Toxic Chemical Release Hazard Distance Determination Using Chemical Exposure Index (CEI) in a Gas Refinery

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ABSTRACT: *Events leading up to the release of toxic chemicals in the processing plants are one of the main hazards of chemical industries that can endanger employees and also people in neighborhood. In this study, DOW's Chemical Exposure Index (CEI) is used to determine hazard distances of possible toxic chemical releases in one of the South Pars gas* refineries. *To do this, 318 considerable release scenarios were identified and by process parameters and CEI equations, airborne quantity, chemical exposure index and hazard distances were calculated. In the worst case of a toxic chemical release, hazard distance of the studied refinery is 10000 meters. The Sludge Catcher unit is the most dangerous unit in terms of toxic chemical release. In addition to the advantages of the CEI observed in this study also some limitations were observed including sensitivity to process parameters, no consideration of the material inventory and the concentration in the CEI calculations.*

KEYWORDS: *Chemical Exposure Index (CEI); Release; Toxic; Airborne.*

INTRODUCTION

The release of toxic chemicals from processing plants is one of the most important hazards of chemical plants that could endanger employees and people in the neighborhood. During the 2000s, more than 3100 accidents happened in the production process, transportation, storage and hazardous chemicals usage [1]. The accidents such as Flixborough, Seveso, Three Mile Island and Bhopal at processing plants are some known disasters in the history of chemical plants [2, 3]. The toxic gas release has caused destructive incidents such as the release of hydrogen sulfide from a natural gas well in Kaixian, China on 23rd of December that leads to more than 240 fatalities [4]. All of the mentioned accidents have in a common factor: a substance released from a processing plant spread in the air and created a risk that endangered the safety of employees, neighbors and even people that are far from the processing plant. These factors cause industries with development in equipment and expanding in size to have more concern about human and economic potential losses [5, 6]. Rapid strides in the advancement of modern

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technology will give less time to experts to learn from lessons. Due to most chemicals' properties like toxicity, explosion, and flammability, these chemicals are potential sources of serious accidents [1]. Risks at industrial processing plants such as gas refineries mainly occur as a toxic chemical release, explosion or fire. According to facts and figures, losses from these risks that lead to accidents in the world are huge and this is the reason that we should consider specific measures, therefore it is important that the risk of the gas refineries be assessed and analyzed in order to provide a safe condition and also to protect the human and the properties [7]. In most gas refineries sour gas in high concentrations exists in inlet feed. Sour gas because of hydrogen sulfide content is very risky for humans, so more safety considerations are required and developing methods to determine the Hazard Distance (HD) around sour gas installations has been always important [8]. To determine HD of toxic chemical release there are several different approaches such as relative risk index, consequence modeling, Computational Fluid Dynamic (CFD), etc. that each one has its own advantages. These methods have been used to obtain toxic chemical dispersion and HDs. *Bagheri et al.* [8] and *Jianwen et al.* [9] used CFD method to simulate the dispersion of hydrogen sulfide-containing gas. *Sanchez et al.* [10] applied ALOHA model to simulate the dispersion of ammonia.

There are several important indices available for relative risk ranking and HD determination, including Dow Chemical Exposure Index (CEI) [11], Dow Fire and Explosion Index (F&EI) [12], Mond Fire, Explosion and Toxicity Index [13], etc. Dow's two indices, F&EI and CEI, have served as a relative risk ranking analysis for the evaluation of the hazard potential of process plants or any changes to facilities [11]. The CEI is one of the relative risk index methods for classification of acute toxic chemical exposure risks and HDs determination for people in the neighborhood and them who are working in the chemical industry when toxic chemical release happens. The most important usage of the CEI is Process Hazard Analysis (PHA) and emergency response planning. The CEI beside HD determination is an index for evaluation of inherent safety. In recent years, number of studies have been conducted to help processing plants prevent fire, explosion or toxic chemical release accidents. The F&EI is used widely in oil and gas refineries and petrochemical plants for quantification of fire and explosion. *Jafari et al.* [14], *Roshan* and *Gharebagh* [15], *Zarranejad* and *Ahmadi* [16], *Nezamodini et al.* [17] and *Ahmadi et al.* [18] have used the F&EI in their studies. In some studies, the CEI is used to determine HD of some toxic materials. *Jahangiri* and *Parsarad* [19] have applied the CEI in a petrochemical company to determine HD of toxic chemical possible release. *Jabbari et al.* [20] have applied the CEI in a petrochemical plant for 1, 3-butadiene. *Atabi et al.* [21] have assessed the safety distance of toxic materials in road transportation accidents by using the CEI. And also the CEI is used as a screening tool. *Gharabagh et al.* [22], in their study over pipelines, used the CEI for ranking pipelines. Behari and Noga [23] have identified LPG toxicity using the CEI. The Results showed that LPG toxicity was not identified as a high consequence. There are other studies in which the CEI is mostly used accompanying with the F&EI or other indices to compare methodologies or evaluation of inherent safety. *Abidin et al.* [24], *Adu et al.* [25], *Etowa et al.* [26], *Hassim* [27] and *Khan et al.* have used the CEI in their studies.

As seen, in the literature, risk assessment and consequence modeling of gas refineries have focused more on fire and explosion risks and focused less on toxic chemical exposure risks. This is also obvious in usage of indices. Classification of acute toxic chemical exposure risks and HDs determination had not been applied before in a gas refinery containing all toxic materials and units. The studied refinery is located at the South Pars zone of the Asalooyeh-Iran. The unique position of this area is due to gas refineries and petrochemical plants next to each other and also a residential area. Accordingly, the sensitivity of this area greatly increases and reveals the need to prepare appropriate plans to deal with any emergencies and crises. In this study, the CEI is used to classify acute toxic chemical exposure risks and determine HDs of possible toxic chemical releases in the South Pars gas refinery**.**

EXPERIMENTAL SECTION

In this study, the CEI was performed in a gas refinery. The required information was gathered. Toxic chemicals in selected gas refinery were determined and by tracking them, pipes, vessels, and tanks that contain these toxic chemicals were determined. Considerable release scenarios based on the CEI [11] were determined and

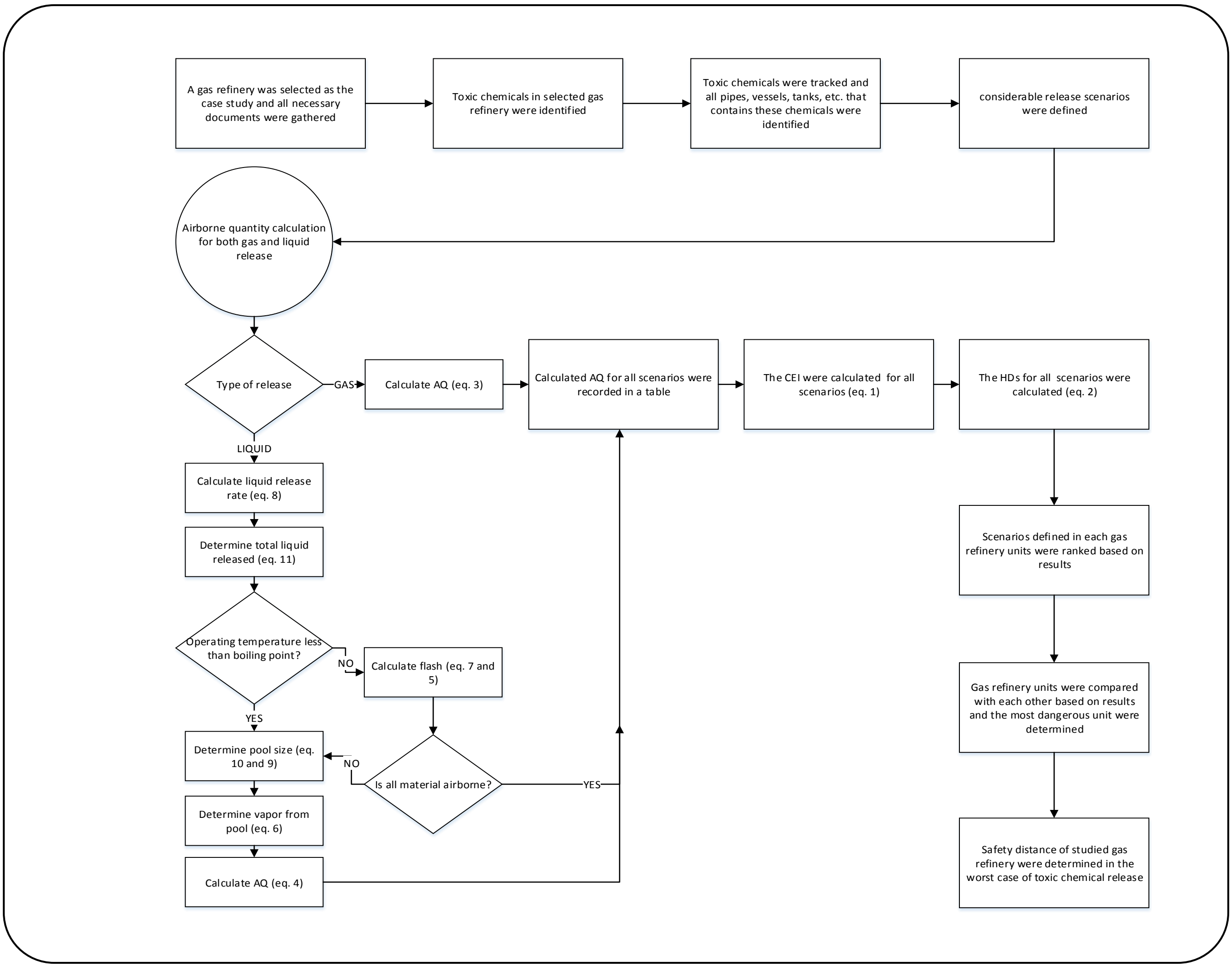

Fig. 1: Flowchart of HD determination using the CEI.

the CEI calculations were done for all scenarios. With the CEI values, HDs of the scenarios were calculated. After that, toxic chemical release risks were ranked. The flowchart of HD determination using the CEI is shown in Fig. 1.

The CEI concept

The CEI provides a comprehensive method for health hazards assessment caused by acute toxic chemicals exposure. The assessment is done for each source identified to have the potential for releasing toxic chemicals [28]. In order to evaluate any source of a toxic chemical release, it is necessary that considerable release scenarios be defined for each source. These resources include process pipes, hoses, vessels, storage tanks, etc. The release scenarios' definitions depend on the container containing toxic chemicals. For example for smaller than 2-inch diameter process pipes, full bore rupture scenario considers. The CEI and HDs are respectively calculated by eq. 1 and eq. 2.

$$\mathrm{CEI}=655.1\sqrt{\frac{\mathrm{AQ}}{\mathrm{ERPG}-2}} \tag{1}$$

$$\mathrm{HD}=6551\sqrt{\frac{\mathrm{AQ}}{\mathrm{ERPG}}} \tag{2}$$

Where *HD* is defined in terms of meter. *ERPG* is Emergency Response Planning Guideline values. American Industrial Hygiene Association (AIHA) has published ERPG values [29] which are intended to provide concentration ranges estimation where one might reasonably anticipate observing adverse effects.

When ERPG values do not exist we can use DOW's Emergency Exposure Planning Guideline (EEPG) values [11].

Airborne Quantities (AQ) in Eq. (1) and Eq. (2) is the rate at which the material can become airborne under process conditions that are calculated for both gases (Eq. (3)) and liquid (Eq.(4)) releases. If the calculated CEI and HDs are respectively greater than 1000 and 10000, the values are considered 1000 for the CEI and 10000 for the HD.

$$AQ=4.751\times10^{-6}D^2Pa\sqrt{MW/T+273} \tag{3}$$

Where D (mm) is the diameter of the release hole; Pa (kPa) is absolute pressure and it is equal to P_g+101.35 where P_g (kPa) is gauge pressure; MW is the molecular weight of the material and T (°C) is the operational temperature.

$$AQ=AQ_f+AQ_p \tag{4}$$

Where AQ_f (kg/sec) is the airborne quantity produced by the flash that is calculated through eq. 5; AQ_p (kg/sec) is evaporated from the pool surface that is calculated through Eq. (6).

$$AQ_f=5(F_v)(L) \tag{5}$$

Where F_v is the fraction of the liquid that will flash (obtained from eq. 7); L (Kg/Sec) is the liquid release flow rate (obtained from Eq. (8))

$$AQ_p=9.0\times10^{-4}\left(A_p^{0.95}\right)\frac{(MW)P_v}{T_p+273} \tag{6}$$

Where A_p (m^2) is the pool area (obtained from Eq. (9)); P_v (kPa) is the vapor pressure of the liquid at the characteristic pool temperature and T_p (°C) is the characteristic pool temperature.

$$F_V=\left(C_p/H_v\right)\left(T_s-T_b\right) \tag{7}$$

Where C_p (J/kg/°C) is the average heat capacity of the liquid; H_v (J/kg) is the heat of vaporization of the liquid; T_s (°C) is the operating temperature of the liquid and T_b (°C) is the normal boiling point of the liquid.

$$L=9.44\times10^{-7}D^2\rho_1\sqrt{1000P_g/\rho_L+9.8\Delta H} \tag{8}$$

Where ρ_1 (Kg/m^3) is the density of the liquid at operating temperature and Δh (meters) is the height of the liquid above the release point.

$$A_p=100\frac{W_p}{\rho_1} \tag{9}$$

Where W_p (kg) is the total mass of liquid entering the pool that is calculated through eq. 10. If the liquid falls into a diked containment area, then the pool size may be equal to the diked area minus the area taken up by the tank. But, if the spill does not fill the diked area or occurs outside the diked area then we use A_p.

$$W_p=W_T\left(1-5F_v\right) \tag{10}$$

Where W_T (kg) is the total liquid that is released that is obtained from eq. 11. If $F_f \geq 0.2$, then AQ_f = L and no pool is formed

$$W_T=900L \tag{11}$$

Gas refinery

An installation that will receive sour gas from sea pipeline and treat it in different units to finally produce the products, the first unit that will receive sour gas is Slug Catcher (unit 100) in which glycol water and condensate will be separated from gas, glycol water will be sent to Mono Ethylene Glycol (MEG) Recovery unit and condensate will be sent to the Condensate Stabilizer unit, the output gas from the slug catcher after passing through high-pressure separators will go to Gas Treatment unit (unit 101) and after gas sweetening, refinery products such as methane, ethane, propane and butane will be extracted. In the gas sweetening process, acid gas is produced that has a large amount of hydrogen sulfide (H_2S) gas. Because of environmental issues, this gas cannot be burned and must be recovered in the Sulfur Recovery unit (unit 108). At last, solid Sulfur is produced and will be kept in storage. In Fig. 2 process block diagram of the selected gas refinery is shown.

By studying the process of the selected gas refinery, H_2S, MEG, and diethanolamine (DEA) were identified as toxic chemicals:

- H_2S is colorless and a highly toxic element, which is easily dissolved in water and is capable of ignition and explosion. It is dangerous and deadly and at low concentrations has the smell of rotten eggs and sweet odor at high concentrations [30]. H_2S exists in inlet sour gas from sea line and also it will go through gas refinery unit 100, unit 101 and unit 108. H_2S amount in inlet gas is 334.6 kgmol/h (0.6571% molar). According to gas refinery

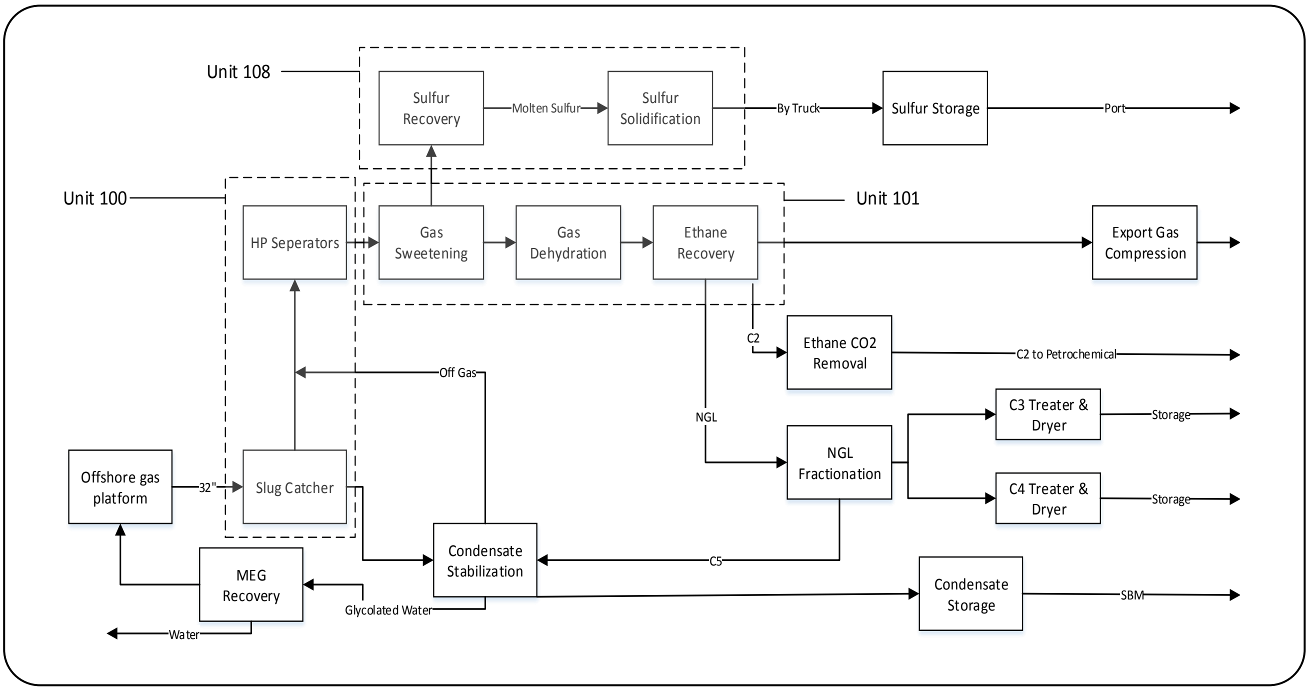

Fig. 2: Selected gas refinery process block diagram.

documents in the beginning, in slug catcher the gas pressure is higher and pipes diameters are larger and by going through other units' gas pressure, it will reduce and pipes diameters will become smaller.

- MEG is a pure, odorless, colorless, thick liquid with a sweet taste. It is toxic and if accidentally a person eats it, he must be under immediate medical attention. Also, contact with its vapor at a high temperature can cause eye and breathing inflammation, dizziness, nausea and vomiting [30]. It is kept inside a tank at chemical storage unit 146.
- Studies show that inhalation of DEA is dumped in mice liver and kidney disorders. DEA may be converted into nitrosamines, which are carcinogenic substances [30]. It is kept inside a tank in unit 146.

RESULTS AND DISCUSSION

As described, there are H_2S as toxic gas and MEG and DEA as toxic liquids in the studied gas refinery. The ERPG/EEPG values of these toxic chemicals are presented in Table 1.

A number of identified scenarios depend on the variety of toxic chemical containers such as tanks, vessels, pipes, hoses, etc. At first, it's not obvious that which container or which scenario has the highest CEI and HD values and because of the impact of process parameters it could not be considered that for example storage tanks or a particular scenario are always the most dangerous situations in case of toxic chemical release. Calculations must be done for all scenarios and then the comparison should be done. *Jahangiri* and *Parsarad* [19] have applied the CEI just for six chemical tanks in the petrochemical industry as the worst case of toxic chemical release without any calculations for all possible scenarios. *Jabbari et al.* [20] have used the CEI just for 1, 3-butadiene in a petrochemical zone.

In this study all of the toxic chemical containers including tanks, pipes, vessels, hoses, etc. have been checked and considerable toxic release scenarios identified. By performing the CEI in the gas refinery a total number of 318 considerable toxic chemical release scenarios were identified and are summarized in Table 2 in each gas refinery unit. Because liquids are kept at storage tanks, one scenario is considered for each toxic liquid. After tracking H_2S in different units of the refinery (100, 101 and 108) by using Process Flow Diagrams (PFD) and Piping and Instrumentation Diagrams (P&ID), a total number of 316 considerable scenarios, among over lots of possible releases were identified.

The process parameters, AQ, CEI, and HDs for all scenarios are presented in Tables 3-6. Scenarios were numbered

Table 1: ERPG/EEPG values of toxic chemicals in the selected gas refinery.

Toxic chemical	ERPG/EEPG-1 (mg/m^3)	ERPG/EEPG-2 (mg/m^3)	ERPG/EEPG-3 (mg/m^3)
H_2S	0.14	42	139
MEG	10	100	500
DEA	7.5	75	375

Table 2: Number of defined scenarios in each gas refinery unit.

Toxic Chemicals	Unit 100		Unit 101		Unit 108		Unit 146	No. of Scenarios
	Vessel	Pipe	Vessel	Pipe	Vessel	Pipe	Storage Tank	
H_2S	80	4	95	7	120	10	-	316
MEG	-	-	-	-	-	-	1	1
DEA	-	-	-	-	-	-	1	1
Total Number of Scenarios								318

Table 3: Scenarios' properties, AQ, CEI and HDs in unit 100.

Scenario No.	Pipe diameter (inch)	T (°C)	Pg (kPa)	AQ (kg/sec)	CEI	HD2 (m)	HD3 (m)
100-001-P	2	25	1250	5.603	239	2392	1315
100-002-P	6	25	1250	10.0854	321	3210	1764
100-003-P	32	25	7400	1592	1000	10000	10000
100-004-P	1	25	7400	7.775	281	2818	1549
100-005-P	12	25	7400	223.93	1000	10000	8315
100-006-P	2	25	7400	31.1024	563	5637	3098
100-007-P	4	25	7400	31.1024	563	5637	3098
100-008-P	2	25	7400	31.1024	563	5637	3098
100-009-P	2	25	7400	31.1024	563	5637	3098
100-010-P	1	25	7400	7.775	281	2818	1549
100-011-D	12*	25	7400	223.9371	1000	10000	8315
100-012-P	26	25	1250	189.38	1000	10000	7646
100-013-P	34	25	1250	323.8544	1000	10000	9999
100-014-P	2	25	1250	5.603	239	2392	1315
100-015-P	26	50	444	73.4096	866	8660	4760
100-016-P	30	25	7400	1399	1000	10000	10000
100-017-P	10	25	7400	155.5119	1000	10000	6929
100-018-P	30	25	7400	1399	1000	10000	10000
100-019-P	10	25	7400	155.5119	1000	10000	6929

Table 3: Scenarios' properties, AQ, CEI and HDs in unit 100 (Continued).

Scenario No.	Pipe diameter (inch)	T (℃)	Pg (kPa)	AQ (Kg/Sec)	CEI	HD2 (m)	HD3 (m)
100-020-P	10	25	7400	155.5119	1000	10000	6929
100-021-P	16	25	7400	398.1104	1000	10000	10000
100-022-P	16	25	7400	398.1104	1000	10000	10000
100-023-P	16	25	7400	398.1104	1000	10000	10000
100-024-P	6	25	7400	55.9843	1000	10000	4157
100-025-P	16	25	7400	398.1104	1000	10000	10000
100-026-P	30	25	7400	1399	1000	10000	10000
100-027-P	32	25	7400	1592	1000	10000	10000
100-028-P	46	25	7400	3290	1000	10000	10000
100-029-P	46	25	7400	3290	1000	10000	10000
100-030-P	46	25	7400	3290	1000	10000	10000
100-031-P	46	25	7400	3290	1000	10000	10000
100-032-P	46	25	7400	3290	1000	10000	10000
100-033-P	46	25	7400	3290	1000	10000	10000
100-034-P	46	25	7400	3290	1000	10000	10000
100-035-P	46	25	7400	3290	1000	10000	10000
100-036-P	20	25	7400	622.0475	1000	10000	10000
100-037-P	10	25	7400	155.5119	1000	10000	6929
100-038-P	46	25	7400	3290	1000	10000	10000
100-039-P	46	25	7400	3290	1000	10000	10000
100-040-P	2	25	7400	31.1024	563	5637	3098
100-041-P	46	25	7400	3290	1000	10000	10000
100-042-P	20	25	7400	622.0475	1000	10000	10000
100-043-P	20	25	7400	622.0475	1000	10000	10000
100-044-P	2	25	1250	5.603	239	2392	1315
100-045-P	1	25	1250	1.4008	119	1196	657
100-046-P	2	25	1250	5.603	239	2392	1315
100-047-P	36	24.2	6870	1875	1000	10000	10000
100-048-P	1	25	7400	7.775	281	2818	1549
100-049-P	24	24.2	851	113.8746	1000	10000	5929
100-050-P	2	24.2	1250	5.6106	239	2394	1316
100-051-P	10	24.2	403.3	10.4761	327	3271	1798

Table 3: Scenarios' properties, AQ, CEI and HDs in unit 100 (Continued).

Scenario No.	Pipe diameter (inch)	T (°C)	Pg (kPa)	AQ (Kg/Sec)	CEI	HD2 (m)	HD3 (m)
100-052-P	1	24.2	1250	1.4026	119	1197	658
100-053-P	24	24.2	851	113.8746	1000	10000	5929
100-054-P	24	24.2	851	113.8746	1000	10000	5929
100-055-P	16	24.2	6870	370.4799	1000	10000	10000
100-056-P	16	24.2	6870	370.4799	1000	10000	10000
100-057-P	16	24.2	6870	370.4799	1000	10000	10000
100-058-P	28	24.2	6870	1134	1000	10000	10000
100-059-P	4	24.2	6870	28.934	543	5437	2988
100-060-P	28	24.2	6870	1134	1000	10000	10000
100-061-P	1	24.2	6870	7.1425	270	2701	1485
100-062-P	2	24.2	6870	28.9437	543	5438	2989
100-063-P	28	24.2	6870	1134	1000	10000	10000
100-064-D	28	24.6	6970	1150.1	1000	10000	10000
100-065-P	2	25	1250	5.603	239	2392	1315
100-066-P	26	24.2	1250	189.6367	1000	10000	7651
100-067-P	20	24.2	1250	46.3633	688	6882	3783
100-068-P	8	25	405	6.7182	262	2620	1440
100-069-P	10	24.2	405.3	10.5176	327	3278	1802
100-070-P	1	24.2	1250	1.4026	119	1197	658
100-071-P	1	24.2	1250	1.4026	119	1197	658
100-072-P	28	25	6775	1117	1000	10000	10000
100-073-P	36	25	6775	1847	1000	10000	10000
100-074-P	2	25	6775	28.511	539	5397	2966
100-075-P	24	25	6775	821.1161	1000	10000	10000
100-076-P	10	24.2	6870	142.8504	1000	10000	6641
100-077-P	36	25	6775	1847	1000	10000	10000
100-078-P	4	25	6745	28.3866	538	5385	2960
100-079-P	4	24	6870	28.5797	540	5404	2970
100-080-P	1	24	6775	7.1397	270	2701	1484
100-081-P	1	25	6775	7.1277	269	2698	1484
100-082-P	36	25	6775	1847	1000	10000	10000
100-083-D	36	24.2	6880	1878.2	1000	10000	10000
100-084-D	28	24.6	6970	1150.1	1000	10000	10000

** For drums and tanks, calculation are based on the largest diameter process pipe attached to the drum or tank*

Table 4: Scenarios' properties, AQ, CEI and HDs in unit 101.

Scenario No.	Pipe diameter (inch)	T (℃)	Pg (kPa)	AQ (Kg/Sec)	CEI	HD2 (m)	HD3 (m)
101-085-P	10	53	418	10.294	324	3243	1782
101-086-P	24	24.4	6610	802.2212	1000	10000	10000
101-087-P	2	24.4	1250	5.6087	239	2393	1315
101-088-P	12	62.9	1250	37.9977	623	6231	3425
101-089-P	6	24.4	6610	50.1388	715	7157	3934
101-090-P	3/4	40	1250	0.7688	88	886	487
101-091-P	2	24.4	6610	27.8549	533	5335	2932
101-092-P	24	24.4	6610	802.2212	1000	10000	10000
101-093-P	8	24.4	6610	89.1357	954	9543	5246
101-094-D	24*	24.4	6710	814.1744	1000	10000	10000
101-095-P	24	24.4	6610	802.2212	1000	10000	10000
101-096-P	10	171.9	427	8.9644	302	3026	1663
101-097-P	24	24.4	6610	802.2212	1000	10000	10000
101-098-P	4	24.4	6610	27.8549	533	5335	2932
101-099-P	4	24.4	6610	27.8549	533	5335	2932
101-100-P	4	24.4	6610	27.8549	533	5331	2930
101-101-P	12	24.4	6610	200.5553	1000	10000	7869
101-102-P	12	24.4	6610	200.5553	1000	10000	7869
101-103-P	24	24.4	6610	802.2212	1000	10000	10000
101-104-P	24	24.4	6710	814.1744	1000	10000	10000
101-105-P	10	34.8	6530	135.2695	1000	10000	6462
101-106-P	10	34.8	6530	135.2695	1000	10000	6462
101-107-P	24	24.4	6610	802.2212	1000	10000	10000
101-108-P	10	190	400	8.3386	291	2918	1604
101-109-P	24	48.6	6490	757.6543	1000	10000	10000
101-110-P	4	45	100	0.8082	90	908	499
101-111-P	4	48.6	6490	21.046	463	4637	2549
101-112-P	3	45	100	0.8082	90	908	499
101-113-P	1	24.04	1250	1.403	119	1197	658
101-114-P	3	45	100	0.8082	90	908	499
101-115-P	10	78.4	1250	25.7988	513	5134	2822
101-116-P	1	24.4	6610	6.9637	266	2667	1466
101-117-P	8	48.55	6485	84.1205	927	9271	5096
101-118-P	10	35.5	750	17.3465	421	4210	2314

Table 4: Scenarios' properties, AQ, CEI and HDs in unit 101 (Continued).

Scenario No.	Pipe diameter (inch)	T (℃)	Pg (kPa)	AQ (Kg/Sec)	CEI	HD2 (m)	HD3 (m)
101-119-P	4	34.75	6530	27.0561	525	5257	2890
101-120-P	1	34.75	6530	6.764	262	2629	1445
101-121-D	24	24.23	6690	812.0159	1000	10000	10000
101-122-P	3	35.8	700	3.264	182	1826	1003
101-123-P	12	35.8	700	23.5006	490	4900	2693
101-124-P	1	35.8	700	0.816	91	913	501
101-125-P	3	40	100	0.8146	91	912	501
101-126-P	3	40	100	0.8146	91	912	501
101-127-P	2	35.8	700	3.264	182	1826	1003
101-128-P	10	35.5	750	17.3465	421	4210	2314
101-129-P	1	35.8	700	0.816	91	913	501
101-130-P	1	35.8	700	0.816	91	913	501
101-131-P	12	43.56	6690	196.7084	1000	10000	7793
101-132-P	3	43.56	6690	27.3206	528	5283	2904
101-133-P	12	35.8	700	23.5006	490	4900	2963
101-134-P	12	111.1	630	19.2308	443	4432	2436
101-135-P	14	56.1	170	10.4919	327	3274	1799
101-138-P	2	132.2	220	1.1426	108	1080	593
101-139-P	2	132.2	220	1.1426	108	1080	593
101-140-P	3	40	100	0.8146	91	912	501
101-141-P	14	132.2	220	11.1978	338	3382	1859
101-142-P	3	40	100	0.8146	91	912	501
101-143-P	3	40	100	0.8146	91	912	501
101-144-P	3	40	100	0.8146	91	912	501
101-145-P	3	100	100	0.7462	87	873	479
101-146-P	3	40	100	0.8146	91	912	501
101-147-P	14	56.11	170	10.4919	327	3274	1799
101-148-P	2	56.11	120	0.8733	94	944	519
101-149-P	2	56.11	120	0.8733	94	944	519
101-150-P	3/4	111.05	630	0.3756	61	619	340
101-151-P	1	111.05	220	0.2934	54	547	300
101-152-P	3/4	111.05	630	0.3756	61	619	340
101-153-P	1	111.05	220	0.2934	54	547	300

Table 4: Scenarios' properties, AQ, CEI and HDs in unit 101 (Continued).

Scenario No.	Pipe diameter (inch)	T (℃)	Pg (kPa)	AQ (Kg/Sec)	CEI	HD2 (m)	HD3 (m)
101-154-P	3/4	111.05	630	0.3756	61	619	340
101-155-P	1	111.05	220	0.2934	54	547	300
101-156-P	3/4	56.11	170	0.1506	39	392	215
101-157-P	14	56.11	170	10.4919	327	3274	1799
101-158-P	1	40	120	0.2239	47	478	262
101-159-P	6	35.76	700	5.8755	245	2450	1346
101-160-P	1	40.2	120	0.2239	47	478	262
101-161-P	16	109.1	140	11.3118	339	3399	1868
101-162-P	12	109.1	140	6.3629	254	2549	1401
101-163-P	12	109.1	140	6.3629	254	2549	1401
101-164-P	12	109.1	140	6.3629	254	2549	1401
101-165-P	12	111.1	630	19.2308	443	4432	2436
101-166-P	14	132.2	220	11.1978	338	3382	2859
101-167-P	16	111.2	434	25.0225	505	5056	2779
101-168-P	3	40	100	0.8146	91	912	501
101-169-P	3/4	100.84	135	0.123	35	354	194
101-170-P	20	110.13	235	24.5986	501	5013	2755
101-171-P	16	109.1	140	11.3118	339	3399	1868
101-172-P	14	60	110	8.124	288	2881	1583
101-173-P	1	60	200	0.2955	54	549	302
101-174-P	3	60	110	0.829	92	920	505
101-175-P	14	60	110	8.124	288	2881	1583
101-176-P	10	60	110	4.1449	205	2058	1131
101-177-P	3	100	100	0.7462	87	873	479
101-178-P	2	60	110	0.829	92	920	505
101-179-P	10	60	200	5.9099	245	2457	1350
101-180-P	2	60	110	0.829	92	920	505
101-181-P	2	60	200	1.182	109	1099	604
101-182-P	2	60	200	1.182	109	1099	604
101-183-P	2	60	110	0.829	92	920	505
101-184-P	4	165.5	105	0.7053	84	848	466
101-185-P	1	60	110	0.2072	46	460	252
101-186-P	14	115.96	235	11.9626	349	3496	1921

** For drums and tanks, calculation are based on the largest diameter process pipe attached to the drum or tank*

Table 5: Scenarios' properties, AQ, CEI and HDs in unit 108.

Scenario No.	Pipe diameter (inch)	T (℃)	Pg (kPa)	AQ (Kg/Sec)	CEI	HD2 (m)	HD3 (m)
108-187-P	20	45	80	14.5578	385	3856	2120
108-188-P	3	45	80	0.7279	86	862	474
108-189-P	2	Amb**	200	1.2095	111	1111	611
108-190-P	20	45	80	14.5578	385	3856	2120
108-191-D	20*	44.7	80	14.5647	385	3857	2120
108-192-P	28	250	57	19.4274	445	4455	2449
108-193-P	28	250	53	18.9367	439	4398	2418
108-194-P	20	256	57	9.8556	317	3173	1744
108-195-P	2	190	450	1.834	136	1368	752
108-196-P	12	165	550	16.0388	404	4048	2225
108-197-P	10	143	Atm***	1.7783	134	1348	740
108-198-P	10	143	Atm	1.7783	134	1348	740
108-199-P	8	165	600	1.7783	280	2800	1539
108-200-P	8	165	600	1.7783	280	2800	1539
108-201-P	2	165	Atm	0.3466	59	595	327
108-202-P	2	165	Atm	0.3466	59	595	327
108-203-P	4	140	250	1.2374	112	1124	628
108-204-P	6	140	250	2.2274	150	1508	829
108-205-P	1	140	250	0.3094	56	562	309
108-206-P	1	140	250	0.3094	56	562	309
108-207-P	1/2	140	250	0.0773	28	281	154
108-208-P	4	140	250	1.2374	112	1124	618
108-209-D	20	100	70	12.7005	360	3602	1980
108-210-P	28	325	49	17.2505	419	4198	2307
108-211-P	28	175	45	19.4	445	4452	2447
108-212-P	3	140	250	1.2374	112	1124	618
108-213-P	2	190	450	1.834	136	1368	752
108-214-P	4	165	600	2.3986	156	1565	860
108-215-P	4	165	600	2.3986	156	1565	860
108-216-P	4	165	600	2.3986	156	1565	860
108-217-P	6	162.9	Atm	0.6254	79	799	439
108-218-P	6	162.9	Atm	0.6254	79	799	439
108-219-P	2	165	Atm	0.3466	59	595	327

Table 5: Scenarios' properties, AQ, CEI and HDs in unit 108 (Continued).

Scenario No.	Pipe diameter (inch)	T (°C)	Pg (kPa)	AQ (Kg/Sec)	CEI	HD2 (m)	HD3 (m)
108-220-P	4	140	250	1.2374	112	1124	618
108-221-P	2	165	Atm	0.3466	59	595	327
108-222-P	1	140	250	0.3094	56	562	309
108-223-P	1	140	250	0.3094	56	562	309
108-224-P	1	140	250	0.3094	56	562	309
108-225-P	3	140	250	1.2374	112	1124	618
108-226-P	3	140	250	1.2374	112	1124	618
108-227-D	28	250	53	18.9367	439	4398	2418
108-228-D	28	324	49	18.2649	420	4200	2308
108-229-P	28	205	43	18.5247	435	4350	2391
108-230-P	28	229.2	39	17.572	423	4237	2329
108-231-P	4	140	250	1.2374	112	1124	618
108-232-D	28	175	45	19.4	445	4452	2447
108-233-D	28	205	43	18.5247	435	4350	2391
108-234-P	28	130	35	19.0568	441	4412	2425
108-235-P	28	130	33	18.7773	438	4380	2407
108-236-P	24	130	33	13.7956	375	3754	2063
108-237-P	24	130	10	11.4338	341	3418	1878
108-238-P	2	190	450	1.834	136	1368	752
108-239-P	8	120	109	2.4303	157	1575	866
108-240-P	3	140	250	1.2374	112	1124	618
108-241-P	3	140	250	1.2374	112	1124	618
108-242-P	3	140	250	1.2374	112	1124	618
108-243-P	3	140	250	1.2374	112	1124	618
108-244-P	3	140	250	1.2374	112	1124	618
108-245-P	3/4	190	450	0.2579	51	513	282
108-246-P	1/2	190	450	0.1146	34	342	188
108-247-P	26	140	250	41.8258	653	6537	3593
108-248-P	1	140	250	0.3094	56	562	309
108-249-P	1	140	250	0.3094	56	562	309
108-250-P	1	140	250	0.3094	56	562	309
108-251-P	1	140	250	0.3094	56	562	309
108-252-P	1	140	250	0.3094	56	562	309

Table 5: Scenarios' properties, AQ, CEI and HDs in unit 108 (Continued).

Scenario No.	Pipe diameter (inch)	T (°C)	Pg (kPa)	AQ (Kg/Sec)	CEI	HD2 (m)	HD3 (m)
108-253-P	3	140	250	1.2374	112	1124	618
108-254-P	3	140	250	1.2374	112	1124	618
108-255-P	3	140	250	1.2374	112	1124	618
108-256-P	3	140	250	1.2374	112	1124	618
108-257-P	4	120	100	0.727	86	861	473
108-258-P	4	142	Atm	0.3561	60	603	331
108-259-P	4	142	Atm	0.3561	60	603	331
108-260-P	4	120	100	0.727	86	861	473
108-261-P	2	120	Atm	0.3659	61	611	336
108-262-D	28	229.2	39	17.572	423	4237	2329
108-263-D	28	130	33	18.7773	438	4380	2407
108-264-P	32	60	60	32.4025	575	5754	3162
108-265-P	32	60	80	36.419	610	6100	3353
108-266-P	24	60	73	19.6949	448	4886	2465
108-267-P	2	60	78	0.7035	84	847	466
108-268-P	2	60	78	0.7035	84	847	466
108-269-P	3/4	60	74	0.0967	31	314	172
108-270-P	3/4	60	74	0.0967	31	314	172
108-271-D	32	60	80	36.419	610	6100	3353
108-272-P	24	45	85	21.5412	469	4691	2578
108-273-P	24	45	85	21.5412	469	4691	2578
108-274-P	24	45	200	34.8347	596	5966	3279
108-275-P	1	45	93	0.195	44	446	245
108-276-P	1	45	93	0.195	44	446	245
108-277-P	3/4	45	93	0.1097	33	334	184
108-278-P	3/4	45	93	0.1097	33	334	184
108-279-P	3/4	45	93	0.1097	33	334	182
108-280-P	3/4	45	93	0.1097	33	334	182
108-281-P	1/2	Amb.	200	0.0756	27	277	152
108-282-D	24	45	93	22.466	479	4791	2633
108-283-P	8	143	10	1.2504	113	1130	621
108-284-P	8	135	Atm	1.1492	108	1083	595
108-285-P	1/2	Amb.	200	0.0756	27	277	152

Table 5: Scenarios' properties, AQ, CEI and HDs in unit 108 (Continued).

Scenario No.	Pipe diameter (inch)	T (°C)	Pg (kPa)	AQ (Kg/Sec)	CEI	HD2 (m)	HD3 (m)
108-286-P	8	190	9	1.1746	109	1095	602
108-287-P	8	190	9	1.1746	109	1095	602
108-288-P	12	140	250	8.9096	301	3017	1658
108-289-P	8	140	250	3.9598	201	2011	1105
108-290-P	10	140	250	6.1872	251	2514	1382
108-291-P	12	140	250	8.9096	301	3017	1658
108-292-P	10	140	250	6.1872	251	2514	1382
108-293-P	10	140	250	6.1872	251	2514	1382
108-294-P	1/2	190	450	0.1146	34	342	188
108-295-P	1/2	190	450	0.1146	34	342	188
108-296-P	10	140	250	6.1872	251	2514	1382
108-297-P	10	140	250	6.1872	251	2514	1382
108-298-P	10	140	250	6.1872	251	2514	1382
108-299-P	2	140	250	1.2374	112	1124	618
108-300-P	2	140	250	1.2374	112	1124	618
108-301-P	2	140	250	1.2374	112	1124	618
108-302-P	2	140	250	1.2374	112	1124	618
108-303-P	2	142.5	260	1.2688	113	1138	625
108-304-P	2	140	250	1.2374	112	1124	618
108-305-P	10	140	250	6.1872	251	2514	1382
108-306-P	12	140	250	8.9096	301	3017	1658
108-307-P	12	140	250	8.9096	301	3017	1658
108-308-P	1	140	250	0.3094	56	562	309
108-309-P	1	140	250	0.3094	56	562	309
108-310-P	1	140	250	0.3094	56	562	309
108-311-P	1	140	250	0.3094	56	562	309
108-312-P	1	140	250	0.3094	56	562	309
108-313-P	1	140	250	0.3094	56	562	309
108-314-P	12	190	450	13.2048	367	3673	2019
108-315-P	12	190	450	13.2048	367	3673	2019
108-316-P	4	140	250	1.2374	112	1124	618

** For drums and tanks, the calculation is based on the largest diameter process pipe attached to the drum or tank*

*** Ambient temperature*

**** Atmospheric pressure*

Table 4: Scenarios' properties, AQ, CEI and HDs in unit 146.

Scenario No.	Material	Pipe diameter (inch)	T_s (°C)	Δh (m)	Pg (kPa)	Dike Area	AQ (Kg/Sec)	CEI	HD2 (m)	HD3 (m)
146-317-T	MEG	3*	45	5.2	Atm**	240	0.0026	3.3174	33	14
146-318-T	DEA	4	45	5.07	Atm	206	0.000022	0.3591	3.6	1.6

** For drums and tanks, the calculation is based on the largest diameter process pipe attached to the drum or tank*

** Atmospheric pressure

Table 7: The distance from units 100, 101, 108 and 146 to the administrative buildings and nearest facilities.

Distance from (m)	Unit 100	Unit 101	Unit 108	Unit 146
Administrative buildings	1150	450	810	750
Nearest facilities	1000	800	1000	760

with a specific format in which the first number represents the gas refinery unit, the second number is the scenario number and the letter that comes, at last, indicates that this scenario is for pipe P, drum D, or tank T.

The distance from units 100, 101, 108 and 146 to the administrative buildings and nearest facilities are presented in Table 7.

The results showed that if a toxic gas release happens in units 100 and 101 based on ERPG-3 values; its HD will be at maximum 10000 meters. On the other hand, a circle with the center of the released point and 10000 meters radios must be considered as the hazard area. This area is smaller for unit 108 and it is a circle with the center of released point and 3593 meters radios. Unit 100, 101 and 108 HDs affect the administrative building and nearest facilities. Also, results showed that the maximum HD in case of toxic liquid release in unit 146 based on ERPG-3 values is 14 meters for MEG and 1.6 meters for DEA. Calculated HD in unit 146 was very smaller than HD in units 100, 101 and 108. The HD of unit 146 do not exceed the unit boundary then does not affect the administrative building and nearest facilities in case of toxic liquid release in this unit. The hazard areas of unit 100, 101 and 108 are shown in Fig. 3. According to the results, unit 100 in comparison with other refinery units is the most dangerous unit in terms of toxic chemical release. This can be one of the reasons that when the refinery is in operational mode, no one is deployed as a standby in this unit.

The scenarios with the CEI greater than 200 require further risk review [11], after calculations and determination of the CEI, scenarios are ranked and those with the need for further risk review are identified. *Gharabagh et al.* [22] have ranked the number of 60 pipelines of a petrochemical zone by calculating the CEI and have identified scenarios that require further risk review. About 97.6 % of the defined scenarios in unit 100, about 56.8 % of defined scenarios in unit 101 and about 36.1 % of defined scenarios in unit 108 had the CEI value greater than 200 and require further risk review that the scope of this paper does not fit.

Of the CEI advantages are that it takes less time to calculate that leads to a reduction in costs it is a powerful technique for classification and screening of toxic chemical release risks. As it is so hard, time-consuming and very costly in some cases to apply consequence modeling or other approaches to identify the HD of toxic chemical releases for all possible scenarios, the CEI makes it simple and possible. As in this study, HDs of 318 scenarios were calculated in a short time. Accordingly, the CEI can be used as a short-cut method as the basis for detailed consequence analysis. By using the CEI, the exposure risks in a process can be identified sooner, and proper risk management decisions can be made early in the process development or predesign stages [31].

Besides the advantages of the CEI obtained from the results of this study, also some limitations were observed. Results showed that any change in process parameters such as a change in diameter, pressure and temperature will lead to a change in results as *Etowa et al.* [26] came to the same conclusion in their study. As in unit 100 both diameter and pressure are greater than units 101 and 108, results were larger numbers of AQ, CEI and HD values. The results also showed that concentration is not considered in the CEI equations. On the other hand change in material, concentration does not affect the results

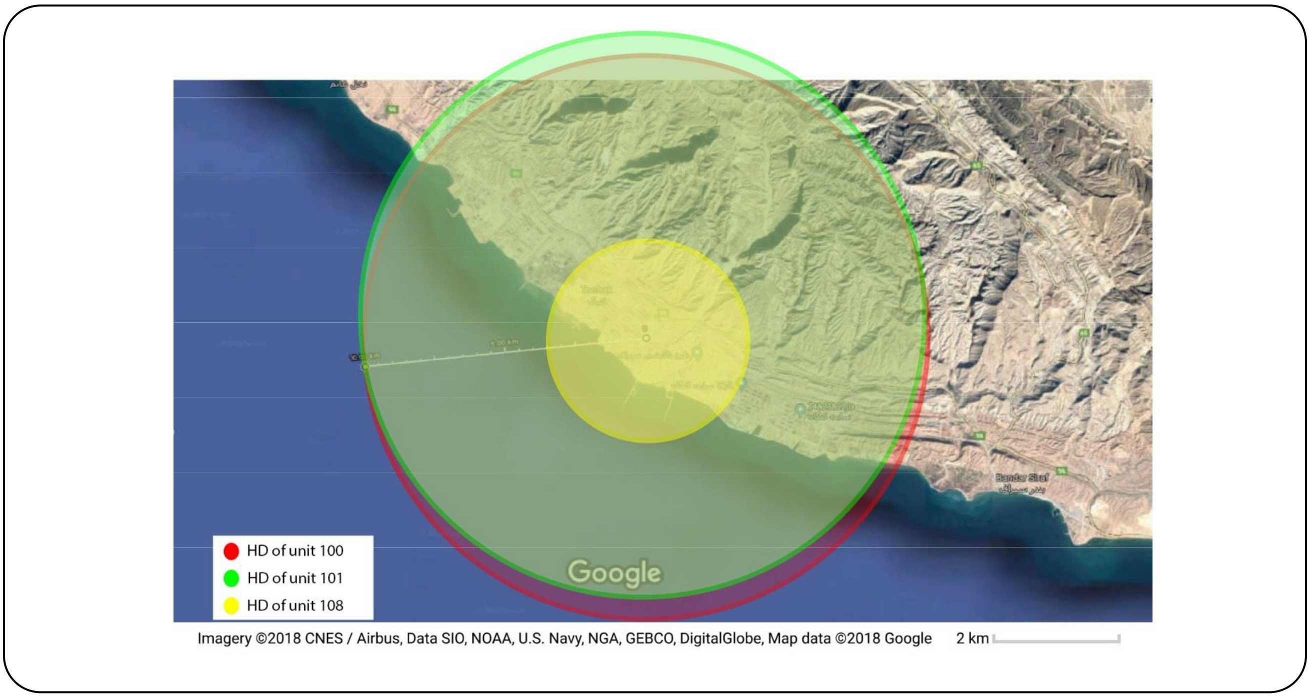

Fig. 3: Units 100,101 and 108 HDs (based on ERPG-3).

of the CEI. The molar percent of H_2S in units 100, 101 and 108 are respectively 0.6324, 0.6895 and 64.54. Although unit 108 has the highest concentration of H_2S, its HD is less than units 100 and 101. It seems that the CEI is considering concentration as 100 percent, but it is not mentioned in the CEI guideline. As *Etowa et al.* [26] came to this conclusion that material inventory is not involved in the CEI airborne equation for toxic chemical releases, the same results were obtained in this study, so any changes in material inventory does not affect the AQ in any of gas release scenarios. For example, scenarios 100-064-D and 100-084-D have different values in volume, flow, etc. and therefore have different values in material inventory although they had the same CEI and HD values. Considering that the CEI has some advantages and limitations, hence it is expected that in future studies, an index is defined based on the CEI considering the CEI limitations.

CONCLUSIONS

In this study, the CEI had been used to determine HDs of considerable toxic chemical releases in a gas refinery. By listing toxic chemicals and tracking them in refinery units 318 considerable scenarios were identified. By process parameters and use of the CEI equations, HDs were calculated. The maximum HD of studied refinery is 10000 meters. In terms of toxic gas release, the Sludge Catcher unit in comparison with other units is the most dangerous. In addition to advantages of the CEI observed in this study such as quick calculations, no need of the high level of expertise, no need of detailed process data, etc. also some limitations were observed including sensitivity to process parameters, no consideration of the material inventory and the concentration in the CEI calculations.

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REFERENCES

[1] Cao H., Li T., Li S., Fan T., An Integrated Emergency Response Model for Toxic Gas Release Accidents Based on Cellular Automata, *Ann. Oper. Res.*, **255**(1): 617-638 (2017).

[2] Badri N., Nourai F., Rashtchian D., The Role of Quantitative Risk Assessment in Improving Hazardous Installations Siting: A Case Study, *Iran. J. Chem. Chem. Eng. (IJCCE)*, **30**(4): 113-119 (2011).

[3] Landucci G., Antonioni G., Tugnoli A., Bonvicini S., Molag M., Cozzani V., HazMat Transportation Risk Assessment: A Revisitation in the Perspective of the Viareggio LPG Accident, *J. Loss Prev. Process Ind.*, **49**: 36-46 (2017).

[4] Zhang B., Chen G-m., Quantitative Risk Analysis of Toxic Gas Release Caused Poisoning—A CFD and Dose–Response Model Combined Approach, *Process Saf. Environ. Prot.*, **88**(4): 253-62 (2010).

[5] Fam I.M., Nikoomaram H., Soltanian A., Comparative Analysis of Creative and Classic Training Methods in Health, Safety and Environment (HSE) Participation Improvement, *J. Loss Prev. Process Ind.*, **25**(2): 250-253 (2012).

[6] Mohammadfam I., Kamalinia M., Momeni M., Golmohammadi R., Hamidi Y., Soltanian A., Developing an Integrated Decision Making Approach to Assess and Promote the Effectiveness of Occupational Health and Safety Management Systems, *J. Clean. Prod.*, **127**: 119-133 (2016).

[7] Mohammadfam I., Ghasemi F., Kalatpour O., Moghimbeigi A., Constructing a Bayesian Network Model for Improving Safety Behavior of Employees at Workplaces, *Appl. Ergon.*, **58**: 35-47 (2017).

[8] Bagheri M., Alamdari A., Davoudi M., Quantitative Risk Assessment of Sour Gas Transmission Pipelines Using CFD, *J. Nat. Gas Sci. Eng.*, **31**:108-18 (2016).

[9] Jianwen Z., Da L., Wenxing F., An Approach for Estimating Toxic Releases of H2S-Containing Natural Gas, *J. Hazard. Mater.*, **264**: 350-362 (2014).

[10] Sanchez E.Y., Represa S., Mellado D., Balbi K.B., Acquesta A.D., Colman Lerner J.E., et al., Risk Analysis of Technological Hazards: Simulation of Scenarios and Application of a Local Vulnerability Index, *J. Hazard. Mater.*, **352**: 101-110 (2018).

[11] Dow Chemical., "Dow's Chemical Exposure Index Guide", American Institute of Chemical Engineers (AIChE), New York (1998).

[12] Dow Chemical., "Dow’s Fire and Explosion Index Hazard Classification Guide", American Institute of Chemical Engineers (AIChE), New York (1994).

[13] ICI Mond Division., "The Mond Index", Imperial Chemical Industries, Explosion Hazards Section, Technical Department, Northwich, UK (1985).

[14] Jafari M., Zarei M., Movahhedi M., The Credit of Fire and Explosion Index for Risk Assessment of Iso-Max Unit in an Oil Refinery, *Int. J. Occup. Hyg.*, **4**(1):10-16 (2015).

[15] Roshan S.A., Gharebagh M.J., Economic Consequence Analysis of Fire and Explosion in Petrochemical Feed and Product Pipelines Network, *Health Scope*, **2**(2):90-4 (2013).

[16] Zaranejad A., Ahmadi O., Fire and Explosion Risk Assessment in a Chemical Company by the Application of DOW Fire and Explosion Index, *J. Occup. Health. Epidemiol. (JOHE)*, **4**(3):163-75 (2015).

[17] Nezamodini Z.S., Rezvani Z., Kian K., Dow’s Fire and Explosion Index: a Case-Study in the Process Unit of an Oil Extraction Factory, *Electron. Physician*, **9**(2): 3878 (2017).

[18] Ahmadi S., Adl J., Mirzaei M., Zarei M., Determination of Fire and Explosion Loss in a Chemical Industry by Fire and Explosion Index, *J. Qazvin Univ. Med. Sci.*, **15**(4): 68-76 (2012).

[19] Jahangiri M., Parsarad A., Determination of Hazard Distance of Chemical Release in a Petrochemical Industry by Chemical Exposure Index (CEI), *Iran Occup. Health J.*, **7**(3):55-62 (2010).

[20] Jabbari M., Sajjadi S.M.H., Gholamnia R., Determination of Airborne Quantity and Consequence Analysis of 1,3-Butadiene Release from a Petrochemical Plant Pipeline, *Appl. Mech. Mater.*, **260**: 56-58 (2013).

[21] Atabi F., Ghorbani R., Jabbari M., Assessment of Safe Distance for Five Toxic Materials Commonly in the Accidents of Chemical Road Transportation Using ALOHA and PHAST Software and CEI Index (Case Study: Tehran-Qazvin Highway), *Iran Occup. Health J.*, **14**(4):42-35 (2017).

[22] Gharabagh M.J., Asilian H., Mortasavi S., Mogaddam A.Z., Hajizadeh E., Khavanin A., Comprehensive Risk Assessment and Management of Petrochemical Feed and Product Transportation Pipelines, *J. Loss Prev. Process Ind.*, **22**(4): 533-539 (2009).

[23] Behari N., Noga M., Risk Assessment Screening Study for Fire, Explosion and Toxicity Effects of Hydrocarbons Stored in a Sphere and Bullet, *J. KONES*, **24**(1):45-57 (2017).

[24] Abidin M.Z., Rusli R., Buang A., Shariff A.M., Khan F.I., Resolving Inherent Safety Conflict Using Quantitative and Qualitative Technique, *J. Loss Prev. Process Ind.*, **44**: 95-111 (2016).

[25] Adu I.K., Sugiyama H., Fischer U., Hungerbühler K., Comparison of Methods for Assessing Environmental, Health and Safety (EHS) Hazards in Early Phases of Chemical Process Design, *Process Saf. Environ. Prot.*, **86**(2): 77-93 (2008).

[26] Etowa C., Amyotte P., Pegg M., Khan F., Quantification of Inherent Safety Aspects of the Dow Indices, *J. Loss Prev. Process Ind.*, **15**(6):477-87 (2002).

[27] Hassim M.H., Comparison of Methods for Assessing Occupational Health Hazards in Chemical Process Development and Design Phases, *Curr. Opin. Chem. Eng.*, **14**:137-49 (2016).

[28] Hassim M., Hurme M., Inherent Occupational Health Assessment During Process Research and Development Stage, *J. Loss Prev. Process Ind.*, **23**(1): 127-138 (2010).

[29] AIHA., "ERPG/WEEL Handbook", American Industrial Hygiene Association (2015).

[30] NIOSH., "NIOSH Pocket Guide to Chemical Hazards", DHHS (NIOSH) (2012).

[31] Mardani M., Ghasemi A., A Credit Approach to Measure Inherent Hazards Using the Fire, Explosion and Toxicity Index in the Chemical Process Industry: Case Study of an Iso-max Unit in an Iran Oil Refinery, *Caspian J. Health Res.*, **1**(1): 1-17 (2015).