Journal of Chemical Health Risks

ORIGINAL ARTICLE

Predictive Assessment of Economic, Social, and Environmental Impacts of Possible Accidents; A case study: Crude Oil Base

Jesús Luis Orozco*[1], Julio A. Dueñas Santana[2], Luc Hens[3], Carlo Vandecasteel[3], Jo Van Caneghem[4], Irina Pedroso [1], Jonathan Serrano[1], Yanelys Cuba Arana[5], Ramón quiza[5]

[1]*Chemistry Engineering Department in the University of Matanzas, Cuba*

[2]*Scuola Superiore Meridionale, University of Naples Federico II. Naples, Italy*

[3]*Flemish Institute for Technological Research, Belgium*

[4]*KU Leuven, Campus Group T, Leuven, Belgium*

[5]*Centre for Advanced and Sustainable Manufacturing Studies, Spain*

(Received: 9 February 2023 Accepted: 10 June 2025)

KEYWORDS

Accident;
Risk;
Explosion;
Fire;
Naphtha spill

ABSTRACT: The development of facilities for the processing, storage, and transportation of oil generates a high level of risks, mainly related to fires and explosions, which might cause serious accidents with a severe impact on the population and the environment. However, the current situation related to COVID-19 has demonstrated the low risk perception of the people and authorities in some countries around the world. For this reason, many authors define predictive risk studies as a moral, legal, and economic necessity. Additionally, there are various methodologies that quantify these damages. However, there is a lack of an accurate combination of these techniques in specialized literature. This research offers a logical methodology which combines risk analysis techniques to address the quantification of economic, human, and environmental impacts due to fire and explosion accidents. Moreover, a case study in Crude Oil Base is analyzed, to estimate the possible economic, environmental, and human effects due to accidents related to fires and explosions. For this purpose, procedures and tools used internationally are carefully selected, such as the Probit equations, the Dow Fire and Explosion Index, and the ALOHA software. Finally, with this research, the high risk of continuing accidents, which lead to a major one in the Crude Oil Base, is proven. Moreover, a leak in naphtha tanks can cause serious economic, environmental, and human damage in the Crude Oil Base of the Territorial Fuel Marketing Division. Hence, the study carried out will allow the management to take measures that avoid or minimize fire and explosion risks that exist in the Crude Oil Base.

INTRODUCTION

The decline in the oil supply, high energy prices and the need to continue using these fossil resources encourage oil companies to use low grade heavy oil deposits. Conventional oil represents only about 30% of the world production, the other 70% are provided by heavy oil and bitumen [1].

Also, [2] mentioned that the rapid decline in crude oil reserves has increased the proportion of sour crude oil. Compared with sweet crude oil, it contains more sulfur, nitrogen, and metal components, which can lead to many negative effects such as oil processing difficulty, decreased quality of refined products, and environmental pollution. On the other hand, the heavy and viscous oils present new challenges that are being overcome with the

*Corresponding author: jesus.luis@umcc.cu ; jesus.luisorozco@gmail.com (J. Luis Orozco)
DOI: 10.60829/jchr.2025.2321681

new technologies and modifications in exploitation methods developed for conventional oils, promising to play a very important role in the future of the oil industry, for which many countries, among them Cuba, they are tending to increase their production [3]. In Cuba, oil production has been expanding since the early nineties [1].

Cuban oil is heavy and contains a high content of sulfur and asphalt, but despite this, represents a real opportunity for the country to counteract energy dependence of other countries and provides basis for local supply of energy from national sources. To distribute and commercialize the national crude oil and its mixtures in the province of Matanzas, the Territorial Fuel Marketing Division (TFMD) was established.

The development of facilities for the processing, storage, and transportation of oil generates a high level of risks, mainly related to fires and explosions, which might cause serious accidents with a strong impact on the population and the environment. The industry linked to hydrocarbons also leads to a greater probability of increasing the risk of occurrence of disasters that have their origin in the breach of technological standards in the handling, transportation, and storage of them. Laurent, et al. [5] demonstrate the need for quantitative risk analysis because process accidents have not decreased either, have decrease number or in severity.

Worldwide examples of multiple disasters associated with the extraction, preparation, and management of hydrocarbon exist. For this reason, it is important to prepare for such an event and carry out predictive risk studies to assess the effects due to spill accidents of flammable and explosive substances. Thus, it is preferred to prevent the accident rather than to solve the issues that can be generated if a major disaster occurs [5]. Regarding this theme, Pey et al. [6] establish the importance of prevention of major accidents and the improvement of emergency plans.

This type of disaster is directly related to the performance of humans in the realization of different technological processes that have a high degree of danger. For this reason, many authors define predictive risk studies as a moral, legal, and economic necessity [7-9]. On the other hand, the European Union has recently published a manual where the guidelines for the surveillance and prediction of industrial risks are established [10]

There are many tools for making predictive studies [9, 11]. For quantifying the effects on the people, the Probit equations have been developed [12-13]. Moreover, one indispensable methodology for determining the economic impact of fire and explosion accidents is the Fire and Explosion Index of the DOW Company [14].

Regarding the present case study, the crude oil currently received in the TFMD from some sources shows a range of viscosity values, whit the minimum in the order of 1400 cSt. The use of dangerous substances in the process of preparation of mixtures converts the Crude Oil Base into one of the most dangerous areas of the Territorial Fuel Marketing Division, hence the importance of the risk assessment in this process, under the concept that the best way to avoid accidents is through their prediction.

Added to this situation, the lack of predictive studies generates a low perception of risk in workers and managers in charge of industrial safety. For example, a low perception of risk could be perceived in Cuba during the occurrence of Hurricane Irma. However, this type of phenomenon is widely disseminated and attended with special interest by the press and the Cuban authorities [15]. The current situation related to COVID-19 has demonstrated the low risk perception of the people and authorities in some countries around the world. These elements allow thinking that technological risks have a lower perception than natural ones. Therefore, ensuring the health and safety of people, from a preventive point of view, is a necessity and an obligation of any company or organization. This type of study will be more effective to the extent that it is accompanied by economic and environmental estimates.

Additionally, there are various methodologies which quantify people, economic and environmental damages [9-11]. However, there is lacking an accurate combination of these techniques in specialized literature. This research offers a logical methodology which combines risk analysis techniques to address the quantification of economic, individual and environmental impacts due to fire and explosion accidents.

The objective of this work is to estimate the economic, environmental, and human effects that may occur as a result of fires and explosions in the area of crude oil of this company and to show the consequences that these phenomena can produce. In addition, this paper offer, in a novel, integrated and overall way, a procedure that allows predicting economic, environmental, and human damages due to accidents related to the storage and treatment of heavy oil.

MATERIALS AND METHODS

The procedure used in this study is summarized in Figure 1. The main steps are described below.

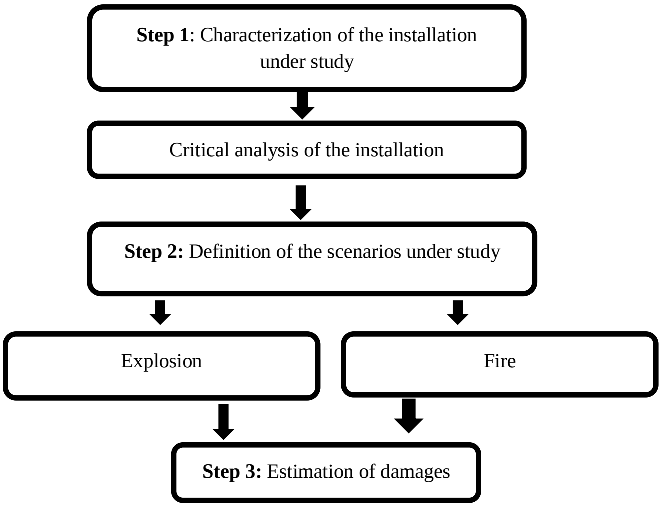


Figure 1. Research rationale.

Step 1: Characterization of the plant

The Fuel Trading Company distributes and commercializes crude oil and derivatives. To this unit, springs and pipelines are unit to transfer the fuel to consumers. This company has four fundamental process areas:

Area 1: Base of crude oil.

Area 2: Base of supply to the Thermoelectric Power Plants.

Area 3: Base of reception of crude oil.

Area 4: Land Base.

The base of crude oil or area 1 (researched area) is the entry point of the oil in the plant. Crude oil is stored and hence transferred to ships, which line the oil country circle distribution centers. From this area, the oil is equally distributed over the plant. Here, the crude oil also gets a first naphtha treatment, which brings the oil in line with the Improved National Crude Oil (NCO) and standard. The naphtha solvent is injected to reduce the viscosity to values in the order of 650, 1100, and 1400 cSt. This area is structured into two main sub-areas: the pump area and the tank area.

Offices for nine people are located in this area. They include the Head of Area, six technicians, a Shift Manager, Control Room Operator and an assistant.

Critical analysis of the installation

The crude currently received by the company shows different viscosity values; the maximum is approximately 2600 cSt. The viscosity reduction up to the agreed value with the customer takes place in the pump area.

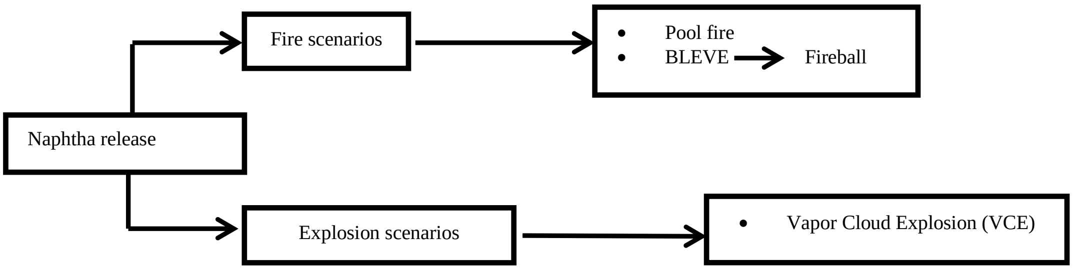
If the current arrival temperature of crude oil (between 30ºC and 40ºC) is taken into account as well as the real possibility of receiving crude oil with very high viscosity, a critical situation in the handling of this product can occur.

The naphtha leaks in this installation have always been associated with faults in the conductive pipes. These events have demonstrated the real possibility of leaks from these tanks and the need to act on it from a preventive point of view.

Step 2: Definition of the scenarios under study

The scenarios under study are based on real life events that may arise from a naphtha leak in the storage tanks or in the pipelines of the solvent. The criteria of the

Technical report by the Joint Research Center, the European Commission's science and knowledge service [10] are taken into consideration. Figure 2 illustrates the scenarios considered by this study.



Note: BLEVE (Boiling Liquid Expanding Vapor Explosion)

Figure 2. Scenarios of fire and explosion caused by a naphtha leak.

The Area Locations Of Hazardous Atmospheres (ALOHA) software is used in this study. ALOHA was developed jointly by the National Oceanic and Atmospheric Administration (NOAA) and the Environmental Protection Agency (EPA) of the United States. The program has been recognized by the Cuban Ministry of Science, Technology and Environment (CITMA) as the recommended tool for this type of study. ALOHA allows predicting the amounts of chemicals released into the atmosphere through pipelines and tanks as a result of evaporation, during explosions. [16-17].

Step 3: Assessment of damages

The human, economic and environmental damages are estimated as a consequence of the occurrence of some of the scenarios shown in Figure 2. For the estimation of the material damages, the losses due to the replacement of the damaged equipment and the fuel losses are quantified.

Human damages

Probit equations for fires and explosions are used to quantify human damage. The damage caused by a hazardous agent needs the quantification of the intensity, duration and consequences of the exposure [18]. This allows calculating the estimated exposure (dose) which can be compared with the health standards. The Probit criteria can be used to determine levels that result in dangerous consequences for vulnerable groups.

Probits exist for almost any hazardous agent, but are typically available for thermal radiation, toxic gas, and blast overpressure effects. Equation 1 represents the probit value (Y) in case of an explosion, and equation 2 the probit value (Y) by fire [12]

$$Y = 5.13 + 1.37 \ln (P) \qquad (1)$$

In which (P) is pressure in bar

$$Y = -10.7 + 1.99 \ln I^{4/3} \times t \qquad (2)$$

Where:

I - Effective radiation intensity (kWm^{-2})

t - Effective exposure time (seconds)

Economic damages

The economic damages are associated to: costs of replacement of the damaged equipment, lost product involved in the accident and interrupted production due to stopping.

The replacement cost of the equipment (Replacement Value) is estimated from equation 3 proposed by Dow's Fire & Explosion Index Hazard Classification Guide [14]

$$\text{Replacement Value} = (\text{Original Cost})\ (0.82) \qquad (3)$$

The Original Cost is the investment value of damaged equipment. It is obtained from the procedure recommended by [19]

The factor 0.82 is an allowance for items of cost not subject to loss or replacement, such as site preparation, roads, underground lines, and foundations, engineering expenses, etc. This factor may be changed if a more accurate estimate exists.

Environmental damages

Environmental damage is associated with the released smoke. The volume of smoke produced depends on the size of the fire and the nature of the fuel in the occupancy in which the fire occurred. The volume rate of smoke produced can be estimated as follows [20-21]:

$$Vs = m * \frac{Ts}{\rho To} \quad (4)$$

$$m = \varepsilon_{smoke} * m_f \quad (5)$$

Where:

Vs = volume rate of smoke production at a specified temperature, m^3 s^{-1}

m = mass rate of smoke produced, kg s^{-1}

m_f = mass rate of fuel burnt, kg s^{-1}

ε_{smoke} = smoke mass conversion factor

Ts = smoke temperature in smoke plume, K

ρ = density of air under ambient temperature, kg m^{-3}

T_o = ambient temperature of the space, K.

The variables described above are taken from the climatological characteristics of the area under study [22], from the results provided by the ALOHA software [23], and BSI Standards [20].

RESULTS AND DISCUSSION

In this study, we start from the following considerations:

- The climatic conditions of the study area are the following:
  - Predominant wind direction: East
  - Air temperature: 32 ºC
  - Cloud cover: 5 oktas
  - Relative humidity: 75%
  - No thermal inversion
- Naphtha leak in the storage tank is a consequence of the rupture of its inlet or outlet pipes.
- All possible scenarios of fires and explosions that may occur in the naphtha tank are analyzed.

Analysis of possible scenarios and their impact

This analysis starts from possible failures in tanks, the decision scenarios and their respective potential hazards. Figure 3 shows the possible scenarios according to the Gyenes et al. [10]; ALOHA User's Manual [24]; The NOAA Technical Memorandum NOS OR & R 43 [25] and Abbasia [26].

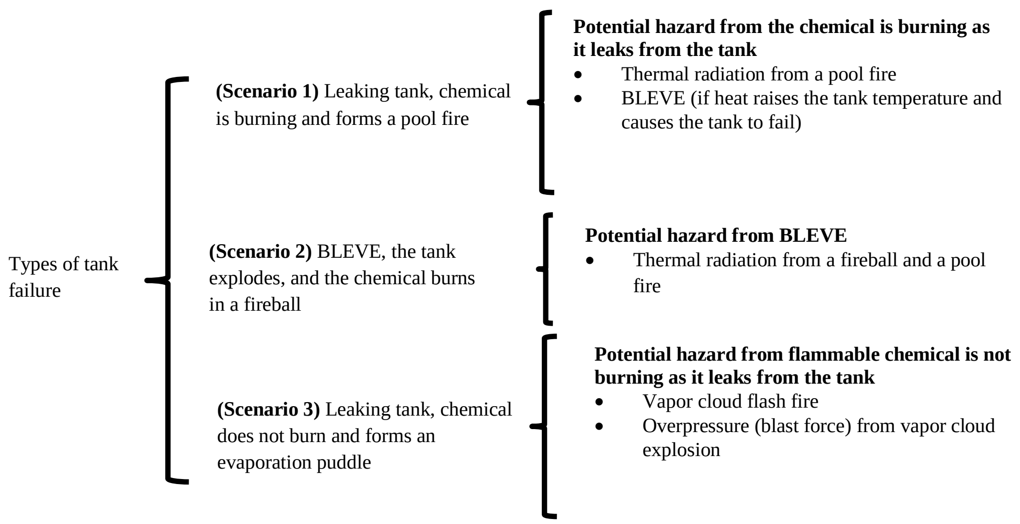


Figure 3. Possible faults in the naphtha tank and its associated hazards

Fire scenarios

As shown in Figure 3, the fire scenarios resulting from a naphtha leak originate due to the formation of a naphtha puddle (scenario 1), which, when incinerated, causes high levels of thermal radiation. Figures 5 and 6 show the range of radiation and radiation levels at different distances from the source, respectively.

Figure 4 shows that when a naphtha leak occurs, a puddle of fuel is produced, and when incinerated, it generates high levels of thermal radiation, which may result in material and human damage. The thermal radiation is potentially lethal up to a distance of 443 m from the emitting source (red zone); second-degree burning will be caused at a distance of 609 m (orange zone). Figure 5 shows that below 100 m from the source, the radiation levels exceed 100 kW.

The intense thermal radiation also generates high temperatures on the surface of the tanks. Equation 6 allows quantifying these temperatures, which are expected reaching 690 ºC (963.15 K). This may cause a fracture in the metallic structure of the tank [27].

$$T = \sqrt[4]{\frac{q}{R*F*\sigma*\tau}} \quad (6)$$

T =Temperature, K

q =Total heat flow over a surface, kWm^{-2}.

R =Radiative fraction, which depends on the incident that manifests (dimensionless).

τ =Atmospheric transmissivity.

F =Vision factor.

$$\sigma = \text{Stefan−Boltzmann Constant}$$
$$5.73 * 10^{-8}\ \text{kWm}^{-2}\text{K}^{-4}$$

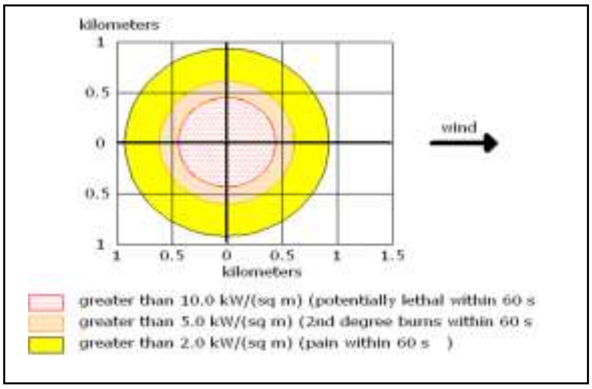


Figure 4. Range of thermal radiation produced as a result of a pool fire.

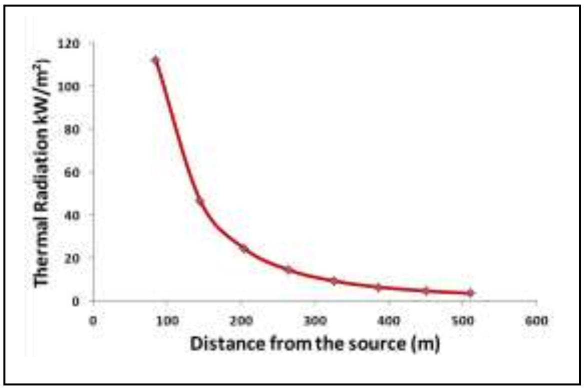


Figure 5. Thermal radiation levels at different distances from the source for a pool fire.

The phenomenon can be aggravated by naphtha tanks containing less than 50% of their capacity. This causes more overheating of the metallic structure and as a result increases the probability of failure [28]. The rupture of the tank, as a secondary accident, can cause a BLEVE (scenario 2). The BLEVE is the initial manifestation of a fireball. This accident is much more damaging than the initial accident. The zone with consequences is shown in Figures 6 and 7.

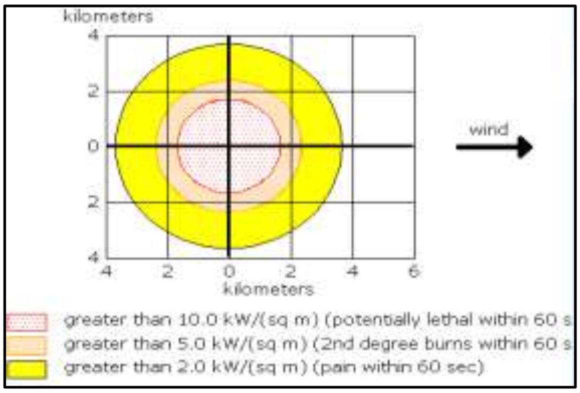


Figure 6. The Import zone of thermal radiation produced by a fireball.

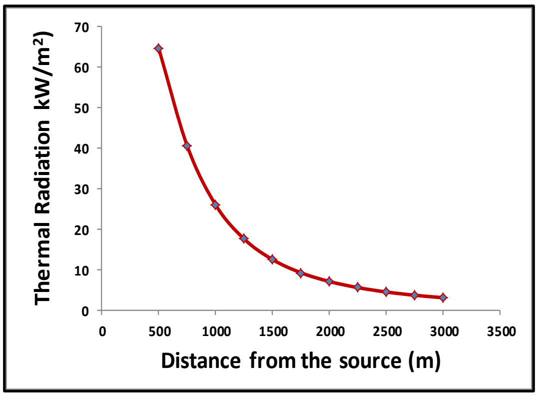


Figure 7. Thermal radiation at different distances from the source for a fireball.

Figures 6 and 7 show how the rupture of the tank is more dangerous than the initial incident. Potentially lethal radiation levels within a distance of 1700 m in any direction of the wind. Moreover, the entire area would be affected, including the three tanks where crude oil is stored for treatment. If by accident, a fire starts at the crude oil surface, this fire progressively heats the fuel layer and, therefore the water layer. As the water is heated, it starts to vaporize, and the vapor generated ejects the fuel from the reservoir. This phenomenon, called boilover, induces violent fuel ejections, flame enlargement, and possible formation of fireballs [29]. When these scenarios occur, by their characteristics, in the process industry called a Major Accident [30].

Explosion scenarios

If at the time of the naphtha leak the puddle originated does not ignite, then an evaporation puddle is formed (scenario 3), forming a flammable vapor cloud (Figure 8). This cloud can ignite and generate a fire or produce an explosion (Figure 9)

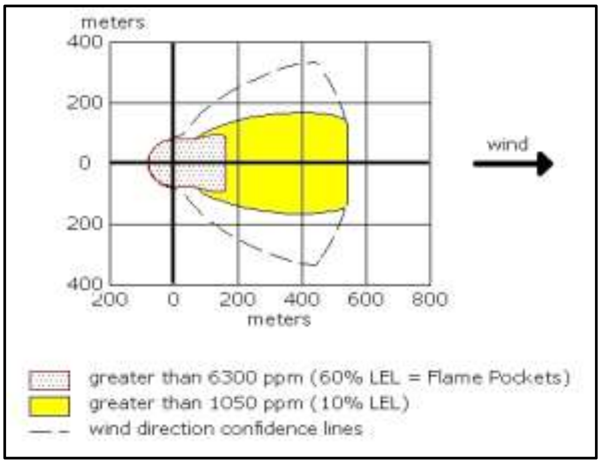


Figure 8. Flammable area of vapor cloud

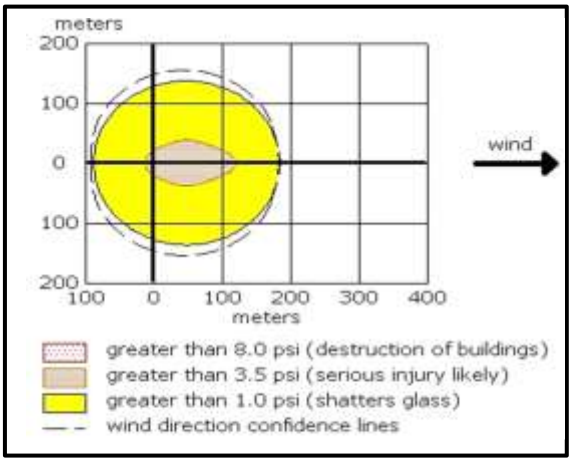


Figure 9. Blast area of vapor cloud explosion

Figure 8 shows the concentration levels of the cloud formed by the evaporation of the naphtha pool. It can be seen that at a distance from the emission point of 163 m, the concentration is 6300 ppm, which is equivalent to 60% of the Lower Flammability Limit (LEL). These values guarantee flammability conditions of the cloud up to that distance. Therefore, any circumstance that may cause a spark will cause the cloud to fire. The area under study, due to its characteristics, has several sources of initial ignition that can cause the cloud to fire.

If the unconfined vapor cloud explodes (figure 9), no first-level damage is predicted, since the software does not offer overpressures greater than or equal to 8 psi (55.16 kPa) for this event. The area of greatest danger, in this case, is given by the orange zone that has a range of 120 m and overpressures are reached in the range of 7.9 and 3.5 psi (54.47 – 24.13 kPa).

Table 1 gives a summary of the main characteristics of possible faults that may occur in the naphtha tank. The information that appears there is provided by the ALOHA software.

Table 1. Summary of the main characteristics of each scenario.

Types of tank failure			
Leaking tank, chemical is burning and forms a pool fire (scenario 1)	BLEVE, tank explodes and chemical burns in a fireball (scenario 2)	Leaking tank, chemical is not burning and forms an evaporation puddle (scenario 3)	
Main characteristics of the accident			
➢ The chemical escaped as a liquid and formed a burning puddle. ➢ Max Flame Length: 32 meters ➢ Burn duration: ALOHA limited the duration to 1 hour ➢ Max Burn Rate: 1400 kg min^{-1} ➢ Total Amount Burned: 83391 kg ➢ The puddle spread to a diameter of 17.6 m.	➢ BLEVE (if heat raises the tank temperature and causes the tank to fail) ➢ Chemical Mass in Tank: 3723 tons ➢ The tank is 100% full ➢ Percentage of Tank Mass in Fireball: 100% ➢ Fireball Diameter: 870 m ➢ Burn Duration: 39 seconds	➢ The chemical escaped as a liquid and formed an evaporating puddle (VCE). ➢ Max Average Sustained Release Rate: 1050 kg min^{-1}. ➢ Total Amount Released: 41554 kg ➢ The puddle spread to a diameter of 126 m	➢ Overpressure (blast force) from vapor cloud explosion ➢ Max Average Sustained Release Rate: 1050 kg min^{-1} ➢ Type of Ignition: ignited by spark or flame ➢ The puddle spread to a diameter of 126 m
Maximum range for each zone (m) (Red, Orange, and Yellow zones)			
Red: 43 m	Red: 1700 m	Red: 163 m (6300 ppm = 60% LEL = Flame Pockets)	Red: LOC was never exceeded --- (8.0 psi = destruction of buildings)
Orange: 62 m	Orange: 2400 m	---	Orange: 120 m (3.5 psi = serious injury likely)
Yellow: 97 m	Yellow: 3700 m	Yellow: 545 m (1050 ppm = 10% LEL)	Yellow: 185 m (1.0 psi = shatters glass)

It is important to point out that the three scenarios studied are not isolated and independent facts; on the contrary, there is a close relationship between them, the occurrence of one of them leads, in most cases, to the manifestation of one or more scenarios as side effects. Thus, for example, when naphtha escapes, a puddle can evaporate and create a cloud of flammable vapor which, when ignited, will lead to the formation of a pool fire, which can overheat the metallic structure of the tank, cause its rupture and generate a BLEVE and its corresponding fireball. This generates a chain of events that ends in the most catastrophic manifestation (scenario 2).

Assessment of damages

The damages that these accidents may cause are associated to: human, economic and environmental damages. Next, each of them will be analyzed separately for the case of a naphtha leak in Area 1: Base of crude oil.

Assessment of human damages

The human damages are associated with the effects on the exposed people of the thermal radiations in the case of fire by the pool fire or the fireball, and in the case of the explosions by the overpressure originated when the unconfined vapor cloud explodes. In both cases, the Probit 1 and 2 equations are used to determine the Probit Value (Y). Through them, the percentage of injured persons is determined. The likely number of injured people can be estimated using the probit transformations tabulated by Lees [12]. The values of thermal radiation or overpressure and the exposure time are obtained from the ALOHA software (Table 2). A maximum distance of 110 m is considered to determine the levels of thermal radiation or overpressure. At this distance is the radius where the affected people are concentrated.

Table 2. Probit values, percentage of humans damaged, and probable number of fatalities for three scenarios under study

Type of accident	Thermal radiation or overpressure	Number of exposed people	Exposure time (s)	Probit Value (Y)	Percentage of injured persons (%)	Number of likely injured persons
Pool fire (scenario 1)	73.8 kWm^{-2}	9	960	17.26	100	9
Fireball (scenario 2)	127 kWm^{-2}	9	39	10.91	100	9
Vapor cloud explosion (scenario 3)	6.36 psi (43.85 kPa)	9	---	4	10.6	1

The results of the application of the Probit equations to determine the number of damaged people show that the fire scenarios are extremely dangerous, causing the death of all the people exposed. In addition, scenario 2 (Fireball) extends outside the installation frames. When this occurs together with the number of expected victims, this event is classified as a major accident [30].

Assessment of economic damages

Table 3 shows the information obtained to estimate the economic damages.

Table 3. Information obtained to estimate the economic damages

Indicator		Value	Ref.	Comments
Unit price of naphtha		17 $USDm^{-3}$	[31]	The prices are established from the equivalence CUP-USD regulated.
Unit price for the sale of crude mixtures		20 $USDm^{-3}$	[31]	
Volume of naphtha lost in the accident		5000 m^3	[32].	According to the radius of the flames, a single tank damaged in the accident is considered.
The Flow of the crude mixture to prepare		7200 m^3d^{-1}	[32]	-----
Chemical Engineering Plant Cost Index (CEPCI)	**CEPCI 1996**	381.7	[33]	Values used to update the investment value of damaged equipment.
	CEPCI 2023	797,9	[33]	

On the other hand, taking into account that this facility prepares a flow of crude oil mixture of 7200 m^3 daily, and as a result of the accident, this can be reduced by half (3600 m^3) due to a lack of naphtha. Due to interrupted production per stop, 72000 USD/day is paid. From AIChE [14], known property damage can be estimated as the maximum probable days of outage (58 days). Once this value is known, the value of the interrupted production is calculated as a stoppage (4 176 000 USD). Table 4 summarizes the economic damages caused by the accident.

Table 4. Economic damages caused by the accident

Nº	Indicator	Monetary value(USD)
1	Original Cost	2510508
2	Replacement Value	2058616
3	The lost product involved in the accident	85000
4	Interrupted production due to stopping.	4176000
5	Total economic damages by the accident (∑2+3+4)	6319616

Assessment of environmental damage

In this case, environmental damage is mainly associated with the emission of large quantities of smoke into the atmosphere due to the combustion of naphtha and the overheating of the air. The emission of other pollutants is not taken into account in the calculations.

Smoke is a suspension in the air of small solid particles that result from the incomplete combustion of a fuel. It is an unwanted product of combustion that goes along with large amounts of carbon monoxide [21].

The calculation of the volume rate of smoke production is only done for scenario 1 (Leaking tank, chemical is burning and forms a pool fire). For this case, it is obtained that 0.44 m^3 s^{-1} of smoke is produced as a consequence of this fire. Under these conditions, BBRYAN [34] considers that visibility is considerably lost when people move through the smoke; this value (Visibility distance) can be reduced by up to 61 cm. This situation, in addition to the serious environmental effects that it causes, prevents evacuation and fire control tasks.

CONCLUSIONS

Firstly, an accurate combination of risk analysis techniques addresses the quantification of economic, individual, and environmental impacts due to fire and explosion accidents. Additionally, with this research, the high risk of continuing accidents, which lead to a major one in the Crude Oil Base, is proven. Moreover, a leak in naphtha tanks can cause serious economic, environmental, and human damage in the Crude Oil Base of the Territorial Fuel Marketing Division (TFMD).

Hence, the study carried out will allow the management in any area of fuel storage to take measures that avoid or minimize fire and explosion risks.

ACKNOWLEDGEMENTS

We appreciate the support of the VLIR UOS through the TEAM project ZEIN2015PR402 - 3942. The contributions provided by the reviewers of KU Leuven, and Flemish Institute for Technological Research of Belgium is gratefully acknowledged.

Conflict of interests

None.

REFERENCES

1. Belani A., 2010. It's Time for an Industry Initiative on Heavy Oil. Journal of Petroleum Technology. 58(6), 40-42.

2. Guo S., Peng M., Ruan J., Wan W., 2013 Cause analysis of the fire and explosion during crude oil desulfurization in China. Journal of Loss Prevention in the Process Industries. 26, 961-967

3. Sánchez A., 2017. Cuba's ambitions for energy self-sufficiency require major investment in the nation's oil reserves and refining industry. Cuba's oil: due for development. : https://www.researchgate.net/publication/313790584. (Accessed 20 Jan 2021)

4. Laurenta A., Pey A., Gurtel P., Fabiano B., 2020 A critical perspectives on the implementation of the EU Council Seveso Directives in France, Germany, Italy and Spain. Process Safety and Environmental Protection. 148, 47-74.

5. Ahmad S., Hashim H., Hassim,M., Rashid R., 2019 A graphical inherent safety assessment technique for preliminary design stage. Process Safety and Environmental Protection. 130, 275-287.

6. Pey A., Lerena P., Suter G., Campos J., 2009. Main differences on European regulations in the frame of the Seveso Directive. Process Safety and Environmental Protection. 87, 53-58.

7. FPA. 2015. Fire Safety and Risk Management for the NEBOSH National Certificate in Fire Safety and Risk Management. First edition. Ed. Routledge.

8. Renjith V.R., Madhu G., 2010. Individual and societal risk analysis and mapping of human vulnerability to chemical accidents in the vicinity of an industrial area. International journal of applied engineering research, Dindigul. 1(1). http://ipublishing.co.in/jarvol1no12010/EIJAER1013.pdf . (Accessed 23 Jan 2018).

9. Dueñas Santana J.A., Orozco J.L., Febles Lantigua D., Furka D., Furka S., García Cruz A., 2021a. Using Integrated Bayesian-Petri Net methodology for

individual impact assessment of domino effect accidents. Journal of Cleaner Production. 294. https://doi.org/10.1016/j.jclepro.2021.126236.

10. Gyenes Z., Wood M., Struckl M., 2017. Handbook of Scenarios for Assessing Major Chemical Accident Risks. EUR 28518 EN.

11. Dueñas Santana J.A., Orozco J.L., Furka D., Furka,S., Boza Matos Y.C., Febles Lantigua, D., González Miranda, A., Barrera González, M. C. 2021b. A new Fuzzy- Bayesian approach for the determination of failure probability due to thermal radiation in domino effect accidents. Engineering Failure Analysis. 120 https://doi.org/10.1016/j.engfailanal.2020.105106.

12. Lees F.P., 2012. Loss prevention in the process industries: Hazard identification, assessment and control, fourth edition. ED. Mannan S., Elsevier Butterworth-Heinemann.

13. Dueñas Santana J.A., González Miranda A., Orozco J.L., Cuba Arana Y., Febles Lantigua D., Serrano Febles J., 2020. How to determine individual risk due to toxic, fire, and explosion accidents in a hydrocarbon processing area? International Journal of Petroleum Technology. 7, 60-73. Avanti Publishers. https://doi.org/10.15377/2409-787X.2020.07.6.

14. AIChE. 1994. Dow´s fire and explosion index hazard classification guide. 7th Ed. Published by the American Institute of Chemical Engineers. New York.

15. Terrero A., 2017 Percepción de riesgo. Granma. Habana. Septiembre. 29, p 2. http://en. granma.cu/impreso/2017-09-29. (accessed 23 Dec 2017).

16. Ding L., Khan F.Y., Ji J., 2020. A Novel Approach for Domino Effects Modeling and Risk Analysis based on Synergistic Effect and Accident Evidence. Reliability Engineering and System Safety. Reliability Engineering & System Safety https://doi.org/10.1016/j.ress.2020.107109

17. Orozco J.L., Van Caneghem J., Hens L., Gonzalez L., Lugo R., Díaz S., Pedroso I, 2019. Assessment of an ammonia incident in the industrial area of Matanzas. Journal of Cleaner Production. 222, 934-941

18. Chen C., Reniers G., y Khakzad N., 2020. A thorough classification and discussion of approaches for modeling and managing domino effects in the process industries. Safety Science, 125, Article 104618.https://doi.org/10.1016/j.ssci.2020.104618

19. Turton R., 1998. Analysis, Synthesis and Design of Chemical Processes. Ed Prentice. New Jersey.

20. BSI Standards. 1994, Draft British Standard Code of Practice for The Application of Fire Safety Engineering Principles to Fire Safety in Buildings, London, UK.

21. Hadjisophocleous and Benichou. 2016. Fire safety design guidelines for federal buildings. NRC Publications Archive. https://nparc.nrc-cnrc.gc.ca/eng/view/fulltext/?id=063cc389-d483-4a62-aa43-b163cf01138d (accessed 20 Jun 2017).

22. Moya, B. (2019). Personal communication. Main specialist in Meteorology. CITMA. Matanzas.

23. ALOHA. 2016. EPA Software. In www.epa.govcameoalohasoftware

24. User´s Manual ALOHA. 2013. U.S. Environmental Protection Agency. Office of Emergency Washington, D.C.

25. NOAA Technical Memorandum NOS OR&R 43. 2013. ALOHA (Areal Locations of Hazardous Atmospheres) 5.4.4. Technical Documentation. Seattle, WA. USA.

26. Abbasia T., Pasmanb H.J., Abbasi S.A., 2010. A scheme for the classification of explosions in the chemical process industry. Journal of Hazardous Materials. 147, 270-280

27. Susan D.F., Eckelmeyer K.H., Kilgo A.C., 2005. Metallurgical Failure Analysis of a Propane Tank. Boiling Liquid Expanding Vapor Explosion (BLEVE). Journal of Failure Analysis and Prevention. 5, 65-74

28. Misuri A., Landucci G.Y., Cozzani V., 2021. Assessment of safety barrier performance in the mitigation of domino scenarios caused by Natech events. Reliability Engineering and System Safety. 205, Article 107278. https://doi.org/10.1016/j.ress.2020.107278

29. Laboureur D., Aprin L., Osmont A, Buchlin J.M., Rambaud P., 2013. Small scale thin-layer boilover experiments: Physical understanding and modeling of the water sub-layer boiling and the flame enlargement. Journal of Loss Prevention in the Process Industries. 26, 1380 – 1389

30. HSE. (2016). Prevention of fire and explosion, and emergency response on offshore installations. Third edition.

31. RESOLUCIÓN No.55. 2017. Ministerio de Finanzas y Precios. Habana. Cuba

32. Manual de Operaciones. 2008. Base de Crudos y Suministro. Empresa Comercializadora de Combustibles de Matanzas. Cuba.

33. Economic Indicators. 2019. Chemical Engineering Plant Cost Index, CEPCI. http://www. chemengonline.com/pci (accessed 12 Jun 2019).

34. BRYAN. 1986. Damageability of Buildings, Contents and Personnel from Exposure to Fire. Fire Safety Journal. 11, 15 - 31