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CASE STUDY

Evaluation of the Possible Hazards of an Ethanol Storage Tank

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Abstract

The presence of chemicals in process industries such as the food industry has always been subject to risks like fire, explosion and release of toxic substances. The occurrence of such incidents have serious impact on the funds and life resources. In this article, we have tried to identify hazards of Ethanol storage tank with PHAST modeling to provide solutions to reduce and manage risks in Behnoush Iran Company. The most dangerous scenarios were selected according to the available conditions 100 mm diameter tank leakage, 3 Inches diameter short pipe leakage and Tank rupture in the summer and winter cases. According to the results, a leak with diameter of 100 mm with radiation of 37.5 KW/m2 and catastrophic rupture are also very dangerous due to the suddenness of the accident and has the ability to damage the tanks. Therefore, by modeling and evaluating the consequences of such accidents, it was proposed to reduce the hazards and prevent the occurrence of more serious accidents by using more advanced fire detection and firefighting equipment, the use of fireproof structures, continuous training of people, and the promotion of safety culture and fire team deployment.

Keyword: Consequence Modeling, Ethanol Storage Tank, Explosion, Fire, PHAST, Toxic Substance.

Nomenclatures

Units	
˚C	Degrees Celsius
Kg/s	kilogram per second
KW	Kilowatt
mm	Millimeter
m/s	Meters per second
m	Meter
m^2	Square meters
m^3	Cubic meters
N	newton
pa	Pascal
Ppm	Parts per million
S	Second
3D	Three-dimensional
2D	Two-dimensional
Acronyms	
PHAST	Process Hazard Analysis Software Tool
DNV	Det Norske Veritas
UDM	Unified Dispersion Model
HEGADAS	Heavy Gas Dispersion from Area Sources
DIERS	Design Institute for Emergency Relief Systems
CCPS	Center of Chemical Process Safety
QRA	Quantitative Risk Assessment
ERPG	Emergency Response Plan Guideline

Introduction

Safety plays a very important role in all stages of chemical process design and is not just a task alongside other tasks [1]. On the other hand, mankind has always been trying to improve his life and their level of prosperity, and in this way, they have tried to use their resources by making changes in nature. However, as a result of these changes and the expansion of this type of activities, the dangers related to these changes have also caused unfortunate accidents, such as the Sanchi ship accident [2] in January 2017, in which the accident caused great damage to lives. It also resulted in toxicity to the environment due to fires and the release of toxic substances into the environment. So standards, guidelines, modeling, and methods for identifying and managing emergencies have all come together to help reduce such unfortunate incidents. One of these methods is risk identification by 'preliminary Hazard Analysis' and modeling of more probable accidents by Process Hazard Analysis Software Tool (PHAST) software [3]. Establishing overall confidence in these assessments requires that each stage in the calculations is accurately modelled [4]. PHAST software is designed and published by Det Norske Veritas (DNV) company and is a software for modeling the consequences of explosion, fire and release of toxic substances. Features of PHAST software

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Ability to predict accidents before occurrence, calculate the risk of industrial activities, calculate the amount of material discharged in case of leakage, determining the phase of toxic substances discharged in case of leakage, it is possible to study different scenarios and present the final results on the map. According to reviews on the validation of PHAST software in the article "Verification and validation of PHAST consequence models for accidental releases of toxic or flammable chemicals to the atmosphere" [4], The Unified Dispersion Model (UDM) numerical results are shown to be in identical agreement against an analytical solution for a 2D isothermal ground-level plume. The UDM has been validated against the set of three 2D wind-tunnel experiments of Mc-Quaid [14], and it was also validated against the HTAG wind tunnel experiments [15]. The UDM PHAST model assumes largescale 3D atmospheric dispersion, and therefore a modified version of the UDM was used to enable this numerical verification and validation for 2D dispersion or wind-tunnel conditions. Finally, the UDM model was verified against the HGSYSTEM model Heavy gas dispersion from area sources (HEGADAS). Behnoosh Iran Company has a long history in the Iranian food industry and like any other manufacturing industry, there is possibility of accidents such as tank explosions, fires and any emergencies.This factory is located at km 7 of Karaj special road with ageographical position of 51.24 Degree longitude, 35.71 Degrees latitude and 1249 meters above sea level and has an ethanol storage tank, a boiler and two pressure vessel of ammonia and carbon dioxide.

Methods

By means of preliminary hazard analysis method, the hazards related to the ethanol storage tank of Behnoush Iran Company were identified and their safety checklists were prepared in order to model the consequences by prioritizing more probable risks. Baziari and Giveh Chi [5] analysed the explosion, bursting of the pipeline and causing fires with PHAST software in oil facilities. Permissible exposure limit, high and low ignition limit and types of fire which are divided into four categories: Jet fire, Flash fire, pool fire and fire Ball [6]. In literature, numerous discharge models can be found key literature including description of discharge models and experimental data include Perry's handbook [7], the Design Institute for Emergency Relief Systems (DIERS) project manual [8],Center of Chemical Process Safety (CCPS) Quantitative Risk Assessment (QRA) guidelines [9], section 15.1-15.9 [10], Chapter 2 in the TNO Yellow Book [11]. According to the Chemical Data Sheet, the two consequences of ethanol are its toxicity and flammability risk [12], so it is necessary to study and analysis the scenarios related to both consequences. The various stages of this project are based on the flowchart shown in Figure (1):

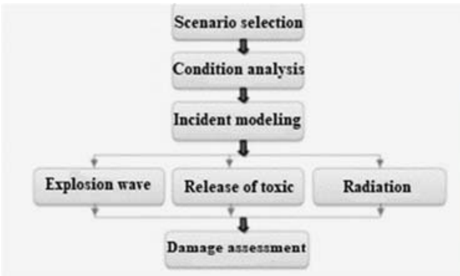


Figure 1. Process of doing the present study [13]

According to the method, the ethanol tank had a capacity of 30,000 Lit at atmospheric pressure and temperature of 4 degrees Celsius. Scenarios of 25 mm and 100 mm ethanol leakage were gradually selected from the tank connections Figure (2), leakage of 3 inches from the Short pipe connected to the tank, and complete rupture of the tank Figure (3), which is an instantaneous release, with the following details:

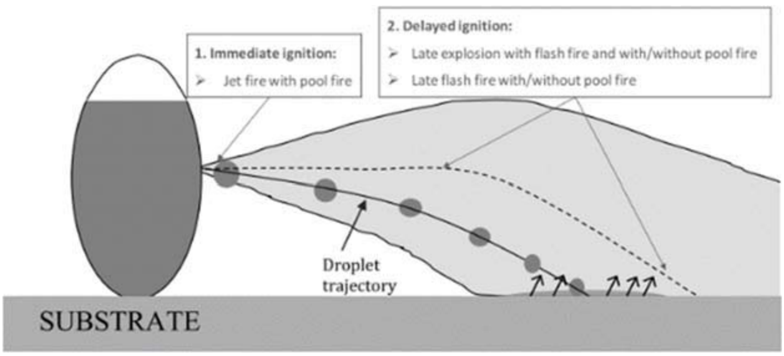


Figure 2. Continuous release of flammable material with rainout [4]

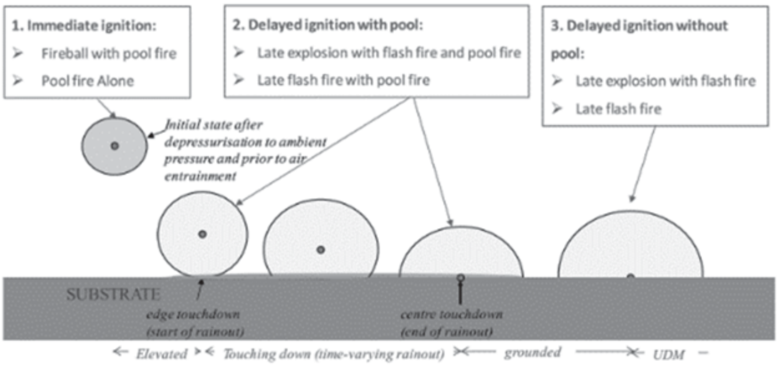


Figure 3. Instantaneous release of flammable material with rainout [4]

Leakage in summer with an average temperature of 36.17°C and atmospheric stability C during the day and an average temperature of 24.96 °C at night with stability D, relative humidity 21.46% and relative wind speed of 10.49 m/s (Table 1).

Table 1. Summer weather conditions of Tehran province during the 2019-2020

Wind speed	Relative humidity	Atmospheric stability	Temperature
10.49 m/s	21.46 %	C	Day Temperature 36.17˚C
		D	Night Temperature 24.96˚C

Leakage in winter with an average temperature of 11.6 °C during the day with atmospheric stability D and investigation of atmospheric stability F due to the possibility of pollution and average temperature of 3.3 °C at night with atmospheric stability D, relative humidity 39.3% and relative wind speed of 10.03 m/s (Table 2).

Table 2. Winter weather conditions of Tehran province during the 2019-2020

Wind speed	Relative humidity	Atmospheric stability	Temperature
10.03 m/s	39.3%	D & F	Day Temperature 11.6 ˚C
		D	Night Temperature 3.3 ˚C

Finally, we will have 20 scenarios, the most acute of which were selected with the help ofPHAST software.This model is entitled "Unified Dispersion Model" using experimental data obtained and modeling the release of materials lighter or heavier than air, modeling for continuous or sudden release, the ability to calculate the mixture of materials, calculations related to the release of materials in the liquid state, in Considering the impact of surface roughness and evaporation from the surface of liquid ponds is also included in this model.

Liquid discharge modelling: Figure (4)

The discharge for draining liquid from an orifice:

Eq. (1)

$$\dot{m}=A.C_D.\sqrt{2\rho \cdot g_C(P_2-P_1)}$$

The discharge of emptying a tank with a liquid column: **Eq. (2)**

$$\dot{m}=\rho.A.C_D.\sqrt{2\left(\frac{g_c P g}{\rho}\right)+g h_L}$$

$\dot{m}$: Output material flow rate (kg/s)

Pg: Relatively high pressure tank (pa)

A: The area of the split created (m^2)

ρ: Density (kg/m^3)

g: Gravitational acceleration (m/s^2)

g_c: Gravitational constant ($N.s^2/kg.m$)

h_L: The height of the liquid at the top of the gap created in the tank (m)

*C_D: The discharge coefficient is one for round and smooth slits. For short pipes connected to a tank, if the length to diameter ratio of the pipe is greater than 3, it can be considered equal to 0.18.

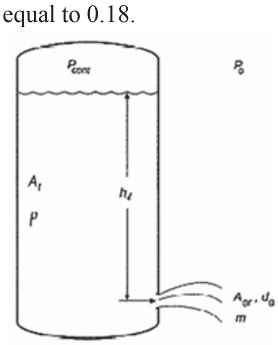


Figure 4. Symbolic form of draining liquid from a tank

Result and Discussion

If a pool of liquid forms around the release source, which gradually began to evaporate and the generated vapors encounter the source of the spark of interior, a pool fire occurs [16], which radiation is one of the consequences of this process hazard.

Radiation is a part of combustion energy that is transmitted as radiant energy (electromagnetic waves). Radiation is the most important physical factor that causes damage to humans and equipment in fire accidents. The effects of fire radiation are presented in (Table 3)[17].

Table 3. Effects of fire radiation

Consequences	Radiation (kW/m^2)Rate
Solarization	0.5
The pain threshold so that the person is able to escape.	4
Reaching this level of radiation causes severe damage to humans and causes death if the rescue team does not arrive.	20
More than this amount of radiation is enough to damage equipment, and if this level of radiation reaches humans, it will cause instant death.	37.5

Types of release:

Continues release

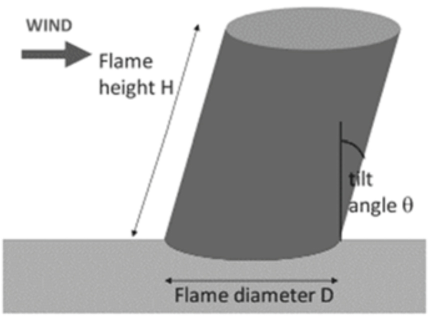
Leakage rates are almost constant over time, like being released from an orifice or from a safety valve

Instantaneous release

The material is suddenly discharged, like rapture a pressure vessel.

This section deals with the verification and validation of flammable effect models (fireballs, pool fires, jet fires and explosions, vapor cloud fires). The most-established empirical models are considered only[4]. Key literature including description of these models and experimental data include Chapters 5–6 of the TNO yellow book [11] and the Center of Chemical Process Safety (CCPS) guidelines [17].

Empirical models for these fires include empirical correlations describing the fire geometry (most commonly a sphere for a fireball, a tilted cylinder for pool fire, and a cone for the jet fire) and the surface emissive power (radiation per unit of area emitted from the fire surface area); see Fig (5).



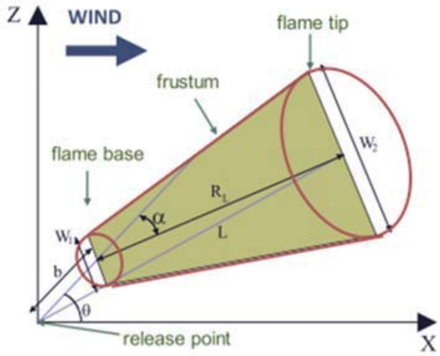


Figure 5. Geometry for pool fire (tilted cylinder) and jet fire (cone) [4]

The most acute scenarios are as follows:

- The first scenario of 100 mm diameter tank leak with a pond diameter of 37.6 m at the time of day and summer.
- The second scenario of 25 mm diameter tank leak with a pond diameter 13.4 m at the time of day and summer.
- The third scenario of leakage from a short pipe with 3 Inches diameter, pond diameter of 28.6 m and at the time of day and summer.
- Finally, The fourth scenario of catastrophic rupture with a pond diameter of 87.5 m at night and winter.

In the first and second scenarios (leakage of ethanol with a diameter of 100 mm and leakage from the Short pipe) due to the gradual nature of these processes and the accumulation of a pool of ethanol in the surrounding environment with the possibility of sparks, the risk of pool fire was considered. Therefore, the severity of damage in this scenario is very likely due to the presence of obstacles and other devices in the facilities of Behnoush Iran factory.

The amount of losses and complications caused by the release of chemicals depends on the concentration of the toxic substance and the time of contact with it. There are various criteria and parameters to evaluate the toxicity effects of chemicals. One of the criteria used in this regard is Emergency Response Plan Guideline (ERPG). The values listed in the guideline ERPG (1,2,3) have been compiled by the American Industrial Hygiene Association.

Table 4. Criteria for assessing the outcome of toxic effects in terms of ppm

Ethanol	ERPG1	ERPG2	ERPG3
	1800 ppm	3300 ppm	Not-Applicable

In this study, given that the presence of pool fire can cause radiation, the risk of injury to people and other equipment is very high. As shown in Figure (6), the blue curve radiates strongly from 4000 watts per square Meter (4 kW/m^2) to a distance of 77 Meters and into carbon dioxide tanks, boilers, ammonia Pressure vessel, production lines. Fridge unit and offices are damaged and affect people within a 77 Meter radius of the fire, but the pain threshold is such that the person is able to escape. The green curve radiates strongly from 12,500 watts per square Meter (12.5 kW/m^2) to a distance of 54.6 meters, further endangering the maintenance unit and causing serious damage to the carbon dioxide pressure vessel in the Maintenance unit, and imports ammonia Pressure vessel from rooftops and production lines. But the red curve of 37,500 watts per square meter (37.5 kW/m^2) was more dangerous, affecting a distance of 32.2 Meters and causing human death and the explosion of existing tanks, including boilers, carbon dioxide Tank and even ammonia Pressure vessel, and causes severe damage to the Maintenance unit's electrical system.

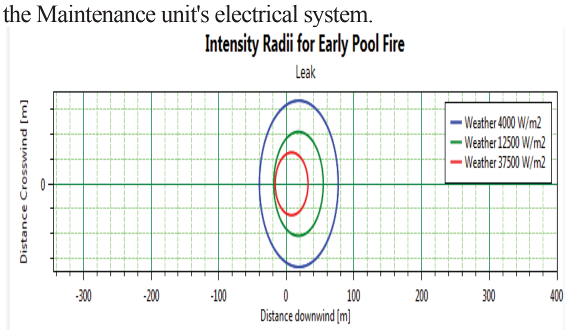


Figure 6. Radiation caused by ethanol leakage to a diameter of 100 mm from the tank and the formation of a pool fire without delay in summer

In all three cases, due to the very low proximity of the tank to other equipment in the Maintenance unit, there is a possibility of damage to the Maintenance unit and the people present in that area. Also, due to the distance of the tank from the highway, if this fire is combined with other accidents, the dangers of fire and explosion are also a threat to the highway Figures (7 and 8).

Figure 7. Aerial map of Behnoush Iran factory

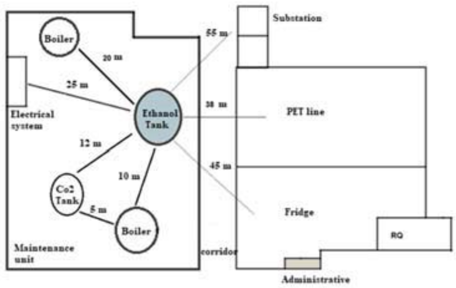


Figure 8. Schematic diagram of ethanol tank from other equipment

According to Figure (9), the release of ethanol is proportional to the time as the following chart, which the continuous blue line indicates the continuity of the release, and the associated pool fire and creases represent the average amount of ethanol release over that period.

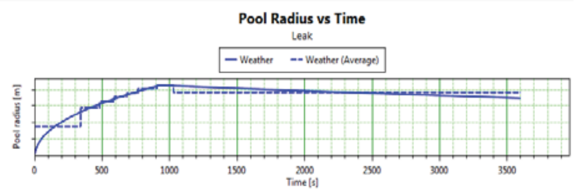


Figure 9. Ethanol leak with a diameter of 100 mm from the tank and the creation of a pool fire appropriate to the time in summer

In the report Sheet, as shown in Figure (10), you will see the result of the leak:

Late Pool Fire Results

Distance downwind to defined radiation levels

The reported radiations are defined in the parameters

Path	Scenario	Weather	Pool diameter [m]	Distance downwind to intensity level 1 (4000 W/m2) [m]	Distance downwind to intensity level 2 (12500 W/m2) [m]	Distance downwind to intensity level 3 (37500 W/m2) [m]
PhastConsequence\Study \Atmospheric storage tank	Leak	Weather	86.1648	118.59	85.8295	48.3385

Figure 10. Result of Repot Sheet Pool Fire Ethanol leak with a diameter of 100 mm from the tank continued to leak

In ethanol leakage with a diameter of 25 mm from the tank, we will first have a cloud whose diffusion is determined from the Figure (11) in weather conditions and can be seen from the side view. According to the concentration of the released cloud, the distance in front of it can be found.

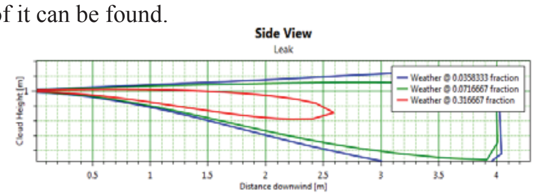


Figure 11. Leakage with a diameter of 25 mm from the ethanol tank from the side view

According to Figure (12) and Report Sheet Figure (13 and 14) Leakage of pool fire due to leakage with a diameter of 25 mm from the ethanol tank in the first moments after leakage in two intensities of radiation (4 kW/m^2) and (12.5 kW/m^2) enters the equipment in the intensity of radiation (4 kW/m^2) blue curve. The resulting pool fire radiation will advance up to 25.65 Meters and in the radiation intensity of (12.5 kW/m^2) green curve. The resulting pool fire radiation will advance up to 19.59 Meters.

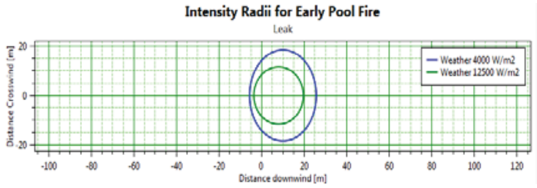


Figure 12. Pool fire radiation at the initial moment of leakage to a diameter of 25 mm from the ethanol tank at the initial moment

Early Pool Fire Results
Distance downwind to defined radiation levels
The reported radiations are defined in the parameters

Path	Scenario	Weather	Pool diameter [m]	Distance downwind to intensity level 1 (4000 W/m2) [m]	Distance downwind to intensity level 2 (12500 W/m2) [m]	Distance downwind to intensity level 3 (37500 W/m2) [m]
PhastConsequence\Study \Atmospheric storage tank	Leak	Weather	13.4856	25.6573	19.5994	n/a

Figure 13. Result of Repot Sheet Pool Fire Ethanol leak with a diameter of 25 mm from at the initial moment of leakage

Late Pool Fire Results
Distance downwind to defined radiation levels
The reported radiations are defined in the parameters

Path	Scenario	Weather	Pool diameter [m]	Distance downwind to intensity level 1 (4000 W/m2) [m]	Distance downwind to intensity level 2 (12500 W/m2) [m]	Distance downwind to intensity level 3 (37500 W/m2) [m]
PhastConsequence\Study \Atmospheric storage tank	Leak	Weather	43.4272	65.7141	48.0931	26.7867

Figure 14. Result of Repot Sheet Pool Fire Ethanol leak with a diameter of 25 mm from the tank continued to leak

In case of leakage with a diameter of 25 mm and late pool fire, if proper emergency prevention is not taken, the resulting pool fire will progress and its radiation will be in three intensities: (4 kW/m^2) blue curve, (12.5 kW/m^2) green curve and (37.5 kW/m^2) red curve. which will move at distances of 65.71 Meters, 48.09 Meters and 26.78 Meters, respectively at Figure (15).

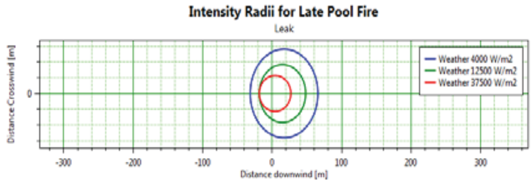


Figure 15. Pool fire radiation from a leak with a diameter of 25 mm from the ethanol tank

The radiation from the pool fire connected to the tank is as follows as shown in Figure (16) and Report Sheet Figure (17), the blue curve strongly radiates from 4000 watts per square meter (4 kW/m^2) to a distance of 60 Meters and extends to production lines, Fridge unit, substations, tanks in Maintenance unit and the power system of the Maintenance unit is damaged but its severity is low.

The green curve radiates strongly from 12,500 watts per square meter (12.5 kW/m^2) to a distance of 42.6 Meters, damaging Maintenance unit and production lines and endangering people within a radius of 43 Meters from thefire source, but the limit The pain threshold is such that the person is able to escape; But the red curve of intense radiation of 37,500 watts per square Meter (37.5 kW/m^2) has advanced to a distance of 23.1 Meters, so that there is a possibility of explosion of tanks in the facility and by nature other accidents and death of employees.

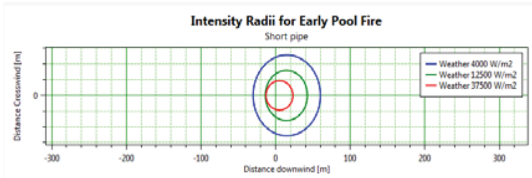


Fig. 16. Radiation from a 3-inch-diameter ethanol leak from a Short pipe tank and the creation of a pool fire in summer

Late Pool Fire Results
Distance downwind to defined radiation levels
The reported radiations are defined in the parameters

Path	Scenario	Weather	Pool diameter [m]	Distance downwind to intensity level 1 (4000 W/m2) [m]	Distance downwind to intensity level 2 (12500 W/m2) [m]	Distance downwind to intensity level 3 (37500 W/m2) [m]
PhastConsequence\Study \Atmospheric storage tank	Short pipe	Weather	84.1751	87.1606	66.2355	n/a

Figure 17. Result of Repot Sheet Pool Fire Ethanol leak with a diameter of 3-inch from the tank continued to leak

Figure (18), as in the previous example, shows the release of ethanol over time, with a continuous blue curve indicating the continuity of release and associated pool fire, and dashed lines showing the average amount of ethanol release over that time period.

In the catastrophic rupture scenario of the tank, due to the instantaneous occurrence of this event, the presence of a spark agent and according to the chemical data sheet of the material in which the flammability of ethanol is mentioned at 11 °C, the possibility of a Vapour Cloud Explosion (due to The tank in the Maintenance unit and the environment is closed) and then we will have a Flash fire.

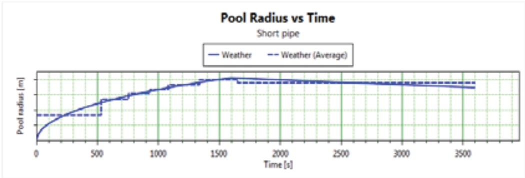


Figure 18. Ethanol leakage 3-inch-diameter from the Short pipe tank and create a pool fire appropriate to the time in summer

In the rupture scenario, all available ethanol reservoirs are released into the environment, which is clearly visible from the top view in the figure below Figure (19). Due to its release, a cloud of gas is formed, which due to the closed space of the Maintenance unit can condense and ignite with a spark, which explodes due to rapid ignition, by continuing this process, we will have a Flash Fire Figure (20).

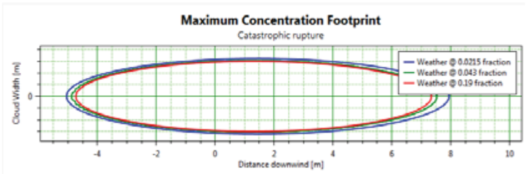


Figure 19. Ethanol Tank catastrophic rupture and release clouds from above view in winter

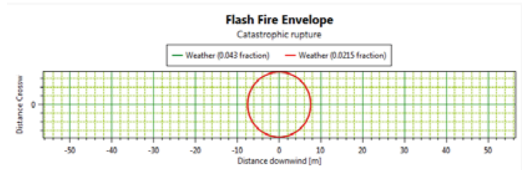


Figure 20. Rupture of ethanol tank and cause Flash fire in winter

*It should be noted that these events in winter can be doubled due to a barrier such as air pollution. As can be seen in Figure (21) and Report Sheet Figure (22) pollution has increased the risk of cloud caused by pool fire proportional to time.

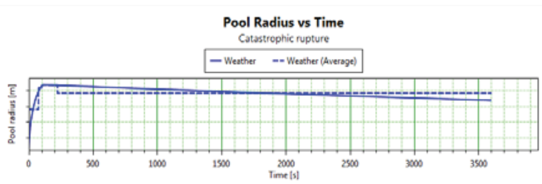
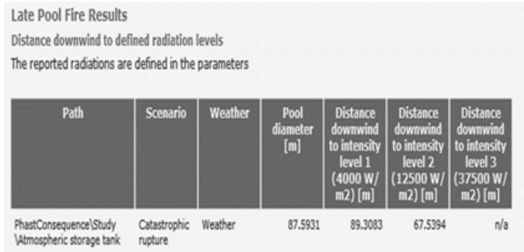


Figure 21. Rupture of ethanol tank and create pool fire in terms of time in winter


Late Pool Fire Results
Distance downwind to defined radiation levels
The reported radiations are defined in the parameters

Path	Scenario	Weather	Pool diameter [m]	Distance downwind to intensity level 1 (4000 W/m2) [m]	Distance downwind to intensity level 2 (12500 W/m2) [m]	Distance downwind to intensity level 3 (37500 W/m2) [m]
PhastConsequence\Study \Atmospheric storage tank	Catastrophic rupture	Weather	87.5931	89.3083	67.5394	n/a

Figure 22. Result of Report Sheet pool fire due to catastrophic rupture of ethanol tank

Conclusion

In order to further investigation, the results of other researches is also compared with the results of the current study, and is presented in table (5).

Table 5. Comparison of the results of the present study with the results of other researches

reference	**consequence**	**Scenarios**	**liquid**	**Type of equipment**	**Row**
Current Study	Pool Fire Flash Fire	Leakage Short pipe Leakage Catastrophic Rupture	Ethanol	Storage Tank	1
[18]	Toxicity	Leakage with a diameter of 30 cm	Styrol	Carrier containers	2
[19]	Toxicity	Catastrophic rupture	Chlorine Gas	Storage tank	3
[20]	Explosion up to a radius of 773 meters and pool fire	Catastrophic rupture	Ethylene oxide	Storage tank	4
[21]	Toxicity up to distance 2674	Catastrophic rupture	Ammonia	Carrier Tank	5
[22]	Flash fire Jet fire	Small Leakage 50 mm Leakage from 100 and 250 mm	methane	Tank V-100	6
[23]	Flash fire Jet fire and Explosion	Leakage from 2mm diameter	methane	compressor	7
[24]	Jet Fire Flash Fire Pool Fire	Catastrophic Rupture	Petrol	Pipe line	8

Based on the modelling performed for different states of each scenario, the larger the leakage diameter from the tank, resulted in the higher the volume of the abandoned liquid pond and the radiation caused by the fire. It increases due to parameters such as wind speed, barley stability class and obstacles such as air pollution, Fire-induced radiation due to the intensity and distance of progress can have very devastating effects, as it was investigated, leakage with a diameter of 100 mm with radiation of 37.5 kW/m^2 is very dangerous and has the ability to damage the carbon dioxide pressure vessel and boilers. The consequence of which can be noted the explosion of both reservoirs, the catastrophic rupture of the reservoir due to the sudden accident and the creation of a cloud of matter in the presence of sparks caused a Flash fire which caused accidents such as damage to the maintenance unit and adjacent units.

Therefore, considering all the scenarios reviewed, some suggestions for reduce hazards were made considering the fire alarm system (Detector) and fire extinguisher (more advanced Fire Sprinklers) for cooling equipment during fire are highly recommended. Depending on the type of fire (Pool fire and Flash fire) and flammable material (that is considered ethanol in this study) using appropriate foam and extinguishers, fireproof structures, use of fire retardant equipment, as well as training people working in the maintenance unit and adjacent units and establishing the fire team, can significantly help to manage these risks and prevent their subsequent accidents.

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