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Assessing the Impact Risk of Gathering New Sour Gas Wells with Original Sweet Ones: A Field Case Study

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Abstract

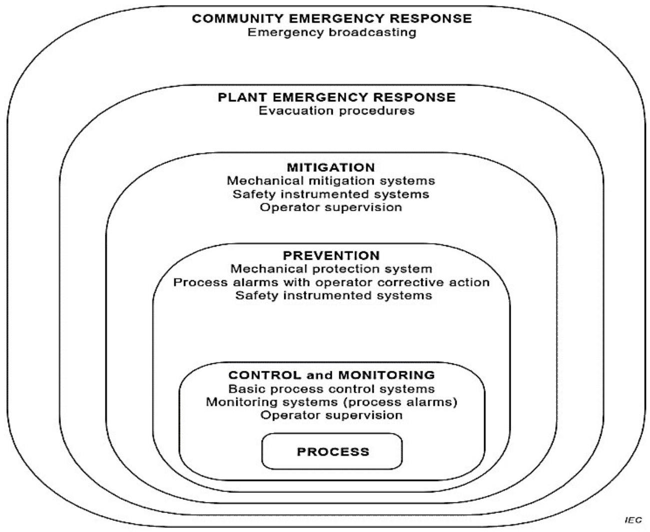
The new project regarding gathering new multi-gas production wells with other old ones has many economical benefits. Unfortunately, the newly discovered gases have different chemical and physical properties than the old wells. This project would increase the potential of various Process safety events (PSEs). Furthermore, the new wells contain very toxic material with a high pressurized flow rate. design improvement and layout redesign is a challenge within such clusters. Also, the production rate should be maintained without interruptions. The main purpose of this study was the risk assessment of receiving traps pipelines and safety scenarios. The study area was located in a very populated area and very close to the international road, which would give rise to domino effects risk. This research was performed on two main bases: Data assortment and Data analysis using the LOPA method.

***Keywords**: Layer of protection analysis (LOPA); Process Hazard Analysis (PHA); Process Safety Management (PSM); Loss prevention; and Toxic and thermal radiation Modeling.*

1. Introduction

Gathering pipelines extract different physical and chemical raw natural gas from production wells; often under high pressure. This benefit is observed from operating conditions analysis and adding gas to an existing plant when excellent opportunities exist. In recent years, with the government's high demand for environmental protection, avoiding PSEs and natural fuel gas supply, gathering many production wells to be transferred and processed in an existing plant has become the most common solution for many oil and gas producers for economic benefits [7].

Raw flow flows through a complex pipeline system that includes elements such as actuated valves, HIPPS system, pressure control stations, metering stations, pressure vessels, and relief valves. Nevertheless, the overall risk of pipeline failure during the depressurization scenario can be minimized to an acceptable limit. The flammability and toxicity nature of oil, gas, and other contaminants have the potential to cause substantial hazards. These hazards may be classified in terms of fatalities, serious injuries, property damages, and environmental degradation. Besides, the new well produces raw gases with different chemical and physical properties. The new connection would create many hazards to the plant [3]. Flammable and toxic gases releasing to the surrounding environment could cause several types of hazards as fire (fireball, jet fire, or flash fire), unsafe dispersion, unconfined Vapor Cloud Explosion (UVCE), etc. Qualitative, Semi-Quantitative, and QRA techniques are used together and/or individually at different stages of the project [1,6,17]. any tools as qualitative, QRA, CEI, and FEI have been used to analyze the new hazards for the new connection [9].



In the present research work, LOPA has been applied to reanalyze and reevaluate the risk-based effects of gathering new high-pressurized sour gas wells with different flow rates, physical and chemical properties with old low-pressure sweet ones. The study mainly focuses on the safety aspects of the considered plant, which is compliant with IEC 61511-3, respecting all the rules.

Fig. 1. Independent protective layers [19]

The main objective of the present study is to assess the potential risk-based approaches of receiving traps pipelines (14”, 24”, and 30”) during the depressurization process 92 to 1.01 bar dynamic state. The best approach should be applicable, matched well with the plant condition, and achieved acceptable residual risk regarding the company ALARP range. This current work is based on the concepts, methods, and definitions adopted in many standards such as IEC 61508, IEC 61511, OSHA, CCPS, API, etc. Often, unexpected problems are encountered when rolling out LOPA. Some scenarios are too complex to be implemented using the LOPA technique, so a more detailed risk assessment technique as QRA is used. LOPA study has many limitations [2,4,8].

During the consequence assessment, the outcome modeling of toxic and thermal heat effects and the magnitude of all scenarios should be estimated. The potential scenario consequences modeling among overall potential loss may be classified as; explosion, overpressure, fire, thermal radiation, fragment projection, toxic exposure and dispersion, physical human harm and eventually casualties, property damage, and the environmental effects [12,14,17].

Also, the well-known ALOHA (Aerial Locations of Hazardous Atmospheres) software packages have been used for the procedure of consequence assessment. It is used to examine the progress of potential incident from the initial release and to estimate the thermal and toxic radiation levels and concentration at various spots around the release point. Too far-field dispersion including modeling of pool spreading and evaporation, flammable and toxic effects where individual risks are to be identified [5].

2. Study area

The study area is in Portsaid, Egypt. This project is located in an industrial area, where there are a lot of other companies and housing areas. The thesis work is Process hazard analysis-based, which is related to the depressurization scenario. For this study base research work, it is needed actual answer the questionnaire for the living-people around this project and the international road.

3. Case study

The present case study considers traps pipeline handling hazardous (flammable and very toxic) fluid, fire, and/or explosion in accidents, which potentially can occur. This study has been performed to assess the potential hazards of slug catcher depressurization.

3.1. Scenario description

The well-receiving traps consist of 5 pipelines, as shown in Figure 2. While a reservoir of very large toxic gases has been discovered, containing a high flow rate of flammable and toxic gases with very high pressure. It was decided to connect the new wells to the old ones to be treated with the same plant (2800 MMSCFD of toxic and flammable gases, and 21 liters/hr of condensate). Minimum and maximum operating pressure are 74, and 92 bar respectively. The Main process Hazards evaluated are: High and low pressure and temperature

- High and low pressure and temperature, H_2S (800 ppm);
- Chemical agents (corrosion inhibitor), pressurized nitrogen, contamination as MEG, etc.;
- Jet, flash-fires for gas releases, pool-fires originated by liquid releases;
- Vapor cloud explosion (VCE).

Fig.2. Satellite image of the study area extracted from the google map

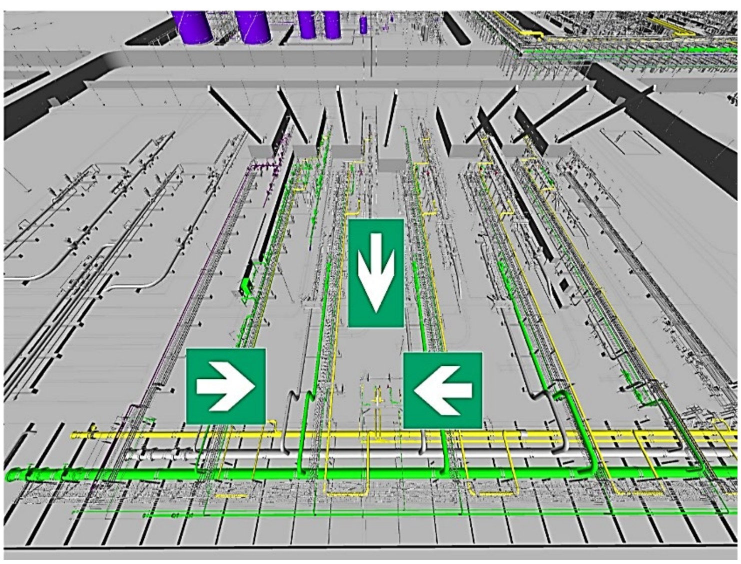


Fig. 3. Well-receiving traps 5 productions, and 2 MEG injection pipelines

During the nominated project hazard review, using HAZOP methodology, one of the very dangerous scenarios was the potential of trap pipeline rupture during emergency depressurization of slug catcher. The expected temperature would be -45ºC, so the pipeline is expected to be embrittlement fragile and ruptured. The pipeline is stainless steel 2500 LB (PN 420) rating, according to ASME B16 5/API 6D, the maximum temperature is 85ºC, MDMT is -10ºC. The max pressure is 300 bar, and the corrosion allowance is 6 mm. Figure 3 shows the trap pipeline flow diagram, while Figure 4 shows the processing plant onshore project extracted from google maps, showing the critical location of the company regarding the international road, other companies, and 10,000 persons living near this project.

Table 1 lists the raw gas composition, as the feed includes very toxic and flammable gases. The HIPPS "Hi-Integrity Protective Pressure System" is used as the last barrier in a series of process protection layers that are implemented and developed as per IEC 61508 and IEC 61511-2016 requirements. The sensing elements, logic solver, and final elements should meet the integrity, operability, and maintainability targets [13].

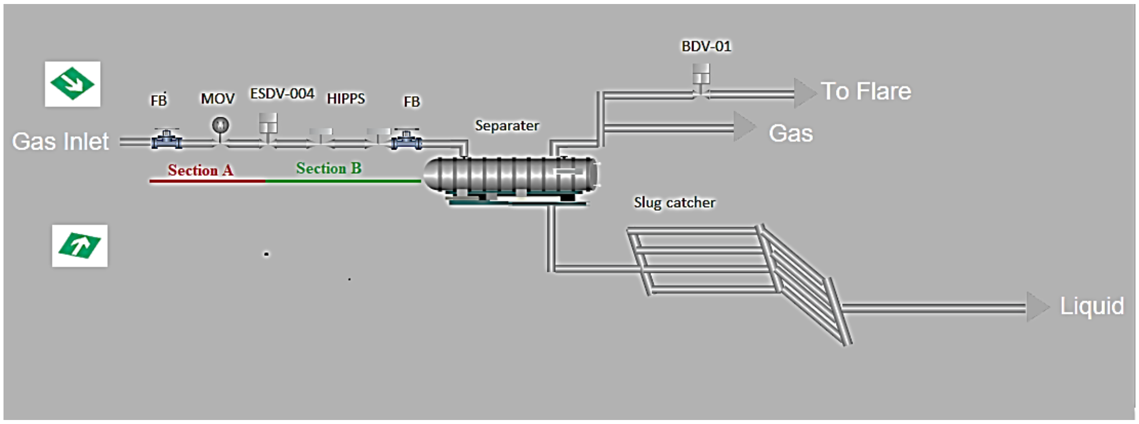


Fig. 4. Traps pipeline PFD
(FB: Full-bore manual ball valve; MOV: Motorized operating ball valve; HIPPS: High integrity Pressure Protective System; BDV: Blowdown Valve, and ESDV; Emergency Shutdown Valve)

Table 1. Raw gas composition

Comp.	%	Comp.	%	Comp.	%
N_2	0.00093	MCH	0.00001	C_7	0.00017
O_2	0.00850	toluene	0.00013	MCP	1.10E-05
H_2S	0.00080	n-Octane	0.00015	C_6H_{18}	0.00003
CH_4	0.98124	et-Benzene	0.00007	C_6H_{12}	0.00001
C_2H_6	0.00328	m-Xylene	0.00006	C_7H_{14}	0.00012
C_3H_8	0.00054	p-Xylene	0.00003	n-C11	0.00051
i-C_4	0.00051	p-Xylene	0.00003	n-C12	0.00082
n-C_4	0.00018	n-Nonage	0.00017	n-C13	0.00076
i-C_5	0.00024	Benzene	0.00002	n-C14	0.00033
n-C_5	0.00011	n-Decane	0.00024	COS	0.3

HIPS is implemented and developed as per IEC 61508 and 61511 requirements. The sensing elements, logic solver, and final elements should meet the integrity, operability, and maintainability targets [13]. Table 2 addresses the hazards and operability analysis (HAZOP) study while Table 3 presents the What-If analysis study for the considered case study.

Table 2. Hazards and operability analysis (HAZOP) study

HAZOP analysis Traps pipeline process hazard and operability analysis			
Deviation	Causes	Consequences	Recommenda-
Loss of temperature	Depressurizing of slug catcher. (Joule Thomason effect).	Very low temperature less than (-10ºC) “Pipeline MDMT”, might lead to material failure and releasing flammable and toxic gases, and liquid.	More studies as LOPA and QRA studies.

Table 3. What-If analysis study

What-If Analysis			
What-if …	Causes	Effect	Recommendation
Depressurizing of slug catcher	Depressurizing of slug catcher (Joule Thomson effect).	Very low temperature less than (-10ºC) “Pipeline MDMT”, would lead to material failure and releasing flammable and toxic gases, and Liquid.	More Studies as LOPA and QRA studies

Table 4. LOPA study

Description	Depressurizing of sludge catcher, so pipeline temperature would reduce up to -45ºC, as the actual MDMT is -10ºC. The pipeline will be fragile material; pipe ruptured and releasing flammable and toxic gas, with the potential of fire and/or explosion.		
Consequence	TEF	1,00E-05	
	Conditional Modifier "CM"	The operator cannot escape (fatalities and/or injuries)	Prob: 1.00
Frequency	Initiating Event "I_E"	Depressurization sludge catcher using BDV-001	Prob:1.00 E-01
	Enabling Events "E"	Pipeline MDMT is. -10°C	Prob: 1.00
UEF[a] (ev/yr.)		1.00 E-01	
Safeguard (Non-IPLs)		N A	
Safeguard (IPLs)		HIPPS and ESD System SIL 2	Prob:1.00 E-02
M_{EF}[b] (ev/yr.)		1.00E-04	
LOPA GAP[c]		1.00E-02	
Additional Required SIL Assigned		SIL 2	
LOPA recommendation: recommendations		IPL with PFD = 0.01 must be added	

4. Results and discussion

As it was requested from the previous qualitative risk assessment studies to use the LOPA model to assess this hazardous impact. The objective is to comply with IEC 61511-1:2016, Annex B [20]. The target event frequency would be < 10-5 and depressurizing likelihood is one time/10 years. The safety analyst noticed a gap between the target estimated risk frequency (TEF) and the mitigated risk frequency (LOPA gap) as shown in Table 4. The LOPA team recommended adding another IPL with PFD 0.01 as another SIS system (SIL 2) downstream of the MOV. The team leader tried to think out of the box and search for other solutions. He has suggested dividing this scenario into two nodes (A, and B) as:

- The human factor (intervention team) is considered as an IPL with PFD 10^{-2} in case of good training and no stress [21-22], as recommended to be [18]:
- Familiar with fire-fighting and evacuation procedures,
- Trained to perform their specific duties,
- Emergency drilled to be conducted regularly,
- New personnel to be trained on the emergency equipment and fire-fighting procedures,
- Familiar with various emergency alarms and understand their specific duties during an emergency,
- Familiar with the various escape devices and know their specific duties during the evacuation,
- Recognized alarms, and to be informed of the action required of them from each alarm, and
- Familiar with evacuation escape ways.
- Human IPL or intervention team shall include the following items [15]:
- A written procedure to clear required actions, and clear communication
- Available equipment to detect a hazardous issue
- Interaction with the process to prevent or alter the undesirable consequence,
- Training, documented, drills/tests,
- Provision of materials or equipment
- Special personal protective equipment (PPE)
- Successful performance benchmarks
- Verify the action/task was performed.

The LOPA team has recommended well training and all recommended PPEs to be available for the intervention team to close the MOV and/or MV in case of this scenario occurred to avoid the 190-km leakage (distance between offshore wells and onshore facility). The LOPA team has accepted this IPL for this section as;

- The distance between section B and MOV is large enough for the intervention team to close the MOV,
- The availability of three escape ways one of them on the main road,
- During depressurization, the intervention team and field operator is to be very close to the MOV,
- The intervention team and some of the production technicians are trained well to deal with these potential hazards,
- The Intervention team to be aware of how to close the manual and MOVs valves.

Node A: The MOV, and MV are located in this section so, no way to depends on the human factor as an IPL. The LOPA team has decided to implement one of the following items:

- Change the material rating to a metal with MDMT -10ºc,
- Transferring the ESDV-004 to be very close to the MOV & MV, or
- Installing other SIS systems, SIL 2 with PFD of 0.01.

The company production team has argued, as this action will affect the production rate badly, they asked for QRA and Risk indices studies to assess the risk of a pipeline rupture.

4.1. Decision-making

As, it is recommended to add another IPL with PFD of 0.01 along with the previous LOPA recommendation for this IPL at section A, B, the company chairman has decided that:

- Section B; No problem to implement this recommendation as no effect on production rate,
- Section A; The chairman decided to implement QRA for section A only and assess the potential hazard for this scenario.

Therefore, QRA, risk indices would be implemented for section A, of all Traps pipeline and establish the following tools. QRA, ETA, F&EI, and ALOHA software programs have been used for this scenario assessment.

4.2. Event tree analysis (ETA)

It is reasonable to assume that the consequence will be a jet fire or liquid spray for immediate ignition or early ignition. Besides, it suggests the time to be dependent on distribution, data are copied from [10]. ETA assumptions are [11]:

- Total ignition probability shall be split 50:50 between early and delayed ignition,
- Wind populated area north is 20:80,
- Flashfire 10:90 ignited jet 10:90, and
- VCE, in case of delayed ignition 30:70 distribution, flash fire, and explosion.

4.3. Leak rate & ignition probabilities

The expected fracture will be very large, so this study will implement the highest size (> 150 mm). The peak initial release can be calculated in kg/s by assuming sonic flow through an orifice [23]:

$$Q_{peak} = \frac{\pi d^2 \alpha}{4} \sqrt{\gamma \rho_0 p_0 \left[\frac{2}{\gamma+1}\right]^{\frac{\gamma+1}{\gamma-1}}} \quad (1)$$

where: α-ratio of effective hole area to pipe cross-sectional area=d2 hole /d^2 pipe; d is pipeline diameter; ρ_0 is stagnation density of gas at operating conditions (92 bar (9316 N; p_0 is stagnation pressure at operating conditions; and γ specific heat ratio of gas. The release rate would be 35 kg/s and the ignition probability is 0.09 [11].

Table 5 shows the pipeline leak frequency while Table 6 lists the consequences probabilities of the investigated case study. All traps pipeline frequencies are very relative to each other.

Table 5. Pipeline leak frequency

Pipeline	Leak frequency	Pipeline	Leak frequency
A-01	2.20 E-05	A-04	4.14 E-05
A-02	2.20 E-05	A-05	4.14 E-05
A-03	4.11 E-05		

Table 6. Consequences probabilities

Plant area	Jet fire	VCE	Flashfire & BLEVE	Safe dispersal
Traps (A)	7.56E-06	1.34E-06	1.34E-06	7.56E-06
Total frequency			1.68 - 4	

4.4. Fire and thermal radiation modeling

Jet and pool fire thermal radiation modeling [12] results are shown in Table 7 and Table 8 respectively. All traps pipeline will suffer the same value of jet fire thermal radiation for each level. Also, the same affected thermal radiation distances (m).

Table 7. Jet fire thermal radiation level (kW/m^2)

Plant area	Thermal radiation level (m)		
	5.0 kW/m^2 Lm= 19 50 Q 0 447	12.5 kW/m^2 Lm= 16 15 Q 0 447	37.5 kW/m^2 Lm= 13 37 Q 0 447
A-01	95.5	79.2	65.5
A-02	95.5	79.2	65.5
A-03	95.5	79.2	65.5
A-04	95.5	79.2	65.5
A-05	95.5	79.2	65.5

Table 8. Pool Fire thermal radiation distance (m)

Plant area	Thermal radiation distances (m)	Plant area	Thermal radiation distances (m)
A-01	17.8	A-04	17.8
A-02	17.8	A-05	17.8
A-03	17.8		

4.5. Risk calculation

Table 9 shows risk indices of the considered case study for the day shift. It was noticed that the night and the day shifts have the same risk indices data.

Table 9. Risk indices of the day shift

Risk indoor	1.68 E-4	% Outdoor	50
Risk outdoor	1.68 E-4	IPRA	8.4 E-5
Manning	4	PLL	3.36 E -4
% indoor	50		

4.6. Aerial locations of hazardous atmospheres (ALOHA)

Egyptian Meteorological Organization (IMO) for the Mahshahr port from 1988 to 2006 copied the atmospheric data used in this study [24]. The result (F&EI) of the meteorological data analysis indicates that two prevailing weather conditions (hot season and cold season) can be intended for the QRA study during daytime and nighttime to cover almost all of the probable conditions. Table 10 shows a summary of the average meteorological data which are used for the consequence analysis. Figures 4, 5 show both thermal radiation, for 10, 5, and 2 kW/m^2; and toxic threat zones modeling for 100, 30, and 0.1 ppm of H_2S using ALOHA software.

Table 10. Average wind speed & ambient temperature for the hot and cold season

	Average wind speed (m/s)	Average ambient temperature (ºC)
Hot season (daytime)	11	36
Hot season (nighttime)	35	28
Cold season (daytime)	7	24
Cold season (nighttime)	1	8

Figure 5 shows that the thermal radiation threat zone will be 130 m. Also Figure 6 shows the toxic threat zone will be 10 km. Figure 7 show the thermal radiation exchange at traps and surrounded areas and the affected area will be the international road and surrounded area.

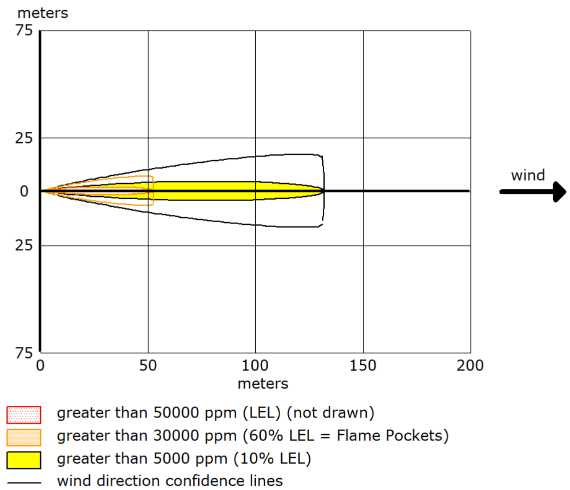


Fig. 5. Thermal radiation threat zone determined using ALOHA software

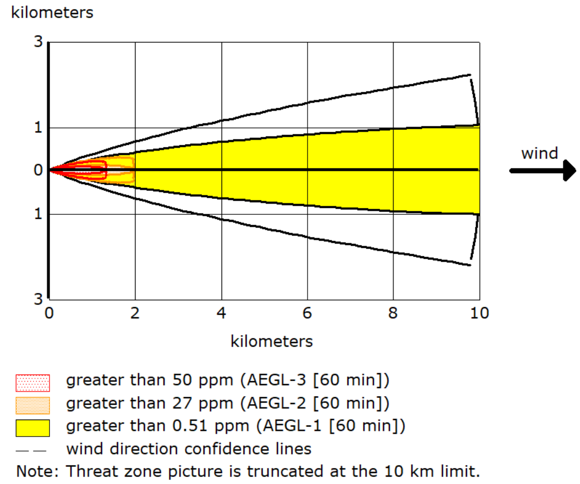


Fig. 6. Toxic threat zone obtained by applying ALOHA software

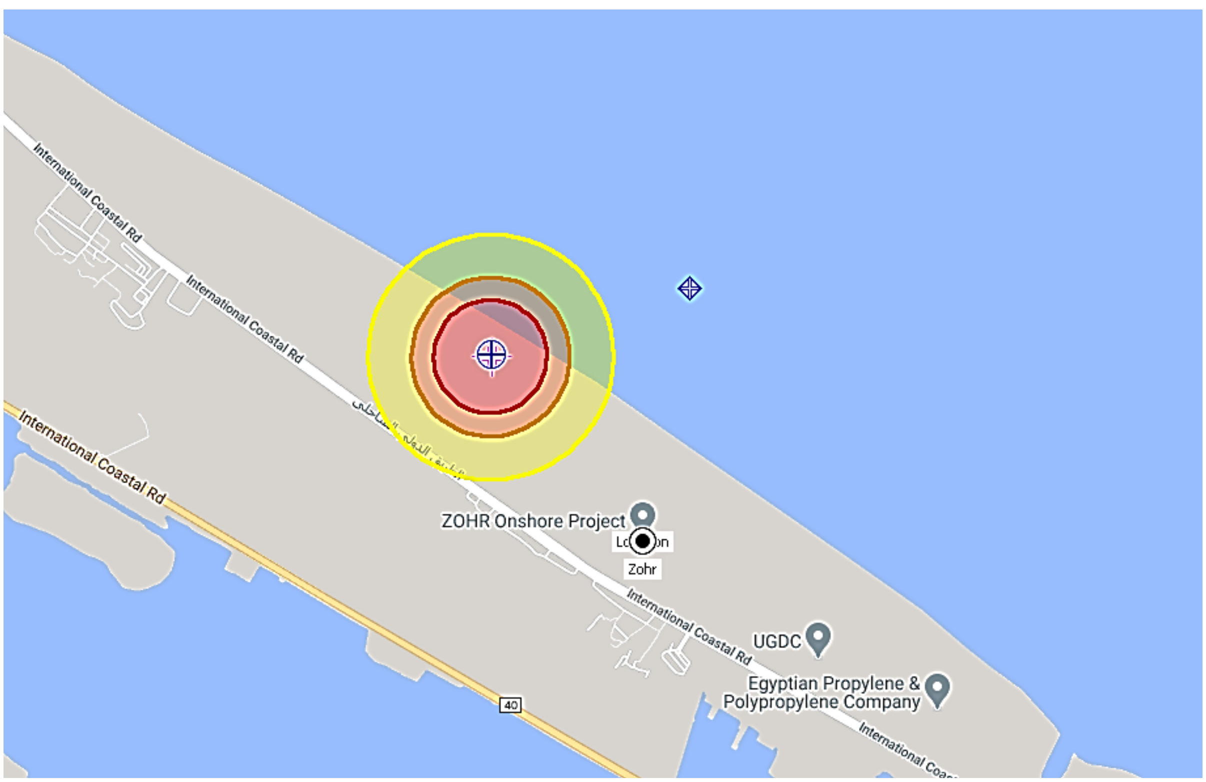


Fig. 7. Thermal radiation exchange at traps and surrounded areas

4.7. Dow's Fire & Explosion Index (F&EI) study

Table 11, shows the results of Dow's fire and explosion index (F&EI) study, as F&EI high sever and the company will lose many millions of dollars, as shown in Table 10.

Table 10. Dow's Fire and Explosion Index (F&EI) study

Parameter	Results
Fire and explosion index (FEI)	158.5
The radius of exposure (m)	20.5
Value of equipment in contact area ($)	MM 30.8
Damage factor	0.81
Most probable base damage ($)	MM 24.92
Loss control credit factor	0.42
Most probable actual damages ($)	MM 10.5
Most likely lost working days	150 days
Interruption losses ($)	MM 350

4.8. Hazard assessment and ALARP

All these studies have been established as a recommendation of the company's high-authorities (chairman) as the plant is located in a medium-densely populated area and very close to an international road. Regarding all the above studies, the risk is intolerable and is not acceptable regarding company ALARP. Besides, the potential fire and/or explosion could cause financial loss of many million dollars and production days, the influence area and damaged assets are very large and expensive. Regarding all these studies, the chairman decided to change the pipeline material. Figure 6 shows the thermal radiation exchange at traps and surrounded areas, as the international road and the surrounding buildings and companies will affect badly.

5. Conclusion

The LOPA team was successful to minimize all capital costs and overall lost time, as they have thought out of the box. They have divided every trap pipeline into 2 sections. Section B; The IPLs would be the intervention team with all requirements as per API. Requirements. Unfortunately, this IPL may not be applicable for section a (10 m), as the valves are located in this section. The LOPA team has discussed many ideas regarding this hazard, especially after the very terrible results of QRA and risk indices. Finally, they agreed to change the material with another one to achieve MDMT -45ºC. The current work aims to estimate the impact risk of gathering new raw sour gas wells with the originally existed sweet ones to be treated in the process plant. Thus, the objective of this paper was directed to evaluate the potential risk-based approaches of receiving trap pipelines during the depressurization process. Recently, the risk evaluation was recommended via the application of a SIL-rated-instrumented system or changing the whole length of the trap pipelines. However, the LOPA team has succeeded to use other barriers that are more practicable, less expensive with trouble on productivity.

LOPA technique is implemented to the high severity consequences, to comply with international standards as IEC 61511, and ensure that the necessary protections are in place, as often not one element to protect the process. For the current case study, new gas wells connections are evaluated by focusing on the expected hazards through using consequence modeling, risk analysis, and cost-effective risk management. By applying the LOPA technique, the production can be maintained without any possible interruptions. This is a good advantage for using the LOPA technique. The results of applying the LOPA model on the investigated case study show that connecting the new gas wells is a good route that satisfies the plant condition, and achieves accepted residual risk regarding the company ALARP range. The achieved results were based on concepts, methods, and definitions adopted in many standards such as IEC 61508, IEC 61511, OSHA, CCPS, and API. This confirms the reliability of using the LOPA approach in estimating the possible risks for most chemical plants without interrupting the production rate.

Nomenclature

QRA	*Quantitative risk assessment,*
CEI	*Chemical exposure index,*
FEI	*Fire and explosion index*
ALARP	*As Low As Reasonably Practicable,*
IEC	*International electrotechnical commissioning,*
OSHA	*Occupational Safety and Health Administration*
CCPS	*Central of process safety*
API	*American Petroleum Institute,*
PFD avg	*Probability of failure on demand*
PHA	*Process Hazard Analysis;*
BPCS	*Basic Process Control System,*
HIPPS	*Hi-Integrity Protective System*
MOC	*Management of Change,*
UEF	*Ultimate event frequency,*
TEF	*Target event frequency,*
ALOHA	*Aerial Locations of Hazardous Atmospheres*

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