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Original Article

Safety and Environmental Sustainability of Strategic Gasoil Tanks, Affected by Fire and Explosion Incidents in the Oil Facilities of Southern Ahvaz

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Abstract

Background: Incidents involving fire and explosions in storage tanks containing petroleum derivatives pose significant safety and environmental risks. The Ahvaz oil field, ranking as the third-largest globally, features numerous storage tanks for petroleum derivatives, raising the likelihood of accidents and necessitating a comprehensive investigation.

Methods: This study aimed to assess the repercussions of gasoline release from two strategically positioned tanks within an oil center in Ahvaz city in the year 1400. The evaluation encompassed two gasoline tanks, one with a capacity of 650 L and the other with 2.3 million L. Numerical calculation methods and the ALOHA model were employed for consequence modeling. The modeling incorporated data on climatic conditions, topographic parameters, geographical characteristics, and tank specifications. The chemical exposure index (CEI) was utilized to prioritize potential health hazards for individuals in the vicinity of the tanks.

Results: The findings indicated that, based on the Emergency Response Planning Guidelines (ERPG) criteria, the minimum safe distance for a fire is 28.5 yards for the 650-liter tank and 76.5 yards for the 2.3 million-L tank. Additionally, the toxic cloud radius resulting from diesel release was 61.2 and 136 yards for the respective tanks, putting 19 employees at risk in this area. Thus, the consequences of diesel release from tanks represent plausible and noteworthy incidents that could lead to significant accidents and damages.

Conclusion: Assessing the repercussions of diesel release serves as an effective management tool in emergencies involving tanks, facilitating safe and appropriate placement measures.

Keywords: Strategic tanks, Safety, Environment, Explosion, Fire, ALOHA

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Introduction

Nowadays, the global population has surged to unprecedented levels, leading to what is commonly termed a population explosion. This uncontrolled growth has resulted in a myriad of social issues, including diminished food security in developing nations, housing shortages in major cities across the world, and environmental pollution caused by industries in numerous countries.[1] Among the various challenges faced in today's world, environmental pollution has emerged as a severe issue in recent years, gradually spreading on a global scale.[2] Petroleum derivatives play a crucial role in human life.[3] The current scientific and technological advancements necessitate the use of these substances in energy production, as well as in the construction and manufacturing of essential products.[4,5] The oil and gas industries contribute remarkably to the global economy, accounting for 16.7% of its total output.[6] These industries are engaged in various sectors, including exploration, exploitation, storage, transportation, refining, and distribution, with tanks being utilized for storage and other operations across many of these sectors. Worldwide, there are approximately 600 000 oil and petroleum derivative storage tanks.[7] In Iran alone, there are around 11 000 large storage tanks containing various chemicals and petroleum derivatives like gasoline and crude oil.[8,9] Given the nature of petroleum derivatives, storing these substances in tanks is inherently associated with the potential for major fire and explosion accidents.[10] According to the model presented by the US Department of Energy, widespread chemical storage tank fires can largely impact various biological and human factors.[11] Determining the radius of damage during accidents related to fires and explosions in oil tanks and other equipment containing these substances is of paramount importance.[12] For this purpose, various mathematical methods and modeling using different software are employed today to investigate the consequences of accidents.[13] This is done to determine the safe zone and risk area so that individuals can be kept away from the danger zone in case of such an event, thereby reducing the level of casualties.[14] Over the past decades, with the development of process industries, accidents related to these industries have increased, primarily due to a lack of proper understanding and evaluation of the existing conditions of these process units and the necessary preparedness to deal with these accidents. Therefore, the first step to overcoming these critical situations is to identify probable scenarios, maneuvers, determine the performance of organizations and individuals, and provide a criterion for evaluating crisis management programs.[15] Various countries have established laws and guidelines for organizing and managing chemical tanks. At the international level, standards like NFPA30 (National Fire Protection Association) and IPS-E-SF-220 (Iranian Petroleum Standards) provide requirements for selecting the location of chemical tanks, distance from other facilities, and deployment methods.[16] Numerous studies have been conducted to analyze the consequences of major accidents in the oil and gas industries using mathematical models. For instance, in a study aimed at assessing the safety risk and environmental effects of LNG (liquefied natural gas) tank explosions in East India, James and Renjith[17] found the potential for high safety damage and controllable environmental risk. Khorram[18] also evaluated the environmental effects of cyanogen release in the vicinity of the Bushehr nuclear power plant using ALOHA and PHAST software. Yang et al[19] assessed the potential for propylene release and explosion from pressurized tanks in Shanghai. Assessing the potential for explosions and fires in petroleum derivative and chemical storage tanks is of particular importance, as these events have safety, health, environmental, economic, and reputational consequences.[20] Diesel is one of the most consumed petroleum derivatives worldwide after gasoline.[21] Gasoline is primarily composed of paraffinic, naphthenic, and aromatic groups, with a minimum flash point of 54 °C and a maximum pour point of 0 °C. Its density at 15.6 °C is between 820-860 kg/m^3. This substance has a high potential for fire.[22] Oil production facilities require many tanks for diesel storage.[23] One of the strategic centers for diesel tank storage in southwest Iran has two tanks with capacities of 650 000 L and 2.3 million L of diesel each. It is worth noting that the Ahvaz oil field is the largest in Iran and the third-largest oil field in the world. Given the number of tanks and oil facilities in this area, researching to assess the safety and environmental risk potential of strategic diesel tanks is essential.

Materials and Methods

The investigated case involved two gasoline tanks, a 650 000-L tank, and a 2.3 million-L tank, located at the Shahid Almasi fuel station. The oil facility has 19 workers, and the tanks are of the vertical type with fixed roofs. The height of the oil tanks above sea level is 22 m, and the station's area is 77 568 m^2. The geographical coordinates of the 650 000-L tank are 31°13'35.44"N and 48°57'51.27"E, while the 2.3 million-L tank is located at 31°13'34.42"N and 48°57'48.30"E in Ahvaz. Ahvaz city, situated at an altitude of approximately 20 m above sea level, has a hot desert climate. The average temperature in Ahvaz is around 30 °C, with the hottest months being June through September, where temperatures often exceed 40 °C. The city experiences high humidity, particularly in summer, reaching up to 70%-80%. The average annual precipitation is around 250 mm, mainly occurring in the winter months. Considering these climate parameters, the consequences of releasing gasoline could vary in different seasons. Therefore, we established two scenarios (winter and summer) to assess the potential consequences. Geographical location of the investigated reservoirs on the Google image is in Figure 1.

The modeling process incorporates various data, encompassing climate conditions (temperature, humidity, and wind rose), topographical factors (elevation above sea level and slope degree), geographical features (longitude and latitude), and specifics of the tanks or pipelines (tank content, tank pressure, tank type, tank height, etc). To assess potential health hazards for individuals working in the area, the chemical exposure index (CEI) was applied. This index provides a relative classification of the risks associated with exposure to toxic substances.[24] The physicochemical properties of gasoline have been detailed in Table 1.

Climate parameters in two scenarios (winter and summer) in Ahvaz city have been presented in Table 2.

Calculation of the Release Amount of the Liquid Phase of Gasoline

Equation 1 was used to calculate the release of liquids (gasoline).

Figure 1. Geographical Location of the Investigated Reservoirs on the Google Image

Table 1. Physicochemical Characteristics of Gasoline

Chemical	Freezing Point	Flash Point	UEL	LEL	IDLH	ERPG-1	ERPG-2	ERPG-3	Molecular Weight
Diesel	-40 °C	126.7 °C	74000 ppm	14000 ppm	5 mg/m³	200 ppm	1000 ppm	4000 ppm	72 g/mol

Table 2. Climate Parameters in 2 Scenarios (Winter and Summer) in Ahvaz City

Climate Parameter	Winter	Summer
Temperature (average)	17 °C	40 °C
Relative humidity (average)	60%	70%
Wind speed (average)	5 m/s	7.3 m/s
Atmospheric stability	D	D
The presence of obstacles	Type-b buildings (less than 15 m height)	Type-b buildings (less than 15 m height)
Type of enclosure (open or closed)	Open area	Open area
Prevailing wind direction	Southern	Southern
The height of the wind speed measurement above the ground	5 m	5 m
Inversion	no	no
Sea level	16	16

$$L_{gasoline} = 9.44\times10^{-8}(D^2)\times(p_1)\sqrt{\frac{1000(P_g)+9.8(p_1)(\Delta h)}{p_1}} \quad (1)$$

Where:
L: Estimated gasoline released (gasoline per min)
p_g: Gauge pressure (kPa)
ρ_1: Density of liquid at operating temperature (kg/m^3)
Δh: Height of liquid above the release point (m)
D: Hole diameter (mm).

The total amount of gasoline released (WT) for a release period of 60 min (1800 seconds) is equal to the total amount of gasoline stored in the tank and for a release period of more than 60 min, it was calculated from equation 2:

$$W_T = 1800\ (L) \quad (2)$$

In this regard: W_T = total gasoline release rate (kg) and L = gasoline release rate (kg/s).[25]

Calculation of CEI

All calculations of this index are based on the assumption of a wind speed of 5 meters per second (m/s) and normal weather conditions (neutral). The method of calculating this index has been as described in equation 3:

$$CEI = 655.1\sqrt{\frac{L_{gasoline}}{ERPG-2}} \quad (3)$$

In this regard, $L_{gasoline}$ gasoline release rate and Emergency Response Planning Guidelines (ERPG)-2 are exposure indicators. If the value of this index exceeds 200, it is necessary to carry out a detailed risk assessment of toxic substance release modeling using ALOHA software in the desired process unit.

Scenario Creation and Consequence Assessment

The process involved scenario development and impact assessment, initiated by determining the risk exposure index for scenarios related to gasoline gas release from tanks. Factors considered included the physicochemical properties of the substance, the season of the incident (winter and summer), release status (leakage diameter, height of the release point, reservoir pressure), and type of release (continuous or sudden). The ALOHA software was employed for impact assessment based on data acquired in preceding stages. The risk radius was ultimately obtained at ERPG1-2-3 distances. Parameters such as the discharge coefficient (CD) and leakage orifice area for gasoline tanks were calculated. Weather stability conditions, specifically class D according to the Pasquill model, were considered in the south of Ahvaz city for both summer and winter seasons. Other weather parameters, including temperature, wind speed, and humidity, were determined through the city's meteorological stations. Numerical calculations were conducted using the Excel 2016 software environment, and impact modeling was executed using ALOHA 5.44 software.

Results and Discussion

The results encompassed the evaluation of the CEI and the analysis of the repercussions of releasing, igniting, and exploding strategic gasoline tanks. In the initial phase, the quantity of gasoline released following a leakage incident was determined through numerical calculations. These calculations assumed continuous gasoline release for a minimum of 60 min across all scenarios before cessation. If the release within the initial 60 min exceeded the total substance volume, the release rate was derived by dividing the available substance by 60 min. Given the operational temperature density of gasoline as 860 kg/m^3, a leakage diameter of 50 mm in the investigation scenario, and reservoir atmospheric pressure at 101 kPa, the release rate is expressed as equation 4:

$$L_{gasoline} = 9.44\times10^{-8}(0.00000001)\times860\sqrt{\frac{1000(101)+9.8(860)(21)}{860}} = 3.649003 \quad (4)$$

Therefore, the gasoline release rate will be equal to 3.64 L/s and 218.94 L/min.

After estimating the release rate, the CEI for gasoline was calculated. Considering the release rate and ERPG-2 level for gasoline is equal to 1000 ppm, the CEI index is based on equation 5:

$$CEI = 655.1\sqrt{\frac{3.64}{1000}} = 39.5237 \quad (5)$$

The calculations show that the chlorine gas CEI has a higher quantity than the other two substances, and its amount is more than 20. This calculation emphasizes the need for a more accurate risk assessment for it. Below are the results of the consequence assessment in hazardous scenarios provided by the ALOHA model.

Results of Consequence Assessment Using ALOHA

The first scenario involves a fire due to a leak from a 50 mm hole in a 650000-L gasoline tank (T1) for 60 min in both winter and summer seasons. The results of the consequence assessment for the release of gasoline in the first scenario - the summer season has been presented in Figure 2.

Scenario 1 (Summer) involved a consequence analysis using the ALOHA software, focusing on a gasoline fuel release from a 650000-L tank during the summer season. The minimum safe distances for fire occurrence were determined based on wind direction, indicating 18.5 yards in the opposite direction of the wind (east), 28.5 yards in the wind direction, and 26.5 yards in the north and south directions (Figure 2A). These distances were determined considering the region's temperature conditions. The time-damage graph, illustrating a 60-min release of gasoline fuel during the summer, indicated the starting point of fire-induced damage predominantly at 61.7 yards in the wind direction (Figure 2B). Figure 2C depicted the highest concentration of the toxic cloud within a 700-yard radius at 4000 ppm. The concentration level based on AEGL-1 (52 ppm) was observed at a 68.5-yard radius in the wind direction (Figure 2D). It is noteworthy that weather conditions and wind speed can influence the dispersion of the toxic cloud from the gasoline fuel leak over a greater distance. The consequence analysis results for Scenario 1 (Winter) have been presented in Figure 3.

Analysis of the Consequence Assessment of the First Scenario (Winter) Using ALOHA Software

In the winter season scenario involving a gasoline release from a 650000-L tank, the minimum safe distances for a fire event were determined as 18 yards in the opposite direction of the wind (east), 14.5 yards in the downwind direction, and 23.5 yards in the north and south directions (Figure 3A). The time-damage graph for a 60-min release of gasoline during the winter season indicated the starting point of fire-induced damage predominantly at 34.3 yards in the direction of the prevailing wind (Figure 3B). Consequence assessment results for gasoline release in this winter scenario are shown in Figure 3C, highlighting the highest concentration of the toxic cloud within a 560-

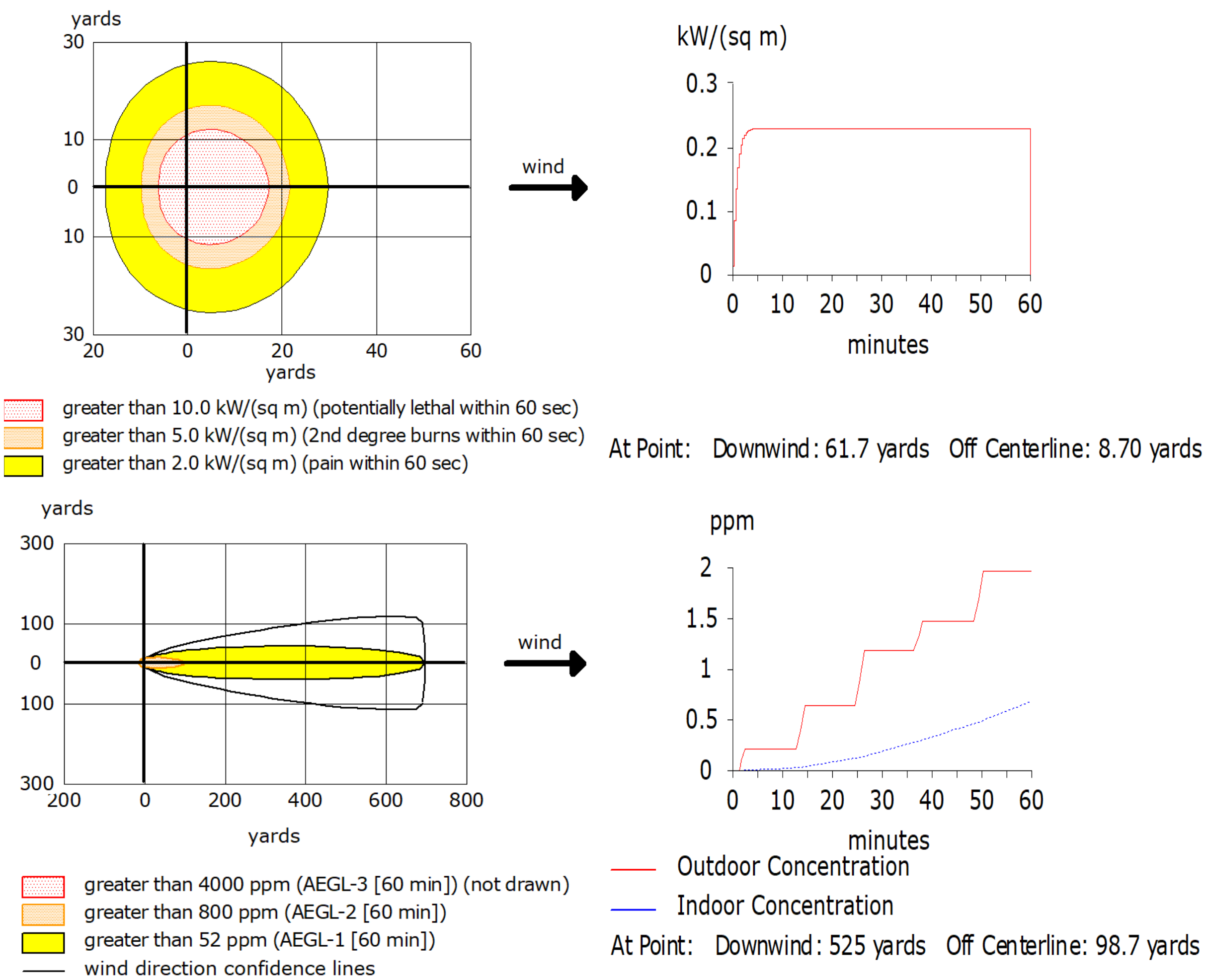

Figure 2. Results of Modeling the Consequences of Gasoline Release From the 650000-L Tank in the Summer Season

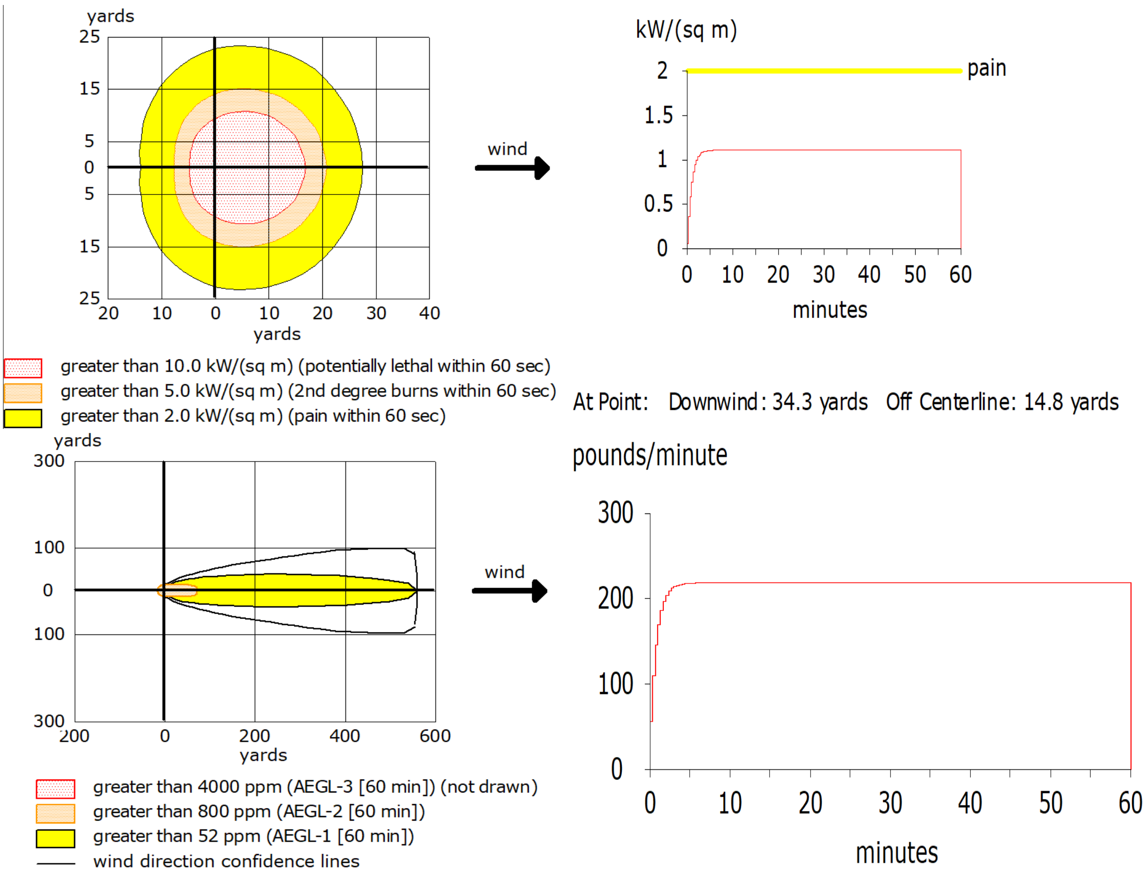

Figure 3. Results of Modeling the Consequences of Gasoline Release From the 650 000-L Tank in Winter Season

yard range at 4000 ppm. The concentration level based on AEGL-1 (52 ppm) is situated at a radius of 44.5 yards in the direction of the prevailing wind. The results of the consequence assessment for gasoline release in the second scenario (summer) Have been presented in Figure 4.

Scenario 2 (Summer) Consequence Analysis Using ALOHA Software

In the winter season scenario involving a gasoline release from a 650 000-L tank, the minimum safe distances for a fire event were determined as 18 yards in the opposite direction of the wind (east), 14.5 yards in the downwind direction, and 23.5 yards in the north and south directions (Figure 4A). The time-damage graph for a 60-min release of gasoline during the winter season indicated the starting point of fire-induced damage predominantly at 34.3 yards in the direction of the prevailing wind (Figure 4B). Consequence assessment results for gasoline release in this winter scenario are shown in Figure 4C, highlighting the highest concentration of the toxic cloud within a 560-yard range at 4000 ppm. The concentration level based on AEGL-1 (52 ppm) is situated at a radius of 44.5 yards in the direction of the prevailing wind. The results of the consequence assessment for gasoline release in the second scenario (summer) are presented in Figure 4.

Analysis of the Consequence Assessment of Scenario 2 (Winter) Using ALOHA Software

In the winter scenario involving a gasoline release from a 2.3 million-L tank, the minimum safe distances for fire occurrence were determined as 45 yards against the wind direction (east), 59 yards in the wind direction, and 54.5 yards in the north and south directions (Figure 5A). The time-damage graph for a 60-min release of gasoline during the winter season indicated the starting point of fire-induced damage predominantly at 66 yards in the wind direction (Figure 5B). Consequence assessment results for gasoline release in this winter scenario have been shown in Figure 4C, highlighting the highest concentration of the toxic cloud within a 575-yard range at 4000 ppm. The concentration level based on AEGL-1 (52 ppm) is situated at a radius of 47 yards in the dominant wind direction.

In the final stage, the outcomes of gasoline gas dispersion derived from numerical calculations were juxtaposed with the results obtained through consequence modeling using the compared software (Figure 6). The R2 coefficient, serving as a metric for evaluating the model's performance, was determined to be 0.9718, signifying an acceptable level of accuracy in assessing the consequences of gasoline gas emissions from strategic reservoirs. The lack of access to field data precluded the possibility of validation for the study results. Nevertheless, the consistency observed in numerical calculations and modeling underscores the favorable potential of these two methods in evaluating the repercussions of toxic gas emissions.

In this study, two scenarios for the release of diesel fuel from strategic diesel fuel tanks in the winter and summer seasons were developed and evaluated. The simulation

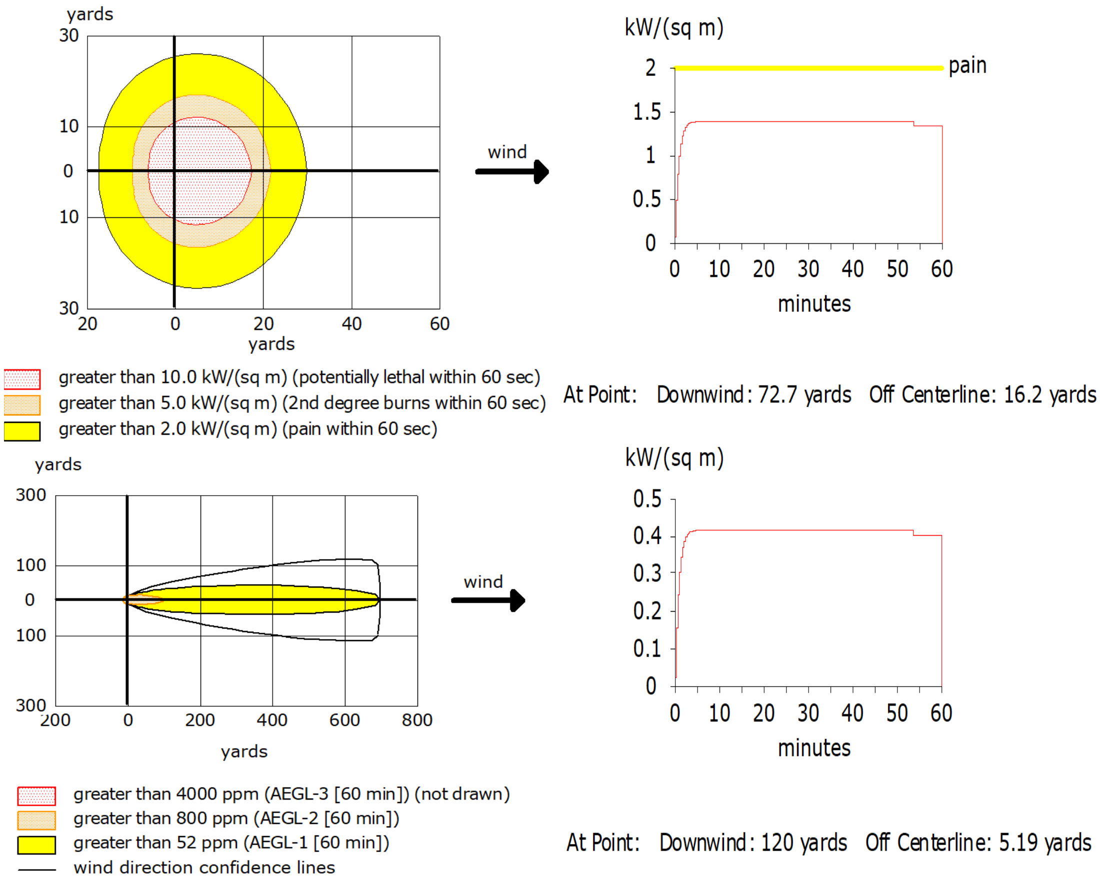

Figure 4. The Results of Modeling the Consequences of Gasoline Release From the 2.3 Million L Tank in the Summer Season

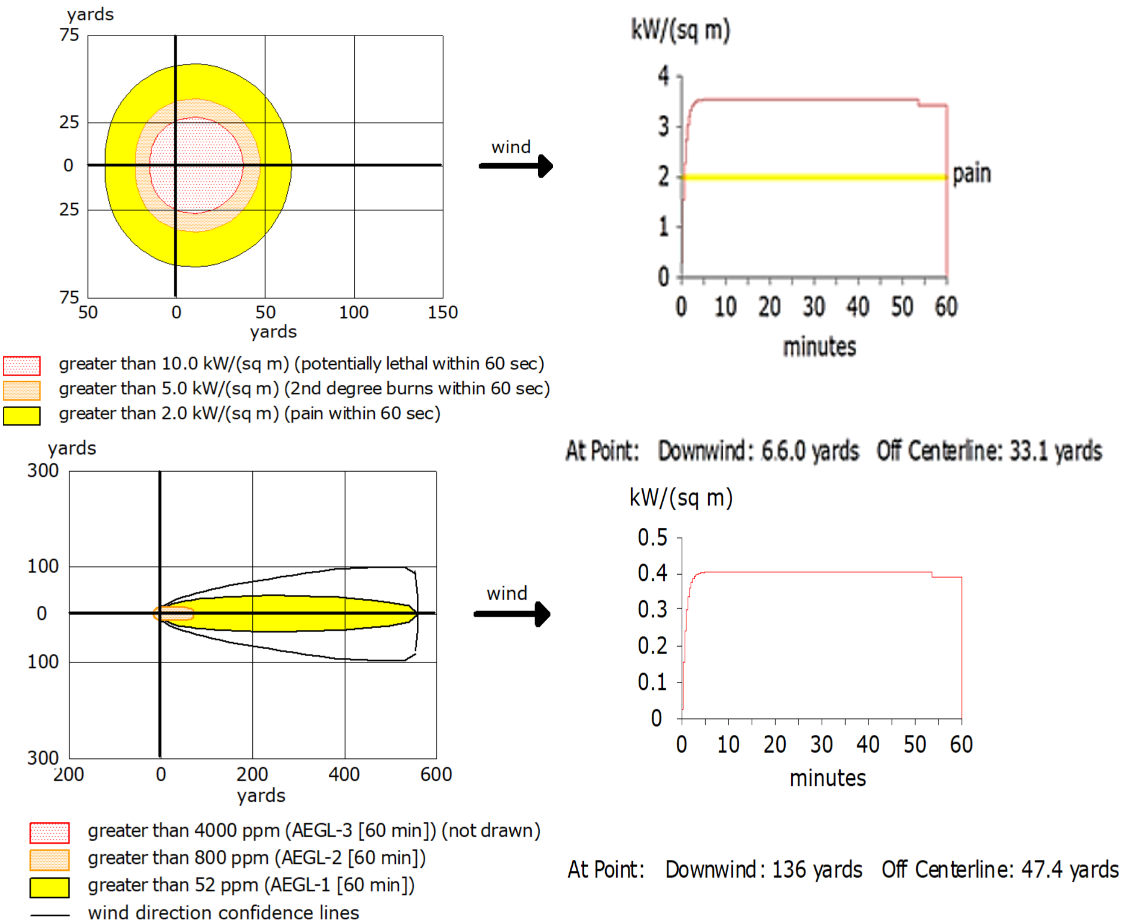

Figure 5. The Results of Modeling the Consequences of Gasoline Release From the 2.3 Million L Tank in the Winter Season

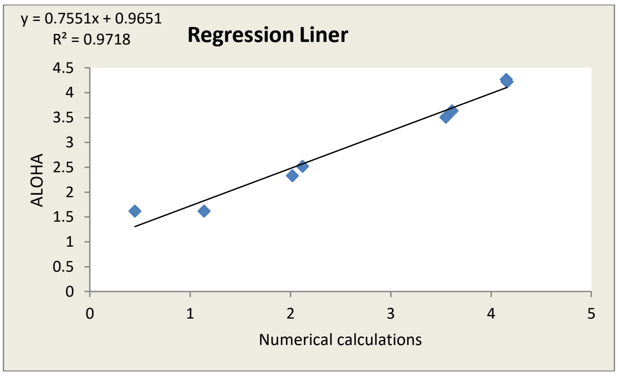

Figure 6. Level of Overlap Between the Results of the Numerical Calculation and the Results Extracted From the Software

results for a leak with a diameter of 50 mm on the tank body were obtained, and these results showed that if a leak occurs on the tank and continues for one hour, weather assumptions including wind speed, relative humidity, stability degree, ambient temperature, and standard atmospheric pressure based on the conditions of Ahvaz city are defined, the minimum safe distance for a 650 000-L tank is 28.5 yards and for a 2.3 million-L tank is 76.5 yards. It should be noted that these figures are determined based on the ERPG indices, and therefore, any installation within these distances from the tanks is unsafe. The radius of the toxic cloud resulting from the release of diesel fuel was also estimated to be 61.2 and 136 yards for 650 000-L and 2.3 million-L tanks, respectively. Various studies, such as Kulynych and Maruta[26] and Patal & Sohani,[27] have shown that the use of mathematical methods leads to more accurate results in evaluating outcomes. Based on the results of research on scenarios of fires caused by diesel tanks, some of the distances and ranges of their hazards have greater contamination and harmful effects, which should be considered prohibited areas and require effective control measures to reduce or prevent accidents. Entry of unrelated individuals is prohibited in this area and traffic restrictions must be observed. Additionally, according to the results obtained, some areas also have an impact on humans (not just facilities). Fan et al[28] and Uvaraja[29] suggested that these areas be used as support group deployment areas and emergency conditions for better and faster control and elimination of hazardous consequences.

Given the possibility of changes in weather conditions, such as wind speed and direction, in the city of Ahvaz, maximum distances should be considered in all geographical directions. Ultimately, the consequences of diesel fuel release from potential incident reservoirs can lead to accidents and significant damages. Therefore, evaluating the consequences of diesel fuel release can be used as a proper management tool in emergency situations related to reservoir placement for safe and appropriate conditions. It can be said that modeling using numerical calculations and software plays a key role in managing reservoir areas in this study.

Conclusion

The study highlights that the consequences of diesel release from tanks represent plausible and investigable incidents with the potential for significant accidents and damages. The evaluation of these consequences serves as an effective management tool for emergency situations, guiding decisions related to the safe and appropriate placement of tanks. The study underscores the pivotal role of modeling, employing numerical calculations and software, in managing reservoir areas and enhancing overall safety measures.

Authors' Contribution

Conceptualization: Seyed Ali Jozi.
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Funding acquisition: Seyed Ali Jozi.
Investigation: Nader Boveirehi.
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Project administration: Seyed Ali Jozi.
Resources: Mahsa Bakhshaei.
Software: Nader Boveirehi.
Supervision: Mahsa Bakhshaei.
Validation: Seyed Ali Jozi.
Visualization: Mahsa Bakhshaei.
Writing–original draft: Mahnaz Mirza Ebrahim Tehrani.
Writing–review & editing: Mahsa Bakhshaei.

Competing Interests

The authors declared no conflict of interest.

Ethical Approval

There were no ethical considerations to be considered in this research.

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