**World Journal of Environmental Biosciences**

Available Online at: **www.environmentaljournals.org**

**Volume 6, Supplementary: 37-42**

**ISSN 2277- 8047**

# Vulnerability Evaluation of Process Unit Control Room Building against the Effects of the Vapor Cloud Explosion (Case Study: Arya Sasol Polymer Co. Olefin Plant)

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**ABSTRACT**

*Among possible process incidents such as explosion, fire and release of toxic gases, explosion is considered as one of the main risks affecting the processing units and intensity of possible consequences of this incident has always caused great concern, so that most damages in processing plants and the destruction of buildings have been caused by explosion. In this regard, buildings also due to the dense presence of staff and valuable material, has always been regarded as the most vulnerable parts in line with the over pressure; therefore, it is often attempted that, as much as possible, these sensitive areas be protected against the effects of explosion. In this study, by using consequence modeling, Olefin unit control room building has been studied that had an operational role and it was within a process unit and with regard to this unit, there was the risk of damage and destruction caused by the vapor cloud explosion. Based on the outcomes of consequence modeling, if the resulting explosion wave at the construction site, according to the guidelines and standards, be less than tolerable level, the building layout will be perfect and this part can be considered as an end for the study. Otherwise, Preliminary Risk Assessment Method (individual risk) and comparing it with the risk criteria have been used and building risk level will be determined. Therefore, based on the analysis of the results, it was shown that the Risk of control room building was in the ALARP (As Low As Reasonable Practicable) region, this means that though the building risk was not acceptable, it was tolerable, and ,if profitable, risk reducing and control efforts must be considered and applied.*

**Keywords:** *Explosion, Buildings, Consequence modeling, Risk assessment*

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## INTRODUCTION

Industrial accidents have always been a part of reality in past centuries. On the other hand, with industrial development and technology growth, increasing the complexity of the operation and the existing structures, risk level and diversity hazards have increased dramatically from the past to the present. Physical and financial problems, environmental and financial events, can either directly or indirectly affect the organization; therefore, today reducing accidents and their consequences has become a priority for organizations and economic consequences will a special position in terms of strategic events for organizations.
On 19 November 1984, a huge fire and subsequent explosion of 15 LPG storage tanks in a LPG terminal near Mexico City killed about 650 people and injured more than 6400 others. The dimensions of explosions were so much that projectiles were observed up to 1 km. Due to the explosion, the entire terminal and a large number of residential houses nearby were destroyed. The interesting point is that residential and populated areas did not exist surrounding the terminal at the beginning of construction of it. These areas have been developed gradually and without sufficient studies and during 20 years have gone over to a distance of 130 meters from the terminal. (Lees, 2005).
According to the above mentioned factors, the importance of building proper placement and strength in process units is determined more than ever before. Since buildings have dense presence of staff and valuable material, has always been regarded as the most vulnerable parts in line with the blast wave; therefore, it is attempted that ,as much as possible, these sensitive areas be protected against the effects of explosion. The nature of this protection can be provided by two different perspectives: First, observing the proper distance between buildings and facilities at risk and secondly, the use of resistant systems of buildings against explosion wave.

### Brief description of Arya Sasol Polymer Co. Olefin Plant

The whole process of olefin unit is schematically shown in **[Figure 1]**. (Ibid, 2001).

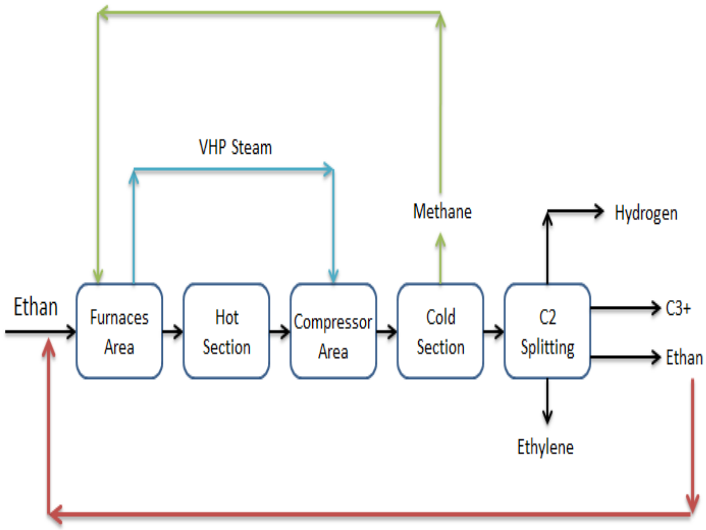


**Figure 1**: **Schematic design of Olefin Plant process**

Ethane gas is Arya Sasol Polymer Co. Olefin plant feed that it is provided by Pars Petrochemical. Feed after mixing with water steam based on suitable ratio, will be injected into the furnaces and in the specified operating conditions with regard to temperature and pressure, during hydrogenation endothermic reaction of ethane the molecules with conversion rate of 60 to 70 percent, Ethylene is produced. Furnace outlet stream includes ethylene, C3+, ethane, methane and hydrogen and the target in the later stages is separating these compounds and the final objective is achieving ethylene product with 99/95 percent purity. Furnace outlet stream that is called cracked gas enters the hot area and in this part most of the heavy hydrocarbon and water are removed from cracked gas. Meanwhile the necessary diluter steam for cracking will be made in the furnace in this part. The emitted crack gas from hot area will enter into the compressor, where its pressure is increased by C-301 up to about 33 bar and then the cracked gas enters the cold area and due to the reduction in the gas temperature, in this section all compounds in cracked gas except hydrogen and methane will be liquidate. Then, in the towers 401, 402, and 403 and 401 reactor, separation and purification operations are carried out in several stages and finally pure ethylene product will be transported to the consumer side or storage tanks.

**Risk assessment structure to evaluate the explosive effect on building**

The structure of the building explosion effect research methodology is shown in **[Figure 2]** that is similar to other risk assessment methods, but with some changes that are as follows: (Api, 1995), (TNO, 2005).

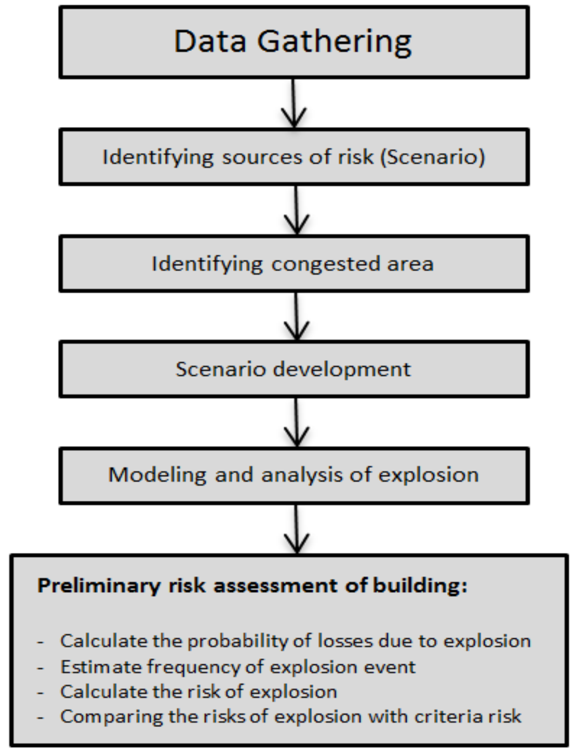


**Figure 2: Explosion risk assessment structure**

**Identifying the sources of risks (scenario)**

This step, which is used to identify risks in a process unit, has great importance. Because any shortcomings at this stage will lead to lack of identification of possible risks and as a result, their risk will not be assessed, so after collecting data at this stage, first of all we need to check the necessity of this research by analyzing the parameters below: (API, 1995).

- The existence of explosive materials in the intended unit,
- The process conditions (temperature, pressure and amount of explosives)
- The special conditions of intended site (equipment density and existence of ignition sources)
- Operational role of Building and its role in emergencies

If one of the four factors does not exist, we won't feel the need to study.

**Identified congested areas**

Based on the GS-SAF 253 reference, vapor cloud explosion occurs when dense gas accumulation can be seen in the environment including the space between the tanks, the space between the lines and holders of, the space between equipment or a relatively closed environment; therefore, degree of equipment compaction and the degree of confinement are two key factors in determining the degree of explosion. Therefore, in line with determination of these two factors, the equipment arrangement deployed in process unit facility should be considered because the release of flammable elements in open spaces faces with low likelihood of explosion. (Total, 2012).

In **[Table 1]** order to calculate dense areas, by approximate measuring of the desired area and multiplying surface area and height, the total volume that has the ability to shut off the vapor cloud can be calculated.

**Table 1: Congested areas specifications**

| Dense area | Area ($m^2$) | Height (m) | Volume ($m^3$) | 50 percent of the volume | Density level |
|---|---|---|---|---|---|
| C2_CA_01 | 2,090 | 45 | 94,050 | 47,025 | High |
| C2_CA_02 | 9,264 | 20 | 185,280 | 92,640 | High |

* Based on references and standards, in oil, gas and petrochemical industries, due to the density and volume of space occupied by structures and equipment, only 50% of the space will be calculated as the volume of trapped gas. (Alche, 2004), (Total, 2012).

**Scenario development**

Due to the lack of devastating effect of the possible fire scenarios in the Olefin unit on buildings (such as: Flash fire, Pool fire, Jet fire) and by taking into account the purpose and scope of this study, (TNO, 2005) just vapor cloud explosion scenario (VCE) is calculated and evaluated. **[Table 2]**

For this purpose, the explosion scenarios of dense spaces in olefin units include:

- The furnaces section (Zone A)
- The compressor section and the hot area of unit (Zone B)

**Table 2: The specifications of the control room building**

| Name of the building | Building type | The distance of building from the source of the vapor cloud explosion (m) | |
|---|---|---|---|
| | | Scenario 1 | Scenario 2 |
| Control room | B5 (structure with reinforced wall or reinforced concrete) | 56 | 75 |

**Modeling and analysis of explosion**

In **[Table 3]** this stage, first, based on the available data, the explosion modeling will be carried out by PHAST software and blast wave charts based on distance will be extracted in **[Figure 3]**. (DNV, Leak ver 3.2.), (DNV, PHAST Risk ver 6.7).

**Table 3: Scenarios 1 and 2 of explosion in congested areas [8]**

| The scenario Number | Dense area | The composition of participating elements in explosion | | | | congested areas volume ($m^3$) | Density level |
|---|---|---|---|---|---|---|---|
| | | Name | Wt% | Name | Wt% | | |
| Scenario No. 1 | Zone A | Water | 25.704 | Ethan | 25.356 | 47.025 | High |
| | | Hydrogen | 2.970 | MADP | 0.018 | | |
| | | CO | 0.079 | Propylene | 0.823 | | |
| | | $CO_2$ | 0.011 | Propane | 0.150 | | |
| | | $H_2S$ | 0.008 | 1-3 Butadiene | 0.051 | | |
| | | Methane | 3.536 | C4 | 0.412 | | |
| | | Acetylene | 0.280 | Gasoline | 1.052 | | |
| | | Ethylene | 38.522 | C10+ | 0.127 | | |
| Scenario No. 2 | Zone B | Water | 0 | Ethan | 31705 | 62.640 | High |
| | | Hydrogen | 3.720 | MADP | 0.021 | | |
| | | CO | 0.114 | Propylene | 0.998 | | |
| | | $CO_2$ | 0 | Propane | 0.182 | | |
| | | $H_2S$ | 0 | 1-3 Butadiene | 1.149 | | |
| | | Methane | 8.591 | C4 | 0.497 | | |
| | | Acetylene | 0.359 | Gasoline | 1.149 | | |
| | | Ethylene | 51.513 | C10+ | 0.002 | | |


**Figure 3: Over pressure per distance in Scenario 1**


**Figure 4: Over pressure per distance in Scenario 2**

**Table 4: Effects of scenarios over pressure on the control room**

| Building name | Building type | Scenario | Received Over pressure | | Over pressure effects on building |
|---|---|---|---|---|---|
| | | | (psi) | (bar) | |
| Control Room | B5 | No.1 | 4.2 | 0.29 | Roof and wall defect under loading and internal walls damaged |
| | | No.2 | 4.3 | 0.3 | Roof and wall defect under loading and internal walls damaged |

**Preliminary risk assessment of the control room building**

In **[Table 4]** According to the obtained data, if the over pressure received by the building has detrimental effects on building strength, preliminary risk must obtain it by calculating individual risk. With this explanation that if received over pressure causes complete destruction of the building, building locating and strength were not suitable and continuing the process of building preliminary risk assessment is not required in **[Figure 3 and 4]**. (Api, 1995).

**Consequence of explosion**

Damaging effects will be imported into the mentioned building through scenario 1 and 2 that it is necessary to calculate the total individual risk of these two scenarios individual risk in **[Figure 5]**.

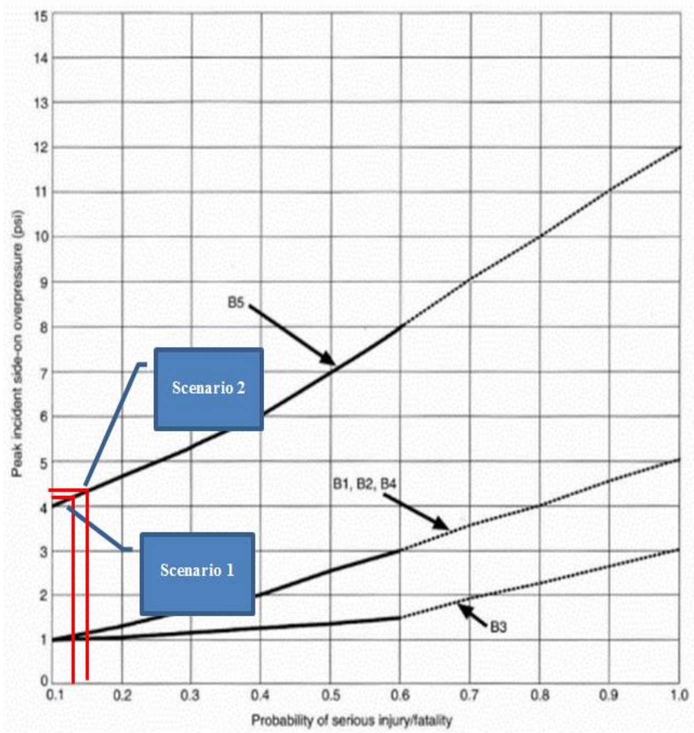


**Figure 5**: **Consequence of scenarios 1 and 2 explosion (probability of losses) on the building**

**Frequency of explosion**

A common way of calculating and estimating the Frequency is utilizing the following **[table 5]** based on the database of past events. (Api, 1995).

**Table 5**: **Explosion Frequency based on past events database**

| **Processing Unit** | Explosion repeatability (1/yr) |
|---|---|
| Alkyl chemical unit | 5.1 e-04 |
| Cracking Catalyst | 6.5 e-04 |
| Reforming catalyst | 2.6 e-04 |
| Crude oil Process Unit | 4.9 e-04 |
| Hydro treating (Refinery) | 2.0 e-04 |
| Hydrocracking | 5.6 e-04 |
| All units | 4.3 e-04 |

**Risk calculation and comparing with risk criteria**

Scenario 1 Individual Risk: 4.3 e-04
(1/yr) × 0.13 = 5.6 e-05 (1/yr)

Scenario 2 Individual Risk: 4.3 e-04
(1/yr) × 0.15 = 6.4 e-05 (1/yr)

Total individual risk for building: 5.6 e-05
+ 6.4 e-05 = 1.2 e-04 (1/yr)

According to the CCPS reference guideline, organizations must determine acceptable levels of risk in accordance with legal requirements, the regional and global criteria or domestic concerns. But in the absence of approved reference risk, standard offer of this reference is considering values less than 1e-6 as a measure of acceptable risk, which is very conservative. (Alche, 2009).

In **[Table 6]** another suggestion that was used in this study and it has been a logical and practical measure of risk acceptance criteria which is offered by the HSE - UK organization in UK. (HSE, 2010).

**Table 6: Individual risk acceptance criteria**

| The probability of losses in a year (1 / yr) | Risk range | Description |
|---|---|---|
| $1.0 \times 10^{-3}$> | Unacceptable | Risk reduction or further risk evaluation is necessary. |
| $1.0 \times 10^{-3}$ to $1.0 \times 10^{-5}$ | ALARP | Risk reduction should be considered. |
| < $1.0 \times 10^{-5}$ | Acceptable | There is no need for risk reduction or further assessment. |

## CONCLUSION

According to the accredited guidelines and standards, vulnerability threshold of buildings type B5 is less than 4.0 psi. This means that the vulnerability of buildings begins from 4.0 psi (received 4.0 psi blast wave causes minor damage to interior walls, ceilings and under load walls) and since the mentioned building is predisposed to the 4.2 psi and 4.3 blast waves of scenario one and scenario two, respectively, after calculating building risk (total product of severity and likelihood of both scenarios), the probability of losses in a year will obtained as 1.2 e-04. The obtained value as compared with the benchmark risk shows that control room building risk is in the ALARP region, this means that though the building risk was not acceptable, it was tolerable, and ,if profitable, risk reducing and control efforts must be considered and applied.

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