ANALYSIS AND SPATIOTEMPORAL EVALUATION OF THE EFFECTS OF THE DETERMINANTS OF ACCIDENTAL ATEX FIRES LINKED TO RAIL MOBILITY: SCENARIO APPROACH

ANALIZA ȘI EVALUAREA SPAȚIO-TEMPORALĂ A EFECTELOR FACTORILOR DETERMINANȚI AI INCENDIILOR ACCIDENTALE DE ATEX LEGATE DE MOBILITATEA FEROVIARĂ: ABORDARE PRIN SCENARII

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Abstract: *This study aims to assess the influence of key factors related to accidental combustion incidents. By formulating various parameter combinations as input data for numerical simulations using the ALOHA software, a linear relationship was observed between ignition zone and temperature, wind speed, hole diameter, and position. Strong correlations were found between thermal radiation zone and temperature, humidity, wind speed, and hole diameter for a jet fire, and between temperature, humidity, and filling rate for a BLEVE. Stable atmospheric conditions are critical for flash fires, neutral for jet fires, and varied for BLEVE. Understanding these parameters can enhance risk management planning for different fire scenarios.*

***Keywords**: parameters; accidental fires; scenario; ATEX, mobility, simulation*

Rezumat: *Acest studiu urmărește să evalueze influența factorilor-cheie legați de incidentele de combustie accidentală. Prin formularea diferitelor combinații de parametri ca date de intrare pentru simulările numerice cu ajutorul programului ALOHA, s-a observat o relație liniară între zona de aprindere și*

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temperatură, viteza vântului, diametrul găurii și poziție. Au fost găsite corelații puternice între zona de radiație termică și temperatură, umiditate, viteza vântului și diametrul găurii pentru un incendiu cu jet și între temperatură, umiditate și rata de umplere pentru un BLEVE. Condițiile atmosferice stabile sunt critice pentru incendiile fulger, neutre pentru incendiile cu jet și variate pentru BLEVE. Înțelegerea acestor parametri poate îmbunătăți planificarea gestionării riscurilor pentru diferite scenarii de incendiu.

Cuvinte cheie: *parametri; incendii accidentale; scenariu; ATEX , mobilitate, simulare*

1. Introduction

Worldwide consumption of petroleum products will continue to rise until at least 2040. Oil and natural gas play an essential role in the energy value cycle and in economic development [1]. The consumption of energy sources is often considered to be a priority need from a technical and economic point of view. Primary energy sources, such as hydrocarbons, are transported to the service points where they will be used. Several means of transport are used in this logistics cycle. Specialised road vehicles and ships are still the most cost-effective means of transporting hydrocarbons. Incidents involving the transport of hazardous materials by road and rail generate 78% of pollutant emissions, 6% in the event of ignition, 28% in the event of fires and 14% in the event of explosions [2]. Rail is a popular means of transport in areas where there are no shipping lanes. In the event of an accident, this form of transport can cause a hydrocarbon spill, resulting in the dispersion of toxic clouds, fires and explosions, with significant consequences [3].An accidental release of flammable hydrocarbons can lead to lethal events such as explosions, fires and the dispersion of materials. Among the possible fires that a release can cause, fires are the most common incidents [4]. In this environment, hazardous substances are stored and are likely to migrate towards the combustion phenomenology, in the presence of air. The mixture of oxidant and fuel in the form of hydrocarbons has a number of consequences, one of which is the thermal radiation from the burning flame and the other the waves corresponding to explosions [5].

In the ARIA (Analysis, Research and Information on Accidents) database [4], a number of accidents involving the release of hazardous products have been recorded. For example, in 2021 at Riverview in the United States, a railcar containing methyl mercaptan (MM) released the product into the atmosphere at 3.47am, and it ignited 22 minutes later. The wagon exploded, completely releasing the product into the atmosphere. In 2016 in Bassens, France, a fire was detected in a 9-tonne tank containing LPG. The fire spread to several tanks, and after 53 minutes, explosions in the form of a BLEVE occurred, and after 73 minutes a second tank containing 2.5t LPG also exploded in a BLEVE. The consequences were severe in the danger zone created by the various fire scenarios [7].

Today, the influence of the danger zones generated by the manifestation of certain fire scenarios is an important subject. Bubbico et al [8] predicted that the impact zone generated by a gas dispersion is influenced by several parameters, such as the boiling temperature of the released chemical, the conditioning pressure and the ambient temperature. The distance of thermal radiation depends more on the ambient temperature and the humidity level, particularly when the latter is high. Zhu et al [9] show that for a pipeline, environmental parameters such as wind speed, ambient temperature, humidity level and ground roughness influence plume dispersion, overpressure distance and thermal radiation. . Da Silva Júnior et al [10] indicate that the synergy between wind speed and the diameter of the release hole, on the one hand, and between wind speed and the position of the release hole, on the other, have an influence on the dispersion of the gas plume. The study led by Anjana et al [11] demonstrates that the danger area generated by a release of a hazardous product is a function of atmospheric conditions. These results suggest an investigation into the influence of hazard zones under the constraint of certain determinants such as: meteorological parameters, zone occupancy conditions, release and filling conditions for certain scenarios such as gas dispersion and a jet fire. Some studies have been carried out to assess the impact of fire scenarios such as gas dispersion, flash fires and jet fires. Parameters such as ambient temperature, wind speed, humidity level, discharge hole diameter and ground roughness have been identified as parameters that can influence the impact distance of certain fire scenarios. However, most hydrocarbon accidents generate a variety of releases, which can then create a succession of fire scenarios, such as a flash fire in an ignition zone, or a jet fire from a tank hole releasing a pressurised liquid into the atmosphere or in the form of a BLEVE. For a more detailed analysis, it is important to list for each fire scenario the parameters that influence their danger zones.

The aim of this study is to analyse the impact of phenomelological parameters on the distance generated by a flash fire, jet fire and BLEVE respectively in hydrocarbon accident scenarios. The aim is to assess the influence of meteorological phenomena such as wind speed, ambient temperature and humidity rate under the constraints of wagon tank filling rates, hole diameters, hole position and land use. These specific influences are evaluated in terms of impact distances for each fire scenario. This work is structured as follows: firstly, analysis of the influence of the parameters on the impact distance of the different fire scenarios, and a comparative study of the influences of the parameters for the different scenarios.

2. Materials and methods

2.1. Simulation tool

The ALOHA© (Areal Locations of Hazardous Atmospheres) software designed by the US Environmental Protection Agency (EPA) can be used to model and simulate different release scenarios separately: toxic gas cloud, BLEVE, jet fires. This software can be used to assess the impact distance of each scenario [12]. The software is limited to a 60-minute interval for assessing impact distances.

2.2. Chemical substance used

The physical properties of the hydrocarbon used are shown in Table 1. Propylene is a colourless gas with a slight petroleum odour [13]. In the event of prolonged exposure to fire or intense heat, containers can rupture violently and rocket away [14].

Table 1 **Product characteristics Hydrocarbon**

Chemical names	**Formula**	**Density**	**Fusion temperature, C°**	**NFPA 704**
PROPYLENE	C_3H_6	1.45	47.7°	

2.3. Fire scenario and consequence

2.3.1. Scenario 1: flash fire and consequences (ignition zone)

Scenario 1, shown in Figure 1, represents the release of a flammable chemical substance into the environment. Equation (1) presents the model governing the dispersion of toxic fumes in the environment. This dispersion can create a flammable zone which is limited by two values: the Lower Explosive Limit (LEL), representing the lowest concentration of a particular gas likely to ignite, and the Upper Explosive Limit (UEL), representing the highest concentration of a gas in air capable of causing a fire when it meets a catalyst.

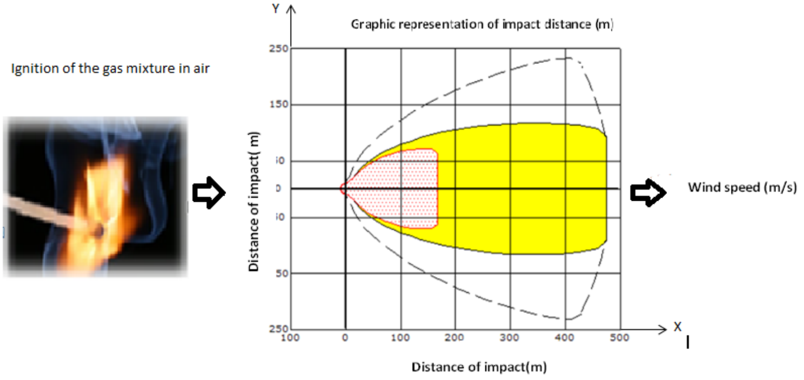

Figure 1: Scenario 1: ignition of a vapour cloud and consequences

$$\left.\begin{aligned} C(x,y,z,t) &= \left\{\frac{\chi}{2}\operatorname{erf}\left[\frac{x}{\sigma_x\sqrt{2}}\right] - \operatorname{erf}\left[\frac{(x-Ut)}{\sigma_x\sqrt{2}}\right]\right\}(t \le t_r) \\ C(x,y,z,t) &= \left\{\frac{\chi}{2}\operatorname{erf}\left[\frac{x-U(t-t_r)}{\sigma_x\sqrt{2}}\right] - \operatorname{erf}\left[\frac{(x-Ut)}{\sigma_x\sqrt{2}}\right]\right\}(t > t_r) \end{aligned}\right] \quad (1)$$

Where σx, σy and σz are the dispersion parameters; U is the wind-related variable and t_r is the leakage time of the substance.

The χ term represents a well-known Gaussian distribution from a steady-state continuous point source (equation 2).

$$\chi(x,y,z,t) = \left(\frac{Q(t)}{U}\right) g_y(x,y) g_z(x,z), \quad (2)$$

The variables gy and gz can be calculated using the equations below,

$$g_y(x,y) = \frac{1}{\sqrt{2\pi\sigma_y(x)}} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y(x)}\right)^2\right] \quad , \quad (3)$$

$$g_z(x,z) = \frac{1}{\sqrt{2\pi\sigma_z(x)}}\left\{\exp\left[-\frac{1}{2}\left(\frac{z-h_s}{\sigma_z(x)}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+h_s}{\sigma_z(x)}\right)^2\right]\right\} \quad (4)$$

where h_s is the height of the chemical leak.

2.3.2. Scenario 2: jet fire and consequences (thermal radiation)

Figure 2 shows scenario 2, which describes a flammable gas escaping from an orifice under pressure, igniting on contact with a spark and creating thermal radiation. The red area in the figure indicates thermal radiation of 10 kW/m^2, which is potentially fatal for people in the area. The orange colour indicates thermal radiation of 5 kW/m^2 causing second degree burns and the yellow colour represents thermal radiation of 2 kW/m^2 causing severe pain

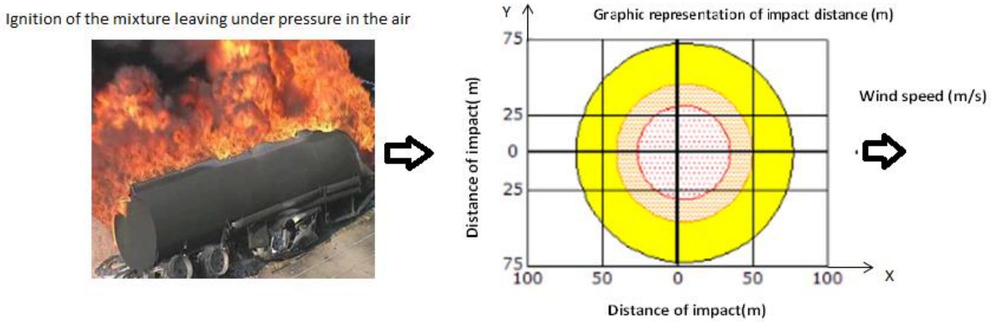

Figure 2: Scenario 2 jet fire and consequences.

2.3.3. Scénario 3: BLEVE (boiling liquid expanding Vapor Explosion).et consequence (radiation thermique)

Bleve, shown in Figure 3, is a physical phenomenon that corresponds to the explosive venting of a mass of liquefied gas by the bursting of a receiver casing. Critical areas are affected by thermal radiation.

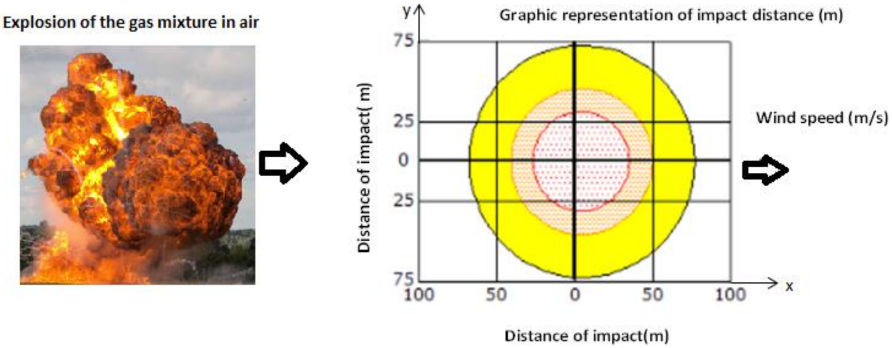

Figure 3: BLEVE fire and consequences

Thermal radiation is emitted by the emissive power of the flame surface equation (5). A target within the impact radius receives this incident thermal energy equation (6).

Emissive power (E) of the flame kW/m^2

$$E = \frac{f_r Q_r \Delta_{HC}}{A} \tag{5}$$

Where f_r is the fraction of heat radiated from the flame surface, Q_r is the mass flow rate (kg/s), ΔHC is the heat of combustion (J /s) and A is the flame area (m^2).

Thermal radiation (I) received by a person (equation 6).

$$I = \tau_a F_{21} E \tag{6}$$

Where I is the thermal radiation flux incident on a vertical surface (W /m^2), E is the thermal radiation energy flux at the surface of the fireball (W /m^2), F_{21} is the geometric view factor, and τ_a is the transmissivity of the atmosphere to thermal radiation.

Table 2: **Boundary conditions of the scenarios' hazard zones**

Consequence	Red	Orange	yellow
Flash fire (the vapour cloud ignites)	60% LEL (17000ppm)		10%LEL (2800ppm)
Thermal radiation (BLEVE - JET fire)	Potential for death for 60s (10.0kW/m^2)	2nd degree burn for 60s (5.0 kW/m^2)	Slight burn for 60s (2.0kW/m^2)

2.4. Data used

The data used to simulate each fire scenario is divided into several categories: meteorological, source release conditions and tank filling.

The meteorological parameters include wind speed, temperature, humidity, ground roughness, and stability conditions assessed through the Pasquill-Gifford relationship, representing varying degrees of atmospheric turbulence throughout the day [16]. Four different atmospheric conditions are used: instability classes B and C, neutral Class D, and stable Class F. These atmospheric parameters are based on Cameroon's atmospheric conditions. Ground roughness refers to irregularities caused by vegetation cover and land development [17]. Three types of land occupancy were considered in the analysis: 30 cm for dispersed residential areas, 100 cm for residential zones, and 200 cm for urban areas.

2.4.1. Discharge parameters

Transport accidents can result in collisions or derailments, leading to various types of releases: instantaneous release (less than a minute); critical release (catastrophic rupture of 300 mm hole diameter); and semi-continuous release for a 50 mm diameter [18]. In this study, the hole diameter ranges from 15 mm to 50mm, with the hole position on the tank varying from 0 to 2m from bottom to top.

2.4.2. Filling rate of wagon tanks

Filling rates must never exceed 95% according to regulations if the free space in the tank is filled with nitrogen. In this study, the fill rate varied from 50 to 95% [19].The tank used has the following characteristics.

- horizontal position;
- length 12 meters;
- diameter 2.9 meters;
- capacity 80 m^3>

Table 3 summarises the data used in this study. When one parameter is variable, the others remain constant. The constant value of each parameter is shown in bold in order to assess its effect on the hazard zone of each scenario.

Table 3: **Simulation parameters**

WEATHER CONDITION				REJECT CONDITION			Soil occupation
Stability class	**Wind speeds (m/s)**	**Temperature C°**	**Humidity %**	**Discharge diameter (mm)**	**Discharge hole height (mm)**	**Filling rate %**	**Roughness (cm)**
Day							
B	2.2; **2.75** ; 3.3	14 ; **24.5** ; 35	30 ; **70** ; 90	15 ; **32.5** ; 50	0 ; **1** ; 2	50 ; **72** ; 95	30 ; **100** ; 200
C	3.2 ; **4.1** ; 5						
D	5 ; **5.55** ; 6.1						
Night							
D	3.2 ; **4.1** ; 5	14 ; **24.5** ; 35	30; **70** ; 90	15 ; **32.5** ; 50	0 ;**1** ;2	50 ; **72** ; 95	30 ; **100** ; 200
F	1.3 ; **1.75** ; 2.2						

2-5. Analysis and processing of data

The data analysed are the impact distances resulting from the simulation of the different scenarios and the input parameters.The relationship between the input data and the responses (impact distance) of the different scenarios is measured by the coefficient of determination R^2. R^2 is generally presented as the quantity that estimates the percentage of variance of the response variable explained by its (linear) relationship with the explanatory variables [20]. Figure 2 shows the various steps taken to achieve the desired results. The method used in this study is identical to that used in [9]and [8].

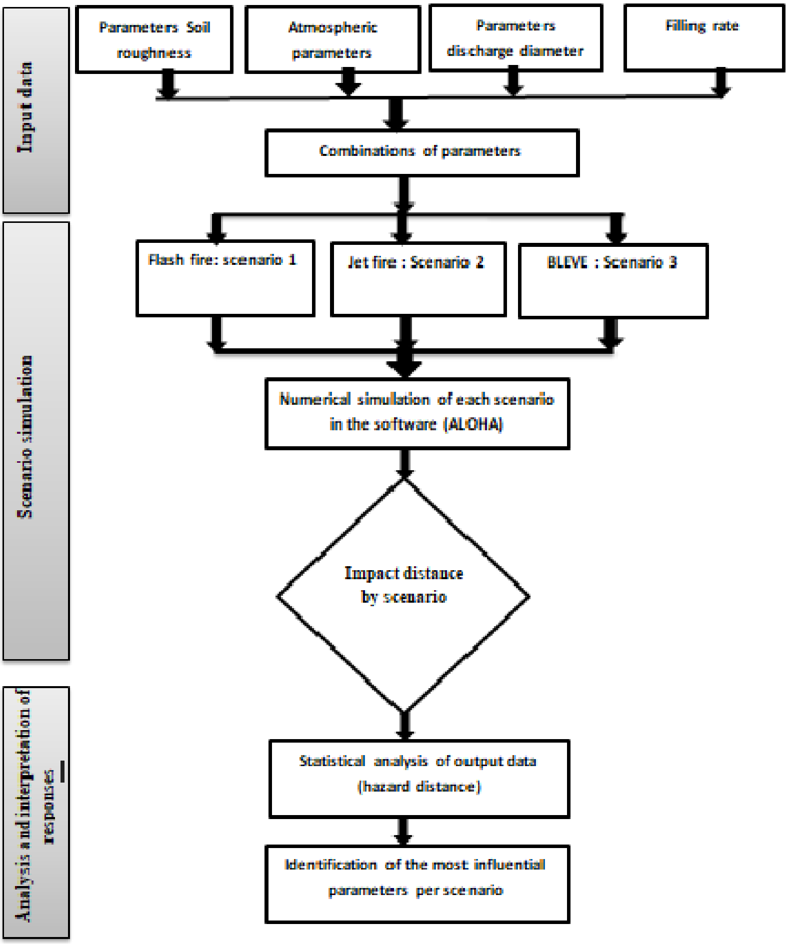

Figure 4: Study organisation chart

3. Results and discussions

3.1. Scenario 1: flash fire consequence: flammable zone

3-1-1. Atmospheric parameters

Figure (5a) shows the results of the influence of wind speed on the probable ignition zone for each atmospheric stability. A similar behaviour of the speed is observed for each stability condition (B, C, D and F), when the wind speed increases the probable ignition zone drops for each class of atmospheric stability and according to table 3 there is a high correlation between the wind speeds and the ignition distance varying from -0.97 to - 0.87.

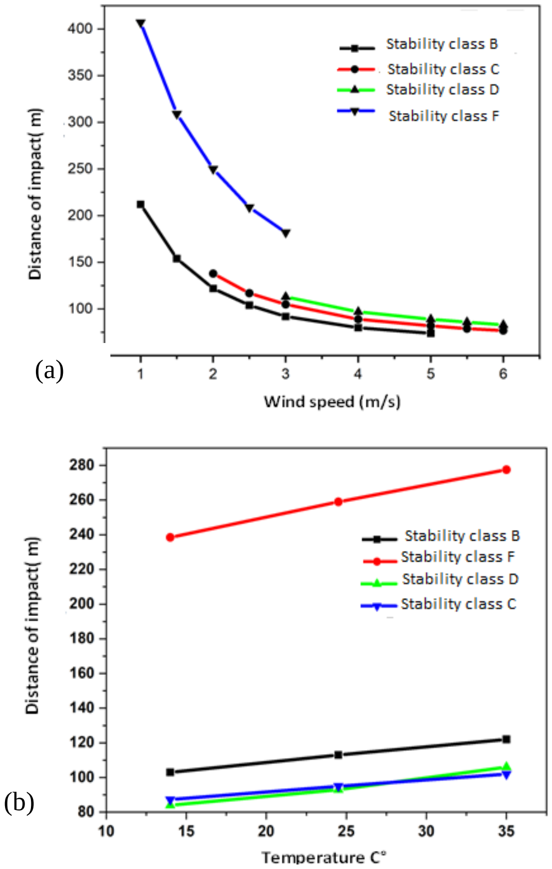

Figure 5: Ignition zone as a function of wind speed (a); ambient temperature (b)

As wind speed plays a diffusion role [21] , it causes the gas vapour of the chemical to disperse in the direction of the wind and the concentration of the gas to dilute, reducing the ignition zone [8]. By observing the impact of high wind speed for each atmospheric condition studied, it can be seen that for stability F the ignition zone becomes higher, varying from 407 to 182 meters for a wind speed of 1 to 3 m/s . This result reveals that the classes of atmospheric stability present at the time of the accidental release have a greater impact on the distance to the ignition zone during the time of day when turbulence is reliable. This hypothesis correlates with the work of [22] , which concluded that wind speed and atmospheric stability are the factors that influence dispersion.

Figure (5b) shows the influence of the ambient air temperature on the ignition zone. The behaviour is identical for each atmospheric condition, with a correlation of 0.99 between temperature and ignition distance (Table 4). The increase in temperature results in a greater ignition distance for each class of atmospheric stability. This result converges with that of Zhu et al [9], which stipulates that this increase in temperature generates turbulence in the atmosphere and the distance to the clouds of flammable steam increases. Looking at the atmospheric stability classes, stability condition F presents a higher ignition zone varying from 238 to 277 meters for a temperature ranging from 14 to 35°C. This stability class F refers more to the evening after sunset, when the impact zone is larger depending on the wind direction [23].

Table 4: **Correlations between speed and temperature as a function of stability classes**

Parameters	**Stability class**			
	B	**C**	**D**	**F**
Wind speed	-0,87	-0,94	-0,97	-0,97
Air temperature	0.99	0.99	0.99	0.99

3.1.2. Parameters related to discharge conditions

From figure (6a) showing the influence of the diameter of the exhaust hole on the ignition zone of the gas mixture, we observe identical behaviour in the impact of the variation in the diameter of the exhaust hole for each class of atmospheric stability. When the diameter of the flue gas hole increases, the ignition distance increases, according to Table 4, the correlation between the diameter of the flue gas hole and the ignition distance is 0.99. This is because the increase in the diameter of the flue gas hole increases the ignition distance.

In fact, this increase in the diameter of the discharge hole in a semi-continuous discharge condition will influence the flow rate of the fluid leaving the tank, which will increase the quantity of fluid evaporated, resulting in an increase in the ignition zone [9] [24]. When atmospheric conditions are observed, the stable class (F) presents a high distance varying from 42 to 420 m from the discharge source for a discharge hole diameter ranging from 1.5 to 5 cm.

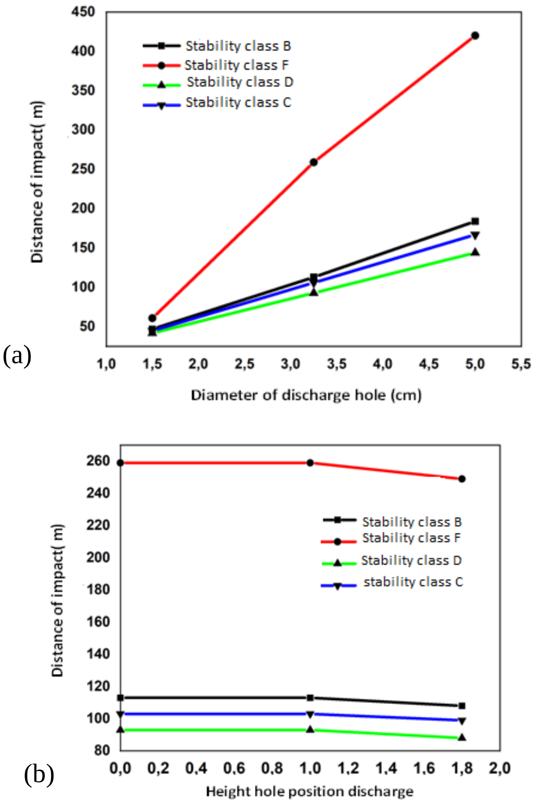

Figure 6: Ignition zone (rejection parameter) as a function of rejection hole diameter (a); hole diameter position (b)

Figure (6b) shows the impact of the height of the discharge diameter on the ignition zone. The behaviour of the impact of the position of the discharge hole is similar in each stability class and the correlation recorded is - 0.83 according to Table 5. According to the results, the diameter of the hole less than one meter (1m) from the bottom of the tank generates a constant ignition zone in each atmospheric condition, but beyond one meter there is a slight drop in the ignition zone in each atmospheric condition. This result could be explained by the fact that the hole moving away from the bottom of the tank reduces the quantity of fluid escaping and the position of the hole towards the bottom favours the total flow of fluid from the tank. The change in leak height influences the impact zone, which is consistent with [25], which states that if the leak hole is located in the middle of the tank rather than at the bottom, the liquid leak will turn into a gas leak. The liquid level is lower than the leak hole. The stability class (F) always reflects a higher ignition distance with a distance varying from 259 to 249 for a hole height ranging from 0 to 1.8 meters from the bottom of the tank.

Table 5: **Correlation between reject hole diameters and positions according to stability classes**

Parameters	**Stability class**			
	B	**F**	**D**	**C**
Height hole position discharge	-0,83	-0,83	-0,83	-0,83
Diameter of discharge hole	0,99	0,99	0,99	0,99

3.2. Scenario 2: jet fire consequence: thermal radiation

3.2.1. Effect of meteorological parameters on the thermal radiation of a Jet fire

The influence of wind speed on the space generated by thermal radiation is shown in Figure 7(a). An almost similar behaviour of wind speed is observed for each atmospheric stability class, but the relationship between wind speeds and distances due to thermal radiation is not always identical in each atmospheric condition. According to the results, atmospheric stability classes such as B, C and F show a relationship between wind speed and radiation distance with a correlation of 0.94, 0.86 and 0.95 respectively. The impact distance of thermal radiation is almost similar between stability classes ranging from 30 to 31 meters from the discharge zone. The disparity observed between the stability classes may be due to the atmospheric conditions prevailing in the impact zone and the flaming liquid leaving the tank with a certain speed higher than that of the wind could also, under certain atmospheric conditions, cause the wind speed to be neglected. This neglect of the wind speed may be due to the maximum impact that the jet fire scenarios have on the wind speed because of the inclination of the fire flame towards the wind direction [24] .

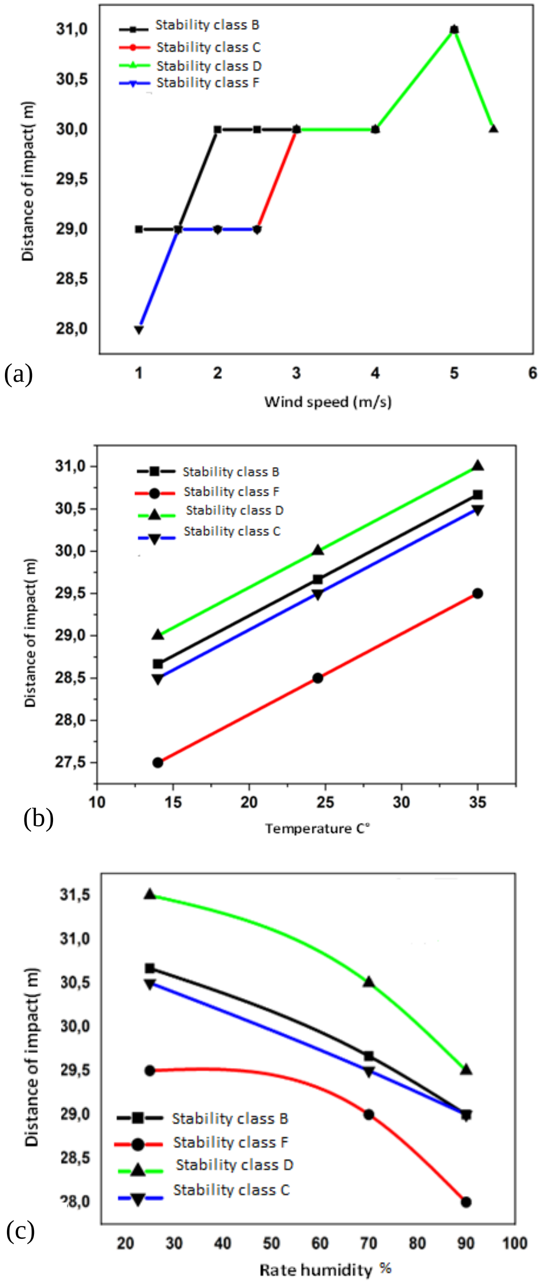

Figure 7: Influence of thermal radiation zones for a Jet fire as a function of wind speed (a), ambient temperature (b) and humidity level (c).

Figure 7(b) shows the influence of ambient temperature on the thermal radiation of a Jet fire. The behaviour of the impact of the ambient air temperature is similar in each class of atmospheric stability. Table 5 shows a high correlation of 0.99 between temperature and impact distance. When the temperature varies from 14° to 35°C, the distance of the radiation zone varies between 28 and 31 meters from the point of the fluid discharge source. In fact, the increase in the mobility of the air molecules due to the rise in temperature must necessarily lead to rapid displacement, and also the speed of the jet of ignited liquid coupled with the temperature increases the evaporation of the chemical substance, which could contribute to the increase in the radiation zone. By observing the atmospheric conditions, we note an increase in the distance of thermal radiation for neutral classes (D) with a distance of 31 meters, during which time the propagation of the radiation is less disturbed to avoid its displacement in the environment.

Figure 7(c) shows the influence of the humidity content on the distance covered by thermal radiation from a jet fire. When the humidity content increases, the impact distance falls for each class of atmospheric stability with a high correlation varying between -0.97 and -0.99 according to Table 6. The increase in humidity makes it difficult for the liquid to evaporate into the environment, as the air is already saturated with water vapour, which reduces the thermal radiation zone. Pimont et al, (2019) [26] already pointed out that the speed of fire propagation could be more sensitive to moisture content, and similarly according to Živanović and (Gocić, 2022) [27] the period when the fire danger is highest is when moisture levels are low, which converges with our results which reveal that moisture levels varying from 25 to 90% generate an average radiation zone ranging from 32 to 28 meters from the fire source. Looking at the atmospheric stability classes, the neutral class (D) has a higher radiation distance of 32 meters than other conditions, even though the variation in radiation distance between atmospheric stability classes is not very high.

Table 6: **Correlation between temperature, humidity and wind speed in each stability class**

Parameters	**Stability class**			
	B	**C**	**D**	**F**
Air temperature	0.99	0.99	0.99	0.99
Rate humidity	-0.97	-0.97	-0.99	-0.99
Wind speed	0.94	0.86		0.95

3.2.2. Effect of discharge parameters on a JET fire

According to the results obtained in the case of a Jet fire, the filling rate of the tank and the roughness of the ground have no impact on the distance of thermal radiation except for the diameter of the discharge hole. Figure 8 shows the impact of the diameter of the discharge hole on the distance of thermal radiation. It can be seen that increasing the diameter of the discharge hole produces similar behaviour in each class of atmospheric stability. When the hole diameter varies from 15 mm to 50 mm, the radiation zone varies between 15 and 45 meters. Reducing the diameter of the leak can lead to a reduction in the maximum leak rate and the mass combustion rate. As a result, the maximum thermal radiation decreases with the reduction in the diameter of the leak, as observed by the work of [28]. Looking at the stability classes, the impact of the diameter of the discharge hole is almost similar between the classes (B, C, D and F).

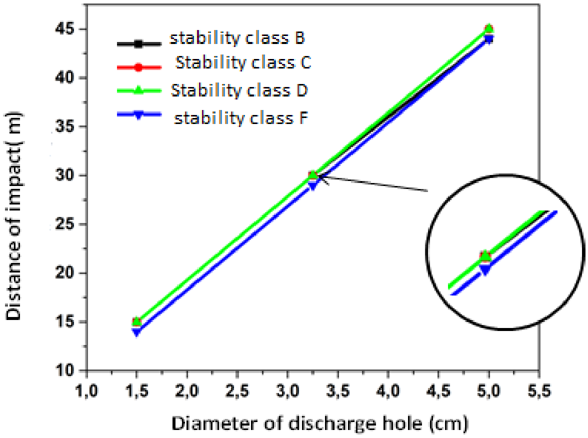

Figure 8: Influence of the Diameter of the Jet Hole for a Jet Fire

3.3. Scenario 3: Thermal radiation from a BLEVE

3.3.1. Effect of meteorological parameters

Figure 9(a) reveals the behaviour of the impact of temperature on the distance of thermal radiation and between these two parameters there is a high correlation of -0.99 according to Table 7. When the ambient temperature is between 14 and 35°C, this results in a reduction in the distance affected by thermal radiation ranging from 429 to 403 meters. This result is similar to that found by [9], which can be explained by the fact that the thermal radiation flux is greater at higher temperatures and therefore the impact distance is shorter. Looking at the atmospheric stability conditions, the instability class (C) has a higher impact distance of 429 meters than other conditions because the unstable air mass due to the air current increases the intensity in the fire and the higher vertical wind speed in the smoke column.

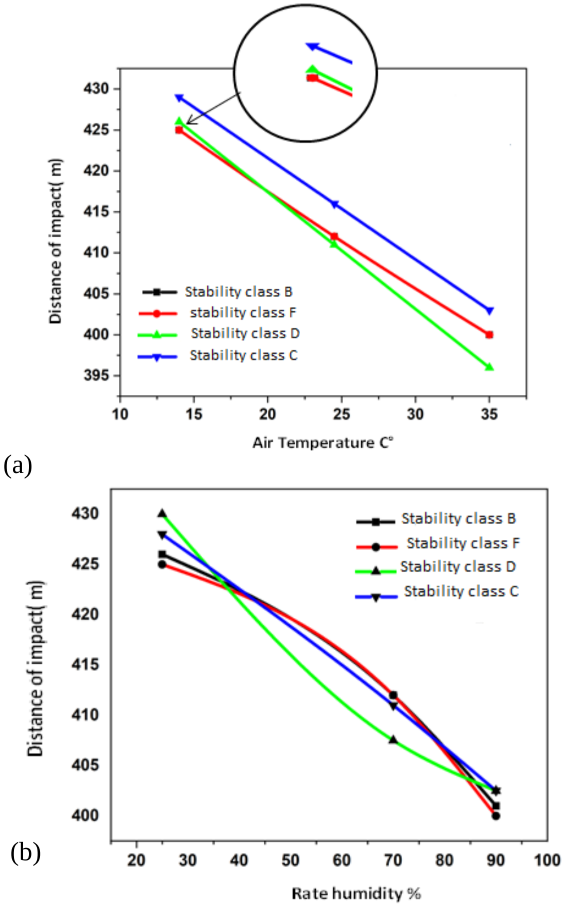

Figure 9: BLEVE impact distance Influence of atmospheric parameters Ambient temperature (a). Humidity level (b)

The influence of moisture content on the thermal radiation of a BLEVE is shown in Figure 9(b). The behaviour of the moisture content is similar for all stability classes with a correlation ranging from -.0.97 to -0.99 according to Table 7. When the moisture content decreases, the impact zone of the thermal radiation of a BLEVE scenario increases. In addition, the maximum impact distance for stability classes varies from 425 to 429 meters and finally, when the humidity level varies, the atmospheric condition (D) where the air is neither stable nor unstable has a high impact distance of 429 meters. The risk of fire becomes dangerous when humidity levels fall, according to (Gocić, 2022) [27] the period when the danger of fire is high is when humidity levels are low. Increasing humidity levels make it difficult for the liquid to evaporate into the environment, as the air is already saturated with water vapour, reducing the impact zone.

Table 7: **Temperature and humidity correlation in each stability class for a BLEVE**

Parameters	**Stability class**			
	B	**C**	**D**	**F**
Air Temperature	-0.999	-0.999	-0.999	-0.999
Rate humidity	-0.988	-0.971	-0.993	-0.997

3-3-2. Effect of discharge parameters

Figure 10 shows the results of the effect of the filling ratio on the hazard distance generated by thermal radiation during a BLEVE. The behaviour of the filling ratio is identical for the different classes of atmospheric stability. When the filling ratio varies from 50 to 95%, the impact space increases within a distance range of 367 to 448 meters. This increase in the filling rate of the tank leads to an increase in the rate of mass combustion, and as the liquid disperses it increases the length of the fire flame, thus posing a high thermal risk [29]. When the classes of atmospheric stability are observed, the impact of the rate on the thermal distance is almost similar between the classes.

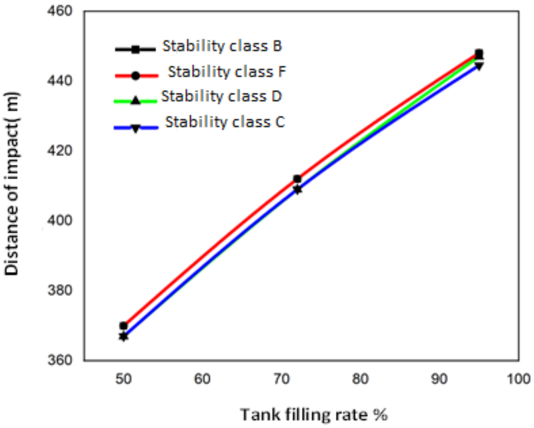

Figure 10: Influence of tank filling rate

3.4. Comparison of scenarios: Evaluation of critical cases

From the diagram in figure 11 (a) we can see that the highest value generated by an atmospheric parameter is the wind speed with an impact distance of 395 meters for a flash fire and for the discharge parameters the hole diameter generates an impact distance of 420 meters. Furthermore, it is under stable atmospheric conditions (F) that the impact values are high, which converges with certain studies stipulating that. The dispersion of hazardous materials is high when atmospheric conditions are stable, because vertical mixing is reduced and pollutants released in stable atmospheric conditions tend to spread horizontally rather than vertically [30]. In the case of this scenario, the diameter of the discharge hole results in impact distances that are greater than the atmospheric parameters.

The comparison between the influential parameters for a Jet scenario is shown in Figure 11 (b). The diameter of the discharge hole results in a thermal radiation distance of 42 meters. This distance is greater than the other parameters under all atmospheric conditions. The influence of the diameter of the discharge hole results in a higher thermal zone independently of the atmospheric stability class. However, the atmospheric parameters for a certain thermal radiation depend on the atmospheric conditions. These results converge with those of [31] which stipulate that atmospheric turbulence has an influence on the dispersion of the fire and that at a certain thermal radiation the danger zones of a jet fire are independent of the atmospheric stability classes according to the discharge diameter.

Figure 11 (c) summarises the parameters influencing a BLEVE. Looking at the atmospheric parameters, only the humidity level has an impact value of 429 meters compared with the others. The filling rate generates an impact distance of 442 meters. These results show that the fill rate has a high impact value compared with the atmospheric parameters. This high impact of the filling rate is almost identical in each atmospheric condition, whether stable or not.

From the results observed for all the fire scenarios studied, it can be seen that atmospheric conditions do not affect the hazard distances in a similar way for the different scenarios. The impact distance caused by meteorological parameters is less than that caused by parameters such as the diameter of the discharge hole and the tank filling rate. Looking at the different scenarios, the Bleve phenomenon generates a greater impact distance than the other scenarios. .

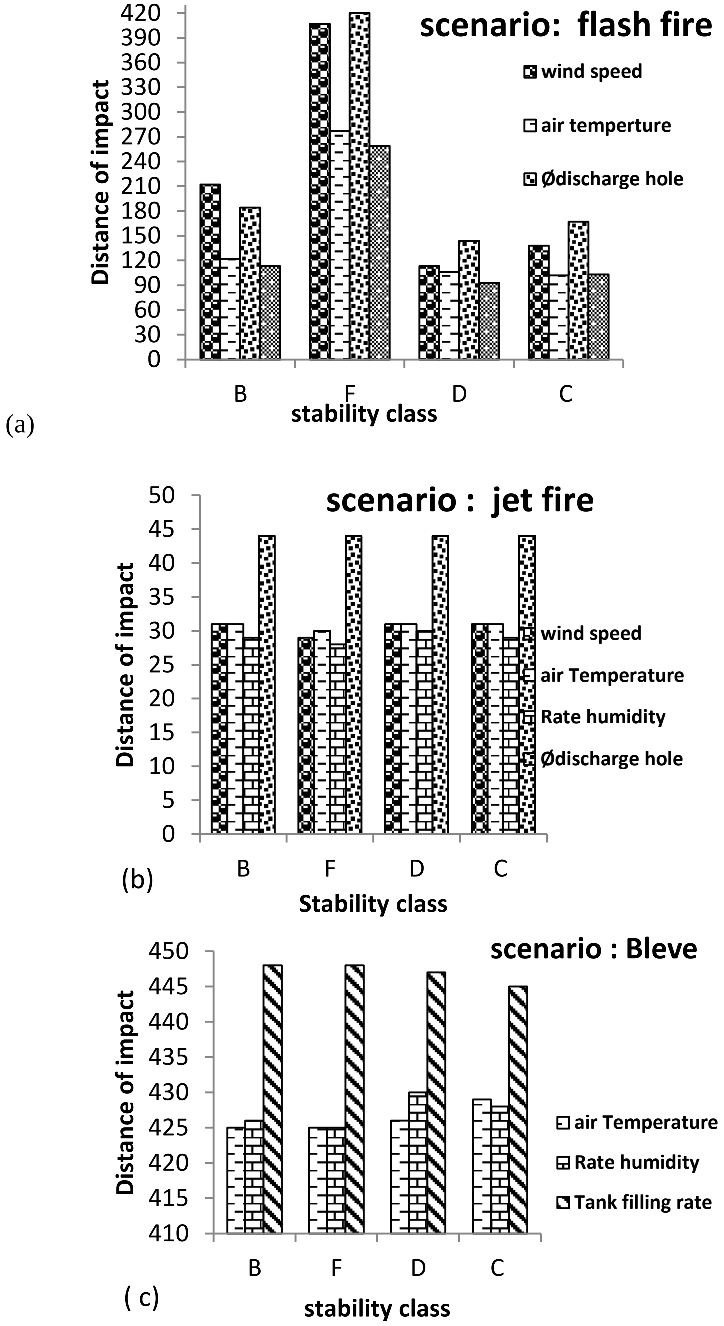

Figure 11: Critical case of parameters as a function of stability classes for the ignition (a), jet (b) and Bleve (c) zones

Table (8) shows the parameters influencing each scenario. This table is based on the parameters having an influence on the hazard distance generated for each fire scenario described in Figure 11. It can therefore be seen that the three scenarios studied do not always have the same parameters influencing the danger distance. According to this table, for a flash fire, the ambient temperature, the humidity level, the wind speed, the diameter of the discharge hole and the position of the discharge hole are parameters that influence the danger distance, while for a fire scenario in the form of a jet, the ambient temperature, the humidity level, the wind speed and the diameter of the hole influence the danger zone. Finally, for a BLEVE scenario, the ambient temperature, the humidity level and the filling rate have an impact on the danger zone. We note that the combinations of the determining parameters are not similar for each scenario. This shows that each consequence of the fire scenarios studied must be understood by taking into account the parameters that are favourable to it.

Table 8: Influencing parameters by scenario

Scenarios	**Accidental consequence**	**Air temperature**	**Rate humidity**	**Wind speed**	**Hole diameter**	**Hole diameter position**	**Tank filling rate**
1 - flash fire	flammable vapor cloud distance	✓		✓	✓	✓	
2- jet fire	thermal radiation	✓	✓	✓	✓		
3- BLEVE	Rayonnement thermal radiation	✓	✓				✓

The results of this study reveal the importance of each parameter as a function of the fire scenarios and also parameters such as the leak hole and filling rate have high impact values compared with the other parameters. A reduction in the diameter of leaks can lead to a reduction in the leakage rate as well as mass combustion, and consequently thermal radiation decreases [32]. The filling rate increases with the impact distance, for safety measures according to [29] for a filling rate of less than 50% there may be a gain in evacuation. Knowing the impact of these parameters on the danger distance generated by each fire scenario is an important parameter for analysing the effects, assessing the risks and taking emergency decisions and preserving hazardous product release accidents.

Conclusion

The succession of fire scenarios can be very dangerous for the environment. Understanding the atmospheric parameters, filling rates and release conditions in areas threatened by fire scenarios such as flash fire, jet fire and BLEVE was the focus of this study. The variability of combinations of input parameters such as atmospheric data, filling rates and release conditions were simulated using the ALOHA software for each distinct scenario. The impact distances (response) were analysed for each scenario using the coefficient of determination R2 in relation to each input. This made it possible to assess the influence of the parameters on the different hazard zones generated by the different scenarios. The results obtained show that:

- Atmospheric parameters: an increase in humidity decreases the radiation zone for a jet fire and the same for a BLEVE phenomenon, and the ambient temperature increases the gas dispersion and radiation zone for a jet fire. For a BLEVE phenomenon, the opposite is true;
- The diameter of the hydrocarbon discharge increases the radiation zone for a jet fire, the gas ignition zone and yet the filling rate increases the radiation zone for a BLEVE phenomenon;
- The filling rate and the hydrocarbon discharge diameters generate radiation zones that are relatively higher than the atmospheric parameters for the BLEVE phenomenon and the Jet fire respectively;

For future studies, a plan of experimentation can be explored for a more extensive analysis of the influence of parameters on the danger zones of fire scenarios. The results of this work can help fire risk analyses and guide improvements in fire risk management planning in order to reduce the influence of certain parameters studied in this study

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