

**NUMERICAL MODELING OF ESCALATION FROM PROPANE
AND BUTANE LEAKS TO EXPLOSIONS AT THE ROMPETROL GAS
PANTELIMON INDUSTRIAL STORAGE FACILITY**

Andrei-Cătălin Caragea¹ , Mihaela Popa² 

¹ Faculty of Industrial Engineering and Robotics, National University of Science and Technology POLITEHNICA Bucharest, Romania

² Faculty of Entrepreneurship, Business Engineering and Management, National University of Science and Technology POLITEHNICA Bucharest, Romania

* Email (corresponding author): a.catalyn@yahoo.com

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ABSTRACT

The storage, transfer, and mixing of propane and butane in proximity to other equipment may facilitate the escalation of a loss of containment. Ignition of a pressurized release may generate a jet fire, which can thermally expose a neighbouring vessel and, under certain conditions, may lead to a BLEVE (Boiling Liquid Expanding Vapour Explosion), an event with a low probability but major consequences. The study analyses whether such an escalation pathway is spatially possible within the Rompetrol Gas Pantelimon site and assesses its consequences for the installation and nearby facilities. Propane and butane were analysed separately in ALOHA by successively modelling the dispersion of the flammable cloud, the thermal radiation generated by the jet fire, and the fireball radiation associated with a conditional BLEVE. The calculated zones were exported in KML format and overlaid in Google Earth Pro onto the actual site configuration. The results show that the flammable clouds cross the process area where ignition sources may be present, while the thermal contours of the jet fires reach the adjacent vessels. This spatial continuity supports the analysis of BLEVE as the final escalation scenario, without assuming that the sequence inevitably occurs. For the input data used, propane generated more extensive consequences at all stages: the flammable zone was more than twice as long as that for butane, while the distances associated with the radiation generated by the jet fire were approximately 45–52% greater. In the BLEVE scenario, the outer thermal radiation boundary reached 951.0 m for propane and 764.4 m for butane. Both zones extended beyond the site boundary and intersected industrial platforms, the Bucharest Ring Road, railway infrastructure, and built-up areas. The study transforms the general scenarios mentioned in the safety documentation into a localized and reproducible analysis that highlights both the potentially affected receptors and the stage at which operator intervention can halt the escalation. Rapid isolation of the source, cessation of transfer operations, and cooling of the exposed vessels before a sustained thermal load is established constitute the principal measures for preventing progression towards a BLEVE. The results confirm that the low probability of this event does not imply the absence of risk and support the integration of external consequences into emergency response planning and public information.

Keywords: industrial risk, flammable, domino effect, BLEVE, thermal radiation.

INTRODUCTION

The storage and transfer of propane and butane in the liquid phase under pressure may lead to several accident progressions following a loss of containment. A pressurized release may form a flammable cloud, whose extent depends on the source characteristics, atmospheric conditions, and site configuration. Delayed ignition may produce a flash fire or, under conditions conducive to flame acceleration, a vapour cloud explosion. Immediate ignition of a sustained release may generate a jet fire, characterized by a directional flame and a high thermal load on nearby equipment [1-3].

A jet fire directed towards a neighbouring vessel may initiate accident escalation. Thermal exposure causes the contents to heat up, the internal pressure to increase, and the mechanical strength of the vessel wall to decrease. If the vessel fails while the liquid is at a temperature above its normal boiling point, a BLEVE (boiling liquid expanding vapour explosion) may occur. In the case of propane or butane, rapid ignition of the released substance may also generate a fireball. The response of the vessel depends on the intensity and duration of exposure, its filling level and geometry, the heated area, and the available protective measures [4-7].

The scientific literature provides models for assessing the release and dispersion of flammable substances and for analysing the response of vessels exposed to fire [1-7]. Accident propagation between items of equipment is addressed through domino-effect models, which include escalation criteria and vulnerability analysis methods [8-10]. Recent studies have applied these tools to accidents involving LPG vessels and road tankers to estimate the extent of the effects and support emergency planning [11-14]. However, the results depend on the quantity and state of the substance, the size of the release source, the meteorological conditions, and the position of the equipment. For this reason, the effect distances and zones obtained for generic installations or other sites are not generally applicable and cannot replace a simulation conducted based on the characteristics of the site under analysis [3], [8-14].

For the Rompetrol Gas Pantelimon site, the need for a specific risk analysis arises from its configuration, as described in the current publicly available documentation. This documentation identifies propane and butane as substances handled at the site and specifies that automotive LPG is prepared on site by mixing them in tanks dedicated to this operation [16]. Conducting storage, transfer, and mixing operations within a relatively confined area, where several tanks and items of equipment are located in close proximity, may facilitate the exposure of a vessel to the thermal effects of a fire occurring at an adjacent item of equipment [15],[16]. Public safety reports describe loss-of-containment releases, jet fires, BLEVE events, and the propagation of effects between items of equipment, and provide estimates for certain explosion and fireball scenarios [15]. Current public information documents acknowledge the possibility that accident effects may extend beyond the site boundary but do not present the input data, calculated distances, or maps corresponding to scenarios defined separately for propane and butane [16],[17]. Therefore, the gap addressed by the present study consists in the absence of a publicly available and reproducible analysis that traces, for the Pantelimon site, the conditional pathway from a defined propane or butane release to a possible BLEVE and relates the calculated zones to the equipment and receptors present in the area [15-17].

The aim of the study is the comparative assessment of the consequences associated with propane and butane, starting from the loss of containment selected as the initiating event based on the site risk matrix [15]. The subsequent progression is analyzed through a conditional worst-case scenario. The novelty of the study lies in applying the same staged and localized approach

to both substances, enabling a comparative assessment of the consequences in relation to the installation configuration and nearby receptors.

MATERIALS AND METHODS

Data sources and tools used

The analysis conducted for the Rompetrol Gas Pantelimon site was based on data regarding the installation configuration, vessel characteristics, storage conditions, and quantities of substances, obtained from the site Safety Report and cross-checked against the updated public information provided by the operator [15],[16]. The risk matrix was used to select the loss of containment as the starting point of the study.

Consequence modelling was performed using ALOHA (Areal Locations of Hazardous Atmospheres), which enables the definition of release scenarios from vessels and the estimation of threat zones associated with flammable clouds, jet fires, and fireballs generated in BLEVE scenarios [18],[19]. ALOHA is used as a screening and emergency response planning support tool, including in localized assessments of installations handling flammable substances [20].

Propane and butane were selected separately from the ALOHA software database, so that each simulation describes the behaviour of a pure substance rather than that of a commercial LPG mixture. For each substance, three distinct scenarios were analysed: a release without immediate ignition and the formation of a flammable cloud; immediate ignition of the release and the formation of a jet fire; and vessel failure followed by the formation of a fireball as part of a conditional BLEVE scenario.

Input data

For the flammable cloud formation and jet fire scenarios, the same release geometry was used for both substances: the release of liquid from a horizontal cylindrical vessel through a circular orifice with a diameter of 5 cm, represented in ALOHA as a short pipe/valve located at the bottom of the vessel. Maintaining the same breach geometry allows a direct comparison of the results for propane and butane. The BLEVE scenario was modelled separately, assuming catastrophic vessel failure, so neither the orifice diameter nor the leak geometry applies to this scenario. Maintaining the same geometry allows the results to be compared, while the substance properties, pressure, and mass involved remain differentiated. The source characteristics influence the discharge rate and vaporization of a pressurized release [2],[3]. The extent of the flammable cloud also depends on the atmospheric conditions and the concentration threshold used to delineate the zone [21]. The values in Table 1 reproduce the conditions used in the simulations performed.

Table 1. General data and definition of the modelled scenarios.

Location	Meteorological conditions	Flammable zone	Jet fire	BLEVE
Source coordinates: 44°27'34.1064" N; 26°14'30.9372" E	Air temperature: 22 °C; relative humidity: 50%; partly cloudy sky; atmospheric stability class D; terrain roughness: urban or forest, wind direction: SW, wind speed: 5 m/s, wind measurement height: 3 m	Release from the vessel, without immediate ignition	Sustained pressurized release, with ignition and the formation of a jet fire	Catastrophic failure of the vessel and combustion of the released substance in the form of a fireball

Wind direction determines dispersion zone orientation and the receptors reached by the flammable cloud. Identical meteorological conditions were used in the propane and butane simulations to ensure comparability. The data regarding vessel geometry, liquid temperature, filling level, and opening size were kept constant, as indicated in Table 2 [15].

Table 2. Input data for propane and butane.

Propane	Butane
Vessel: horizontal cylinder	Vessel: horizontal cylinder
Nominal volume: 90 m ³	Nominal volume: 90 m ³
Liquid temperature: 20 °C	Liquid temperature: 20 °C
Input internal pressure: approximately 10 bar	Input internal pressure: approximately 2.1 bar
Filling level: 80%	Filling level: 80%
Quantity involved: approximately 36.2 t	Quantity involved: approximately 41.8 t

Modelling procedure for successive scenarios

The analysis was conducted by following a conditional escalation branch. In this study, the term worst-case denotes continuing the analysis to the severe final consequence when the conditions established for each stage are met. In the first stage, the release without immediate ignition and the formation of the flammable cloud were simulated. ALOHA was used to delineate the distances corresponding to concentrations of 60% and 10% of the lower explosive limit (LEL), represented in Figure 1. The contours describe the potential extent of the flammable atmosphere under the specified conditions [18],[19].

ALOHA Source Point

Time: September 30, 2026 1230 hours ST
Chemical Name: PROPANE
Wind: 5 meters/second from SW at 3 meters

THREAT ZONE:

Red : 73 yards --- (12600 ppm = 60% LEL = Flame Pockets)
Yellow: 228 yards --- (2100 ppm = 10% LEL)

Model: ALOHA Flammable Area of Vapor Cloud

Figure 1. Representation of the Lower Explosive Limits (LEL).

In the second stage, the ignition of a sustained pressurized release and the thermal radiation generated by a jet fire were modelled. The ALOHA thresholds of 10.5, and 2 kW/m² were used (Figure 2), and the contours were related to the positions of the adjacent vessels [18],[19]. These thresholds are defined in the program for assessing effects on people and do not constitute direct vessel failure criteria [4-6].

The third stage consisted of the conditional simulation of a BLEVE for the vessel considered to be affected. The option used assumes that catastrophic failure has occurred and estimates the thermal radiation from the fireball at thresholds of 10.5, and 2 kW/m² (Figure 3) [18],[19]. In addition to thermal radiation, a BLEVE may produce overpressure and projected fragments [22-24].

ALOHA Source Point

Time: September 30, 2026 1213 hours ST
Chemical Name: BUTANE
Wind: 5 meters/second from SW at 3 meters

THREAT ZONE:

Red : 22 yards --- (10.0 kW/(sq m) = potentially lethal within 60 sec)
Orange: 32 yards --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)
Yellow: 49 yards --- (2.0 kW/(sq m) = pain within 60 sec)

Model: ALOHA Thermal radiation from jet fire

Figure 2. Representation of thermal radiation thresholds for a jet fire.

ALOHA Source Point

Time: September 30, 2026 1213 hours ST
Chemical Name: BUTANE
Wind: 5 meters/second from SW at 3 meters

THREAT ZONE:

Red : 492 yards --- (10.0 kW/(sq m) = potentially lethal within 60 sec)
Orange: 695 yards --- (5.0 kW/(sq m) = 2nd degree burns within 60 sec)
Yellow: 1084 yards --- (2.0 kW/(sq m) = pain within 60 sec)

Model: ALOHA Thermal radiation from fireball

Figure 3. Representation of thermal radiation thresholds for the BLEVE explosion.

Spatial representation of the results

The threat zones calculated in ALOHA were exported in KML format and overlaid in Google Earth Pro using the same point of origin. The maps were used to identify internal equipment and industrial, road, railway, and built-environment assets located within or near the calculated zones [12],[13],[20].

The numerical distances were obtained from the ALOHA reports and converted from yards to metres using the relationship $1\text{ yd} = 0.9144\text{ m}$. To compare the substances, the radius ratio and percentage variation were calculated. In the BLEVE case, the theoretical area of the circular zones was also compared using the relationship: $A = \pi r^2$. Receptor identification was based on the features visible in the cartographic images.

The “Urban or Forest” option selected in ALOHA approximates the relatively high aerodynamic roughness of the Pantelimon industrial site but does not capture its three-dimensional geometry or local obstacle effects on flow and dispersion. Calculated hazard zone boundaries should therefore be interpreted as screening-level estimates rather than exact physical limits.

RESULTS

The results are presented in the order of the stages analysed: formation of the flammable cloud, thermal exposure generated by the jet fire, and the thermal consequences of a possible BLEVE. The reported distances were obtained from the numerical results, while the representations in Google Earth Pro were used to identify the equipment and infrastructure elements intersected by the calculated zones.

Formation and dispersion of the flammable cloud

In the butane scenario (Figure 4), the flammable cloud originates at the release point and moves northward in the direction of the wind. The affected zone crosses the site, covers the group of vessels, and extends over the vegetation and land located beyond the storage area. Thus, the main exposed elements are the LPG vessels, nearby installations, and persons located in the path of the cloud.

In the propane scenario, shown in Figure 5, the flammable cloud has a greater longitudinal and transverse extent. The inner zone covers the release point and a significant part of the group of vessels, while the outer zone extends beyond the northern boundary of the site and over the nearby land.



Figure 4. Dispersion of the butane cloud and the zone corresponding to the 10% LEL threshold.



Figure 5. Dispersion of the propane cloud and the zones corresponding to the 60% and 10% LEL thresholds.

The results presented in Table 3 show that the difference between the two substances is not determined exclusively by the stored mass. Although the quantity of butane involved is greater, the higher storage pressure and volatility of propane promote a more intense release and vaporization, leading to the formation of a more extensive flammable atmosphere.

Table 3. Comparative analysis of flammable dispersion zones.

Analysed indicator	Butane	Propane	Comparative interpretation
60% LEL zone	39 yd $\approx$ 35.7 m	73 yd $\approx$ 66.8 m	The predicted distance for propane is approximately 1.87 times that for butane.
10% LEL zone	128 yd $\approx$ 117.0 m	228 yd $\approx$ 208.5 m	The predicted distance for propane is approximately 1.78 times that for butane.

Therefore, propane generates the most severe conditions for accident initiation: a larger ignition zone, a greater number of items of equipment potentially encompassed by the cloud, and a higher spatial probability of encountering an ignition source. [18],[19].

ALOHA modelled flammable cloud releases from a finite tank inventory. The propane release lasted 49 min, while the butane calculation was limited to 1 h. Maximum sustained release rates were approximately 794 and 273 kg/min, respectively.

Thermal radiation generated by the jet fire

In the second stage, ignition of the sustained pressurized release was assumed. Because the contents continue to be discharged under pressure, combustion stabilizes in the form of a continuously supplied flame jet. In the case of butane (Figure 6), the red zone (10 kW/m²) has a radius of approximately 21.0 m, is concentrated around the release point, and covers the nearby process installations, pipelines, internal manoeuvring routes, and the area where the fire

is fuelled. The orange zone (5 kW/m²) reaches approximately 30.2 m and approaches the southern boundary of the group of adjacent vessels. The yellow zone (2 kW/m²), extending to approximately 45.7 m, overlaps part of the nearby equipment and internal process routes.

The propane scenario illustrated in Figure 7 presents more extensive thermal zones. The red zone, with the greatest extent and thermal load (32.0 m and 10 kW/m²), reaches the edge of the group of tanks located to the north. Consequently, the first vessels are directly exposed to the maximum thermal level represented in the model. The contours of the orange and yellow zones (5 and 2 kW/m²) extend to approximately 4.9 m and 67.7 m, respectively, overlapping a larger part of the group of equipment and the process area.



Figure 6. Thermal radiation zones generated by the butane jet fire.



Figure 7. Thermal radiation zones generated by the propane jet fire.

The results in Table 4 show that the propane jet fire generates more extensive thermal zones than the butane jet fire. Consequently, the thermal radiation reaches a larger proportion of the neighbouring installations and vessels, indicating a greater potential for domino-effect propagation. In the jet fire scenarios, propane combustion lasted 49 min, while ALOHA limited the butane calculation to 1 h. Maximum burning rates were approximately 798 and 273 kg/min, respectively.

Table 4. Comparative analysis of jet fire scenarios.

Thermal zone	Butane distance	Propane distance	Comparative interpretation
10 kW/m ²	23 yards, ~21.0 m	35 yards, ~32.0 m	The radius obtained for propane is approximately 52.2% greater
5 kW/m ²	33 yards, ~30.2 m	48 yards, ~43.9 m	The radius obtained for propane is approximately 45.5% greater
2 kW/m ²	50 yards, ~45.7 m	74 yards, ~67.7 m	The radius obtained for propane is approximately 48.0% greater

Thermal consequences of the BLEVE scenario

Prolonged exposure of a vessel to a jet fire causes heating of the metal shell and the stored substance. The temperature and internal pressure increase, while the mechanical strength of the wall decreases, followed by depressurization, rapid vaporization of the liquid, and ignition of the vapour mass in the form of a fireball [7],[18],[19], [23-25].

For butane, represented in Figure 8, the red zone (10 kW/m²) has a radius of approximately 347.5 m and encompasses the Rompetrol Gas site, the internal equipment, and some of the nearest sections of the neighbouring commercial platforms. The orange zone (5 kW/m²) extends to approximately 490.1 m, exceeding the site boundary and intersecting the Bucharest Ring Road, commercial platforms, and industrial land located south and west of the source. The yellow zone (2 kW/m²) reaches approximately 764.4 m and includes a larger part of the industrial area, the railway infrastructure, the land to the north, and the edge of the built-up areas located to the west.

In the case of propane (Figure 9), the red zone (10 kW/m²) extends to approximately 432.5 m, covering the site and a significant part of the neighbouring industrial facilities. The orange zone (5 kW/m²) reaches approximately 609.9 m and encompasses a larger area of the industrial platform. The yellow zone (2 kW/m²), with a radius of approximately 951.0 m, extends significantly beyond the site boundaries and intersects road and railway infrastructure, other economic facilities, and nearby built-up areas. For all the thresholds analysed, the radii of the BLEVE zones are approximately 24.5% greater for propane, resulting in an affected area approximately 55% larger than that for butane. In the Table 5 is presented a comparative analysis of the thermal zones associated with a BLEVE.

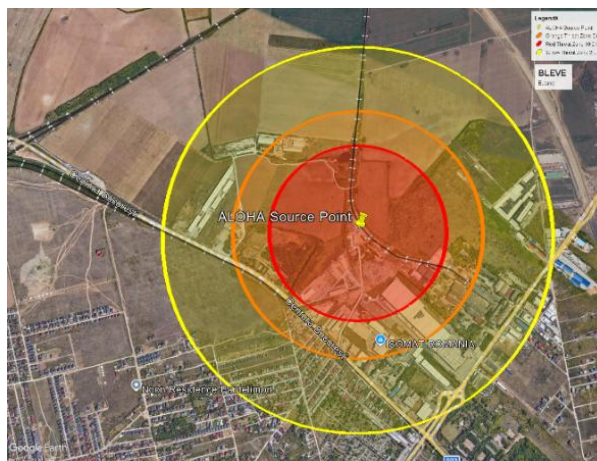


Figure 8. Thermal radiation zones of the BLEVE scenario for butane.

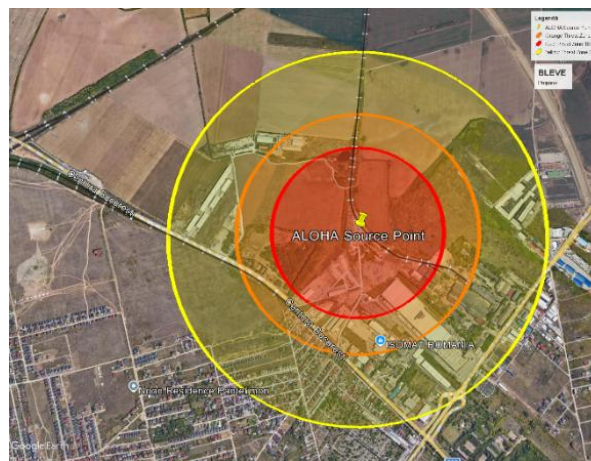


Figure 9. Thermal radiation zones of the BLEVE scenario for propane.

Table 5. Comparative analysis of the thermal zones associated with a BLEVE.

Thermal radiation threshold	Butane	Propane
10 kW/m ²	380 yards, ~347.5 m	473 yards, ~432.5 m
5 kW/m ²	536 yards, ~490.1 m	667 yards, ~609.9 m
2 kW/m ²	836 yards, ~764.4 m	1,040 yards, ~951.0 m

The overlay of the BLEVE scenario zones, illustrated in Figure 10, shows an almost constant difference between the two substances. BLEVE scenarios assumed 100% of the tank inventory contributed to fireball formation, with burning durations of 12 s for propane and 13 s for butane.

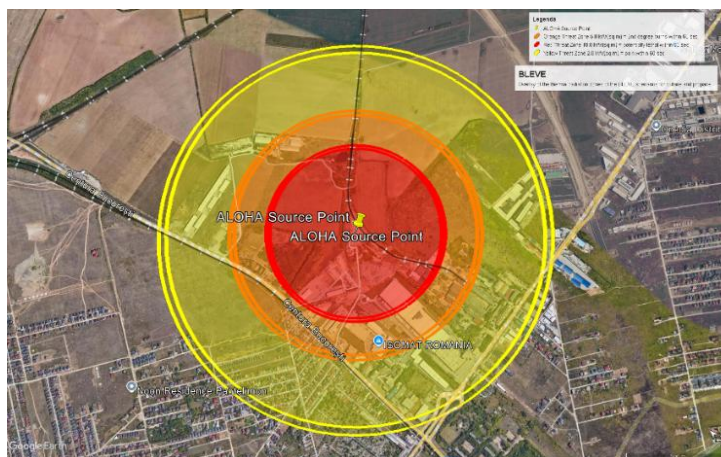


Figure 10. Overlay of the thermal radiation zones of the BLEVE scenarios for butane and propane.

The ratio between the radii calculated for propane and butane is approximately 1.244 for each threshold. Since the area enclosed by a circular contour is proportional to the square of the radius, the ratio of the areas is:

$$\frac{A_{\text{propane}}}{A_{\text{butane}}} = \left(\frac{R_{\text{propane}}}{R_{\text{butane}}} \right)^2 \approx 1.55 \quad (1)$$

The area enclosed by each thermal zone is thus approximately 55% larger for the propane scenario. The difference results from the combined properties of the substance and the data entered into the model and cannot be attributed to a single parameter, such as mass or storage pressure.

DISCUSSIONS AND CONCLUSIONS

The spatial analysis identified a conditional continuity between the three stages. The calculated flammable clouds intersect the process area where ignition sources may be present, while the jet fires generate thermal contours that reach the adjacent vessels. These overlaps justify examining the BLEVE as the final escalation scenario without demonstrating that the sequence inevitably occurs.

Propane generated the most extensive consequences at all stages. The 10% LEL zone was approximately 1.78 times longer than that for butane, while the radii of the thermal zones generated by the jet fire were approximately 45–52% greater. For the BLEVE, the calculated radii were approximately 24–25% greater, corresponding to a potentially affected area approximately 55% larger. The outer thermal zone reached approximately 951 m for propane and 764 m for butane, confirming the need to analyse the two substances separately.

Although a tank explosion is associated in the site risk matrix with a lower probability than loss-of-containment events [6], the consequences of the BLEVE scenario cannot be considered negligible. For both substances, the thermal zones extend beyond the site boundaries and include industrial platforms, road and railway infrastructure and, in the case of propane, the edges of built-up areas. A BLEVE therefore represents a lower-probability scenario, but one with potentially major off-site effects.

The analysis identifies a critical stage for operator intervention before the adjacent tanks are subjected to a prolonged thermal load. Leak detection, source isolation, cessation of transfer operations, and activation of the cooling and protection systems, performed using the available means and in accordance with the internal emergency plan, may interrupt the escalation at the release or jet-fire stage [2],[3]. Following significant heating of a vessel, the options for local intervention decrease, and priority shifts towards protecting personnel, evacuating the exposed areas, and limiting the consequences.

The results are also relevant to public information because the analyzed documents mention possible accidents but do not present the input data, distances, and maps required to understand separate scenarios for propane and butane [6],[7]. Public presentation of the calculated zones, together with an explanation of the assumptions used, would allow the population and neighbouring economic operators to be aware of the potentially exposed facilities and to understand the role of protective measures and the recommended behaviour in the event of an accident.

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