

Optimal Layout of a LPG Storage Facility to Minimize Risk to Human

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Abstract— Application of LPG is extensive in domestic and industrial use. Because of the wide range application of LPG, the quantity of LPG increases every year. Due to the characteristics of LPG that are flammable and explosive, the LPG need to be handle with safe. Storage facility plays an important roles in the industry especially petrochemical product and gaseous product. Storage facility functions are to accumulate industrial product. In chemical industry, all product contain hazardous material that can cause vast impact and disaster to human and environment since they are the sources of catastrophic accident like fire and explosion and they also can cause harm to human health when toxic release occur. The chemical plants facility layout usually have been set up and installed without considering the optimal siting based on minimum risk consequences value. This research aim to identify optimum location for a LPG storage facility in order to minimize the risk to human. Here, in this work, probit equations were applied to estimate damage produced by thermal radiation on human (for second degree burns and lethality). An analysis is then performed to evaluate the percentage of affected people in the LPG damage, results shows the optimal layout consists of low percentage of affected people.

Keywords— Optimal layout, LPG, Storage facility, Risk consequences value, Probit.

I. INTRODUCTION

Safety is the first thing that need to be considered in the chemical industry world. During the last decades several accidents have occurred in industrial facilities, which have represented several fatalities and high economic losses [12]. The inadequate facility layout has been identified as one of the most important causes of accidents [12]. Incident investigation is nowadays widely recognized as an important part of a comprehensive and efficient process safety management [2]. The interest in take care of every human safety, property and also environment have become a global issue. Safety awareness towards chemical hazards is acknowledges internationally especially with resulting bad chemical accidents. This also made the public awareness to chemical industrial safety to rise.

Chemical industry involves activity like fabricating and deal with many hazardous material which contribute to higher risk to chemical accidents. Therefore the knowledge of safety is required to monitor and control the hazard in the chemical industry. Effective method of safety management should avoid accidents from happening and minimize adverse effects of accidents on human, properties and environment. Different techniques have been developed in recent years and they are widely available in the literature [3]. Facility siting focuses on identifying hazard scenarios that could have significant impacts on process plant buildings and building occupants [9]. Chemical process layout optimization is a task to efficiently determine the relative position of the equipment or facility of the process [7]. The arrangement of process

equipment and buildings can have on a large impact on plant [10]. The overall layout development should incorporate safety considerations while providing support for operations and maintenance [10]. Facility layout represents an effective option to reduce the risk of accidents in production systems [5]. Starting with the full plant flow diagrams, this activity has been associated with the process design stage: the process design should not be declared as done if the plant layout has not been covered. [16]. One of the major causes of the accident in Flixborough (1974), which resulted in 28 fatalities, and Pasadena Texas (1989), which led to 24 fatalities, was due to inadequate separation distances between occupied buildings (control rooms) and the nearby process equipment [6,10]. The siting of a hazardous plant near a densely populated area has resulted in fatal disasters, most notably in Seveso (1976) and Bhopal (1984) [4, 10]. In the toxic gas released in Bhopal incident, major victims were not only workers within the plant but also residents who lived in the surrounding area [8, 10]. . In Chiba, a refinery operated by Cosmo Oil lost 17 LPG storage vessels which were either heavily damaged or totally destroyed by fires and explosions in the refinery [11]. Therefore, civilians who didn't partake in the risk assessment during the layout [10].

Among varied chemical industrial sites, storage facility have been the highest number for catastrophic accidents. Configuring process layout is an essential part of plant design and one of the most important task before plant construction where in the past heuristic and graph methods were used for facility layout which only considered best use of the available plant [13-15]. Storage facility is the place where all petrochemicals like oil and gaseous product like LPG are being stored. The product are being transported to the customers respectively. A storage area typically includes tank and for LPG it is usually in cylindrical tank form. An area generally includes tanks, either on top of ground or underground, and gantries for discharging the chemical product to the road tankers or alternative vehicles (such as barges) or pipelines.

Storage facility area unit typically settled near the oil refineries or in locations wherever marine tankers containing products will discharge their load. Some storage facility unit are associates to the pipelines that of the process plant. Storage facility play a crucial role within the supply of crude oil, fossil fuel and many chemical product. Like underground gas storage, they can facilitate scale of the impact of travel period, and can increasingly turning into a crucial energy commerce tool of the area that contains an outsized amount of fuel and hazardous chemicals. Different types of hazards which can cause severe impacts on human health, environmental and properties. Hazards contribute by the storage facility rely upon the material and on the sort of storage.

Liquefied petroleum gas (LPG) is a clean fuel and is used as a multipurpose material in the industrial chemical, commercial, residential, transportation and other sectors of economy [18]. LPG (Liquefied Petroleum Gas) is a mixture of gaseous hydrocarbons, produced from natural gas and oil extraction (66%) and from oil

refining (34%) [14]. It occurs naturally in oil and gas fields and is separated from the other components during the extraction process from the oil or gas field.

LPG is also one of the by-product of the oil refining process. Liquefied Petroleum Gas contains Propane (C_3H_8) and Butane (C_4H_{10}). The molecules of propane and butane can be seen in figure 1. They can either stored separately or together as a mix. LPG can be liquefied at normal temperature by application of a moderate pressure increase, or at normal pressure by application of cooling using refrigeration. Butane and propane are gaseous alkanes. Butane is present natural gas and can also be obtained when petroleum is refined. But propane can be obtained only when petroleum is refined. Propane is colourless. Butane is usually supplied to customers in cylinders. Propane can be supplied in cylinders or in bulk for storage in tanks at the customer's premises. All hydrocarbons in which the carbon atoms are joined by a single bond have a name which end in -ane, such as methane ethane and butane.

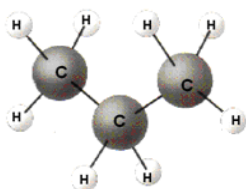


Figure 1. (a) Propane (C_3H_8)

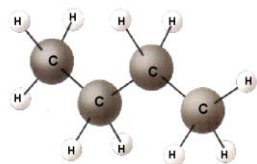


Figure 1. (b) Butane (C_4H_{10})

LPG exists in 2 forms: fuel and gas. The distinction in their properties means they're significantly suited to specific uses. Propane's lower boiling purpose suits out of doors storage and is primarily used for heat, preparation and diverse business applications. Butane that does not add colder conditions, is best used inside and is ideal for powering indoor transportable heaters. LPG's characteristics enable it to be hold on and transported in numerous ways based on it uses. For heating and bigger industrial applications, LPG are hold on in bulk storage vessels, either on top of or below the bottom. Wherever less gas is needed, or house is at a premium, there's a whole vary of transportable cylinder sizes out there. In developing and developed countries such as in Malaysia, LPG is an essential fuel. LPG is a mixture of commercial butane and commercial propane having both saturated and unsaturated hydrocarbons. Table 1 shows the properties of LPG.

Types of LPG are strictly depends on the gaseous that present inside the LPG. It can also can be determine from the origin of the gaseous and what the gaseous are being employed for. In normal conditions, LPG accommodate mix of gaseous including butane and propane and a few amount other gaseous that are naturally present. In some country likes in UK, LPG cylinder that contains butane are in blue colour. Whereas LPG cylinder that contain propane are in red or green colour.

According to (Shah Md. Toufiq et al.) designing of process plants is a complex and demanding task where configuring process layout is an essential part of plant design and one of the most important tasks before plant construction [14]. Many optimization method have been proposed before this from the researchers for instance facility layout optimization based on risk and analysis

[14]. In the present work, probit equations were applied to estimate damage produced by thermal radiation on human (for second degree burns and lethality). To evaluate the percentage of affected people in the LPG damage, the probit obtained were evaluated. In this research, the plant layout of Shell Refinery Sdn Bhd at Port Dickson, Negeri Sembilan was adopted for the purposed.

Table 1. Properties of LPG

Properties	Data
Boiling point	42-0 ° C
Flash point	-60 ° C
Ignition temperature	410-580 ° C
Colour	Colourless
Odour	Faint smell
Toxicity	Slightly toxic
Heat of combustion	46050j/kg
Density	1.898 kg/m ³

II. METHODOLOGY

A. Obtain detail about the process plant description

In this research, the plant layout of Shell Refinery Sdn Bhd at Port Dickson, Negeri Sembilan was adopted for the purposed. The following steps were carried out to optimize the layout of the chosen facility within the processing area. At first, all the significant information about the process area, for instance plant layout, process description, chemical and physical properties were obtained. The process plant layout were needed to obtain the locations of the facilities within the plant including control room, process area, administration office, canteen and parking lots. The process area layout which includes the coordinate of major equipment such as reactor, column and storage tank were also needed. In this work, six building within the plant have been choose to evaluate it percentage of affected people. Figure 2 shows the facilities in the plant. In addition, chemical and physical characteristic of LPG and the reactions that occurred in the process were obtained. The chemical and physical characteristics of LPG can be obtained from LPG safety data sheet.



Figure 2. The facilities in the plant

B. Identify major hazardous installation unit

All major hazardous installation unit within the process plant area were identified. There was a massive amount of the total hazardous installation unit in Shell Refinery.

C. Find total process area and discretize the area

Next total processing unit of LPG Caustic Treating Facilities (Unit 7600) was found out. The total area of Shell Refinery Sdn Bhd is 70000 m² while the total area of LPG Caustic Treating Facilities (Unit 7600) is 4000 m². The entire process area of LPG Caustic Treating Facilities was discretized to small grid that still available within the entire area of the Shell Refinery Sdn Bhd. In this work, the LPG Caustic Treating Facilities (Unit 7600) that having one hundred (10m x 10 m) square grid was identified in this work. Figure 3 shows the discretized grid area.



Figure 3. The discretised grid area

D. Selection of critical units and facilities

The most critical unit of the Shell Refinery Sdn Bhd area were identified based on the distance between public area and operating area and temperature. For this research, the existing LPG Caustic Treating Facilities (Unit 7600) was identified for layout optimization. Find total area and discretize the area. In this work, 10 grids within the Shell Refinery Sdn Bhd were adopted in this optimal layout work.

E. Risk estimation

The damage caused by the thermal radiation on human for second degree burns and lethality were considered to estimate the risk in the discretized area. ALOHA (Area Locations of Hazardous Atmospheres) software is used to obtain the value of thermal radiation. The time exposure is kept constant which is 15 seconds. Probit analysis is then being carried out. Two different probit analysis were used.

1. Probit due to second degree burns:

$$Y = -43.14 + 3.02 \ln(Q_{dose}^{4/3} t)$$

2. Probit due to lethality:

$$Y = -36.38 + 2.56 \ln(Q_{dose}^{4/3} t)$$

Where Q = Thermal radiation (kJ/m²)
 t = time exposure

F. Display risk mapping

The probit analysis performed were used to evaluate the percentage of affected people in the LPG damage. The probit is converted to percentage to determine the consequences. The damage which is the number of people affected can be evaluated in percentage. Analytical expressions for converting both probit variables to percentages affected people and percentages of affected people to probit variables:

G. Optimization based on minimum risk score value

Based on the percentages from the analytical expression, the lowest percentage value of between the 10 discretized grids was identified. The identified grid was the optimal sitting for the LPG Caustic Treating Facilities (Unit 7600).

III. RESULTS AND DISCUSSION

The risk score for catastrophic failure due to fire and explosion were determined. The thermal radiation for the source of explosion was considered. For LPG Caustic Treating Facilities (Unit 7600) the consequence blast overpressure due to BLEVE was determined using ALOHA. A continuous release from top of the LPG tank was assumed in the simulation. The wind velocity, atmospheric temperature and relative humidity were taken to be 1.5 m/s, 31°C, and 60%, respectively, for worst case scenarios. A cylindrical tank of 2.5 m Diameter and 12 m height which contains the LPG was considered. The consequences of these units were calculated considering the worst case scenarios for each grids. Figure 4 shows the combined threat zone plots for explosion for these for units in the grid area 1, OptRisk 1. The red rectangle represents the thermal radiation for second degree burns and the yellow rectangle represents the people that affected the pain consequence of the explosion. Different facilities have different distance from the source points. Therefore the heat expected which are the thermal radiations are different.

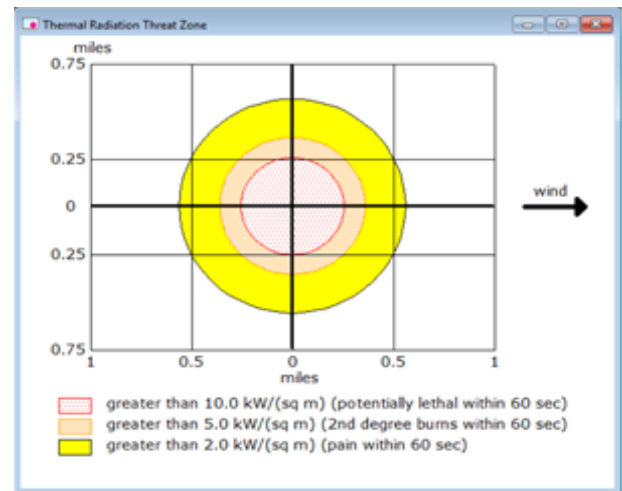


Figure 4. Threat zone for grid 1

After that, the probit function risk scores for second degree burns and lethality were calculated. The number of people affected by the damaged are converted to percentage. Table 2 shows the probit second degree burn percentage of each facilities at each grids. The highest percentage represent highest number of people affected with second degree burn. Meanwhile, the lowest percentage represent the least number of people affected with second degree burn from the source point, the grid OptRisk. The results shows OptRisk 1 has the highest percentage of probit for second degree burn and OptRisk 10 has the lowest percentage of probit for second degree burn.

Table 3 shows the probit lethality percentage of each facilities at each grids. The highest percentage represent highest number of people affected with lethality. Meanwhile, the lowest percentage represent the least number of people affected with lethality from the source point, the grid OptRisk. The results shows OptRisk 1 has the highest percentage of probit for lethality and OptRisk 10 has the lowest percentage of probit for lethality.

For each facilities, the probit percentage were rank in table 4 for second degree burn and table 5 for lethality. In the optimum layout, LPG Caustic Treating Facilities (Unit 7600) optimum location was in grid OptRisk 10 because the consequences for every building are the lowest for both second degree burn and lethality impact during explosion.

IV. CONCLUSION

In this work an optimal layout work has been proposed for an LPG layout facility using risk value analysis. The location of the LPG storage facility was optimized with respect to the least value of risk analysis. Risk mapping for each grid was evaluated using ALOHA for BLEVE explosion and the risk value were analyzed from the probit due second degree burns and probit due to lethality. This work is based on the methodology proposed by Jung et al .the methodology that has been proposed is to stimulate in the real plant scenario. The optimization of the plant layout is an important approach in order to minimize risk of hazardous material in a chemical plant. This works plays an important role in integrating safety in the design layout of the LPG storage facility.

Table 2 Percentage of probit for second degree burn

	Administration office	Contractor office	Canteen	Laboratory	Car park 1	Car park 2
Opt risk 1	54.49%	100.00%	99.98%	43.59%	29.97%	99.51%
Opt risk 2	20.08%	100.00%	100.00%	32.42%	11.66%	99.93%
Opt risk 3	7.02%	100.00%	100.00%	16.98%	3.93%	99.38%
Opt risk 4	1.19%	100.00%	100.00%	24.85%	0.81%	99.82%
Opt risk 5	0.00%	99.98%	99.99%	0.05%	0.00%	98.62%
Opt risk 6	0.00%	97.97%	96.72%	0.00%	0.00%	88.28%
Opt risk 7	0.00%	84.88%	88.91%	0.00%	0.00%	69.29%
Opt risk 8	0.00%	42.46%	51.64%	0.00%	0.00%	30.28%
Opt risk 9	0.00%	1.78%	2.09%	0.00%	0.00%	0.71%
Opt risk 10	0.00%	0.74%	0.97%	0.00%	0.00%	0.34%

Table 3 Percentage of probit for lethality

	Administration office	Contractor office	Canteen	Laboratory	Car park 1	Car park 2
Opt risk 1	32.35%	100.00%	99.29%	43.59%	15.88%	94.93%
Opt risk 2	10.30%	100.00%	99.96%	32.42%	5.88%	98.42%
Opt risk 3	3.56%	100.00%	99.98%	16.98%	2.04%	94.12%
Opt risk 4	0.67%	100.00%	99.99%	12.93%	0.48%	97.20%
Opt risk 5	0.00%	99.30%	99.58%	0.04%	0.00%	90.58%
Opt risk 6	0.00%	88.16%	84.31%	0.00%	0.00%	67.54%
Opt risk 7	0.00%	62.59%	68.53%	0.00%	0.00%	44.98%
Opt risk 8	0.00%	23.73%	30.20%	0.00%	0.00%	16.07%
Opt risk 9	0.00%	0.97%	1.13%	0.00%	0.00%	0.42%
Opt risk 10	0.00%	0.44%	0.56%	0.00%	0.00%	0.22%

Table 4.1

	Administration office	
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OptRisk 1	54.49%	1
OptRisk 2	20.08%	2
OptRisk 3	7.02%	3
OptRisk 4	1.19%	4
OptRisk 5	0.00%	5
OptRisk 6	0.00%	6
OptRisk 7	0.00%	7
OptRisk 8	0.00%	8
OptRisk 9	0.00%	10
OptRisk 10	0.00%	9

Table 4.2

	Contractor office	
OptRisk 1	100.00%	4
OptRisk 2	100.00%	3
OptRisk 3	100.00%	1
OptRisk 4	100.00%	2
OptRisk 5	99.98%	5
OptRisk 6	97.97%	6
OptRisk 7	84.88%	7
OptRisk 8	42.46%	8
OptRisk 9	1.78%	9
OptRisk 10	0.74%	10

Table 4.3

	Canteen	
OptRisk 1	99.98%	5
OptRisk 2	100.00%	3
OptRisk 3	100.00%	2
OptRisk 4	100.00%	1
OptRisk 5	99.99%	4
OptRisk 6	96.72%	6
OptRisk 7	88.91%	7
OptRisk 8	51.64%	8
OptRisk 9	2.09%	9
OptRisk 10	0.97%	10

Table 4.4

	Laboratory	
OptRisk 1	43.59%	1
OptRisk 2	32.42%	2
OptRisk 3	16.98%	4
OptRisk 4	24.85%	3
OptRisk 5	0.05%	5
OptRisk 6	0.00%	6
OptRisk 7	0.00%	7
OptRisk 8	0.00%	8
OptRisk 9	0.00%	10
OptRisk 10	0.00%	9

Table 4.5

	Car park 1	
OptRisk 1	29.97%	1
OptRisk 2	11.66%	2
OptRisk 3	3.93%	3
OptRisk 4	0.81%	4
OptRisk 5	0.00%	5
OptRisk 6	0.00%	6
OptRisk 7	0.00%	7
OptRisk 8	0.00%	8
OptRisk 9	0.00%	9
OptRisk 10	0.00%	10

Table 4.6

	Car park 2	
OptRisk 1	99.51%	3
OptRisk 2	99.93%	1
OptRisk 3	99.38%	4
OptRisk 4	99.82%	2
OptRisk 5	98.62%	5
OptRisk 6	88.28%	6
OptRisk 7	69.29%	7
OptRisk 8	30.28%	8
OptRisk 9	0.71%	9
OptRisk 10	0.34%	10

Table 5.1

	Admin	
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OptRisk 1	32.35%	1
OptRisk 2	10.30%	2
OptRisk 3	3.56%	3
OptRisk 4	0.67%	4
OptRisk 5	0.00%	5
OptRisk 6	0.00%	6
OptRisk 7	0.00%	7
OptRisk 8	0.00%	8
OptRisk 9	0.00%	10
OptRisk 10	0.00%	9

OptRisk 1	43.59%	1
OptRisk 2	32.42%	2
OptRisk 3	16.98%	3
OptRisk 4	12.93%	4
OptRisk 5	0.04%	5
OptRisk 6	0.00%	6
OptRisk 7	0.00%	7
OptRisk 8	0.00%	8
OptRisk 9	0.00%	10
OptRisk 10	0.00%	9

Table 5.2

	Contractor	
OptRisk 1	100.00%	4
OptRisk 2	100.0 %	3
OptRisk 3	100.00%	1
OptRisk 4	100.00%	2
OptRisk 5	99.30%	5
OptRisk 6	88.16%	6
OptRisk 7	62.59%	7
OptRisk 8	23.73%	8
OptRisk 9	0.97%	9
OptRisk 10	0.44%	10

Table 5.5

	Car park 1	
OptRisk 1	15.88%	1
OptRisk 2	5.88%	2
OptRisk 3	2.04%	3
OptRisk 4	0.48%	4
OptRisk 5	0.00%	5
OptRisk 6	0.00%	6
OptRisk 7	0.00%	7
OptRisk 8	0.00%	8
OptRisk 9	0.00%	9
OptRisk 10	0.00%	10

Table 5.3

	Canteen	
OptRisk 1	99.29%	5
OptRisk 2	99.96%	3
OptRisk 3	99.98%	2
OptRisk 4	99.99%	1
OptRisk 5	99.58%	4
OptRisk 6	84.31%	6
OptRisk 7	68.53%	7
OptRisk 8	30.20%	8
OptRisk 9	1.13%	9
OptRisk 10	0.56%	10

Table 5.6

	Car park 2	
OptRisk 1	94.93%	3
OptRisk 2	98.42%	1
OptRisk 3	94.12%	4
OptRisk 4	97.20%	2
OptRisk 5	90.58%	5
OptRisk 6	67.54%	6
OptRisk 7	44.98%	7
OptRisk 8	16.07%	8
OptRisk 9	0.42%	9
OptRisk 10	0.22%	10

Table 5.4

	Laboratory	
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Thank you to my supervisor

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