CHEMICAL ENGINEERING TRANSACTIONS
VOL. 77, 2019

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Genserik Reniers, Bruno Fabiano

ISBN 978-88-95608-74-7; **ISSN** 2283-9216

DOI: 10.3303/CET1977102

Inherent Safety Application in a Hydrocarbon Unit in the FEED Phase of a Project

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Many of the existing chemical processes require the storage of hazardous substances, and/or demand that severe operating conditions are maintained during production. The operation of this type of processes requires high standards of safety. In this context it is introduced the Inherent Safety (IS), which focuses on eliminating or reducing the hazards associated with a set of conditions, seeking to remove the hazard at its source, rather than accepting it and later on trying to mitigate its effects. The application of IS analysis is more effective in the early stages of the project (research and conceptual phases), where it is still possible to make huge changes in the process (e.g. substitution of solvents). As the process moves through the life cycle (Front End Engineering Design (FEED) and Detailing Engineering) it becomes more difficult, but it is still possible. The FEED phase for example stablishes the following points where IS principals can be applied: the critical operating parameters and safe operating envelope of temperature and pressure; selection of construction materials; unit layout. This paper aims to demonstrate how IS strategy can be applied in the FEED phase of a project with focus in the unit layout definition. A good layout with sufficient spacing between hazards, equipment and units can reflect in several benefits. The study case was done in a real petrochemical unit that had an accident that burned down one entire section of the plant. Toward in finding a safer solution for the new design, an IS methodology was proposed and applied. The results showed the advantages of using inherent safety to design the unit layout in the FEED phase and how it can contribute to build a safer design and operation by minimizing the risks, such as domino effect.

1. Introduction

Nowadays, many of the existing chemical processes require the storage of hazardous substances, and often in large quantities. Furthermore, many processes demand that severe operating conditions are maintained all the time, such as refineries requiring the manipulation of hydrogen or flammable gases in high pressure and temperature and/or reactors that deal with huge inventories of hazardous substances. The operations of these types of processes require high standards of safety. The modern concept to have a safe chemical process is to apply the process risk management theory, which includes the recognition of hazards indicated by the process and the risk analysis aiming to reduce them to the minimum applicable. To reduce the risk, it is necessary to decrease or eliminate the occurrence of a hazardous event or its consequence, which increases the safety (Cetesb, 2010). In this context it is introduced the Inherent Safety (IS), proposed by Trevor Kletz in 1977 (Heikkilä et al., 1998, Kletz, 1984, 1985 and 1991), which focuses on eliminating or reducing the hazards associated with a set of conditions, seeking to remove the hazard at its source, rather than accepting it and later on trying to mitigate its effects. In summary, a project is called inherently safe if it eliminates or reduces the hazards associated with materials and operations used in the process and such elimination or reduction is permanent and inseparable (Souza et. al., 2003). Although an inherently safe process is not exempt from the use of design procedures that maximise safety, it has advantages such as the generation of a simpler process, for instance with less instrumentation for emergency plans inside and outside the unit, reducing the cost of both installation and operation.

Paper Received: 24 January 2019; Revised: 20 May 2019; Accepted: 25 June 2019

Please cite this article as: Pinto J., 2019, Inherent Safety Application in a Hydrocarbon Unit in the FEED Phase of a Project, Chemical Engineering Transactions, 77, 607-612 DOI:10.3303/CET1977102

1.1 Inherent safety analysis

According to Kletz (Heikkilä et al., 1998, Kletz, 1984, 1985 and 1991), a project based on IS considerations should have the following principles: intensification, substitution, attenuation, limit of effects, simplification,change early, avoiding knock-on effects, status clear, incorrect assembly impossible, tolerance, ease of control and administrative controls/procedures. Making use of any of these aspects does not mean you have a safe process, but should make the plant design and operation safer.

There are basically two levels of Inherent Safety (IS) where the principles can be applied. The first one focusses on the elimination of the hazard (e.g. designing pressure vessels/piping to exceed the maximum potential pressure), where it is easier to apply the first two IS principles. The second level, being less efficient than the first, refers to reduce the hazard intensity or likelihood of occurrence (e.g. reduce the inventory of hazardous storage tanks).

The application of inherent safety analysis is more effective in the early stages of the project (research and conceptual phases), where it is still possible to make huge changes in the process, especially using the first level of IS (e.g. substitution of solvents and/or catalysts for less hazardous ones). As the process moves through the life cycle (Front End Engineering Design (FEED) and Detailing Engineering) it becomes more difficult to apply Kletz`s principles but it is still possible, specially through the second IS level. The FEED phase for example establishes the following points where IS principals can be applied: the critical operating parameters and safe operating envelope of temperature and pressure; selection of construction materials; unit layout.

This paper aims to demonstrate how Inherent Safety strategy can be applied in the FEED phase of a project with focus in the unit layout definition. The study case was done in a real petrochemical unit that converts oil into middle distillates. The process involves extreme conditions of pressure and temperature and several flammable and combustible substances, which makes it very dangerous and hard to operate.

2. Study case and discussion

2.1 Description

The study case was developed from a petrochemical refinery that had an accident that burned down one entire section of the plant. During the life time of the unit, a number of leaks were reported before the accident. Furthermore, several issues from a maintenance point of view were highlighted as topics of improvement for the redesign/reconstruction of the unit. Between them, it is relevant to mention the following:

Equipment situated too close to each other making the online maintenance difficult and/or impossible. Sample points located in inaccessible places.

High number of hazardous equipment (i.e. equipment dealing with flammable/combustible substances in high temperature and/or pressure) situated in a small space, making the location excessively crowded, creating hot atmosphere and thus making the maintenance routines dangerous.

During the accident the fire started in one single piece of equipment and escalated in a domino effect destroying a large number of equipment and a whole section of the refinery.

Toward finding a safer solution for the new design, an inherent safety overview of the unit layout was done. It was identified that by using the principle “avoiding knock-on effects” a more reliable layout could be proposed. This principle, also known as domino effect, focusses on designing units for the case that, if an incident occurs in one section of the plant, the consequences are restricted to that area and do not propagate to other sections as per domino effect.

A structured study about the type of equipment, hazardous substances, and operational conditions of each piece of equipment in each area was performed. The methodology applied is described in the following section and the results showed that the new less crowded layout decreased the hot spots of the unit, making the maintenance rounds easier, less dangerous and sample points more accessible for the operators.

2.2 Methodology

A proper plant layout and adequate spacing between hazards are essential to loss prevention and control of the unit. Making use of the principle avoiding “knock-on” effects, a safety distance study was performed, reviewing all spacing in the process unit.

The inherent safety approach begins with the evaluation of the process hazards and classification in high, intermediate or moderate hazard groups. This classification was done with the help of industry guidelines (GE GAP, 2001 and PIP, 2013). According to the guidelines a key aspect to prevent a domino effect is to separate one hazardous unit from another, avoiding the fire to spread. For instance, it is recommended to place a moderate or even lower hazard unit between two high hazard units as a way to reduce the escalation factor.

Another general recommendation is to locate large vessels and equipment that need overhaul maintenance, or cleaning unit boundaries to allow easy access of operators and cranes.
The study area contains heat exchangers, air coolers, vessels and pumps as can be seen in Figure 1 and Table 1. For the hazard classification of the equipment the following criteria was applied.

- **Heat exchangers**: typically, heat exchangers, other than air cooled, should be located at grade, grouped, clear and with access for cleaning and/ disassembly in order to facilitate the maintenance. Furthermore, consideration should be given for vapor cloud explosion risks as identified in the results of a risk assessment analysis. When it is not possible to locate exchangers beneath other facilities, the channel should be clear of overhead obstructions and readily accessible for removal.
- **Aircoolers**: air cooled heat exchangers may be located on the top level of pipe racks. Pumps for this case should be located such that the wet end is located outside the pipe rack and the driver should not extend more than 0.76 m (2 ft-6 in) inside the center line of the pipe rack column. Access to air cooled exchangers should be provided for cooler removal, cooler maintenance, fan motor maintenance, and header box access. It’s good engineering practice to avoid locating any equipment handling hydrocarbons close to an air cooler, due to the forced air flow created below it and the capability to faster increase the rate of an underdevelopment fire.
- **Vessels**: sufficient drop space, free of obstructions should be provided for removal of drum internals and relief valves.
- **Pumps**: pumps are considered high hazard if one of the three following aspects is met: Pump handling flammable and combustible liquids, operating at temperatures above 500°F (260°C) or above the product auto-ignition temperature. Pump handling flammable and combustible liquids and operate at pressures above 500 psi (34.5 bar). Pump Handling liquefied flammable gases. All other pumps handling flammable or combustible liquids are considered intermediate hazard. Canned and magnetic pumps are classified as lower fire hazard with no need of minimum spacing requirements.

According to the hazard classification, the industry guideline (GE GAP, 2001) offers a minimum inter-spacing requirement between equipment in oil and chemical plants that will be followed in this study. The distances differ depending on the type of equipment and degree of hazard. It is important to say that the spacing can be increased where appropriate (e.g. after QRA results).

2.3 Original layout

Figure 1 presents the original layout of a small part of the petrochemical unit chosen as the study area for the demonstration of the inherent safety approach. In this region the following equipment were situated: seven heat exchangers (H-001/002/003/004A/B/005A/B), two air coolers (A-001/002), one blowdown drum (V-001), five pumps (P-001A/B/C, P-002A/B) and two steam vessels (V-002/003)). Only the equipment highlighted in green were destroyed during the accident and/or are new to the process and thus will be studied in this paper. The layout was divided into 5 study areas to facilitate the results exhibition.

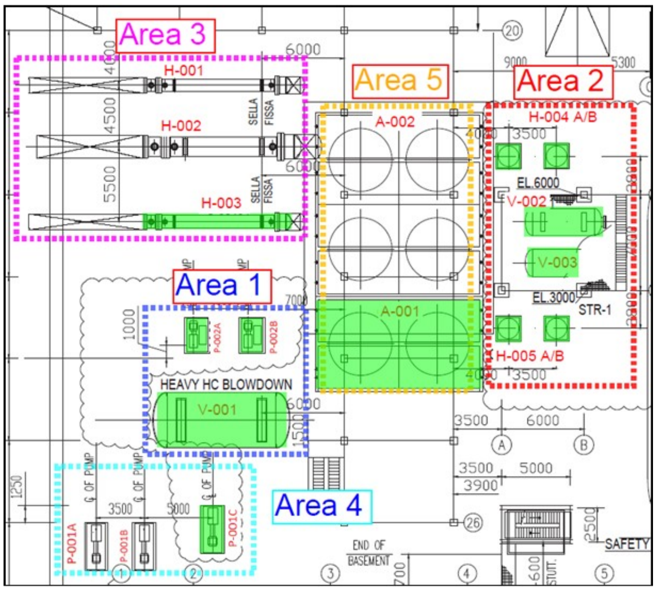

Figure 1: Original layout of the study area

Table 1 presents the process conditions and service of all equipment. It can be noticed that almost all equipment handle hazardous fluids in extreme temperature and pressure conditions which makes a few of them a potential source of leak.

Table 1: Process conditions and service of equipment under study

Equipment	Type	Service	Temperature (ºC)	Pressure (barg)	Area
H-001	Heat Exchanger	Diesel, vacuum gasoil	Shell:315 Tube: 195	Shell: 15.5 Tube: 42	3
H-002	Heat Exchanger	H2S, C1-C4, Naphtha, Kerosene, diesel, vacuum gasoil, water	Shell: 316 Tube: 218	Shell: 10 Tube: 41	3
H-003	Heat Exchanger	Heavy vacuum gasoil	Shell: 190 Tube: 258	Shell: 12.6/Tube: 15.5	3
H-004 A/B	Heat Exchanger	Vacuum gasoil	Shell: 195 Tube: 300	Shell: 13 Tube: 10	2
H-005 A/B	Heat Exchanger	Hydrogen, H2S, C1-C4, Naphtha, Kerosene, Fuel gas, diesel, vacuum gasoil, water	Cold side: 220 Hot side: 425	Cold side: 23.2 Hot side: 9	2
A-001	Aircooler	Naphtha, Kerosene, diesel, vacuum gasoil	190	1	5
A-002	Aircooler	Kerosene, diesel, vacuum gasoil	114	14	5
V-001	Blowdown Drum	Hydrogen, H2S, C1-C4, Naphtha, Kerosene, Fuel gas, diesel, vacuum gasoil, water	250	0.5	1
V-002	Vessel	Water	195	13	2
V-003	Vessel	Water	220	22	2
P-001 A/B/C	Pump	Water	30	2	4
P-002 A/B	Blowdown Pump	Naphtha, Kerosene, Fuel gas, diesel, vacuum gasoil	250	23.7	1

2.4 Hazard Classification

In Area 1 is located the heavy blowdown system, with one drum (V-001) and two pumps (P-002A/B). The operation occurs in temperatures higher than the flash point, and considering that V-001 has a large inventory (100 m^3) it is considered a high risk equipment since it is a potential source of leak. The pumps operate with a capacity higher than 45m^3/h and are considered an intermediate hazard.
In Area 2 are placed four heat exchangers (H-004A/B and H-005A/B) that handle hydrocarbons and two steam water generator vessels, V-002 and V-003. The vessels are located in elevated structures of six and three meters respectively. They are not considered hazardous but they are large and heavy equipment.
Area 3 contains three heat exchangers (H-001, H-002 and H-003). All of them handling hydrocarbons with temperature higher than the flash point and inventory higher than 5 m3, which is considered high risk source of leak.
In Area 4 are located the cooling water booster pumps (P-001A/B/C), not considered hazardous.
Finally in Area 5 are placed two air coolers (A-002 and A-001), both handling hydrocarbons. It is considered a high risk area.

2.5 Spacing study between equipment from original layout

After the hazard classification it is possible to analyze the minimum spacing between the equipment. Figure 2 presents the results. In all cells that contain the word “ok” the spacing fulfil the minimum safety requirements. The cells filled with “NA” (in red) highlight the cases where the minimum distance was not achieved. The empty cells refer to the equipment not damage and thus not analyzed in this study.
In all “NA” cases, the minimum distance should be five meters (GE GAP, 2001). It can be seen that the major issue refers to the distances from Area 5 (air coolers A-002 and A-001). Firstly the heat exchangers H-003, H-004A/B and H-005A/B are located too close to the air cooler A-002. Three of them within less than 2 meters. Besides that, all of them handle hydrocarbons which, together with the forced air flow below the air coolers, increases the risk of fire escalation.
Secondly is the nearby location of the blowdown drum V-001 and pump P-002B, as well as the heat exchangers H-005A/B from the air cooler A-001. The first two pieces of equipment are considered highly hazardous because they both handle flammable fluids in temperature higher than the flash point. Furthermore, the heat exchangers H-005A/B are spiral type, and require frequent maintenance.

H-001[1]	---																
H-002[1]		---															
H-003	ok	ok	---														
P-002A	ok	ok	ok	---													
P-002B	ok	ok	ok	ok	---												
V-001	ok	ok	ok	ok	ok	---											
P-001A[1]			ok	ok	ok	ok	---										
P-001B[1]			ok	ok	ok	ok		---									
P-001C	ok	ok	ok	ok	ok	ok	ok	ok	---								
A-002[1]			NA	ok	ok	ok			ok	---							
A-001	ok	ok	ok	ok	NA	NA	ok	ok	ok	ok	---						
H-004A	ok	ok	ok	ok	ok	ok	ok	ok	ok	NA	ok	---					
H-004B	ok	ok	ok	ok	ok	ok	ok	ok	ok	NA	ok	ok	---				
V-002	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	---			
V-003	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	---		
H-005A	ok	ok	ok	ok	ok	ok	ok	ok	ok	NA	NA	ok	ok	ok	ok	---	
H-005B	ok	ok	ok	ok	ok	ok	ok	ok	ok	NA	NA	ok	ok	ok	ok	ok	---
	H-001	**H-002**	**H-003**	**P-002A**	**P-002B**	**V-001**	**P-001A**	**P-001B**	**P-001C**	**A-002**	**A-001**	**H-004A**	**H-004B**	**V-002**	**V-003**	**H-005A**	**H-005B**

Figure 2: Safety distance analysis of the original layout (GE GAP, 2001)[1]

3. Results

3.1 New layout proposal

After careful examination of the original design and applying the inherent safety methodology described in section 2.2 a new layout was proposed in Figure 3.

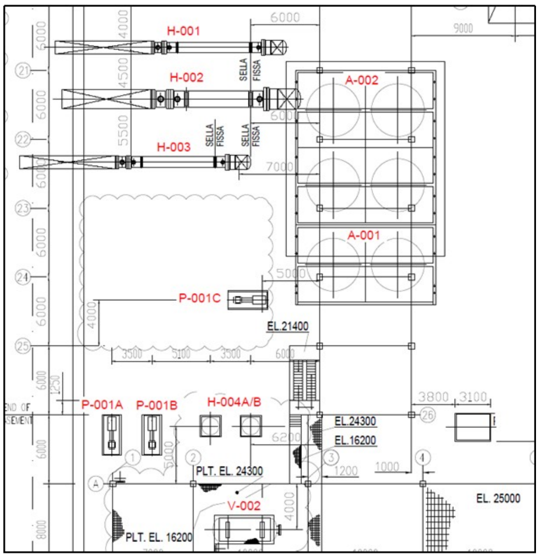

Figure 3: Inherent safer layout proposal

The blowdown drum V-001 and pumps P-002A/B from Area 1 were moved further away from the air cooler A-001 and have now a dedicated area just for the blowdown distant from any air cooler, eliminating the risk of fire escalation from this region.
All equipment placed in Area 2 were relocated away from the air coolers A-001 and A-002 to fulfil the safety distance requirements. The heat exchangers H-004A/B are now located in Area 4. Steam vessel V-002 previously located in an elevated structure is now below Area 4 at ground level. Vessel V-003 and heat exchangers H-005A/B are placed elsewhere in the unit for better accessibility.
There is a slight modification in Area 3. H-003 was moved a few meters away from A-002. The distance now corresponds to four meters and cannot be higher because of process reasons. It is better than in the original layout but still does not fulfil the requirement of five meters. In this case it is recommended to improve the

[1] Equipment not in bold were not analysed in the safety distance study because was not destroyed during the accident and thus cannot be relocated.

fireproofing requirements in the new and existing structures/supports in this region according to API 2218 (API, 2013).

In order to lower the high risk areas, pump P-001C (not hazardous) from Area 4 is relocated to Area 1 within the minimum spacing requirement from A-001. In pump P-001C original location is now the heat exchangers H-004A/B as already mentioned.

Finally Area 5 did not suffer any modification, since all the neighboring equipment were moved which eliminates the fire escalation from Area 2 and decreases the fire escalation from Area3.

Overall the balance between high/moderate/low risk areas is improved. The new layout is less crowded easing the maintenance/inspection rounds and sample assessment. Additionally the rate of gas clouds and/or plumes dilution was increased.

4. Conclusions

A good layout with sufficient spacing between hazards, equipment and units can reflect in several benefits. This work illustrated the advantages of using inherent safety to design the unit layout in the FEED phase of a project. The use of the principal “avoiding knock-on effects” can contribute to build a safer design and operation by minimizing the domino effect in case of a fire in one equipment/section of the plant.

The new layout proposed was less crowded and offered a better separation of hazardous risk areas from each other. With this new configuration a number benefits were achieved. They include the reduction or even elimination of fire escalation risk; less explosion damage since overpressure from an explosion decreases rapidly with distance; easier access to equipment for maintenance, sampling, inspection and firefighting purposes; decrease of radiation intensity in other areas; higher dilution rate of gas clouds or plumes; and easier spill fire control in open areas.

This study was done not considering the results of a quantitative risk assessment, which can change the scenario and even increase the safety distances. It is important to mention that by using the inherent safety approach to design a layout does not mean that the process is safe, but it is indeed safer.

Other inherent safety principles can also be applied in this phase of the project, for example by reducing the leak points of pipe connections making them welded instead of flanged. Another approach can be in the material selection, increasing the reliability of equipment against corrosion, overpressure or high temperatures. These few modifications would make the process even safer.

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