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Determination of risk zones by thermal flow, generated by BLEVE to a tank with LP gas, using mathematical models and ALOHA® software

Determinación de zonas de riesgo por flujo térmico, generada por BLEVE a depósito con gas LP, utilizando modelos matemáticos y software ALOHA®

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Abstract

The objective of this research work was to determine the risk areas for thermal radiation, generated by BLEVE and fireball in a 13,000 L tank with LP gas, located in the municipality of Nicolás Romero, State of Mexico, from of mathematical models and the ALOHA® software, in order to compare and analyze the results obtained.

In order to carry out the solution of this work, first the event and hypothetical scenario in which the type of applicable source was defined, which is BLEVE followed by fireball, is judged, and later different data were determined for the present study. Based on the above, the corresponding modeling was carried out to determine the risk zones of affectation by thermal radiation, the dimension of the diameter and the duration of the fireball.

As a result, a comparative analysis was obtained in which it was possible to observe and conclude that the results obtained through mathematical models, in general, present more conservative results, compared to the modeling used by ALOHA®.

BLEVE, Fireball, Thermal Flux inductor, Integrate, Simulations

Resumen

El objetivo del presente trabajo de investigación fue determinar las zonas de riesgo por radiación térmica, generada por BLEVE y bola de fuego (fireball) a depósito de 13,000 L con gas LP, ubicado en el municipio de Nicolas Romero, Estado de México, a partir de modelos matemáticos y el software ALOHA®, con el fin de comparar y analizar los resultados obtenidos.

Para poder llevar a cabo la solución del presente trabajo, primero se determinó el evento y escenario hipotético en el cual se definió el tipo de fuente aplicable, que es BLEVE seguido por bola de fuego, y posteriormente se determinaron diferentes datos para el presente estudio. A partir de lo anterior, se realizaron los modelados correspondientes para la determinación de zonas de riesgo de afectación por radiación térmica, dimensión del diámetro y duración de la bola de fuego.

Como resultado, se obtuvo un análisis comparativo en el cual se pudo observar y concluir, que los resultados obtenidos por medio de modelos matemáticos, de forma general, presentan resultados más conservadores, comparado con el modelado utilizado por ALOHA®.

Bola de fuego, Inductor de flujo térmico, Integrar, Simulaciones

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Introduction

LPG is a petroleum derivative composed of propane and butane gases. For ease of handling, it is converted to a liquid state through compression and cooling, from which it takes the name liquefied petroleum gas or LP gas (CENAPRED, 2019).

LPG has been used for industrial and domestic purposes since the beginning of the 20th century (CONUEE, 2015).

Liquefied Petroleum Gas can go into BLEVE (Boiling Liquid Vapour Expansion Explosion) within minutes, so the main hazards are: Fire, thermal radiation from fire, explosion and projectiles (PEMEX, 2015).

BLEVE are among the most feared events, when there are closed tanks of hazardous materials in liquid or gaseous state that are exposed to fire (Garza, 2015). It corresponds to a violent vaporisation of an explosive nature after rupture (loss of confinement) of a tank containing a liquid at a temperature significantly higher than its normal boiling point at atmospheric pressure (AIChE/CCPS, 2010).

In the case of flammable substances, BLEVE is often followed by a fireball (Salla, 2006). Moreover, the combined action of a BLEVE fireball can be summarised in the following effects (Casal, 2017):

- Thermal radiation.
- Pressure wave.
- Flying fragments.

Likewise, in this document, the simulation of a possible thermal risk, hypothetical scenario, is determined for a storage tank of 13,000 L of LP Gas, located in the municipality of Nicolás Romero, State of Mexico.

The purpose of this simulation is that from a hypothetical scenario, a BLEVE and a fireball are produced, and from mathematical models and the ALOHA® software, a comparison of results is made, in which the areas and/or zones of affectation by thermal radiation are determined. These zones and

These zones and their respective radiation parameters are defined on the basis of the Civil Protection Technical Standard NTE-002- CGPC-2018. It is worth mentioning that the different zones mentioned correspond to the lethality zone, risk zone and buffer zone, corresponding to the risk of BLEVE due to the effect of thermal radiation.

Methodology

Hypothetical event

The event is considered in which the LPG tank, with a capacity of 13,000 L, is exposed to fire, due to the domino effect of another event.

Hypothetical scenario

Derived from this overheating, the substance enters the boiling liquid expansion phase, thus generating a violent explosion, denominating this BLEVE type effect which is followed by a fireball.

Collection of miscellaneous data for modelling

The various data and values needed to carry out the respective modelling are as follows:

a) Volume of the liquid (propane) = 13 m3

b) Density of liquid at 15°C = 510 kg/m3

c) Radiative fraction of heat of combustion = 46,354.854 kJ/kg

d) Partial vapour pressure of water = 785.517022 Pa

e) Relative humidity = 52%.

f) Ambient temperature = 285.65 K

Mathematical modelling

In order to carry out the mathematical modelling of the effect of BLEVE by thermal radiation, the following concepts were determined.

Physical parameters of BLEVE

Useful formulae for the physical parameters of BLEVE are (AIChE/CCPS, 2000):

Maximum fireball diameter D_{Max} (m):

ISSN 2444-4928

June 2023, Vol.9 No.23 29-35

$$D_{MAX} = 5.8\, M^{1/3} \quad (1)$$

Duration of fireball combustion t (s):

$$t_{BLEVE} = 0.45\, M^{1/3} \text{ para M < 30,000 kg} \quad (2)$$

$$t_{BLEVE} = 2.6\, M^{1/3} \text{ para M > 30,000 kg} \quad (3)$$

Where:

M = is the initial mass of the flammable liquid (kg).

Height of the centre of the fireball H_{BLEVE} (m):

$$H_{BLEVE} = 0.75 \quad (4)$$

Heat radiation flux of the fireball BLEVE

Figure 1 shows the geometrical relationship (distance) from the centre of the fireball to the receiver; X_C (m).

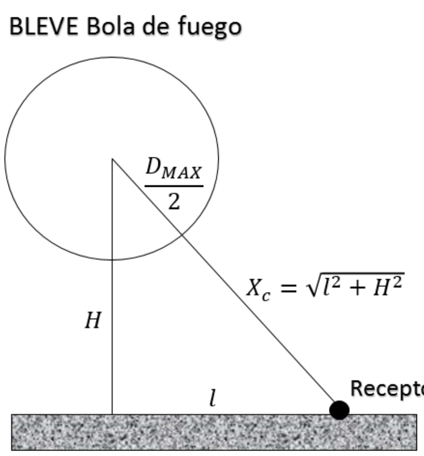

Figure 1 Geometry of the centre of the fireball at the receiver

In other words:

$$X_c = \sqrt{l^2 + H^2} \quad (5)$$

Where:

l : Distance from the point on the ground

Hymes (1983, as cited in Garza, 2015) gives an equation for estimating the heat flux to the surface, based on the radiant fraction of the total heat of combustion:

$$E_r = \frac{2.2\tau_a R H_c M^{\frac{2}{3}}}{4\pi X_c^2} \quad (6)$$

Where:

$\boldsymbol{E_r}$ = Radiant flux received by the receiver (W/m^2)

τ_a = Atmospheric transmissivity (unitless)

R = Radiant fraction of heat of combustion (without units)

H_c= Net heat of combustion per unit mass (J/kg)

M = Initial mass of fuel in the fireball (kg)

The atmospheric transmissivity can be expressed from the following equation (CCPS, 2000):

$$\tau_a = 2.02 \left[P_w((H^2 + l^2)^{\frac{1}{2}} - \frac{D_{MAX}}{2})\right]^{-0.09} \quad (7)$$

Where:

τ_a = Atmospheric transmissivity (unitless)

P_w = Partial pressure of water (Pascals, N/m^2)

H = Height of the center of the fireball H (m)

l = Distance from point on the ground, directly below the center of the fireball, to the receiver

Mudan and Croce (1988, as cited in AIChE/CCPS, 2000) give an expression for the partial pressure of water as a function of relative humidity and air temperature:

$$P_w = 1013.25(R_H)exp\left(14.4114 - \frac{5328}{T_a}\right) \quad (8)$$

Where:

P_w = Partial pressure of water (Pascals, N/m^2)

R_H = relative humidity (%)

T_a = Room temperature (K)

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Modelling the event using ALOHA

The ALOHA® software was used to simulate the hypothetical scenario of interest, based on the determination of the thermal radiation risk zones. To carry out the simulation, the methodology used to obtain the results consisted first of establishing the location of the site where the LP Gas tank was located, this location was taken as a reference in the municipality of Nicolás Romero, State of Mexico, then the substance to be analysed was determined, in this case propane was considered as the substance with the greatest presence in the LP Gas.

Likewise, the atmospheric data of the place was determined, as well as the dimensional characteristics of the tank, among others. Finally, it was established in ALOHA® that the type of event generated was a BLEVE. It is worth mentioning that the tank was considered to contain only liquid due to the storage pressure and temperature conditions.

Based on the above, the results of the radii and/or zones affected were obtained in the ALOHA® program, and these were linked to the Google Earth® software, in order to obtain these radii on a georeferenced aerial map and compare these results with those obtained from the mathematical modelling mentioned above.

Results

In order to determine the results, both for the mathematical modelling and for the modelling using ALOHA, different values of thermal radiation limits and their respective zones have been considered. These values and zones are based on the CIVIL PROTECTION TECHNICAL STANDARD NTE-002-CGPC-2018. It should be noted that, for the present modelling, the tank has been estimated with LPG at 80% of its maximum capacity.

Results obtained using mathematical models

By simulating the heat flux (thermal radiation) risk scenario, different parameters related to the BLEVE risk have been obtained.

Table 1 below shows the parameters and results obtained for the BLEVE fireball.

Thermal radiation zone	Radiatiolimit E_r (kW/m^2)	Distance to receiver X_C (m)	Maximum fireball diameter D_{MAX} (m)	Duration of the fireball t_{BLEVE} (s)	Height of the fireball H_{BLEVE} (m)
Lethality zone	10.00	241.45	108.96	8.45	81.72
Risk area	5.0	336.38	108.96	8.45	81.72
Buffer zone	1.4	618.62	108.96	8.45	81.72

Table 1 BLEVE fireball parameters

From the results obtained for the three different heat flux risk zones; lethality zone (10 kW/m2), risk zone (5 kW/m2) and buffer zone (1.4 kW/m2), respectively, in the following Figure 2, the relationship of the distance from the centre of the fireball to the receiver is graphically represented, observing that as the distance from the receiver to the centre of the fireball increases, the heat flux (radiation) decreases, i.e., it decreases.

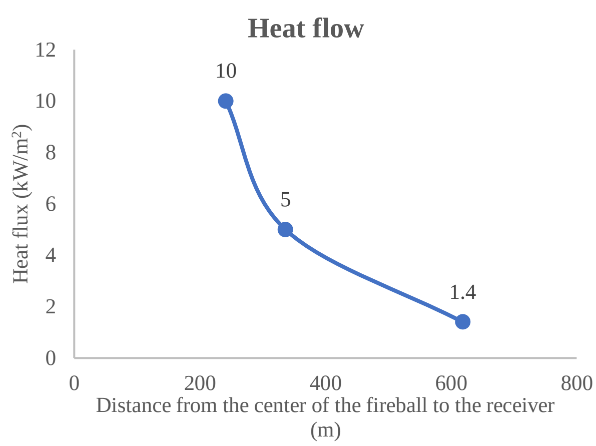
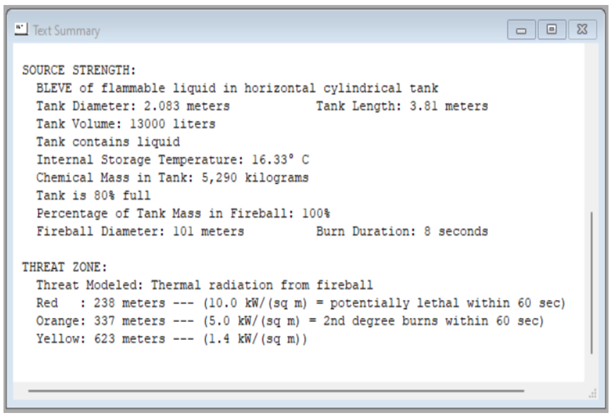


Figure 2 Heat flux radiated by the explosion of the LPG container at different distances from the source of the explosion

Results of modelling the event using ALOHA

Diameter, duration and threat zones of the fireball

Figure 3 below shows the results for the diameter, duration and threat zones of the fireball. ALOHA® automatically determines these results by providing information related to the atmospheric conditions at the event site, physico-chemical properties of the substance involved and dimensional data of the deposit, primarily.



Text Summary

SOURCE STRENGTH:
BLEVE of flammable liquid in horizontal cylindrical tank
Tank Diameter: 2.083 meters Tank Length: 3.81 meters
Tank Volume: 13000 liters
Tank contains liquid
Internal Storage Temperature: 16.33° C
Chemical Mass in Tank: 5,290 kilograms
Tank is 80% full
Percentage of Tank Mass in Fireball: 100%
Fireball Diameter: 101 meters Burn Duration: 8 seconds

THREAT ZONE:
Threat Modeled: Thermal radiation from fireball
Red : 238 meters --- (10.0 kW/(sq m) = potentially lethal within 60 sec)
Orange: 337 meters --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)
Yellow: 623 meters --- (1.4 kW/(sq m))

Figure 3 Results of the radii and/or thermal radiation threat zones for the LP-Gas explosion in a BLEVE

Thermal radiation threat zones

The thermal radiation threat zone due to the BLEVE explosion of the 13,000 L LP gas tank can be seen in Figure 4 below.

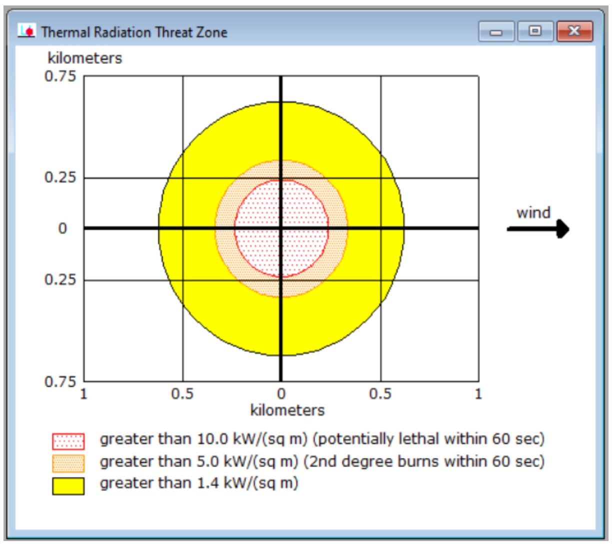


Figure 4 Threat zones due to thermal radiation from the LP gas explosion

From the results obtained, these are transferred to Google Earth® in order to identify the site of the LP gas tank on a cartographic level, as well as the respective threat zones already mentioned. This information can be seen in Figure 5 below.

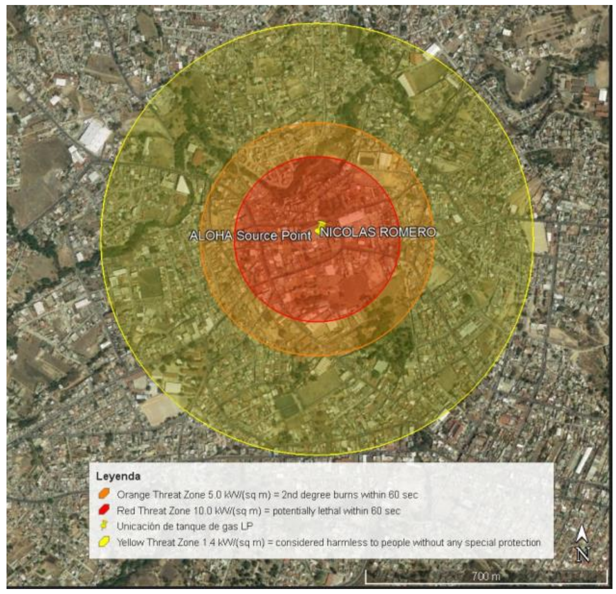


Figure 5 Cartographic representation of thermal radiation hazard areas

It is worth mentioning that the results obtained with ALOHA® show that from the site of the explosion and up to a distance of 238 m, it would be determined as a lethal zone and would experience thermal radiation that could cause death; between a distance of 238 m to 337 m corresponds to a risk zone and second degree burns would be experienced in 60 seconds of exposure, and between 337 m and 623 m would correspond to a buffer zone in which this zone is considered harmless for people without any special protection.

Comparative analysis of the results obtained

Based on the results obtained, both from the use of mathematical models and from the use of ALOHA®, Table 2 below shows the results for the zones of risk and/or affectation by thermal radiation, as well as the respective percentage difference between them.

Thermal radiation zone	**Radiation limit E_r (kW/m^2)**	**Models Mathematicians Distance to receiverX_C (m)**	**Models Mathematicians Distance to receiverXC (m)**	**ifference etween odels sed (%)**
Lethality zone	10.00	241.45	238	1.428
Risk area	5.0	336.38	337	0.184
Buffer zone	1.4	618.62	623	0.703

Table 2 Comparative results of thermal radiation risk zones

Likewise, the following Table 3 presents a comparison of the results obtained, corresponding to the diameter and duration of the fireball.

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Parameter	Models Mathematics	Modelling in ALOHA ®	Difference between models used (%)
Diameter maximum fireball diameter D_MAX (m)	108.96	101	7.305
Duration of fireball fireball tBLEVE (s)	8.45	8	5.325

Table 3 Comparison of results of diameter and duration of the fireball

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Conclusions

The following conclusions can be drawn from this research:

- The results obtained to determine the thermal radiation risk zones, with respect to the comparison of mathematical models and modelling with ALOHA®, as can be seen in Table 2, show that the lethality zone presents the highest percentage difference between these models, with a value of 1.428%. Likewise, the widest value of this lethality zone is presented by the application of the mathematical modelling, considering a more conservative result for this zone. Likewise, for the case of the risk zone and buffer zone, the percentage difference is 0.184% and 0.703%, respectively, which represents a minimum percentage between them. It is worth mentioning that, for the comparison with respect to the results of the diameter and duration of the fireball, presented in Table 3, the percentage difference of the applied modelling corresponds to 7.305% and 5.325%, respectively. It can be seen that the highest values obtained for both the diameter and the duration of the fireball are obtained from the mathematical modelling. Likewise, it can be concluded, in general, that the results obtained from the use of mathematical models present the most conservative values of the present work carried out.
- On the other hand, the use of modelling from the ALOHA® software for the present research work is simpler to carry out, as well as illustrative, since it allows the linkage with other programs, such as Google Earth®, in which the different areas of risk due to thermal radiation can be visualised at satellite image level, based on the study site.

It is worth mentioning that LP gas is a fuel that is in great demand for use in industries, shops, restaurants, homes, vehicles, etc. and it is vitally important to consider regulatory aspects for its transport and storage, given that it is highly flammable and can generate a risk of explosion if it leaks and accumulates in a closed and/or confined space.

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June 2023, Vol.9 No.23 29-35

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