Risk Analysis Using HAZOP -Fault Tree - Event Tree Methodology

Case Study: Naphta Stabilizer-A Reflux Drum (LPG separation) in RA1K

Seif El Islam Bouasla, Youcef Zennir, EL-Arkam Mechhoud
Department of Process Engineering and Petrochemistry, Skikda University, Skikda, Algeria
Automatic laboratory, Skikda University, Skikda, Algeria
Department of Process Engineering and Petrochemistry, Skikda University, Skikda, Algeria
seifelislam.bouasla@sonatrach.dz, youcefzennir@yahoo.com, e.mechhoud@univ-skikda.dz

Abstract: the purpose of this work is the risk assessment of a stabilizer reflux drum using HAZOP - Fault tree - Event tree approach. This risk assessment approach aims first of all to identify potential accident scenarios using Hazard an Operability study (HAZOP), these scenarios need more detailed frequencies estimation, it is performed thanks to fault tree analysis. Then, to analyze events issuing after success or fail of safety barriers, the event tree is used. Finally, in order to better appreciate accident scenarios, ALOHA is utilized to simulate them.

Keywords: risk analysis, HAZOP, Fault Tree, Event tree, stabilizer reflux drum

1. INTRODUCTION

Risk analysis is a Systematic use of available information to identify hazards and to estimate the risk to individuals, property, and the environment. A risk analysis is always a proactive approach in the sense that it deals exclusively with potential accidents.

In this context, The main purpose of this paper is to analyze risks of a stabilizer reflux drum at crude oil unit in Skikda refinery (Algeria) and reduce them to a level that is acceptable using a structured approach that combines the following methods: HAZOP (Hazard and Operability studies), FT (Fault Tree) and ET (Event Tree).

2. DEFINITIONS

A hazard is an inherent physical or chemical characteristic that has the potential for causing harm to people, property, or the environment. In chemical processes, it is the combination of a hazardous material, an operating environment, and certain unplanned events that could result in an accident [1].

Risk is usually defined as the combination of the severity and probability of an event.
In other words, how often can it happen and how bad is it when it does happen? Risk can be evaluated qualitatively or quantitatively [1].
Risk = Frequency × Consequence of hazard

Risk analysis is the development of a quantitative estimate of risk based on engineering evaluation and mathematical techniques for combining estimates of incident consequences and frequencies [2].

Risk assessment is the process by which the results of a risk analysis (i.e., risk estimates) are used to make decisions, either through relative ranking of risk-reduction strategies or through comparison with risk targets [2].

HAZOP study is a highly disciplined procedure that identifies how a process may deviate from its design intent [3]. It is a structured analysis of a system, process, or operation for which detailed design information is available, carried out by a multidisciplinary team. This is done by using a set of guidewords in combination with the system parameters to seek meaningful deviations from the design intention. A meaningful deviation is one that is physically possible—for example, no flow, high pressure… It's a method used for hazard identification. One of the limitations of this method is non-consideration of combinations between different causes leading to the same consequence [4]. For that fault tree is used to overcome this limitation.

Fault tree is used in reliability and safety risk assessments. It represents graphically the logical interactions and probabilities of occurrence of component failures and other events in a system [5]. It is used to develop the causes of an event. It starts with the event of interest, the top event, such as a hazardous event or equipment failure, and is developed from the top-down. Events that lead to a predefined undesired event (top event). The fault tree is both a qualitative and a quantitative technique. Qualitatively it is used to identify the individual paths that led to the top event, while quantitatively it is used to estimate the frequency or probability of that event [6].

Event Tree is used to develop the consequences of an event. It is a commonly applied technique used for identifying the consequences that can result following the occurrence of a potentially hazardous event [7]. Event Tree starts with a particular initial event such as a power failure or pipe rupture and is developed from the bottom-up. It tree is both a qualitative and a quantitative technique. Qualitatively it is used to identify the individual outcomes of the initial event, while quantitatively it is used to estimate the frequency or probability of each outcome [6].

3. PROPPSED METHODOLOGY

The methodology followed to achieve the objective of this study is summarized as follows:

- Functional description of the studied plant.
- Identify risks associated to the plant.
- Estimate and evaluate risks.
- Identify and evaluate different events by studying the success and fail of safety barriers.
- Simulate accident scenarios to determine impact zones.

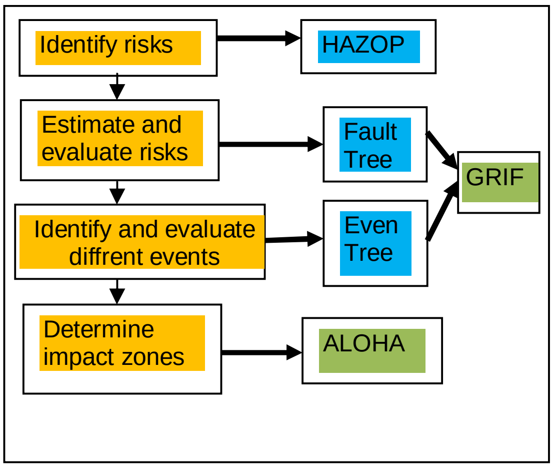

Fig. 1 Methodology steps

A. *Functional description of the studied plant: Spliter-I [8]*

Before each development of a risk analysis, it is first necessary to define the different dimensions (operation, control loop, safety system, etc.) related to the plant to be studied. In this study the plant concerned is a Naphta stabilizer-A reflux drum (Fig 2) [6], located at crude oil unit in Skikda refinery (Algeria).

The vapors of column C-5 overhead are condensed in air cooler Stabilizer-A Overhead Product Condenser (EA-2A~G), and Stabilizer-A Overhead Trim Condenser (E-11), and then collected in accumulator Stabilizer-A Reflux Drum (V-8).

The reflux drum is operated at temperature and pressure condition of 43°C and 7.0 kg/cm2 g. Pressure in the reflux drum V-8 is controlled by PIC-21 acting in "split control" on valves PV-21 and PV-21A. Uncondensed vapor fuel gas flow is controlled through PV-21 and further incondensable materials accumulated in stabilizer-A Reflux Drum (V-8) can be discharged to the blow-down through PV-21A.

The liquid which is accumulated in the receiving tank of overhead V-8 is sucked by pumps MP-93A/B at the temperature indicated by TI-112 and sent partly to the overhead of column C-5 as reflux under flow controlled of FIC-53 through flow control valve FV-53 and partly constituting the production of column overhead in unit 30 with the flow rate controlled by FIC-55 operating in cascade with level controller LIC-21, equipped with alarm for low level LAH/LAL-21.

Interface level between LPG and oily water in V-8 is controlled by LIC-30 by controlling flow through LV-30 located in discharge line of boot.

As an extra safety hydrocarbon detector AI-2151 and AI-2152 has been provided near the reflux drum (V-8) bottom and reflux pump (MP-93 A/B).

Further as a part of safety LI-2151 has been provided with High-High and Low-Low level alarm LAHH-2151 & LALL-2151. In case of LAHH-2151 interlock I-2164 will get actuated and UV-2160 in the overhead line of V-8 will get closed. In case of LALL2151 gives signals the interlock I-2164 will get actuated and close the on/off valve UV2154 installed in the suction line of MP-93 A/B.

For the boot level another interlock I-2165 will be actuated by LALL55 A/B/C (2oo3 logic) to close UV-2157 A/B in order to protect LPG leaking.

Table 1 Different safety systems protecting stabilizer-a reflux drum [8]

Safety systems	Landmark	Description
Pressure Safety Devices	PSV-50	Starting pressure 9.8 kg / cm^2g
	PV-21	Discharge To FG line
	PV21A	Discharge To Blow down
Interlocks	I-2156	Activated by HS-2154A/B and Action on: Close UV-2154 Stop pump MP93
	I-2164	Activated by LT/LAHH-2151 and Action on: Close UV-2160. Close PV-21. Open PV-21A
		Activated by LT/LALL-2151 and Action on: Close UV-2154 Stop Pump P-93A/B
	I-2165	Activated by LT/LALL-2155A/B/C and Action on: Close UV-2157A/B
Alarms	PAH-21	V-8 Pressure 7.7 kg/cm2g
	PAL-21	V-8 Pressure1.1 kg/cm2g
	LALL-2151	V-8 Level 300 mm
	LAHH-2151	V-8 Level 1705 mm
	LALL-2155	V-8 Root Level 230 mm
	LAL-21	V-8 Level 300 mm
	LAH-21	V-8 Level 1450 mm
	LAL-30	V-8 Interface Level 290 mm
	LAH-30	V-8 Interface Level 470 mm
	FAL-55	LPG Flow (MP-93 A/B) 39 m3/hr
Gas detectors	10-AI-2151	near the reflux drum (V-8) bottom
	10-AI-2152	Near reflux pump (MP-93 A/B)

B. *Identify risks using HAZOP*

HAZOP study leads to identify different accident scenarios resulting from parameters deviations. Thanks to its global analysis which facilitates the choice of a consequence to be evaluated by using Fault tree. For our study we have chosen two possible deviations which can lead to catastrophic accidents (no level of LPG and no level of oily water).

C. *Estimate and evaluate risks by Fault Tree*

The use of Fault Tree allows us to determine quantitative values concerning the reliability and the failure frequency. The computation of these values depends on the complexity of the studied system. In this paper we used the GRIF software (Graphic Interactive for Reliability Forecasting) [9], which can calculate different measures including: the unconditional failure intensity w (t) and the unavailability Q (t). To calculate these two measures, it is necessary to use reliability and failure data which are shown in Table III. The chosen scenario is LPG leak (Fig 3 and 4).

Table 2 Reliability and failure data used in GRIF software [10, 11, 12]

Equipment	λ (h^{-1}) Failure rate	μ (h^{-1}) Repair rate	T_1 (h) Periodic test	β	PFD
LT	2.1×10^{-6}	0.1	8760		
FT	4.5×10^{-5}	0.1	8760		
LI/FI	2.8×10^{-6}	0.1	8760	0.1	
FIC/LIC	7×10^{-7}	0.1	8760		
LV/FV	1.14×10^{-5}	0.1	8760		
Alarms				0.1	10^{-3}
Human error					10^{-1}
UV	1.1×10^{-5}	0.1	8760	0.1	
HS	1.1×10^{-7}	0.1	8760	0.1	

Using the data in the table II we obtain calculation result of the event (Fig. 3). Tolerable Risk Acceptance Frequencies for RA1K SKIKDA Refinery- Algeria are shown in the table III.

Table 3 Tolerable risk acceptence frequencies for skikda refinery (RA1K) [13, 14]

	Probability				
Severity	E:P < 10^{-5}	D:10^{-4} > p > 10^{-5}	C:10^{-3} > P > 10^{-4}	B:10^{-2} > P > 10^{-3}	A:P > 10^{-2}
G5:disastrous					
G4:catastrophic					
G3: important					
G2: serious					
G1: moderate					

Using the data in the table II and III we compare the acceptance of the resulting event (LPG leak).

D. *Identify and evaluate different events by Event Tree*

Event Tree is used to identify initiator event consequences after discussing the success and failure of each safety barrier. In our case study, the initiator event is the LPG leak (Fig 5). To evaluate consequences, GRIF software is used [9].

The structured combination between the previous methods allows us to move deeply from simple hazard identification to evaluate risks basing on combining causes, and then identify different scenarios resulting from a top event once it’s happened. In our case we started from level deviation, then we evaluated LPG leak, and we finished by identifying events such as: UVCE, jet fire …

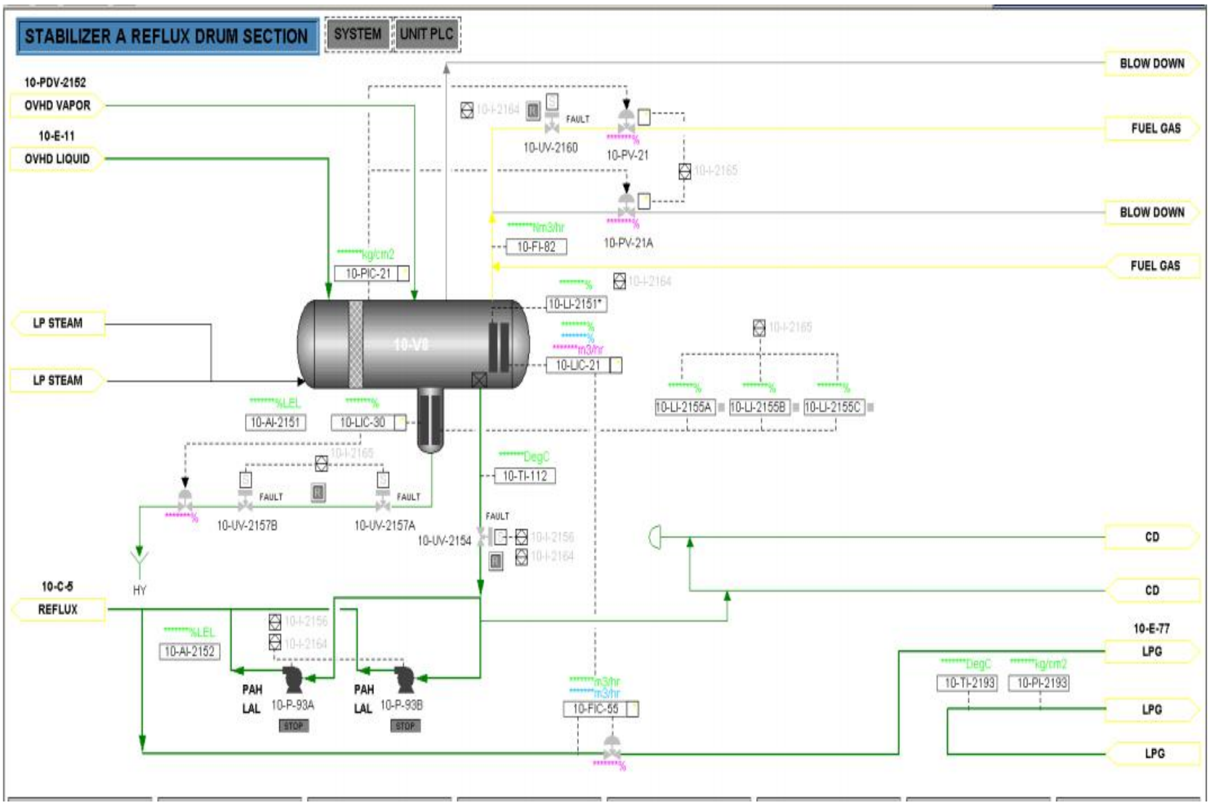

Fig. 2 diagram related to the naphta stabilize-A reflux drum [15].

Table 4 HAZOP Analysis "no level of LPG" and "no level of oily water" related to reflux drum 10-v-08

Deviation		Causes	Consequences	Warnings	Protection means
Parameter	Guide word				
Level of LPG in V8	NO	- Insufficient cooling of overhead vapor due to EA2 and E11 failure. - BPCS of LPG level failures: LT 21 failures LIC 21 failures FIC 55 failures FV 55 failures (does not close) - BPCS of LPG flow failures: FT 55 failures FIC 55 failures FV 55 failures (does not close)	- cavitations of the pump MP 93 - gas leaking to atmosphere - fire - UVCE	- Alarm LAL on LIC 21 - Alarm LALL on LIC 2151 - Alarm AAH on AI 2152	- Interlock 2156 (close UV 2154 and stop pump MP 93) - Interlock 2164 (close UV 2154 and stop pump MP 93)
Level of oily water in boot	NO	- BPCS of oily water level failures: LT 30 failures LIC 30 failures LV 30 failures (does not close)	- gas leaking to atmosphere - jet fire - pool fire - UVCE	- Alarm LAL on LIC 30 - Alarm LALL on LIC 2155 - Alarm AAH on AI 2151	- Interlock 2165 (close UV 2157 A/B)

To combine the consequences that lead to the same event, fault tree is needed as shown below in figure (3 & 4):

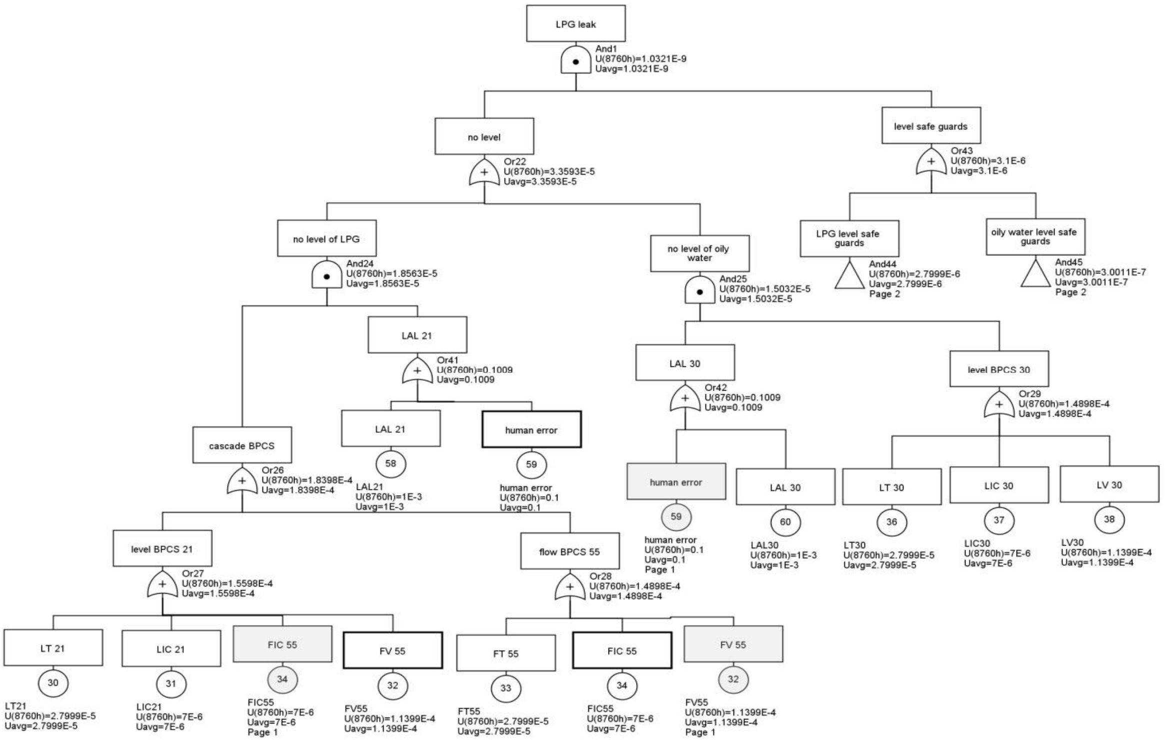

Fig. 3 Fault Tree of the consequence "LPG leak from stabilizer A reflux drum 10-V-8".

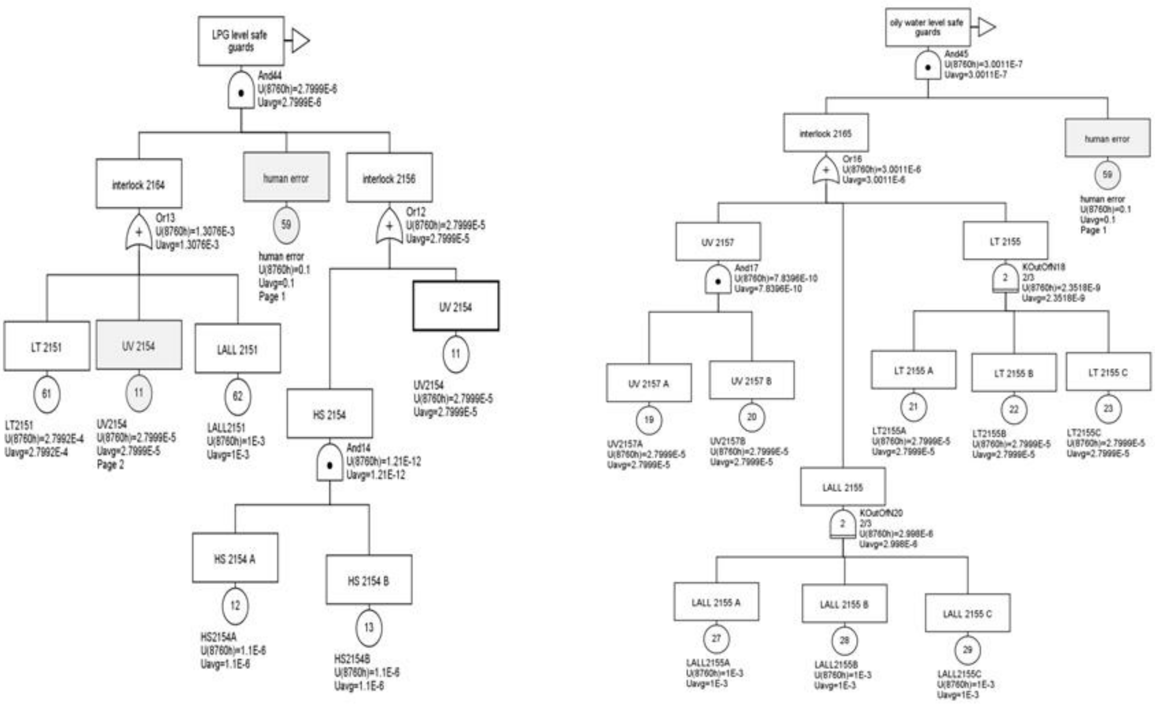

Fig. 4 Fault Tree of the consequence "LPG leak from stabilizer A reflux drum 10-V-8".

To identify the consequences of the same initiator event, Event Tree is needed as shown below in figure (5)

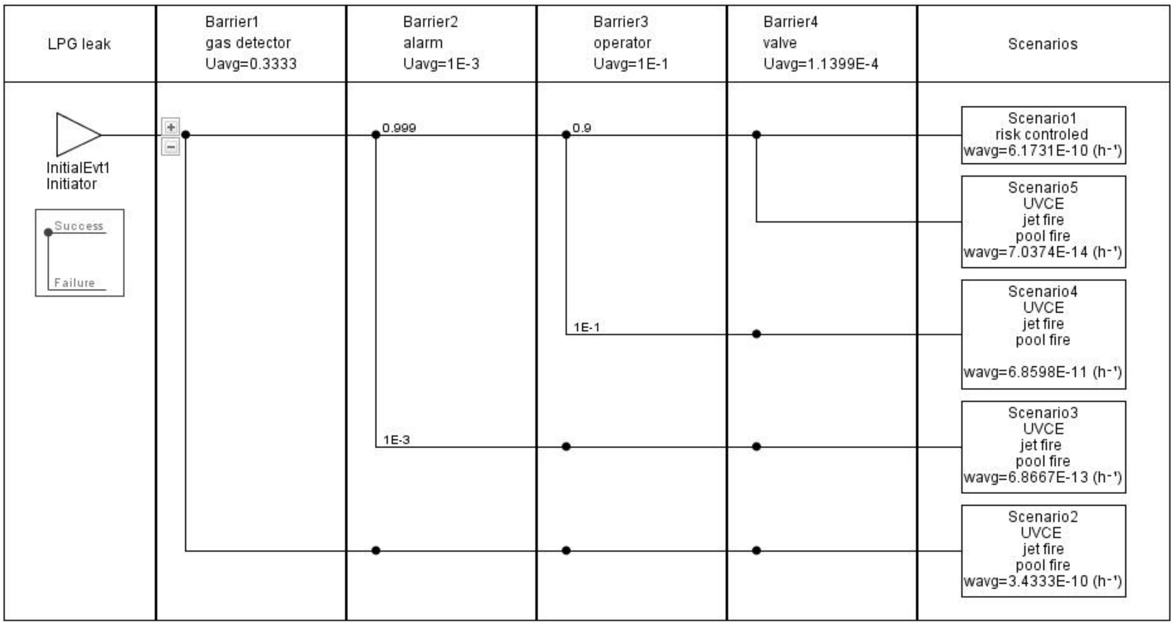

Fig. 5 Event Tree of the initiator event "LPG leak from stabilizer A reflux drum 10-V-8

E. Simulate accident scenarios to determine impact zones by ALOHA

After identifying consequences resulting from the initiator event (LPG leak), ALOHA is used to simulate threat zones. In our study, UVCE (unconfined vapor cloud explosion) is the chosen event to be simulated (Fig 6, 7, 8 and 9).

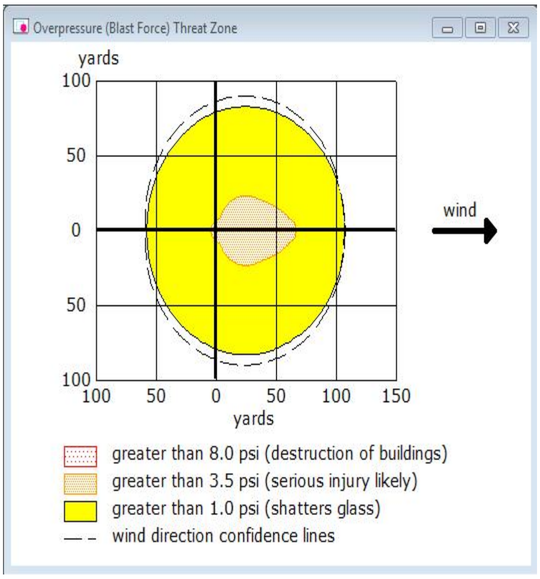

Fig. 6 Overpressure effects

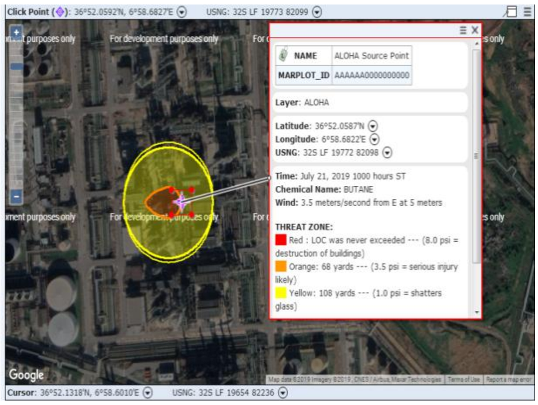

Fig. 7 Areas threated by overpressure effects (MARPLOT)

Distances and threat zones related to the UVCE overpressure effects resulting from LPG leak in stabilizer A reflux drum in SKIKDA Refinery- Algeria are shown in the table V.

Table 5 Distances and areas threated by overpressure effects

Threshold	distance	Threat zones
08 Psi	/	/
3.5 psi	70 m	U10, South of U100
01 Psi	105 m	U10, Nord of U11, U100

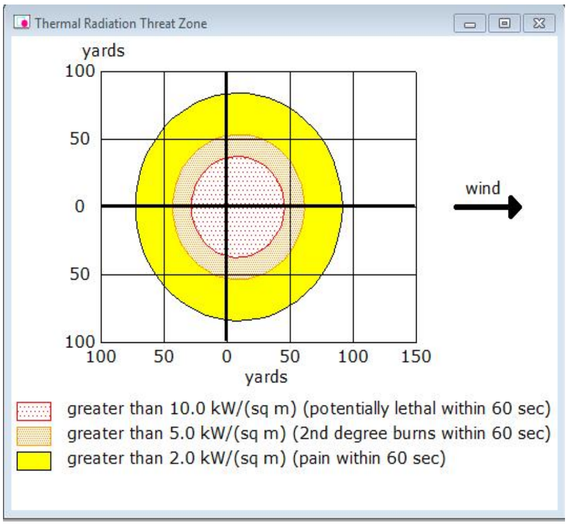

Fig. 8 Termal effects

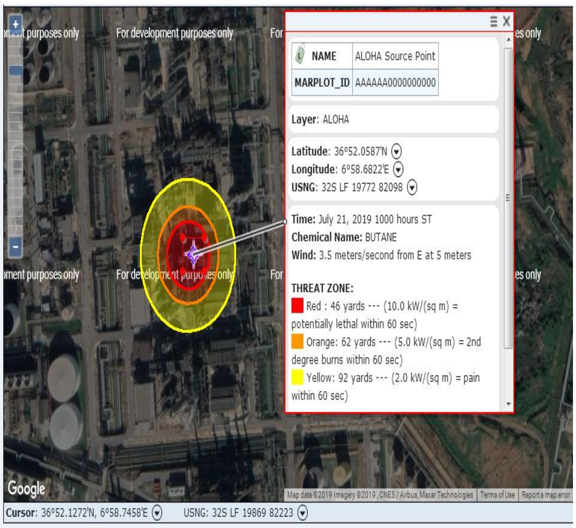

Fig. 9 Areas threated by termal effects (MARPLOT)

Distances and threat zones related to the termal effects resulting from LPG leak in stabilizer-A reflux drum in SKIKDA Refinery-Algeria are shown in the table VI.

Table 6 Distances and areas threated by termal effects

Threshold	distance	Threat zones
10 KW/M2	45 m	U10, South of U100
05 KW/M2	60	U10, U100
02 KW/M2	90 m	U10, Nord of U11, U100

4. RESULTS AND DISCUSSIONS

Based on the results obtained from the application of the proposed approach at the stabilizer-A reflux drum, some weaknesses should be corrected by the following recommendations:

– Provide a strong preventive maintenance program for all equipments
– Move the gas detector 10-AI-2151 and put it close to the exit of level valve (LV-30) instead of near the vessel V-8 (LPG is dense and the vessel is located at 5 m above the ground.
– Carry out another study about SIL verification.
– Carry out Continuous inspections for gas detection system and consider the possibility of connecting gas detection to a safety instrumented system.
– Consider the possibility of draining the oily water in the boot to a closed system or deflect it in case of detection.
– Regular refresher training for operators and firefighters
– Insist on strict compliance with the procedures and especially that relating to Lockout and Tag out,
– Carry out regular internal audits to identify all significant deficiencies and material weaknesses.
– Increase the frequencies of the metal thickness surveys to anticipate outbreaks of leaking or weakening metal and mastered any corrosion progress,
– Regular staff awareness about the risks associated to LPG.

5. CONCLUSION

The main objective of this work was risk assessment of a stabilizer reflux drum at crude oil unit located at Skikda Refinery. For that a structured methodology based on the combination of various approaches was proposed and applied on the above mentioned facility starting with HAZOP, Fault Tree, Event Tree and finishing with accident simulation using ALOHA.

References

[1] DAVID Macdonald, Practical Hazops, Trips and Alarms, IDC Technologies, Cape Town, South Africa, 2004.

[2] J. S. Arendt, D. K. Lorenzo, Evaluating Process Safety in the Chemical Industry, “a user’s guide to quantitative risk analysis”, CCPS, New York, USA.

[3] J. Luis de la Mata, M. Rodriguez, ―Abnormal Situation Diagnosis Using D-higraphs‖, ESCAPE20, 2010 Elsevier B.V.

[4] FRANK Crawley, BRIAN Tyler, "HAZOP: guide lines to best prqctice for the process and chemical industries," 3rd ed, Atkins, University of Strathclyde.

[5] B.PN Rajkumar, A.M. Digvijay, B.K. Pruthwiraj, B.S. Kothavale, Fault Tree Analysis: A Case Study from Machine Tool Industry, VJTI, Mumbai, India, 2018.

[6] SAM Mannan, Fault tree analysis. 3rd ed, "lees' loss prevention in the process industries", hazard identification, assessment and control, Texas, USA, A&M university.

[7] J.D. Andrews, S.J. Dunnett, Event-tree analysis using binary decision diagrams, IEEE Transactions on Reliability, 49(2), 230–238.

[8] J.M. Song, Operation And Maintenance Manual For CDU-10, Skikda Refinery, 2012.

[9] GRIF-Workshop, (2018), Graphical interface for reliability forecasting software, Available at: http://grif-workshop.com.

[10] DIANOUS Charlotte BOUISSOU and Ahmed ADJADJ, Programme EAT-DRA-34 - Opération j, Intégration de la dimension probabiliste dans l'analyse des risques – partie 2: données quantifiées, 146 pages, 2005.

[11] Travaux du groupe d'échange « Fréquence des événements initiateurs d'accidents », Fréquence des événements initiateurs d'accidents et disponibilité des barrières de protection et de prévention, ICSI, 18 pages.

[12] SM, Safety integrity level (SIL) classification study report of crude distillation unit I&II (unit 10/11), skikda refinery, 2006.

[13] NOUGER Nicolas, VERHAEGHE Mylene, étude de dangers de la raffinerie de skikda, chapitre B1 : distillation atmosphérique (topping 10 et 11)

[14] T.P. Sin, Hazard and opperability study (HAZOP) repport, unit: 10, 30, 1120, 700, 701, Skikda refinery, 2010.

[15] B.S Kim, DCS Graphics Static Layout Printouts (SRR1), skikda refinery, 2011.