and sulfur separation and solidification. At the beginning of the study, several scenarios of hazardous processes were defined. Finally, using the HAZOP method, four worst-case scenarios were determined and analyzed to assess the risk of fire and explosion. These four scenarios included butane decontamination ray boiler defect, ethane tower flow control system defect, methane pressure control valve defect, and propane dehydration tower defect.

Fire and Explosion Index Calculation (F&EI)

Material Factor (MF), Process General Hazard Factor, and Process Specific Hazard Factor are among the factors affecting fire and explosion risk that are quantitatively evaluated in F&EI.

Material Factor Calculation

According to Table1, Material Factor (Material Flammability and Reactivity defined by NFPA[15]) was calculated according to the reactivity (N_R) and the degree of flammability (N_F) of the materials obtained through the hazardous loop.[16] Since the NF and NR values are used for operating temperatures of 60°C (140°F), temperature correction should be carried out if the temperature exceeds 60°C .[1]

Process General Hazard Factor (F1)

To calculate the process general hazard factor, the penalty factor for the heat and warming of chemical reaction, transfer and displacement of materials, encapsulated process units, access, and leakage control were determined at the beginning. Besides, the summation of them was calculated as F1.

Table 1. Determination of material factor for flammable gases

Combustibility of gases	N_F	N_R 0	1	2	3	4
Non-combustible	0	1	14	24	29	40
93.3°C<Flash point	1	4	14	24	29	40
37.8°C ≤Flash point≤ 93.3°C	2	10	14	24	29	40
22.8°C ≤Flashpoint<37.8°C 37.8 °C ≤Boiling point	3	16	16	24	29	40
Flashpoint<22.8°C Boiling point<37.8°C	4	21	21	24	29	40

Process Specific Risk Factor (F2)

Process Specific Risk Factor was obtained by summing the penalty factor of parameters such as toxic substances, low atmospheric pressure, operating flammable substances, dust explosion, discharge pressure, low temperatures, flammable materials, gases process fluids, leakage of connections, flame heaters, hot oil heat exchange system, and rotary equipment.

Process Unit Risk Factor (F3) Calculation

According to Equation 1, the Process Unit Risk Factor was obtained from the multiplication of general and specific risk factors.[15]

$$F3 = F1 \times F2 \quad (1)$$

Determination of fire and explosion index (F&EI)

This index was obtained by equation two by the multiplication of the unit risk factor in the material factor.[15, 17]

$$F\&EI = F3 \times MF \quad (2)$$

According to the DOW guideline, the minimum and maximum indices are 1 and 320, respectively, and their risk level is outlined in Table 2.[18, 11]

Fuzzy Logic

Membership functions define fuzzy logic. For each weighting parameter between 0 and 1, according to prior knowledge, expert opinions were obtained through either existing or collected data because not all parameters share equally in a set. The membership function of the set Y is as follows:

$$\mu_Y : X \rightarrow [0.1] \quad (3)$$

Also, the set Y is defined as Equations (4) and (5):

$$Y = \{(\mu_Y(X)).x \in X.\mu_Y(X) \in [0.1]\} \quad (4)$$

OR

$$\mu_Y \begin{Bmatrix} = 1 & x\ is\ full\ member\ of\ Y \\ \in (0.1)) & x\ is\ partial\ member\ of\ Y \\ = 1 & x\ is\ full\ member\ of\ Y \end{Bmatrix} \quad (5)$$

The function of the functions is also presented in the equations of (6) and (7):

Triangular membership function:

$$f(x: a.b.c) = max\left(min\left(\frac{x-a}{b-a}.\frac{c-x}{c-b}\right).0\right) \quad (6)$$

Trapezoidal membership function:

$$f(x: a.b.c.d) = max\left(min\left(\frac{x-a}{b-a}.1.\frac{d-x}{d-c}\right).0\right) \quad (7)$$

Finally, the membership functions of the parameters involved in the fire and explosion index, such as penalty factors, were classified according to fuzzy rules.

Results

The parameters affecting the F&EI index are given in Table 3, and the parameters such as hot oil heat exchanger and pressure lower than atmospheric pressure are ignored. According to Table 3, the general process hazard penalties such as control and drainage, confinement and pressurization of equipment, and access to equipment were the same for all scenarios concerning the design of the separation unit and the gas liquefaction extraction of the refinery. The specific process hazards vary according to the pressure, temperature, and amount of flammable material in each scenario (in kg) for each of the process equipment, causing a difference in the fire and explosion risk index.

As shown in Figure 1, the membership functions of each degree of risk in Table 5 were determined based on the fuzzy rule classification system. The linguistic variables were selected over 50% based on the membership functions of Table 4. Linguistic variables, including " Light, "Moderate, "Intermediate, "Heavy," and " Severe " were classified based on triangular and trapezoidal membership functions.

Table 2. Hazard ratings

Degree of hazard	F&EI Index range
Light	1-60
Moderate	61-96
Intermediate	97-127
Heavy	128-158
Severe	159<

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Table 3. The values of the parameters involved in the fire and explosion index

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
General process hazard penalties (F1)	Penalty factors			
Base Factor	1	1	1	1
Enclosed or internal process units	0.45	0.45	0.45	0.45
access	0.35	0.35	0.35	0.35
Drainage and leakage control	0.5	0.5	0.5	0.5
Calculation of General Process Factor (F1)	2.3	2.3	2.3	2.3
Special process hazard penalties (F2)	Penalty factors			
Base Factor	1	1	1	1
Toxic substances	0.2	0.2	0.2	0.2
Operations close to the ignition range	0.8	0.8	0.8	0.8
Operating pressure (psig or kpa)	0.35	0.56	0.63	0.54
Amount of flammable/volatile Substances (kg)	0.6	0.8	0.85	0.5
Joints leakage	1.5	1.5	1.5	1.5
Rotating equipment	0.5	0.5	0.5	0.5
Special process hazard factor	4.95	5.36	5.48	5.04
Process hazard penalty factor	F3			
F1 × F2 = F3	11.38	12.33	12.6	11.6
Fire and explosion index	F&EI			
F&EI =F3 × MF	231.3	258.9	262.1	243.6

Table 4. F&EI membership functions

F&EI	Degree of hazard	Membership functions	Normalized membership functions
1-60	Light	[0 0 30 78]	[0 0 0.17 0.43]
61-96	Moderate	[30 78 111.5]	[0.17 0.43 0.62]
97-127	Intermediate	[111.5 142.5 159]	[0.43 0.62 0.72]
128-158	Heavy	[111.5 142.5 159]	[0.62 0.79 0.88]
159<	Severe	[142.5 159 180 180]	[0.79 0.88 1 1]

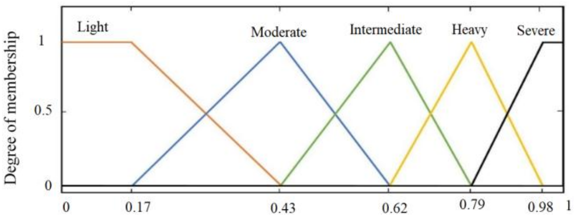

Figure 1. Range of Fire and Explosion Index Risk Level (F&EI)

Table 5. The characteristics of gas stream constituents and their material factor

MF	NR	NH	NF	MF
Butane	0	1	4	21
Ethan	0	1	4	21
Methane	0	1	4	21
Propane	0	1	4	21

Table 6. F&EI Risk Assessment and fuzzy Logic Results.

Chemical	F&EI	Risk level	Fuzzy	Risk level
Butane	231.3	Severe	248.6	Severe
Ethan	258.9	Severe	259.1	Severe
Methane	262.1	Severe	265.6	Severe
Propane	243.6	Severe	255.1	Severe

According to NFPA classification, the degree of flammability and hygiene for the main components of the gas flow were 4 and 1, respectively, in the extraction and separation unit of natural gas liquids (Table 5). Also, their reactivity was zero in these units. According to Table 1, the material factor was calculated as 21 for the same degree of flammability and reactivity of butane, methane, ethane, and propane materials.

The level of fire and explosion risk was calculated for the butane, ethane, methane, and propane chemicals using the F&EI method and the fuzzy logic algorithm, as shown in Table 6. Risk values were calculated using fuzzy logic for all four chemicals that were higher than the risk values obtained using F&EI. In both methods, the degree of methane risk, which was 262.1, according to the fire and explosion index and was 265.6 for fuzzy logic, was higher than the other gases. In contrast, the lowest degree of risk was related to butane (231.3 for fire and explosion index, and 248.6 for fuzzy logic).

Discussion

In this study, the fire and explosion risk levels were obtained as "very high" using the proposed algorithm and the F&EI index for butane, methane, ethane, and propane. However, it is worth noting that the values

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obtained with the proposed algorithm are higher than the F&EI index, which illustrates the difference in numerical quantification of fire and explosion risk using the two methods mentioned above. Numeric risk values can be used to prioritize safety, corrective, and preventive measures. The most important parameters influencing the defect of the methane desiccant control valve were the operating pressure and the amount of discharge regulating pressure, drainage and leakage control, the amount of flammable material produced in the processing unit, and leakage of seals. The values of these parameters in the separation and extraction unit were higher than those in other scenarios.

Abel Pinto et al. described risk assessment as complicated because of the need to consider different parameters. Therefore, using qualitative risk assessment is not sufficient for eliminating ambiguities. Thus, quantitative risk assessment and the use of fuzzy logic to overcome uncertainty is evident.[19] The results of the present study also improved the results of the quantitative method by using fuzzy logic. It also reduced the uncertainty in the results. Feed gas K.O DRUM unit fire and explosion index in Mehrshad's study was calculated as 235.62, which is lower than the results of the proposed algorithm.

The most critical parameters affecting methane gas include operating and discharge regulating pressure, drainage, leakage control, the amount of flammable material in a processing unit, leakage of fittings, and seals that exceed the above parameters in separation and gas extraction units in comparison with methyl isocyanate. Besides, the parameters mentioned in the results of the gas refinery were in line with the results of the study conducted by Jafari et al.[13] The results of the studies of Suardin, Etowa, and Hendershot identified the process risk factor as the most critical factor in the value of the fire and explosion index,[10, 16] which is consistent with the results of the proposed algorithm in this study and its impact on the process risk factor. In previous studies, fire and explosion risk assessment was performed using only the provided quantitative data sheets and indices, and no investigation was conducted in the field of risk assessment using the fuzzy algorithm. Previously presented quantitative indices, in addition to spending too much time on the results, are often uncertain due to the computational complexity of most of their final answers. Therefore, using fuzzy logic is an excellent way to reduce errors and computational time. Furthermore, the results provided are closer to reality and more subtle. In the present study, four worst-case scenarios were evaluated among the scenarios identified by the HAZOP method. Since studying all scenarios requires many expenses, further scenarios should be taken into consideration in future studies.

Conclusion

The results of the fire and explosion index calculations showed severe risk values. These results were repeated in fuzzy logic with greater confidence. The present study tries to minimize the computational error and provides the results which are closer to reality using the proposed algorithm. As the results show, this algorithm is a more suitable tool for fire and explosion risk assessment in comparison with the F&EI index.

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