Consequences on port facilities of a tanker explosion

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Abstract

The explosion scenario of a 30,000 m^3 naphtha tanker that lay at anchor in port is simulated. The tanker geometry is enforced by a double steel plate, with the hazardous gas storage in the middle tanker containment. Baker's method was used to determine overpressures levels and damage distance from a potential confined vapour cloud explosion. The people vulnerability study at the port facility vicinity is also elaborated by using Probit equations. The explosion can be started by a simple electrostatic spark, human error, by sabotage or by acto of terrorism. Safety measures are recommended.
Keywords: risk analysis, fire, explosion, hazardous materials transportation, safety.

1 Introduction

Globalization has promoted an increase in the amount of hazardous materials transportation by road, air or sea. Great tankers transporting oil, petrochemical products and flammable gases, discharge these products in ports all over the world. At peace time this is a normal activity, but in conflict areas this simple activity may represent a great danger to port facility activities, its vicinity and materials that can result in a catastrophe. Besides process safety procedures, port security activities have also to be enforced in order to guarantee port safety. In Brazil, the International Ship and Port Security (ISPS) code regulations are attended to enhance maritime security, according to the International Maritime Organization (IMO) Diplomatic Conference of December 2002.

As accidents can happen, prevention studies can be performed to figure out fire or explosion damages extension. Risk analysis is a strong tool to help port

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safety and security. Consequence and vulnerability analyses are part of the risk analysis methodology [1, 2]. Baker's method [3] was applied to define physical impacts of the potential confined vapour cloud explosion. A vulnerability study was performed by using Probit [4] calculations to define the impact to port facility employees and to the near-by community. Finally, mitigation actions are recommended.

2 Risk analysis

Risk analysis methods are used to evaluate the confined explosion severity of naphtha reservoir installed inside a tanker. For confined vapour cloud explosions (CVCE) calculations model, we used Baker's method [3], which is a conservative approach, with added elements of the TNO multi-energy method [3]. Details of the method will not be described here. The method present results of the overpressure and impulse estimates due to the blast waves from the cylindrical reservoir rupture from pressurized gas, located at ground level. A ground level correction is also performed for the case studied. The method depends on the phase of the reservoir contents, its boiling point at ambient pressure, its explosion scenario critical and local temperatures and assumes that the flammable product combustion is complete.

2.1 Explosion scenario description

For the confined explosion scenario, it is assumed that the explosion will occur when the naphtha concentration inside the reservoir reaches the low flammable limit of 1.4% v/v. To the calculations, naphtha is considered as n-pentane. The maximum explosion pressure of n-pentane in air of 8.7 bar gauge [5] is considered in the calculations. The naphtha reservoir geometry is 12 m high with a squared bottom of 10 m. The gaseous phase volume of the naphtha reservoir is 1,200 m^3.

2.2 Calculation of the explosion energy

To calculate the explosion pressure attenuation of the naphtha reservoir, it is considered the naphtha combustion reaction presented in equation 1:

$$C_5H_{12} + \quad {}_8O_2 \quad + \quad N_2 \quad \text{-----}\rightarrow \quad {}_5CO_2 \quad + \quad {}_6H_20 \quad + N_2 \qquad (1)$$

$$1 \qquad 8 \qquad (0{,}79/0{,}21) \times 8 \qquad 5 \qquad 6 \qquad (0{,}79/0{,}21) \times 8$$

The naphtha combustion heat (ΔH) is 10,750 kcal/kg. The internal energy varies according to equation 2:

$$\Delta U = \Delta H - \Delta PV \qquad (2)$$

The moles number variation before and after the combustion is 2. The naphtha mass inside the reservoir will be calculated when it reaches the low flammable limit of 1.4% v/v (40,570 mg/m^3). For a reservoir of 1,200 m^3 this corresponds to 48.7 kg of naphtha. The internal energy variation corresponds to the liberated energy from the explosion, which is shown in equation 3.

$$\Delta U = -10,750\frac{kcal}{kg}(48.7kg)1,000\frac{cal}{kcal} - 1.987(373)(2) = \\ 5.23x10^8 cal = 2.2x10^9 J \quad (3)$$

The explosion energy must be corrected to the ground reflection effect, because the naphtha reservoir is not above ground level. For this reason, the explosion energy must be duplicated, resulting in 4.4 x 10^9 J. The input data to the Baker's method is shown in Table 1.

Table 1: Input data1.

Description	Value
Flammable substance	Naphtha (n-pentane)
Local temperature (^{o}C)	22.7
Tanker gaseous volume (m^3)	1,200

3 Results

The Baker's method calculation results are shown in Table 2. The resulting explosion overpressure attenuation is presented in Figure 1.

Table 2: Explosion overpressure results.

Physical Impact Description		Value
Naphtha Flammable Mass (kg)		48.7
Vapour Cloud Explosion (VCE)	Distance to 3.84 kgf/cm^2	20 m
	Distance to 0.53 kgf/cm^2	40 m
	Distance to 0.3 kgf/cm^2	60 m
	Distance to 0.16 kgf/cm^2	100 m
	Distance to 0.07 kgf/cm^2	160 m

1 kgf/cm^2 = 10^5 Pascal.

3.1 Vulnerability results

Eisenberg et al. [4] report the following Probit equations to:

$$\text{Lung haemorrhage: } Pr = -77.1 + 6.91 \times \ln (P) \quad (4)$$

$$\text{Eardrum rupture in humans: } Pr = -15.6 + 1.93 \times \ln (P) \quad (5)$$

where: P = peak overpressure, in Pascal or kgf/cm^2.

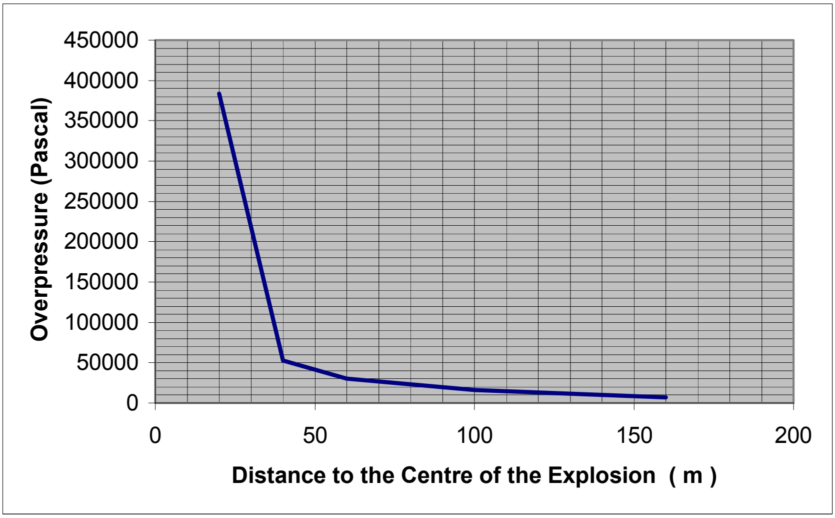

Figure 1: Overpressure attenuation graphic.

Table 3: Vulnerability results.

Effect	Overpressure (kPa)	Probability (%)	Distance (m)
Lung haemorrhage	100	1	36
Eardrum rupture	100	95	36
Eardrum rupture	13.8	1	130

4 Mitigation and conclusions

The port facility supervision work is very important to avoid security violations such as acts of terrorism or sabotage. Closed circuit TV (TVCC) with backup installed on port facility as well as intrusion supervision system are reliable systems against undesirable actions. On the process side, static electricity represents a hazard. Equipment must be earthed and the area of the tanker discharge must be electrically classified according to IEC norm 60079-10 [6].

To enhance port facility safety, the following documents must be prepared: risk analysis, security assessment, security plan and to appoint the port facility security officer.

The physical impact of the naphtha tanker explosion on port facility is equivalent to the mass of 940 kg TNT.

From Figure 1, it is concluded that the safe distance is normally considered at the overpressure peak of ca. 0.02 kgf/cm^2. At this level, the probability 95% of no serious damage is 320 m from the tanker. At overpressure levels of 0.16 kgf/cm^2 reparable damages to structures occur. Above this level, overpressure peaks results in the total destruction of buildings. With regards to human safety, the probability of lethality of 1% or 95% eardrum rupture from direct blast are reached at 36 m from the tanker and up to the distance of 130 m from the tanker, people can be thrown down to the ground that can cause secondary injuries.

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