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An investigation into DOW and MOND indices with fuzzy logic based on fire and explosion risk assessment in Iran oil refinery

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ABSTRACT

With regard to a study on accidents in chemical industries, approximately 2.3 percent of the damage is related to explosion. The explosions happen in no time and there will be no opportunity to avoid them, therefore, explosion damage is more than fire damage. Fire and explosion risks always exist in gas and oil industries. The present paper intends to assess fie, explosion, and toxicity risks based on MOND and DOW indices, and then compare the indices with each other regarding fuzzy logic. The last version of fire, explosion, and toxicity index introduction was used in the process subunits in northern Iso- max unit of Tehran oil refinery. The important process subunits in northern Iso-max unit were recognized based on process effective factors such as pressure, temperature, and value of the materials. In the next step, factors affecting fire, explosion and toxicity index (TF& EI) were recognized and estimated. Moreover, (TF& EI) index was calculated for each subunit, and then time duration and real rate of damage and their effects were studied. The results indicated that 6 subunits out of 8 had high fire, explosion and toxicity degree of risk. One of the subunits had high and the other had medium degree of risk. 2V432 catalytic conversion reactor is the most important subunit of northern Iso- max unit; it has the highest rank of fire, explosion, and toxicity risk; its fire risk equals 232.4 and its toxicity risk equals 49.3. 2H432 reactor feed heater with 124.8 degree of fire risk and 7.2 degree of toxicity risk has the minimum fire risk and the medium toxicity risk, respectively. The research shows that fire, explosion and toxicity index is a proper method to determine the most and least hazardous points of an industry. Catalytic conversion reactor is the most critical unit regarding fire, explosion, and toxicity.

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1.Introduction

Since 18[th] century and at the time of industrial revolution, issues related to safety, health and environment in industries found an important position. In between, fire and issues associated with preventing it drew attentions to themselves. Furthermore, development of industries ,variety of chemicals, variety of products, and exploiting exothermic processes increased fires and explosions. Releasing inflammable gases and liquids from over-thermal equipment and hot surfaces, defect in electrical equipment of pipelines, welding, and cutting are the main factors that lead to fire in the chemical industries. Moreover, undesirable control of chemical reactions, explosion of the fuels within the equipment, non- restricted vapor clouds, pressure increase, and matters analysis are the main causes of explosions in chemical industries[18]. Fire and explosion damage is mainly caused by thermal radiations, throwing parts of the equipment to a far distance, and beating waves. With regard to the development of oil industries during the recent years, variety of chemicals and products, and exploiting different exothermic processes, it has been more important to prevent damage caused by fire and explosion. Moreover, studies indicated that majority of the disastrous fires and explosions have happened for the first time, therefore, it is necessary to exploit new safe methods to prevent them. Techniques of risk assessment are one of the new and safe methods; applying this method helps to estimate fire and explosion potentials as well as their consequences[18].

The statistics show that approximately 75 to 80 percent of fires are predictable and preventable. Annually, fires and explosions in large and small industries bring about individual, environmental, and property damage for different societies. In Iran, annually, around 1400 people are killed and over 4500 people are injured as a result of fires occurrence. Moreover, the fires bring about damage equal to 450 milliard rials for the society (the office of social and economic statistics and calculations, 2004). In 4[th] of November, 1966, release of propane made an explosion in a France refinery that killed 18 people. In 1968, overflow of hydrocarbon made a small explosion in one of the operating units of oil refinery in Netherlands (city of Pernice) that resulted in the explosion of other sections of the refinery. Consequently, 2 people were killed and 85 people were injured [3].

In an oil refinery located in Texas, increase of pressure in one of the liquid gas reservoirs made a horrible fire in 1978 that killed 7 people and injured 11 people. In an oil refinery located in Mexico City, an explosion occurred in 1984 November as a result of loading in the central reservoir of the liquid gas. The explosion led to destruction of all the unit foundation and absolute destruction of 200 homes around the company. As a result, 542 people were killed and 4248 people were injured [2].In 6th of October, 2005 a cloud of inflammable vapours was ignited and made a huge explosion in Formosa plastic making company in Mexican gulf. The explosion was resulted from a collision between a vehicle and the pipe under pressure including propylene. The flames resulted from the fire went up to the height of 150 meters. It destroyed a producing unit and its explosion wave killed and injured some people. Research committee declared that the explosion occurred in Olefin unit2 that changed oil into propylene and ethylene via natural gas heaters. The research paid attention to the design of the unit and how to prevent fires[9].Prandson (2001) used DOW hazards index in order to recognize toxic and chemical hazards in an industrial unit. Jeff Sardine (2003) and Sam Mennen (2003) performed Dow fire and explosion index integration in order to design the process and optimized inherently safe design via layers of protection (LOP)[15]. Sam Mennen (2003) calculated DOW fire and explosion index value in order to measure credit and loss of the industries. Tilver , B. J. (2004) used MOND index to measure inherent hazards[13].

2.Main body

Rey refinery complex which is called Tehran refinery includes the 1st and the 2nd refineries; moreover, it is a complex for oil production and refinement. The first refinery is associated with need of Iran market for providing domestic and industrial fuels as well as car petrol. In the 22th of October 1965, the contract of design and construction of the refinery was made between Iran oil national company of construction and engineering office and a contracting group, then its design and construction was started. In 21st of April 1968, the refinery was founded with oil production capacity of 85000 barrels a day [20]. The 2nd refinery was supposed to increase consumption and provide needs of the domestic market; it began its activity with the 1st refinery simultaneously. The first refinery had the required utilities and enough empty space, however, the 2nd refinery was constructed after addressing defects of the 1st refinery. The construction of the 2nd refinery began from the late 1971 and finished in the early 1973, it began its activity with oil production capacity of 100000 barrels a day. Petroleum resources of Ahvaz provided the needed petroleum for these refineries. The purpose of designing and selecting each purification device was to maximize production of distillation products such as oil and kerosene. To achieve this purpose, conversion technique was applied. The northern Iso-max unit of Tehran refinery with a feed equal to 14400 barrels a day has been designed by Chervon Company. It is supposed to convert gas oil of distillation unit into gasoline, kerosene, butane, heavy naphtha, light naphtha, and lighter gases; all these conversions are done via unified reactors and next to the catalyst[20].

As a result of materials flammability and reactivity, high temperature, operating pressure, volatility, liquids evaporation and making a cloud of explosive and flammable vapours, fire and explosion risk is very important in chemical industries especially oil and petroleum industries. Therefore, fire and explosion are respectively the first and second risks in the mentioned industries. Though explosion has more damage, fire is taken more seriously as a result of being more common. There are different techniques to analyze fire and explosion risk in chemical industries[2]. Fire and explosion index is one of the risk indices developed during the recent two decades. It is a fairly simple and complete method that calculates overall risk of process units. Its execution does not need a high level of expertise and accurate information and results could be easily interpreted by using numerical values[2].

Herbert Dow founded Dow Company in 1890. For the first time, fire and explosion index has been represented by Dow chemical company. In the past 29 years, the index has developed and via which relative risk of process units has been formed to decrease fire and explosion potential. From 1964 to 1994, index guide has faced some changes; finally, American institute of chemical engineers (AICHE) published the last reviewed version of the guide in 1994. Fire and explosion index is a kind of fire and explosion risk analysis that includes a systematic assessment of fire and explosion potential, process equipment reactivity and materials available in them. The system is generally used for operations in which the processed materials are flammable and reactive. Moreover, majority of safety analyses are qualitative and a method that could relate process arameters to safety is rarely accessible. Therefore, the presented methods and equations in this index facilitate process safety analysis via making a relation between safety and operating parameters. I this method, safety (fire and explosion risk) is a function of operating parameters[2,3].

3.Methodology

It is a descriptive research which is done based on survey method. Field and library methods are used to collect the required data and relevant tools such as observation, interview, questionnaire and other relevant forms are also used.

Research hypotheses

1. There is the perpetual risk of fire and explosion in oil refineries, however, it is not controlled and decreased properly.
2. Engineering and managing factors play an important role in increasing fire and explosion accidents.
3. Rate of fire and explosion in oil refineries is increasing.
4. Fire and explosion index is not correctly investigated in oil refineries.

DOW index calculation stages

1. Choosing the important company regarding fire and explosion
2. Determining value of the hazardous materials and investigation their flammability and reactivity
3. Investigation the previous events such as fire and explosion

4. Investigating previous risk assessments such as HAZOP study in order to determine unacceptable risk points
5. Investigating operating pressure and temperature
6. Determining the location under study
7. Date of index calculation
8. Name of the company
9. Names of the assessing group members
10. Names of the review group members, if the index was previously calculated
11. Describing the assessed process unit
12. Determining exploiting state
13. Materials used by the process unit
14. Determining the main material based on which the index is calculated
15. Calculation of material factor
16. Calculating general process hazard (GPH)
17. Calculation of special process hazard (SPH)
18. Calculation of process unit hazard (PUH)
19. Calculation of DOW fire and explosion index
20. Calculation of ranking of hazard
21. Calculation of loss control credit factor
22. Determining radius of exposure
23. Determining value of the area of exposure
24. Determining damage factor
25. Determining base maximum probable property damage (MPPD)
26. Determining actual maximum probable property damage
27. Determining maximum probable days outage (MPDO)
28. Determining business interruption damage (BI)

3.1.Operating instructions/ procedures

Providing documented instructions and procedures is an important part of desirable process control of a unit. Such instructions are needed in order to do different processes such as setting up, emergency shutdown, protecting, and normal operating condition safely. Based on the type of instruction and its level of significance in process controlling, credit factor of this section will be determined. Credit factor limit is between 0.91 and 0.99. For each of the instructions, a special credit factor which is obtained after doing the needed calculations is considered as follows:

- Setting up: 0.5
- Routine production stop: 0.5
- Normal condition for exploiting: 0.5
- Turndown operating condition: 0.5
- Readiness in service condition: 0.5
- Conditions upper than the defined capacity: 1.00
- Company resetting up a short period of time after operation stop: 1.00
- Company resetting up a short period of time after repairing and protecting: 1.00
- Repairing and protecting instruction: 1.5
- Operation stop in emergency conditions: 1.5
- The instruction to add and improve pipelines and equipment at the time of presenting new designs: 2.00
- Defect prediction instruction in abnormal conditions: 3.00

Credit factor is calculated after determining the credit factors, summing up them and following the below formula:

1.00 – (X/150)

If the company has all instructions thoroughly, credit factor will be equal to:

1.00 – (13.5)/150 = 0.91

Reactive chemical review

Review of programs in which chemicals are shifted, saved, changed in the process unit, made in the process unit, or enter the process are considered as important factors. If programs are completely performed, credit factor will be equal to 0.91; otherwise, it will be equal to 0.98. Credit factor limit varies between 0.91 and 0.98.

Other process hazards analysis

If process risk analysis program is a logical component of plant operation, control and prevention of process risks are properly performed. Moreover, each of the risk analysis techniques assesses different risks regarding risk analysis performance mechanism and has a different level of significance. According to DOW guide, the techniques have a credit factor varying between 0.91 and 0.98 based on their importance in risk analysis and process control.

- Quantitative risk assessment: 0.91
- Detailed consequence analysis: 0.93
- Fault tree analysis: 0.93
- Hazard operability study (HAZOP): 0.94
- Failure mode & effect analysis: 0.94
- Environment, health, safety, and loss prevention reviews: 0.96
- What if study : 0.98
- Check list evaluations: 0.98
- Management of change review: 0.98

The basis of fuzzy logic mathematics is derived from the theory of fuzzy sets. The theory of fuzzy sets is a generalized form of classic set theory. It is useful to get familiar with new opinions, symbols and operators of fuzzy sets to understand the principles and applications of them. The fuzziness is the characteristic of a communicating language and its main source is the inaccuracy present in definitions and use of symbols. For instance, consider a set of chairs in a room, according to the theory of sets, considering the objects in the room, the set of chairs is formed by determining the responses to the question whether the object is a chair or not. In the theory of classic sets, one is allowed to use two responses: yes, no. lets codify 1 as yes and 0 as no, therefore, the responses are limited in a set with two members {0, 1}. If the response is 1, the element will belong to the set and if the response is 0, the element will not belong to the set. At the end, by summing up all the objects labeled as 1, the set of available chairs in the room will be determined. Now, imagine the question is change in this way, “which objects in the room could have a performance similar to a chair?” For the second time the question “is it possible to use the object as a chair? “is asked about each of objects in the room. Arbitrarily, the response to this question is limited to a set with two members {0, 1}. In this condition, not only chairs but also objects such as tables, boxes, and a part of room floor that have a performance similar to a chair are included in the set[8]. Such a set is not exclusively defined; its definition depends on our purpose to mention the word "performance". Words such as performance have many meanings and they could be used in different situations. The meaning of these words and using them might be different regarding the difference in individuals, environmental conditions, goals and intentions that depend on specifications of each special situation. With regard to what was mentioned, it is possible to say that a set of objects in a room that have a performance similar to a chair make a fuzzy set. In fact, the characteristics needed for belonging to a fuzzy set are not clearly defined[11]. Objects such as tables and boxes have a performance similar to a chair; however, they are not inherently fuzzy. In fact, the characteristic of having a performance similar to a chair is considered as a fuzzy characteristic, this characteristic is indicated based on a set of symbols. Usually, being fuzzy is one of the characteristics of patterns, computational procedures and spoken language[7,8].

4.Discussion and results

After getting familiar with the production process of Iso-max unit of Tehran refinery, investigating process equipment of Iso-max unit with regard to parameters such as pressure, temperature, reactivity, materials, hazardous matters, and consulting with unit officials, 8 process units were determined as important process units regarding fire and explosion. Table 1 indicates a list of important process units. Results of analyzing DOW fire and explosion index have been presented regarding each of the mentioned eight process units. In order to execute system of DOW fire and explosion index in the eight process units, it is needed to study operating condition and type of materials for each of them. In the next stage, material factor is determined and corrected if needed. Moreover, fire and explosion index related to the mentioned process units is investigated with regard to general and special risks of the process. Finally, control factor of each unit and other factors related to this index will be investigated[4,17].

Table 1: the list of important process units regarding fire and explosion risk and operating condition

Operating pressure (pound per square inch)	Operating temperature (centigrade)	Code of the process unit	Process unit	Row
2497	389	2H-432	Reactor feed heater	1
2498	444	2V-432	Catalytic reactor heater	2
2500	60	2V-433-(H.P.S)	High Pressure Separator	3
500	60	2V-436-(L.P.S)	Low Pressure Separator	4
80	205	2V-437	Recycle Splitter Feed Flash Drum	5
30	388	2H-433	Heater of distillation section	6
28	374	2V-439	Recycle Splitter	7
25	260	2V-444	Diesel Stripper	8

In order to determine the material factor, it is needed to determine chemical and physical information within each of the process units. The following tables show chemicals available in each process unit as well as materials properties within each Iso-max unit

Table 2: chemicals available in Iso-max under study units

Hydrogen sulfide	LPG	Ethane	Methane	Diesel	kerosene	Gasoline	Gas oil	Hydrogen	combinations process unit
-	-	-	-	-	-	-		-	Reactor feed heater
-	✓	✓	✓	✓	✓	✓	-	✓	Catalytic conversion reactor
-	✓	✓	✓	✓	✓	✓	-	✓	High pressure separator
-	✓	✓	✓	✓	✓	✓	-	✓	Low pressure separator
-	✓	✓	✓	✓	✓	✓	-	✓	Recycle splitter feed flash drum
✓	✓	✓	✓	✓	✓	✓	-	✓	Heater of distillation section
-	✓	-	-	✓	✓	✓	-	-	Recycle splitter
-	-	-	-	✓	-	-	-	-	Diesel stripper

Table 3: physical and chemical properties of materials in process units

MF	IT(c)	BP©	FP(c)	NR	NH	NF	Combinations
21	500	-252	gas	0	0	4	Hydrogen
10	257	166	56	0	1	2	Gas oil
16	420	121	-42	0	1	3	Gasoline
10	210	115	۴۳	0	1	2	Kerosene
10	257	157	55-38	0	0	2	Diesel
21	537	-162	<38	0	1	4	Methane
21	472	-89	<38	0	1	4	Ethane
21	468	-43	<38	0	1	4	LPG
21	450	-76	gas	0	4	4	Hydrogen sulfate

4.1.Reactor feed heater (2H-432)

Reactor feed heater that includes fresh and circulating gas oil (Isofid) is provided by 2P-431 A pumps, and then after the primary heating and thermal exchange in convertor 432, it enters the heater. Operating temperature of the heater equals 389 degree of centigrade and its operating pressure equals 2500 pound per square inch. After heating the feed in the heater tubes, the feed enters the convertor 432 and is mixed with the hydrogen which is purified up to 98 percent by the hydrogen storage section and compressors 401. In the next stage, it enters since gas oil has filled all the heater tubes, only properties of gas oil should be determined to calculate material factor. Material factor for reactor heater is determined 10 with regard to degree of flammability (N_F =2), and degree of reactivity (N_R = 0) of the gas oil as well as the table of a guide to determine material factor of DOW fire and explosion index. The material factor is for condition of environmental temperature equal to 60 degree of centigrade. Since risk of material reactivity and inflammability changes with increase of temperature, material factor for temperature condition of the heater (operating temperature of the heater equals 389 degree of centigrade) will be corrected if needed[20].

Table 4: temperature correction of material factor in Iso-max (AICHE, 1994)

NR	NF	Temperature correction of material factor
0	2	1. Enter degree of reactivity and flammability
		2. Send it to row 5, if operating temperature of process unit is less than 60 degree of centigrade
	1	3. Enter number 1 under Nf, if operating temperature is higher than material ignition point
1		4. Enter number 1 under Nr, if operating temperature is higher than material flammability temperature
1	3	5. Sum up the column numbers. If the summation of each column equals 5, enter number 4
16		Factor of corrected materials

Operating temperature of the heater (389 degree of centigrade) is higher than inflammation point and gas oil self- burning point. Therefore, number 1 is added to flammability and reactivity degrees. As a result, the corrected material factor of reactor heater equals 16. With regard to temperature condition higher than 60 degree of centigrade in process units under investigation, the results of tables 4 and 5 are used for all factors except for the high and low pressure separators and the need for correcting their material factors.

Table 5: temperature correction of material factor in Iso-max

Diesel stripper		Recycle splitter		Heater of distillation section		Recycle splitter feed flash drum		Lowpressure separator		Highpressure separator		Catalytic conversion reactor		Reactor feed heater		Temperature correction of material factor
NR	NF	NR	NF	NR	NF	NR	NF	NR	NF	NR	NF	NR	NF	NR	NF	
0	2	0	4	0	4	0	4	0	4	0	4	0	4	0	2	Enter reactivity and flammability degrees
																If operating temperature of process unit is less than 60 degree of centigrade, send it to row 5
	1		1		1		1		-		-		1		1	Enter number 1 under Nf, if operating temperature is higher than material ignition point
1		0		0		1		-		-		1		1		Enter number 1 under Nr, if operating temperature is higher than material flammability temperature
1	3	1	4	1	4	1	4	0	4	0	4	0	4	1	3	Sum up the column numbers. If the summation of each column equals 5, enter number 4
16		21		21		21		21		21		21		16		Factor of corrected materials

4.2.Determination of general and special risks

General and special risks of the process are other important factors needed to calculate DOW index. Since general and special risks make fire and explosion risk, DOW guide has presented a numerical limit called penalty factor. After investigating the conditions and considering the effective factors, the special penalty for each process is selected and its results are presented in table6.

Table 6: determining fire and explosion index based on material factor, general and special risks of the process in reactor feed heater 2H-432 (AICHE, 1994)

Process unit: reactor feed heater 2H-432	Producing unit: Iso-max	Location: Tehran refinery
The main materials to determine material factor: gas oil	Process unit materials: gas oil	Operating condition: normal
Operating temperature: 489(C)	Corrected material factor: 16	Material factor: 10
Date :	Reviewer : Doctor Lavasani	Producer: Masoud Mardani
The selected penalty factor	Limit of penalty factor	General risks of the process
1	1	The basic factor
0	0/30-1/25	Exothermic chemical reactions
0	0/20-0/40	Endothermic processes
0	0/۲۵-۱/05	Material storage, transition, and displacement
0	0/۲۵-0/90	Internal or restricted units
0	0/20-0/35	Access
0.5	0/25-0/50	Drainage and leakage control
1.5		General risks of the process
		Special risks of the process
1	1	The basic factor
0.2	0/20-0/80	Toxic materials
0	0/50	(<۵۰۰ mmHg)Pressure less than atmosphere
0	0/30-0/80	Operation close to the area of flammable material
0	0/50	The area of reservoirs for keeping flammable liquids
0	0/30	The process which is flammable at the time a functional defect exists
0	0/80	Constant presence of flammable area
0	0/25-2/00	Dust explosion
1.2	0/16-1/50	Drain pressure, operation pressure based on kpa or psig"2500 Regulating drain pressure based on kpa or psig

Table 7: scoring results of MOND index in catalytic conversion reactor

MOND index / Scoring	Material factor B	Special risks of the process M	General risks of the process P	Special risks of the process S	Value of risks K		Material area risks L			Toxicity risks T
					K	Q	L	H	N	
EX_1	21	875	60	1205	62	1000	260	20.18	9.4	220.1
EX_2	21	800	40	1005	62	1000	300	20.18	9.4	220.1
EX_3	21	775	60	1165	62	1000	250	20.18	9.4	220.1

According to the following formula, DOW/ICI fire index, D is obtained:

(1)
$$D = B \times \left(1 + \frac{M}{100}\right)\left(1 + \frac{P}{100}\right)\left(1 + \frac{S + Q + L}{100} + \frac{T}{400}\right)$$

Fire index (F):

Fire index is related to value of flammable materials in the unit, their released potential, and unit location. It is obtained based on the following formula:

(2)
$$F = B \times \frac{K}{N} \times 215$$

Internal explosion index (E) is a criterion for probability of an explosion occurrence in a unit which is calculated based on the following formula:

(3)
$$E = 1 + \frac{M + P + S}{100}$$

Air explosion index (A)

Air explosion index is related to the value of vapour explosion resulted from releasing flammable materials. The materials are present in the unit as a liquid and at the temperature higher than atmospheric boiling point. The index includes qualitative and quantitative factors and is calculated based on the following formula:

(4)
$$A = B \times \left(1 + \frac{m}{100}\right) \times \frac{Q \times H \times E}{1000} \times \frac{t}{300} \times (1 + p)$$

The overall risk is used to compare the unit with all kinds of risks and its formula is obtained as follows:

(5)
$$R = D\left(1 + \frac{\sqrt{F \times U \times E \times A}}{10^3}\right)$$

Toxicity index of unit (U): it is obtained from multiplying internal explosion by hygienic risks factor:

(6)
$$U = \frac{T}{100} \times E$$

Table 8: indicates results of the above formulas calculations

Table 8: form of MOND risk analysis in catalytic conversion reactor 2V-432

Overall risk rank (R)	Unit toxicity index (U)	Air explosion index (A)	Internal unit explosion index (E)	Fire load (F)	explosion index	Material factor B	Main materials	Characteristic of the responding individuals			Ranking the respondents
								Job experien	Educated	Age	
103748203	49.3	4121409	22.4	29779.7	9810.72	21		7	BA	27	EX_1
48298378	42.8	2220287	19.45	29779.7	6509.2	21		5	MA	32	EX_2
75635359	46.2	3467532	21	29779.7	7555.8	21		35	Diploma	59	EX_3

With regard to the scoring tables, risk rating was done for catalytic conversion reactor 2V-432, the results indicated that DOW/ICI fire and explosion index was disastrous, fire load was disastrous, radius of the explosion are was very high, air explosion index was severe, unit toxicity index was severe, and generally risk rating was very high .tables 9 to 14 indicates summary of MOND results with regard to the experts' opinions. Tables 15 to 18 indicate summary of analysis of MOND fire, explosion, and toxicity risk analysis[5,6].

Table 9: MOND results based on the experts' opinion in diesel stripper 2V-444

MOND index / Scoring	Material factor B	Special risks of the process M	General risks of the process P	Special risks of the process S	Value of risks K		Material area risks L			Toxicity risks T
					K	Q	L	H	N	
EX_1	16	150	40	225	11.25	200	70	12	8.2	55
EX_2	16	160	45	244	11.25	200	80	12	8.2	50
EX_3	16	160	50	185	11.25	200	75	12	8.2	50

Table 10: MOND results based on the experts' opinion in recycle splitter feed flash drum 2V-437

MOND index / Scoring	Toxicity risks T	Material area risks N	Material area risks H	Material area risks L	Value of risks Q	Value of risks K	Special risks of the process S	General risks of the process P	Special risks of the process M	Material factor B
EX_1	100	6.2	8.53	90	400	11.25	370	60	430	21
EX_2	100	6.2	8.53	90	400	11.25	325	45	375	21
EX_3	100	6.2	8.53	75	400	11.25	305	35	355	21

Table 11: MOND results based on the experts' opinion in low pressure separator 2V-436

MOND index / Scoring	Toxicity risks T	Material area risks N	Material area risks H	Material area risks L	Value of risks Q	Value of risks K	Special risks of the process S	General risks of the process P	Special risks of the process M	Material factor B
EX_1	70.1	9.2	10	60	300	15	190	55	355	21
EX_2	70.1	9.2	10	40	300	15	205	60	345	21
EX_3	70.1	9.2	10	50	300	15	190	45	335	21

Table 12: MOND results based on the experts' opinion in low reactor feed heater 2H-432

MOND index / Scoring	Toxicity risks T	Material area risks N	Material area risks H	Material area risks L	Value of risks Q	Value of risks K	Special risks of the process S	General risks of the process P	Special risks of the process M	Material factor B
EX_1	95	9.04	12	150	500	18.75	445	70	145	16
EX_2	90	9.04	12	150	500	18.75	430	50	125	16
EX_3	90	9.04	12	150	500	18.75	410	50	155	16

Table 13: MOND results based on the experts' opinion in heater of distillation section 2H-433

MOND index / Scoring	Toxicity risks T	Material area risks N	Material area risks H	Material area risks L	Value of risks Q	Value of risks K	Special risks of the process S	General risks of the process P	Special risks of the process M	Material factor B
EX_1	60.1	9.04	11	80	400	18	175	45	400	21
EX_2	73.1	9.04	11	90	400	18	185	45	390	21
EX_3	85	9.04	11	100	400	18	190	35	455	21

Table 14: MOND results based on the experts' opinion in recycle splitter 2V-439

MOND index / Scoring	Toxicity risks T	Material area risks N	Material area risks H	Material area risks L	Value of risks Q	Value of risks K	Special risks of the process S	General risks of the process P	Special risks of the process M	Material factor B
EX_1	90	22.8	34.4	100	600	37.5	200	70	490	21
EX_2	90	22.8	34.4	130	600	37.5	145	45	425	21
EX_3	90	22.8	34.4	105	600	37.5	155	70	485	21

Table 15: form of MOND fire, explosion, toxicity risk analysis in diesel stripper 2V-444

Ranking the respondents	Overall risk rank (R)	Unit toxicity index (U)	Air explosion index (A)	Internal unit explosion index (E)	Fire load (F)	Fire and explosion index (DOW/ICI)	Material factor B	Main materials	Characteristic of the responding individuals: Job experience	Educated	Age
EX_1	5786.2	2.83	3709.4	5.15	4719.5	340.9	16	Diesel	12	BA	30
EX_2	6880.7	2.74	4034.1	5.49	4719.5	383.9	16	Diesel	8	MA	32
EX_3	5915	2.47	4032.7	4.59	4719.5	357.2	16	Diesel	35	Diploma	59

Table 16: form of MOND fire, explosion, and toxicity risk analysis in recycle splitter feed flash 2V-437

Ranking the respondents	Age	Educated	Job experience	Main materials	Material factor B	Fire and explosion index (DOW/ICI)	Fire load (F)	Internal unit explosion index (E)	Air explosion index (A)	Unit toxicity index (U)	Overall risk rank (R)
EX_1	30	BA	12		21	1754	8192	9.6	733787	9.6	414616
EX_2	32	MA	8		21	1359	48192	8.45	43656	8.45	218525
EX_3	59	Diploma	35		21	1167.3	8192	7.95	30790	7.95	148550

Table 17: form of MOND fire, explosion, and toxicity risk analysis in catalytic conversion reactor 2V-432

Ranking the respondents	Age	Educated	Job experience	Main materials	Material factor B	Fire and explosion index (DOW/ICI)	Fire load (F)	Internal unit explosion index (E)	Air explosion index (A)	Unit toxicity index (U)	Overall risk rank (R)
EX_1	30	BA	12		21	9810.72	29779.7	22.4	4121409	49.3	103748203
EX_2	32	MA	8		21	6509.2	29779.7	19.45	2220287	42.8	48298378
EX_3	59	Diploma	35		21	7555.8	29779.7	21	3467532	46.2	75635359

Table 18: form of MOND fire, explosion, and toxicity risk analysis in high pressure separator 2V-433

Ranking the respondents	Age	Educated	Job experienc	Main materials	Material factor B	Fire and explosion index (DOW/ICI)	Fire load (F)	Internal unit explosion index (E)	Air explosion index (A)	Unit toxicity index (U)	Overall risk rank (R)
EX_1	30	BA	12		21	3743.3	14389	15.7	172325.9	9.4	2268173.6
EX_2	32	MA	8		21	603.7	14389	15.1	192740.9	9.5	311383.3
EX_3	59	Diploma	35		21	3247.9	14389	14.8	132307.5	8.8	1620517.3

Results of the risk assessment have been explained with regard to DOW fire and explosion index, and MOND fire, explosion, and toxicity index. First, fuzzy logic is presented and its analytic model is explained. Moreover, it is mentioned how to make fuzzy fire indices.

DOW fuzzy modeling index

With regard to determining risk degree in DOW index, the considered index was scored and its fuzzy model was formed based on fuzzy logic.

Table 19: Dow (F& EI) risk rating based on fuzzy logic)

Fuzzy rating	Risk degree	F&EI Dow
(0,0,0.1,0.2)	Very low	60 -1
(0.1,0.25,0.4)	Low	96 – 61
(0.3,0.5,0.7)	Medium	127 - 97
(0.6,0.75,0.9)	High	158 – 128
(0.8,0.9,1,1)	Very high	Over 159

Figure 1: Dow (F& EI) risk rating based on fuzzy logic via MATLAB software

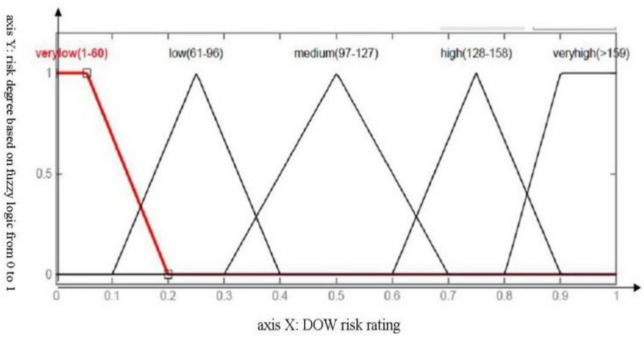
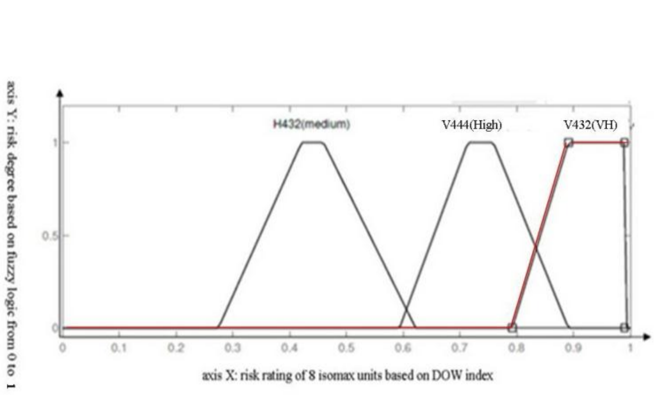
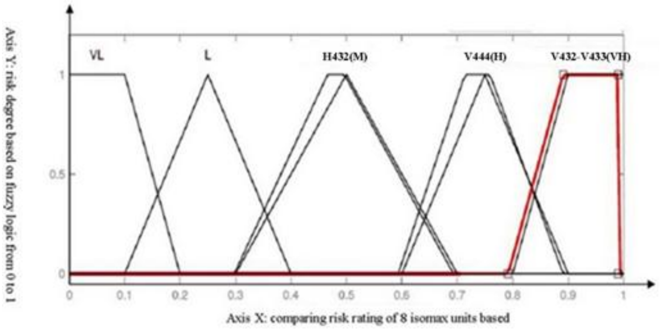


Figure 2: results of DOW fire index analysis based on MATLAB software



Axis Y: risk degree based on fuzzy logic from 0 to 1

Figure 3: results of comparing 5-4 and 6-4 figures



4.3.MOND index fuzzy

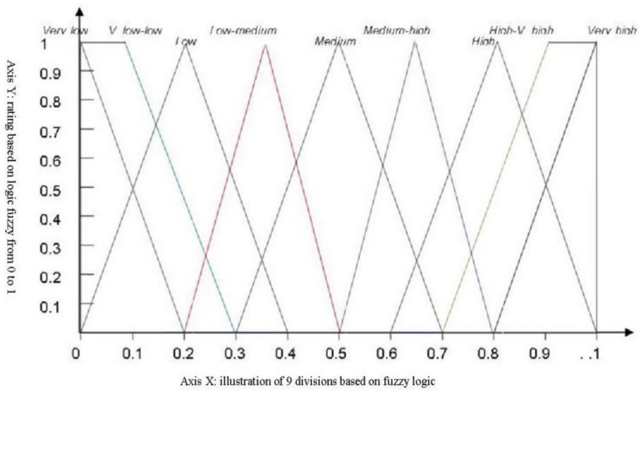
The experts' opinions technique is used in order to make the data of MOND model fuzzy. This method has been presented by Chen and Hwang in 1992. Based on the tables of this method, the final comparison is done. In order to determine the experts' characteristics that have scored the MOND model, the experts' inference method is used. In this method, homogeneous and heterogeneous groups are used to select the experts. The homogeneous group indicates the highest credit in the expert's scoring regarding the subject significance, and the heterogeneous group indicates the lowest degree of credit. Since the heterogeneous group takes advantage of experts ranking from the high to the low degree of credit, it has superiority over the homogeneous group in which opinions of a special group is considered. The experts of heterogeneous group assess the probability of ambiguous events occurrence and rate of human error. Grading people of experts' opinions E_k= (K=1.2,…, M)varies from number 1 to M; based on each expert's opinion, the considered number of each expert is multiplied by the weight of each expert obtained from every individual's ranking set and finally the final number of scoring in MOND model is obtained via the set of calculations. For instance, the calculation of experts' opinion was applied for a unit[7,14].

$$\text{Assuss ofExpert}_1 = W_1 \times R_1$$
$$\text{Assuss ofExpert}_2 = W_2 \times R_2$$
$$\text{Assuss ofExpert}_3 = W_3 \times R_3$$

From the set of $\mathbf{W_3} \times R_3 + \mathbf{W}_2 \times R_2 + \mathbf{W_1} \times \mathbf{R_1}$, final number of each expert with regard to the considered index was obtained and assesses in scale 9 by Chen and Hwang (1992) [7,13].

Score	Classification	Classification
۵	M.A.	
۴	Student	
۳	Engineer	Position
۲	Technician	

Figure 4: illustration based on 9 divisions via fuzzy logic of Chen and Hwang



In table 20, ranking the experts is done based on their position, job experience, and education.

Table 20: weighing different scores by the experts [1,13]

Score	Classification	Classification
5 4 3 2 1	M.A. Student Engineer Technician Worker	Position
5 4 3 2 1	30years≥ 20 - 29 10 - 19 6 - 9 5≤	Job experience
5 4 3 2 1	PhD M.A B.A Higher than diploma Diploma	Education

The concept of linguistic variables is useful for confronting complicated situations. Therefore, the linguistic value is indicated via approximate interference of fuzzy number. A linguistic variable is a variable that declares worth of words or sentences in a natural or artificial language. Chen and Hwang (1992) represented eight scales for different conversions.

Table 21: DOW/ICI fire and explosion index

Results classification	Fuzzy rating	Total degree of risks	Fire and explosion index limit DOW/ICI
1	(0,0,0.2)	Very low	0 – 20
2	(0,0,0.1,0.3)	Low	20 – 40
3	(0,0.2,0.4)	Medium	40 – 60
4	(0.2,0.35,0.5)	More than medium	60 – 75
5	(0.3,0.5,0.7)	High	75 – 90
6	(0.5,0.65,0.8)	Too high	90 – 115
7	(0.6,0.8,1)	Very high	115 – 150
8	(0.7,0.9,1,1)	Potentially disastrous	150 – 200
9	(0.8,1,1)	Disastrous	More than 200

Figure 5: rating DOW/ICI fire and explosion index

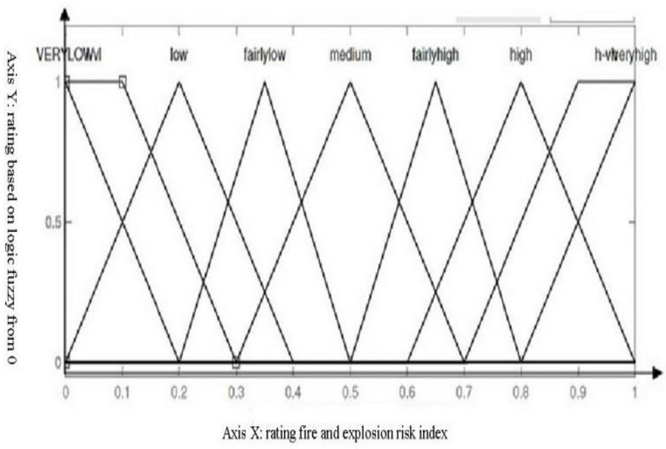


Table 22: fire load and fire time duration rating

Results classification	Fuzzy rating	Fire limit based on hour	Qualitative rating	Fire load(F) 10^3 BTU/ft^2
1	(0,0,0.1,0.2)	0.25-2	Very low	0-200
2	(0,0.2,0.4)	2 – 4	Low	200-400
3	(0.2,0.4,0.6)	4 – 10	Low toward high	400-1000
4	(0.4,0.6,0.8)	10 – 20	Medium toward high	1000-2000
5	(0.6,0.75,0.9)	20 – 50	High	2000-5000

Figure 6: fire load and fire time duration rating

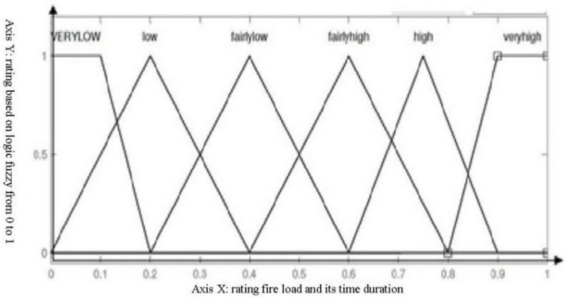


Table 23: rating unit explosion

Results classification	Categorization	Qualitative rating	Internal unit explosion index
1	(0,0,0.2)	Very low	0 – 1
2	(0.1,0.2,0.3)	Low	1 – 2.5
3	(0.3,0.5,0.7)	Medium	2.5 – 4
4	(0.6,0.8,1)	High	4 – 6
5	(0.8,1,1)	Very high	More than 6

Figure 7: rating internal unit explosion

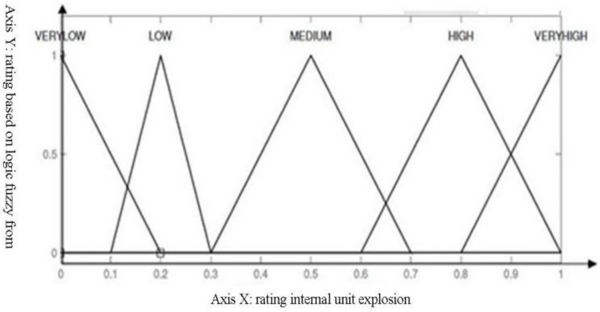


Table 24: rating air explosion index

Results classification	Categorization	Qualitative rating	Air explosion index
1	(0,0,0.2)	Very low	0-30
2	(0.1,0.2,0.3)	Low	30 – 100
3	(0.3,0.5,0.7)	Medium	100 – 400
4	(0.6,0.8,1)	High	400 – 1700
5	(0.8,1,1)	Very high	More than 1700

Figure 8: rating air explosion index

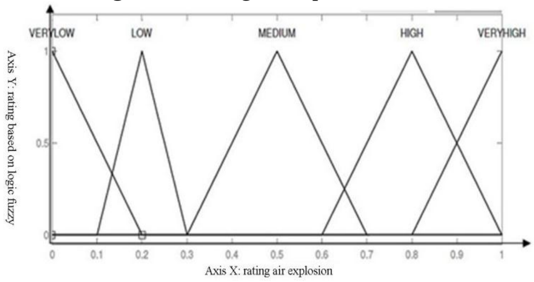


Table 25: rating unit toxicity index

Results classification	Fuzzy rating	Qualitative rating	Unit toxicity index U
1	(0,0,0.2)	Very low	0-2.5
2	(0.1,0.2,0.3)	Low	2.5 – 5
3	(0.3,0.5,0.7)	Medium	5 – 12
4	(0.6,0.8,1)	High	12 – 30
5	(0.8,1,1)	Very high	More than 30

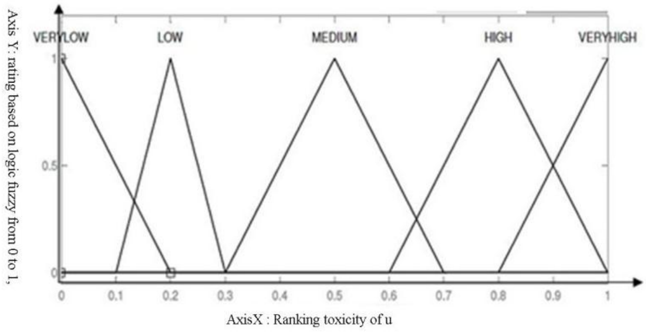
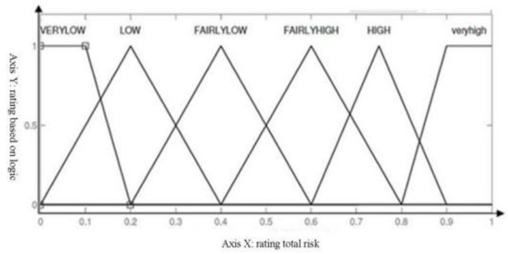


Figure 9: rating unit toxicity index

Table 26: rating overall risk

Results classification	Fuzzy rating	Qualitative rating	Overall risk index
1	(0,0,0.1,0.2)	Very low	0-500
2	(0,0.2,0.4)	Low	500 – 1,100
3	(0.2,0.4,0.6)	Low to high	1,100 – 2,500
4	(0.4,0.6,0.8)	Increasing high level	2,500 – 12,500
5	(0.6,0.75,0.9)	High	12,500 – 65,000
6	(0.8,0.9,1,1)	Very high	More than 65.000

Figure 10: rating overall risk



5.Conclusion

Categorization of fire and explosion risk of the eight process units is observed in the summarized form of risk analysis in Iso-max unit. Calculation of DOW fire and explosion index and risk analysis of the mentioned units indicates that the following 6 units out of 8 units have been selected because of having risk severity (F&EI> 159):

1. Catalytic conversion reactor 2V-432
2. High pressure separator 2V-433
3. Low pressure separator 2V-436
4. Feed flash drum of distillation section 2V-437
5. Recycle splitter feed flash drum 2H-433
6. Recycle splitter 2V-439

The other two units have heavy and medium risk severity, respectively. Diesel stripper 2V-444 has a heavy risk severity (128< F& EI < 158) and reactor feed hater 2H432 has a medium risk severity (97< F& EI < 127). Material factor in reactor feed heater and diesel stripper equals 16 and it equal 21 in other units. This is because of the difference between inherent potential energy within the two mentioned groups.In other words, gas oil and diesel which are the main materials of the reactor heater and diesel stripper have less flammability and reactivity than hydrogen and liquid gas which are the main materials of the other units. Therefore, regarding the direct relation between the material factor and fire& explosion index, the difference in the above two groups makes a considerable difference in their index values so that units with material factor equal to 21 have a severe fire and explosion risk. This issue indicates that in inherently safe designs, less hazardous materials decrease risks in the chemical processes. The minimum value of general risks equal to 1.3 is related to catalytic conversion reactor. General risk of other units is equal to 1.5. According to the gas phase of the materials in the reactor, this unit accepts no penalty associated with system of drainage and leakage control; however, other units have a penalty as a result of not being associated with the needed cases in DOW guide, the penalty factor equals 0.5. According to DOW guide, penalty factor equal to 0.3 belongs to exothermic reactions of hydro-cracking occurring only in the reactor section. Therefore, by considering number 1 as the basic number in calculating the general factor, general factor in the reactor equals 1.3 and it equals 1.5 in other units. Reactor feed heater with special risk value equal to 5.2 and high pressure separator with special risk value equal to 7.2 have the minimum and maximum values of special risks respectively. The main causes of special risks difference in these two units have been mentioned as follows:

The presence of hydrogen sulfide gas with health risk degree of 4 is the most hazardous toxic material in high pressure separator, while gas oil with health risk degree of 1 in the reactor feed heater is the least hazardous toxic material. The maximum and minimum values of fire and explosion index equal to 233 and 121 respectively belong to catalytic conversion reactor and reactor feed heater. The difference between inherent potential of the materials, value of the materials available in the process, and the most hazardous toxic material in these two units have made a difference approximately equal to 100 in fire and explosion index of the two mentioned units. Anyhow, it should be mentioned that the operating pressure in two units is the same. The maximum value of damage factor (DF) belongs to heater of distillation section. It means that if fire or explosion occurs in the units, 100 percent destruction does not happen in the equipment and the destruction equals approximately 84 percent. Damage factor in different units depends on two variables of material factor and unit risks factor. On the other hand, the maximum value of a unit risks considered for determining damage factor equals 8. Therefore, with regard to the equality of material factor in the above units and considering number 8 for the unit risks, damage factor is maximized and equal for all of the units. This factor could affect decrease of damage resulted from probable fire and explosion in the above units up to 16 percent. The minimum damage factor equal to 0.66 belongs to reactor feed heater, the cause of this fact refers to the above explanations as well as low material factor and low process risks of the unit in comparison with other units. This leads to decrease of the basic damage caused by fire and explosion up to 34 percent.

Moreover, the maximum loss control and credit factor indicating low level of actions controlling fire and explosion occurrence belongs to catalytic conversion reactor with the value equal to 0.70. The minimum control and credit factor belongs to low pressure separator. Indicating desirable level of actions for controlling fire and explosion in these units compared with other units. Although fire and explosion risk severity and radius and area of exposure in high pressure separator are higher than that of low pressure separator, the most probable real damage and number of lost working days are associated with low pressure separator. Index calculation, risk categorization, the estimation of real damage caused by equipment destruction, and calculation of the lost working days resulted from probable fire and explosion are in important part of the present study. The most probable real damage was calculated after considering factor of damage to equipment of exposure area and considering loss factor, consequently, its value was calculated as half of the value of equipment present in risk are of each of the eight process units. The maximum real damage caused by the probable fire and explosion is related to high pressure separator and it is 6.82 million dollars, while the minimum real damage caused by the probable fire and explosion is related to diesel stripper equal to 2.17 million dollars. The available controlling features especially protection against fire such as proving water for fire, fire proofing structures, manual fire quencher, and protection of cables have led to decrease of damage to equipment in the exposure area up to 20-45 percent. For instance, value of replacing equipment in catalytic conversion reactor is 8.11 million dollars, after considering damage factor equal to70 percent, the loss decreased to 5.43 million dollars, and after considering the available controlling features the loss decreased to 3.80 million dollars. Therefore, the loss of 3.80 million dollars was the most realistic loss caused by fire and explosion in the reactor.

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