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ORIGINAL ARTICLE

Risk Assessment of the Controlling Methods to Prevent the Harmful Environmental Effects from Fire and Explosion: A Case Study

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ABSTRACT

Oil and gas production is an inherently hazardous activity due to the large volume of flammable and explosive hydrocarbons stored or processed in a facility. Therefore, formal risk assessments are necessary for various phases of the asset life cycle because they help personnel identify, evaluate, and control the hazards that could result in loss of life, injury, pollution, property damage, or business disruption. The aim of this study was to assess the risk of fire and explosion (F&E) in the Gas Treating Unit of a gas refinery using the DOW'S fire and explosion index in order to examine the influence of the controlling methods. Accordingly, the important processes of the subunits in the Gas Treating Unit were identified based on the important influential parameters such as process pressure, temperature, and material value. In the next step, the most important parameters affecting the fire and explosion index were calculated for each subunit. In each case, the corresponding control methods were identified and their effects were investigated. The results revealed that 5 subunits out of the 5 studied had a severe risk of fire and explosion. The feed gas K.O DRUM (Knock-out Drum) was the most critical subunit of the Gas Treating Unit, given an F & E index value of 235.62. According to the research findings, the controlling methods could reduce the F&E index but not less than 98.7.

KEYWORDS: *Risk Assessment, Environmental Impacts, Hydrocarbon Refining, Storage Facilities*

INTRODUCTION

Hazards are intrinsic and the basic properties of the material or their conditions of use [1-3]. Loss prevention in the chemical process industries (CPI) is generally done in two traditional and modern ways.

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The traditional way involves the use of procedural (administrative) controls and the addition of safety devices at the end of the design to deal with hazards that have already been identified. The other involves the elimination or reduction of the process hazards using inherent properties of materials/

processes and process equipment. The emphasis here is on the complete elimination of hazards [4]. However, it is usually quite difficult to achieve total elimination; consequently, the overall effect is a kind of hazard reduction [5]. This approach is referred to as inherent safety [6-8]. Fire and explosion, as the most common accident and a serious threat in natural gas installations, is one of the most important issues in risk control in factories [9-11]. Due to the importance of the subject and the catastrophic consequences of these accidents, numerous studies have been conducted worldwide to assess and control it. The outputs of these studies are a variety of tools and approaches for assessing and managing fire and explosion risk in chemical processing industries. As such, Shi and Kui Xu [12] in 2014 developed a quantitative approach based on the combination of AHP (Analytical Hierarchy Process) and FFTA (Fuzzy Fault Tree Analysis) methods to assess the occurrence probability of fire and explosion accidents in steel oil storage tanks.

They concluded that this approach, by identifying the most crucial basic events, is useful for giving insights to the managers on how to develop effective mitigation measures. Sano et al. [13], by adding indirect cost to the Center for Chemical Process Safety (CCPS) developed a new index to evaluate the damage incurred by a company in reality. According to their findings, the new index introduced "fire and explosion outside the studied reactor" as the highest severity event. Hsu et al. [14] studied fire and explosion accidents in a plant in Taiwan producing cumene hydroperoxide, phenol, and dicumyl peroxide. They reported that fire and explosion accidents could be avoided by DIERS (Design Institute for Emergency Relief System) technology and OSHA (Occupational Safety and Health Administration) 1910.119. Kee Paik et al. [15] introduced some procedures for assessing fire and gas explosion risks in offshore installations. They also proposed a number of mitigation measures, such as appropriate layout designing and isolation of ignition sources, to control fire and explosion in the industries. Zengin et al. [16] investigated a fire accident due to the explosion of a liquefied petroleum gas tanker in Turkey. They recommended that all personnel related to the liquefied petroleum gas industry should be trained and use advanced fire equipment to minimize the mortality and morbidity due to fire and explosion in these industries.

A large chemical plant, especially those storing processing hydrocarbons are potentially explosive and flammable. Even if this potentiality actualizes, it leads to the loss of life, serious injuries, huge financial damage to workers, and permanent damage to the environment [17-18]. In order to follow precaution about such devastating potential, many process plants use either the "Dow's Fire & Explosion Index Hazard Classification Guide" [19] or MOND fire, explosion, and toxicity index (Mond, 1993) to calculate the fire and explosion index (F&EI). The MOND guide can be used to estimate the effects of various safety and preventive measures (called the loss control measures, LCM) as well as for several extra features and is more elaborate than the DOW [20] but it's not used widely. In addition, the MOND guide implementation requires more effort but less professional knowledge about its special feature. Having considered these issues, in the present study, the DOW guide was used [20]. The objectives of this study were to assess the risk of fire and explosion at gas treating units using the DOW'S fire and explosion index and to study the effects of the controlling methods.

MATERIAL AND METHODS

The last published version of F&EI in 1994 was applied for the present study. The general F&EI guide procedure has been shown in Figure 1, which involves the following steps:

Initially, based on the statistics and history of accidents and consulting with supervisors and unit experts, the important process units' parameters were selected such as hazardous materials quantity, temperature, operating pressure, flammability, and reactivity of materials.

The Material Factor (MF), which measures the potential energy released by the studied material, was determined first from the database, material safety datasheet (MSDS) or manual calculation, when required. This was achieved using flammability (NF) and reactivity values (VR). A sum of potentialities that contributes to loss probability and its magnitude was then estimated. This was called the general process hazard factor (F1). The special hazard factor process (F2) was another parameter determined in this step. This factor is a sum of factors that can increase the probability and it has contributed to major fire and explosion incidents, historically.

General process hazards cover six items although it may not be necessary to apply all of them. These items include exothermic chemical reactions, endothermic processes, material handling and transfer, enclosed or indoor process units, access and damage, and spill control. Special process hazards cover 12 items including operation near flammable range, hot oil heat exchange system, leakage-joints, packing sub-atmospheric pressure, quantity of flammable/unstable material, dust explosion, relief pressure, toxic material, low temperature, corrosion and erosion, fire and flame ignition equipment, and rotary equipment. Each item was represented in terms of "potential" and "credit factors". The fire and explosion index was then calculated using Equations 1 and 2 [22].

$F_3=F_1\times F_2$ (1)

$F\ \&\ EI = MF\times F_3$ (2)

In the next step, the exposure area radius using Equation 3 was determined. Any equipment and facility within this area would be exposed to hazards.

$R = 0.256 \times F\&EI$ (3)

After that, the damage factor, which represents the overall effect of the fire and blast damage, was estimated. This is the damage to the unit equipment due to fire, blast, release of fuel, or reaction energy. Having considered the original equipment cost and value of production per month (VPM) as inputs, the actual maximum probable damage (actual MPPD) could be determined [22]. The degree of the hazards in the plant was assessed using Table 1.

Table 1. *Hazard Assessment based on the F&EI [22] (AICHE), 1994)*

No.	Degree	F&EI
1	Light	1-60
2	Moderate	61-96
3	Intermediate	97-127
4	Heavy	128-158
5	Severe	159-Up

The maximum probable day outage (MPDO) was estimated using the actual MPPD and considering the parameters affecting the costs of production interruption (parallel or secret production line, economic sanctions, etc.) as well as comparing with the diagram presented in the DOW fire and explosion index guide.

It should be noted that the actual MPPD was calculated through the following procedure:

First, the value of replacing existing equipment in the contact area with fire and explosion hazard in each of the process units with the new equipment was calculated based on the company's financial documents. Since all equipment in the contact area would not be destroyed by fire and explosion; therefore, the damage factor (or percentage of damage) was determined using material factor and risk factor (F3) of the unit. Then, the BASE MPPD (base maximum probable property damage) was obtained by multiplying the damage factor in the value of replacing damaged equipment in the contact area of the process unit using the following formula.

BASE MPPD ∗ Loss Control Credit Factors = Actual Maximum Probable Property Damage (actual MPPD)

A calculation spreadsheet in excel was developed for this study. Its validity was tested using the step by step validation of the calculation process, comparing the results with the results of manual calculation. A total validation of the calculation sheet was implemented. The compared validations were run prior to the final calculation.

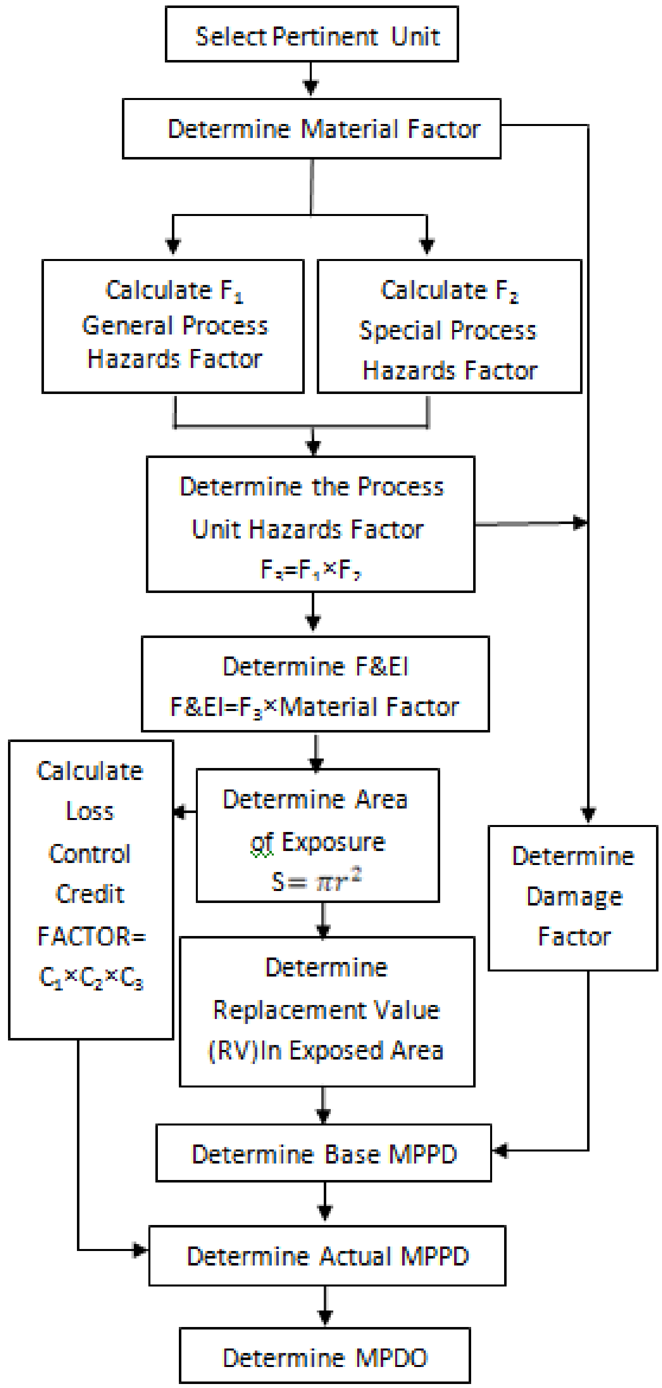

Figure 1. F&EI procedure (DOW, 1994)

Case study:

South Pars gas field (called North Dome on the Qatar side) is one of the largest independent gas resources in the world, located on the joint Iranian-Qatari border line in the Persian Gulf, about 100 km from the south coast of Iran. The area of this field is 9700 km^2 and the part belonging to Iran is 3700 km^2. The gas in this reservoir is sour and in 4 layers and the amount of hydrogen sulfide (H2S) gas in the different layers is about 5000 ppm.

The case of the present study was a gas refinery established in 2005. Gas treating unit is one of the main units of this refinery.

The gas treating unit schematic has been illustrated in Figure 2. The purpose of the gas desalination unit is to separate the H_2S from the injected sour gas. The gas feed, in addition to H_2S, contains CO_2 and mercaptan. The H_2S and mercaptans must be separated from the gas before injecting it into the outlet pipe. The gas treating unit designed to reduce the H2S in the feed gas down to allowable amount before pumping by the national pipeline; however, it is not necessary to fully absorb the CO2 before injection to the mainline. The overall design capacity of gas treating units is the required amount for processing 2000 MMSCFD (million standard cubic feet per day) of fluid in the underground tank. This capacity should be divided into 4 parallel and separate trains so that each train receives 25% of the sour gas. Each train designed for 535 MMSCFD (26698 Kmol/h) of the sour gas. The minimum operating capacity of each unit is 40% of the design capacity, i.e. 195 MMSCFD. According to the opening time of refinery in 2005, the lifespan of the equipment is approximately 15 years, and they have recently undergone overhaul repairs.

Basically, the process includes three main sections:

1- Absorption section. It is where the raw gas is contacted at high pressure with the amine solvent (Methyl Di Ethanol Amine "MDEA" aqueous solution).

2-Thermal regeneration/The rich amine stream is routed to a conventional thermal regeneration column. The CO_2 and H_2S are stripped from the rich amine by water vapor generated in a kettle type reboiler. Then, the lean amine is recycled back to the absorption section. This thermal regeneration section is necessary because it provides an efficient means to break the chemical bonds between CO_2, H_2S, and amine. This makes it possible to produce a regenerated amine stream with very low residual CO_2 and H_2S content.

3-Facilities/Amiscellaneous section. It gathers common facilities such as solvent filtration, drain systems and sumpdrum, anti-foam make-up and injection system, lean solvent storage, etc.

Fire and explosion index was determined for the existing status of 5 sub-sections including feed gas K.O drum, feed gas filter Coalescer, amine absorber, treated gas K.O drum, and rich amine flash drum. The F&EI was also predicted after the application of the proposed control measures in these sub-sections.

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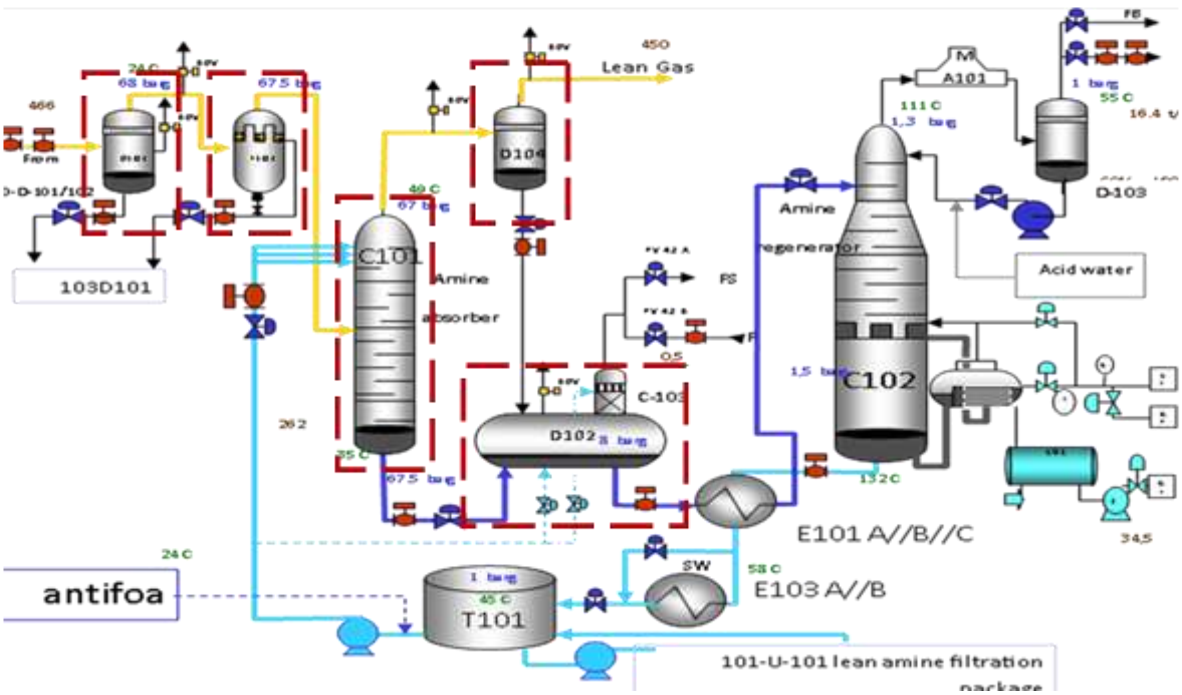


Figure 2. Gas treating unit schematic

RESULT

At the present condition, all 5 subunits have severe risks (Table 2). The implementation of the proposed control measures would reduce the risk factors significantly (Table 2).

***Table 2**. risk categories of the gas treating unit before and after the proposed interventions*

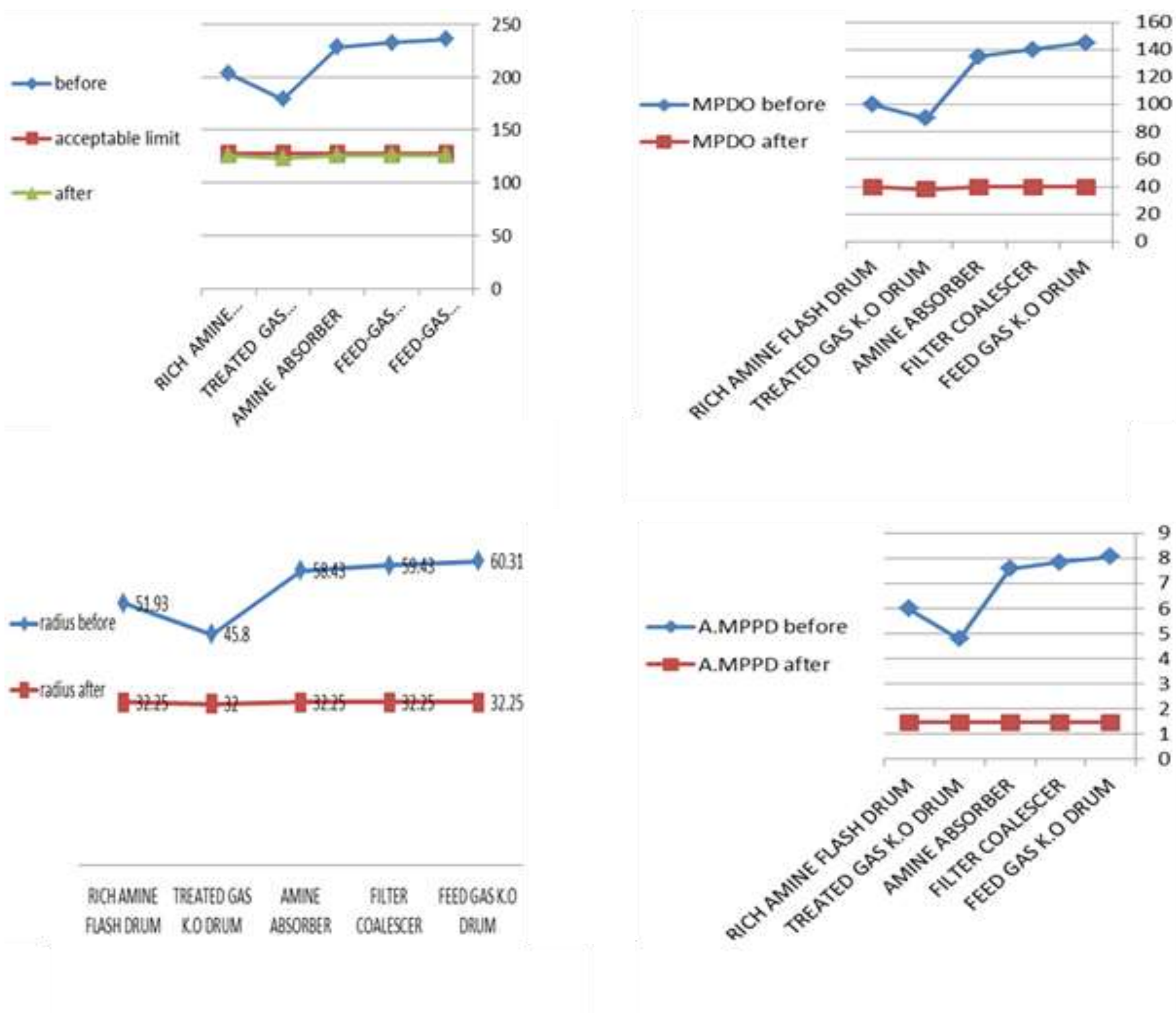
Process Unit	Before Intervention		After Intervention	
	F&EI	Risk Category	F&EI	Risk Category
Feed gas K.O. drum	235.62	Severe	126	Intermediate
Feed gas filter Coalescer	232.15	Severe	126	Intermediate
Amine Absorber	228.27	Severe	126	Intermediate
Treated gas K.O. drum	178.92	Severe	123.37	Intermediate
Rich amine flash drum	202.86	Severe	126	Intermediate

The predicted F&EI for the 5 sub units showed that the maximum and minimum F&EI values were 235.62 and 178.92, respectively. After the application of the proposed control measures, the values would be reduced to 128 and 123.37, respectively (Figure 3).

According to the results, the feed gas K.O. drum with the maximum F&EI of 235.62 was the most critical subunit. In case of a fire and explosion in the feed gas K.O. drum, the plant will experience the highest outage (MPDO=145 days), while an explosion at the treated gas K.O drum will shut down the plant for at least 90 days. After the implementation of the proposed control steps, the plant was expected to experience the highest and lowest outages of 40 (in 4 subunits) and 38 days (in the gas treating K.O. drum) if fire and explosion occurs in the subunits (Figure 4).

The gas treating unit will experience the maximum exposure radius (ER) of 60.31 m and the minimum ER of 45.8 m in the case of fire and explosion in the feed gas K.O drum and treating gas K.O. drum, respectively (Figure 5).

The plant is expected to experience the highest ER (exposure radius) of 32.25m and the lowest ER of 32m in case of fire and explosion at the 4 sub-units and treating gas K.O. drum, respectively, after the implementation of the control measures (Figure 5). According to the results, in case of fire and explosion, the highest and lowest actual MPPDs in the 5 subunits would be US$ 8.06 and 4.79 million, respectively. With the application of the proposed control measures, the values were expected to reduce to US$ 1.45 and 1.44 million, respectively (Figure 6).



Figures 3, 4, 5, 6. The predicted F&EI values for the 5 sub units schematic

DISCUSSION

In fact, the control methods were assessed to be effective from two viewpoints, as listed below:

1- Control methods are related to the penalty factors (Figure 7), which can affect the radius of exposure and reduce the fire and explosion index, involves the following 5 methods:

1-1. Leakage risk control:

- Use of double glazed glasses,
- Programmed and disciplined maintenance,
- Use valves that, in the event of a possible breakage of the glass installed on the tank, act on the pressure difference and pressure drop and blocks the leakage path of the tank content, and
- Create a metal valve on the glass installed on the tank that can only be opened by the operator for a short time when needed to check the contents of the tank and then, is closed again.

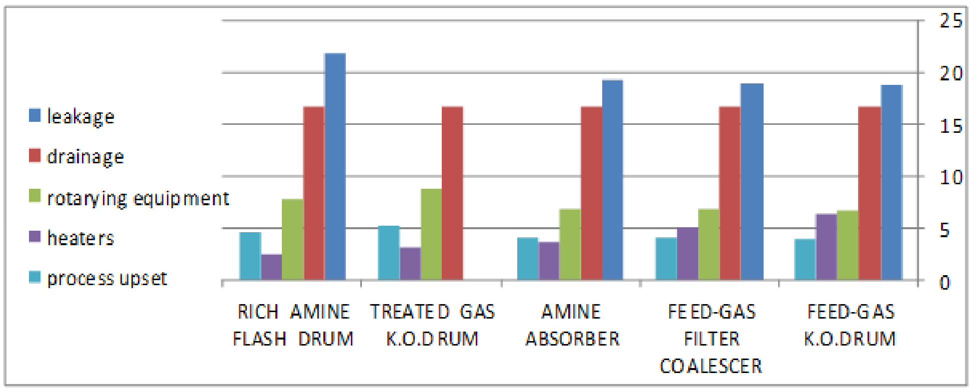


Figure 7. Penalty factors impact on the equipment in the gas treating unit

1-2. Drainage and spill risk control: Creating a three-sided wall around the equipment to direct the leaked material into a pool.

1-3. Rotary equipment risk control: Develop a codified operational plan to work on rotating pumps in which, based on the cooling time of the internal components of the pumps, the repair team was allowed to open the equipment for repairs.

Other option is installing gas detectors especially around the equipment and on free distances based on the radius of the hazard zone. In case of gas leakage and probability of reaching to hot surfaces, these gas detectors can send messages to the control center to stop the hazardous pump.

1-4. Heaters risk control: Using hot oil or hot pressurized steam instead of the naked flame to increase the temperature. Another measure is to use the internal burning furnaces.

1-5. Process upset or purge failure risk control: Equipment is purged with N_2 packages and washed with the pressurized steam.

2- Updating methods of credit factors influencing on MPDD and MPDO (Figure 8), which involve 7 methods as followings:

2-1. Updating factors related to fire monitors and fire extinguishers: Equipping monitors with foam injection package and controlling from central control room (CCR),

2-2. Updating factors related to foam: Equipping the deluge system with the premix expansion foam,

2-3. Updating factors related to steel structure: Increasing the fireproof protection above 10 meters (especially for the amine absorber),

2-4. Updating factors related to drainage: Design a checklist for the scheduled purge, 2-5. Updating factors related to other process analyses: Hazard identification and risk assessment are to be done based on a plan,

2-6. Updating factors related to inert gas system: Using a purging system instead of the manual purging, and

2-7. Updating factors related to cable protection: The cable trench cover using aluminum.

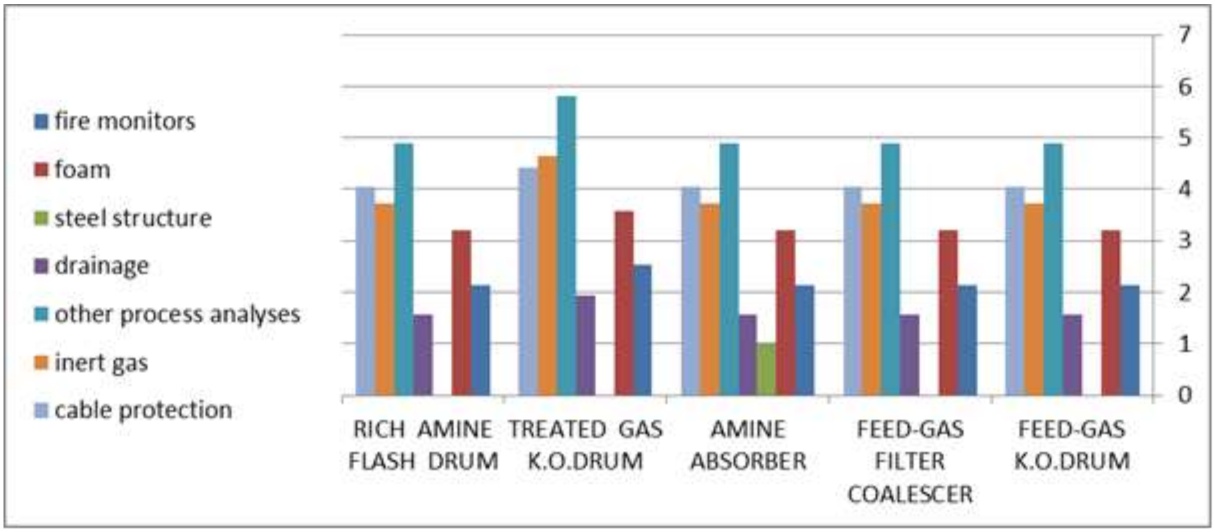


Figure 8. Effects of the control methods related to the credit factors in the gas treating unit's equipment

The results of this study showed that in case of fire and explosion, the highest and lowest of actual MPPD in 5 studied subunits would be US$ 8.06 and 4.79 million, respectively. The financial damage of fire and explosion was also reported by Zaranejad and Ahmadi in 2015 [23]. They assessed the fire and explosion risk in a chemical company using the DOW index and found that fire or explosion could potentially cause financial damage of US$ 51 million. Sadat Nezamodini et al. [24] estimated fire and explosion damage cost in an oil extraction company using the DOW index as approximately USD 4.15 million in 2008. Atrkar Roshan and Jabbari Gharedagh in 2013 [25], in a study on the estimation of the economic damage caused by fire and explosion in petrochemical feed and product pipelines, concluded that the damage would be rise to 3.9 million USD.

The results of the present study also showed that the application of controlling methods may reduce the F&E index but not less than 98.7. The findings were in line with those reported by Jafari et al. [26]. They assessed fire and explosion index credit in risk assessment at Tehran Oil Refinery and conclude that the value of the F&E index would considerably be reduced if proper controlling methods were applied. The integration of Dow's fire and explosion index (F&EI) was another recommendation in this study. This finding was also approved by Mardani et al. study's results [27].

In order to promote the inherent safety of the design and optimization of the reactor and distillation column system under study, they proposed the integration of Dow's fire and explosion index (F&EI) into the design process. Jensen and Jørgensen et al. [21] and Gupta et al. (2003) [20] also emphasized the promotion of the Dow index by integrating it with the explosion index (F&EI). Because of some deficiencies in the fire and explosion index, it was recommended in the current study to apply the index with complementary software such as PHAST.

The use of this software was also proposed by Bekhouche and Mounira [28] in research on fire and explosion risks of natural gas liquefaction in Algeria. They believed that this software may provide a real image of fire and explosion hazards. Mihai Pasculescu et al. [29] claimed that the software was a state-of-the-art hazard nalysis software package, with a capability of using in different design/operation stages of those industries with the explosive nature.

To the best of our knowledge, in the present study, the conceptual analysis of the effects of credit and penalty factors on the determination of MPDD was applied while in other similar studies, the results were only based on the DOW's fire and explosion index guide.

CONCLUSIONS

In this study, the efficiency of the DOW application was confirmed as an index that in addition to covering almost all operational parameters of the process can save time and cost, and finally, quantifying the damage caused by the identified risks can be effective in improving safety and environmental conditions.

Accordingly, the Actual MPPD and the environmental consequences of fire and explosion of the studied units were estimated at US$ 34.22 million, totally. In addition, prevention of leakage in equipment and design of suitable drains to safely guide materials were found to be the most important control measures, indicating the role of environmental controls in reducing damage.

The mentioned credit factors in the DOW index could only impact on actual MPDD; indeed, these could influence and decrease the hazardous radius, whereas the importance was not mentioned in the index. Among all causes' impact on the fire and explosion index, three factors were found to be inherently dangerous in the process including material toxic level, pressure, and liquids and gases. As a result of these risks, inherently safe studies at the time of design (inherently safer designs) should be used.

In order to decrease fire risk, it is recommended to locate furnaces in the plant's design phase out of units at a distance beyond the explosion and fire radius. Considering the DOW fire and explosion index, it was found that the indexes include most of the factors effective on process, so, it could be considered an appropriate method. To moderate the consequences of these risks, it is required to use inherently safer studies design phase.

Based on the material factor of the units in this study, methane gas by a 21factor value was the most effective factor. Since pressure, toxicity, and liquids/gases were the process inseparable factors; therefore, it was not possible to reduce the obtained F&EI to less than 98.7, as an indication of medium risk severity. According to the results of this study, hazard radius was the highest fire and explosion index, the most probable real damage, and lost days of work are related to feeding gas in K.O. drum unit's equipment. The most effective control methods of penalty factors were the leakage and drainage control, while the most effective credit factors were the scheduled process analysis. Based on the DOW's fire and explosion index assessment, among 5 equipment under inspection, prior to corrective actions, all were in sever risk limit which could be shifted in the medium risk severity category applying corrective measures.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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