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A Study on Improvement Measures to Prevent Explosion Accidents Caused by Leakage of Oil Storage Tanks

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Abstract

Purpose: This study aims to investigate the causes of fire and explosion accidents in oil storage tanks and to propose preventive improvement measures using the PHAST (Process Hazard Analysis Software Tool) simulation method. By analyzing representative domestic cases—namely the 2018 Goyang oil depot fire, the 2021 Yeosu chemical plant explosion, and the 2025 Ulsan Onsan oil tank explosion—this research identifies common technical and managerial shortcomings, such as vapor leakage, vent system defects, and poor maintenance of flame arresters. **Research design, data and methodology:** The study applied PHAST simulations to evaluate accident scenarios under varying environmental and operational conditions, including gasoline release volume, atmospheric pressure, and wind speed. The simulation revealed that thermal radiation from a pool fire could reach up to 95 meters with a peak intensity of 20 kW/m^2, while a BLEVE could result in wide-area damage due to fireballs and overpressure effects. Based on these findings, the study proposes enhancements to monitoring systems, systematic inspection protocols, and on-site emergency response training. **Conclusions:** These integrated safety measures are expected to minimize damage and prevent recurrence. Future research should focus on incorporating emerging technologies and big data analytics to establish a more predictive and proactive risk management framework for hazardous material storage.

Keywords : Oil Storage Tank, Fire and Explosion, PHAST Simulation, Safety Management, Risk Assessment

JEL Classification Code : E44, F31, F37,

1. Introduction

Background and Necessity of the Study

Oil storage tanks are major industrial facilities used to store large quantities of hazardous materials such as crude oil, petroleum products, and chemical solvents. Leakage accidents from these storage tanks can lead to fires and explosions, causing significant environmental pollution and human casualties. Particularly, poor maintenance, design flaws, and external impacts can result in severe fire and explosion incidents.

Representative cases include the 2018 Goyang oil depot fire, the 2021 Yeosu national industrial complex chemical plant explosion, and the 2025 Ulsan Onsan industrial complex oil tank explosion. These consecutive accidents

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have revealed critical problems in the safety management of oil storage tanks. The main causes identified include vapor leakage, poor maintenance of flame arresters, and design defects in venting systems.

Such issues are not merely due to management negligence but are often the result of design-stage errors and insufficient maintenance of aging equipment. Therefore, technical improvements and reinforcement of the safety management system are essential to prevent accidents involving oil storage tanks. In addition, policy-level improvements based on international cases are needed, along with the development of prevention measures suited to domestic conditions.

This study aims to analyze the potential damage range using PHAST and to propose technical and safety management improvements for accident prevention. By analyzing domestic case studies, the study seeks to develop effective prevention measures and reduce the recurrence of similar accidents.

2. Theoretical Background

2.1. Types and Shapes of Storage Tanks

Flammable liquid storage tanks can be classified based on their shape, capacity, and the type of roof structure. The selection of a storage tank depends on the spatial characteristics of the installation site and the physical properties of the liquid to be stored (Choi, 2019).

Outdoor storage tanks are categorized into various types depending on their shape and structural features (see Figure 1).

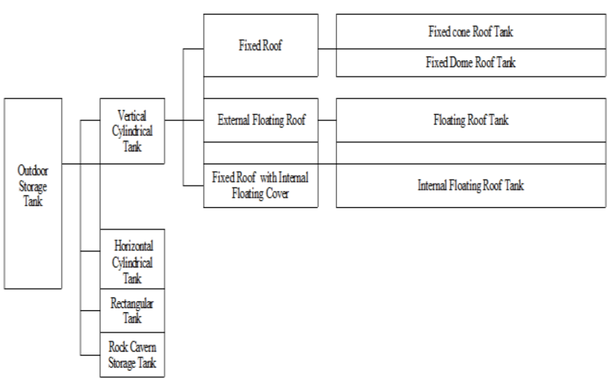
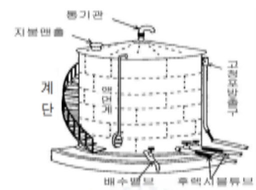
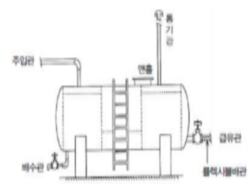
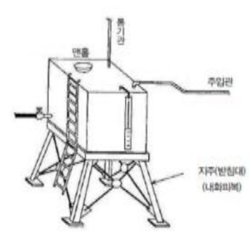
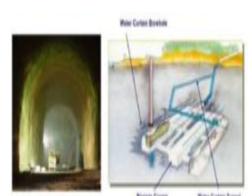


Figure 1: Classification of Storage Tanks by Shape and Roof Type

The classification based on the shape of the tanks is shown in Table 1.

Table 1: Classification of Tank Shapes (Lee, 2020)

Shape of the Tank	Classification	Details
	Vertical Cylindrical Tank	The most common form, it is mainly used for the large-scale storage of volatile hazardous materials
	Horizontal Cylindrical Tank	The structure has rounded sides and a bottom, demonstrating excellent pressure resistance and is used as a pressure tank
	Rectangular Tank	It is mainly installed in high locations, and large capacity tanks are not commonly used due to their weak structural strength
	Rock Cavern Storage Tank	A space for storing hazardous materials below the groundwater level by excavating natural rock formations. It is located underground, which reduces the risk of fire and explosion, and allows for large-volume storage

2.2. Classification by Roof Type

Cylindrical outdoor storage tanks can be classified into cone roof, dome roof, floating roof, and fixed roof with internal floating cover types. The cone roof typeis the most common, typically supported by multiple columns, although self-supporting designs also exist (Lee, 2020). The dome roof typeis structurally stronger against internal pressure and is used in cases where pressure resistance is required or where support columns cannot be installed.

The floating roof typeminimizes the space between the roof and the liquid surface, making it suitable for storing large volumes of highly volatile petroleum products (Choi, 2019). The fixed roof with internal floating cover typeis a design that combines a fixed roof with an internal floating cover, providing protection against the intrusion of rainwater and other contaminants in practical use (Lee, 2020).

2.3. Components of Storage Tank Facilities

A storage tank is not a simple vessel, but a complex facility composed of various safety devices and systems. The main components are as follows:

Tank Body: The primary structure used for storing crude oil, petroleum products, and chemical solvents.
Piping System: Responsible for the loading and unloading of oil; it is one of the most critical areas affected during leakage incidents.
Vent System: Regulates internal pressure and releases vapor, thereby preventing explosion risks.
Firefighting Equipment: A protective system designed for immediate suppression in the event of a fire.
Flame Arrester and Vent Pipe: Essential safety devices that prevent vapor explosions.
These components must function in a coordinated and integrated manner to ensure the safe storage of oil. However, when maintenance is neglected or facilities become outdated, imbalances between components can arise, significantly increasing the risk of fire and explosion.

2.4. Status and Analysis of Fire and Explosion Accidents in Korea

According to a study by KOSHA (2018), among the 329 cases of fire, explosion, and chemical leakage/contact accidents in the manufacturing industry between 2008 and 2017, 166 fatalities (50.5%) occurred during routine operations, while 117 fatalities (35.6%) occurred during non-routine operations, showing a 6:4 ratio favoring routine tasks.
Non-routine operationsinclude maintenance work, post-production inspections, abnormal condition responses, replacement and transition tasks, sample collection, trial runs, and other irregular tasks not performed on a regular basis or not included in standardized procedures. Despite their shorter duration, non-routine tasks tend to result in a high number of accidents.
Fire and explosion accidents occurred in 141 cases (52.4%) during routine operations and 94 cases (34.9%) during non-routine operations, showing a similar trend to the overall proportion of chemical accidents. In contrast, chemical leakage/contact accidents occurred in 25 cases (41.7%) during routine tasks and 23 cases (38.3%) during non-routine tasks, indicating a relatively higher fatality rate during non-routine operations compared to fire/explosion accidents.

According to the Ministry of Employment and Labor (MOEL, 2020–2024), the number of deaths caused by fire, explosion, and rupture accidents was 72 in 2020, 44 in 2021, 45 in 2022, 29 in 2023, and 55 in 2024. Over the past five years, the annual average number of fatalities from such incidents has been 49.

3. Fire Damage Analysis through Fire and Explosion Simulation

3.1. Theoretical Mechanism of Fire and Explosion

3.1.1. Small-Scale Leakage

When a small amount of oil leaks from a storage tank, the liquid begins to vaporize in the atmosphere. During this process, volatile substances mix with air to form a flammable mixture.

Vaporization Mechanism: Due to the high volatility of the leaked oil, it rapidly evaporates into the atmosphere. The resulting vapor mixes with ambient air, and if the concentration reaches or exceeds the Lower Explosive Limit (LEL), the risk of explosion increases.

Explosion Conditions: If an ignition source is present while the flammable mixture exists, an explosion may occur. Ignition sources may include electric sparks, static electricity, or welding flames.

3.1.2. Large-Scale Leakage

When a large volume of oil leaks from a storage tank, it can spread rapidly across a wide area and cause pool firesor BLEVEincidents.

Pool Fire: A large volume of oil spreads on the ground, forming a thin liquid layer. If ignited, this results in a pool fire accompanied by large flames. Key characteristics include: High temperatures, Wide flame spread, Rapid propagation

Risk of secondary explosions due to flame extension to nearby tanks or equipment

BLEVE (Boiling Liquid Expanding Vapor Explosion): When a large leak causes internal tank pressure to rise, the heated liquid may boil, and the expanding vapor can lead to an explosive rupture. Key characteristics of BLEVE include: Instantaneous and intense explosion

Projection of metal fragments and flames over a wide area

Formation of a fireball, causing severe damage to surrounding facilities

4. Explosion Range Simulation Using the PHAST Program

The PHAST (Process Hazard Analysis Software Tool)program was utilized to simulate the potential explosion range resulting from oil storage tank leaks. PHAST is a widely used quantitative risk assessment tool developed by DNV that enables the modeling of various accident scenarios such as toxic releases, fireballs, jet fires, and vapor cloud explosions (VCE).

In this study, simulation scenarios were configured based on factors such as:

- Type and volume of the leaked substance
- Weather conditions (temperature, wind speed, atmospheric stability)
- Tank size and pressure
- Presence of ignition sources

The simulation results include:

Thermal radiation radius: The distance at which heat from a fire can cause burns or ignite other materials

Overpressure zones: Areas affected by pressure shockwaves from an explosion

Fireball diameter and durationin the event of a BLEVE (Boiling Liquid Expanding Vapor Explosion)

Vapor dispersion patterns, which help determine the risk of flammable vapor accumulation

Through the PHAST-based analysis, this study aims to identify realistic hazard zones, suggest safe separation distances, and provide a basis for developing emergency response plansand design improvementsfor oil storage facilities.

Basis for Fire/Explosion and Spread Impact

According to the criteria for fire, explosion, and spread impact, all measured positions are based on ground level(See Table 2).

Table 2: PHAST program input values are as follows:

Item	Input Value	Calculation Basis
Material	Gasoline	Flammable liquid storage tank
Detecting System Grade	B	[Ref. 6] P-107-2025 Guideline for Selecting Worst-Case Leak Scenario
Blocking System Grade	B	
Release Duration (s)	1,200	
Mass Flow Rate (kg/s)	100	Gasoline tank outlet flow rate
Mass Inventory (kg)	120,000	100 kg/s × 1,200 s
Operating Temperature (°C)	25	Process Data
Operating Pressure (barg)	Atmospheric	
Phase	Liquid	
Hole Diameter (mm)	Floating roof seal side	[Ref. 6] P-107-2025 Guideline for Selecting Worst-Case Leak Scenario
Elevation (m)	15	Technical estimation guideline
Bund Area (m²)	7,100	Process Data
Bund Height (m)	1.6	

Damage Prediction Summary (Spread)

KOSHA Guide P-102-2021

Guidelines for Accident Damage Prediction Technology(See Table 3).

Table 3: Target Workplace & Facility

Category	Details
Site Name	OO Tank Terminal
Address	Wongung-myeon, Iksan-si, Jeollabuk-do
Target Facility	Gasoline Storage Tank (D-205B)

The simulation was conducted under the following environmental and meteorological conditions:

The wind speedwas 3 meters per second, blowing from the north-west direction. The ambient temperaturewas measured at 13.3°C, with a relative humidityof 69.4%. The release was assumed to occur during the daytime.

The surrounding topographywas characterized by a surface roughness length of 1 meter, representing areas with regular large obstaclessuch as suburban environments or forests, as defined in PHAST(See Table 4).

Table 4: Weather Data and Site Conditions

Parameter	Value
Wind Speed	3 m/sec
Wind Direction	North-west wind
Temperature	13.3 °C
Relative Humidity	69.4%
Release Time	▪ Day □ Night
Surrounding Topography	1m surface roughness length (Regular large obstacle coverage such as suburb, forest) in PHAST

The substance involved in the simulation was gasoline, classified as a liquid. It posed a flammability and inhalation risk, rather than toxicity. The release densitywas 740 kg/m³, and the total release amountwas estimated at 120,000 kilograms.
The gasoline was released from the floating roof seal sideof the D-205B gasoline storage tank. The release occurred at a temperature of 25°Cunder atmospheric pressureconditions.
This event was modeled as a continuous releasewith a total duration of 1,200 seconds(See Table 4).

Table 5: Hypothetical Scenario

Parameter	Value
Substance Name	Gasoline
Physical Classification	Liquid
Toxicity/Flammability	□ Toxic ▪ Flammable/Inhalation Risk
Release Density	740 kg/m³
Total Release Amount	120,000 kg
Release Source	Gasoline Tank (D-205B)
Release Location	Floating roof seal side
Release Temperature	25 °C
Release Pressure	Atmospheric (kgf/cm²)
Release Type	▪ Continuous □ Instantaneous
Release Duration	1,200 sec

The ERPG-2 concentrationwas not applicable (NA) in this scenario, and the Explosive Lower Limit (LEL)concentration was set at 1.2%. The distances for ERPG-1, ERPG-2, and ERPG-3were not available, and the explosion lower limit distancewas also not determined. The simulation was conducted using the Unified Dispersion Model (UDM), classified as "Other" in the PHAST modeling options.

Table 6: Damage Assessment Results

Parameter	Value
ERPG-2 Concentration	NA
Explosive Lower Limit Concentration	1.2%
ERPG-1 Distance	NA
Explosion Lower Limit Distance	-
ERPG-2 Distance	NA
ERPG-3 Distance	NA
Model Used	Other (Unified Dispersion Model, UDM in PHAST)

5. The Results of a Study

After the release, a pool formed that covered the entire bund area at approximately 266 seconds.
Below is the pool radius as a function of time (see Figure 2).

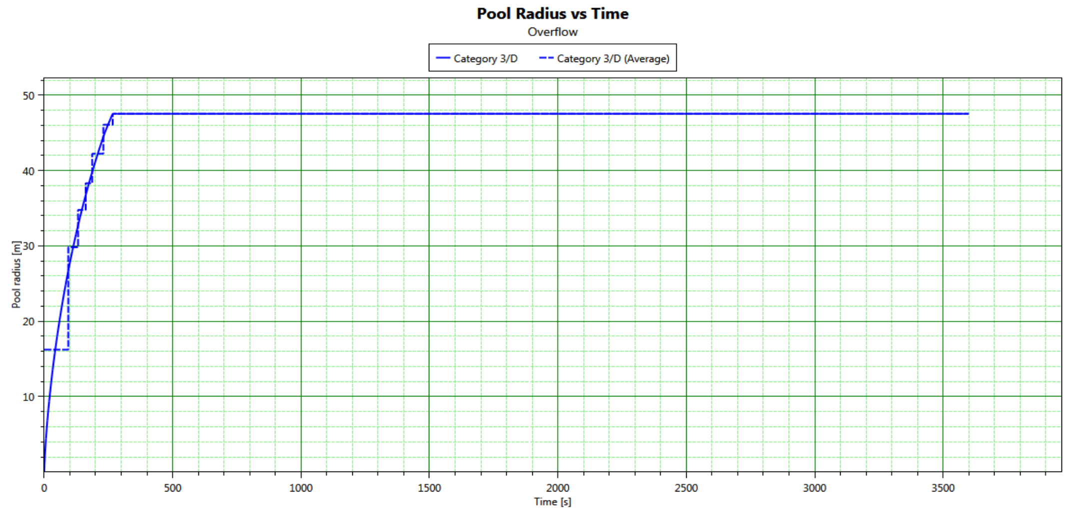


Figure 2: **Pool Radius vs Time**

During the pool fire scenario, the thermal radiationextended up to a distance of 95 meters, with a peak radiation intensityreaching 20 kW/m², as illustrated in the graph below(see Figure 3).

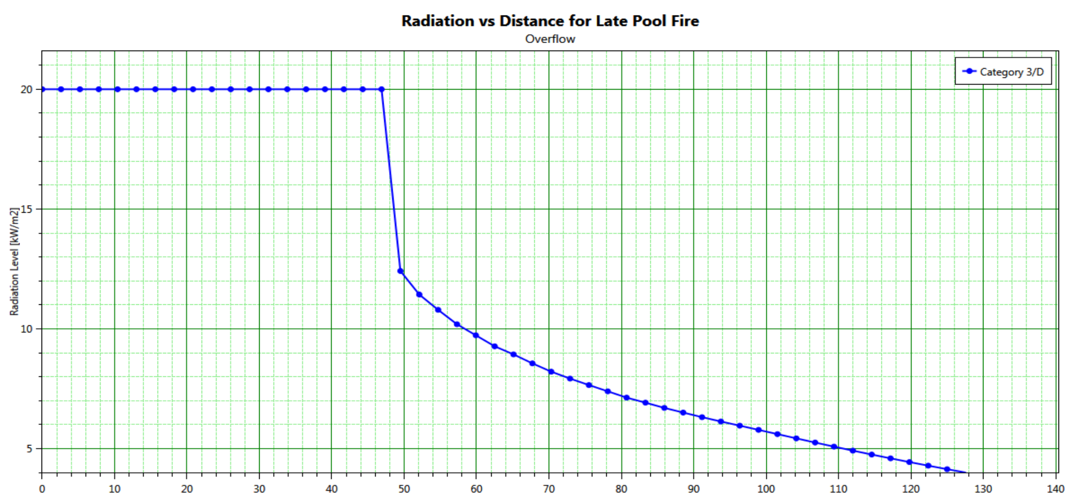


Figure 3: **Radiation vs Distance for Late pool fire**

During a pool fire, the range of radiation intensity reaching 5 kW/m² extends up to 110 meters.
For radiation capable of causing secondary accidents (12.5 kW/m²), the range extends up to 49 meters.

Refer to the intensity radius graph below for detailed visualization(see Figure 4).

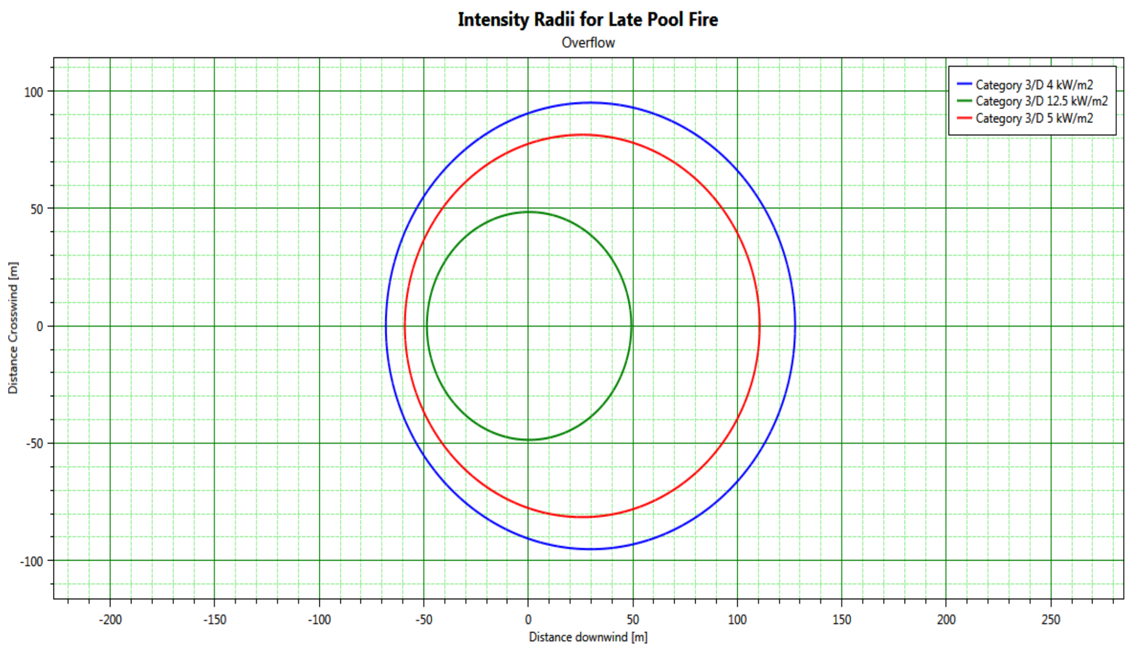


Figure 4: **Radiation Threshold Range for Pool Fire**

6. Conclusions

This study aimed to analyze the causes of fire and explosion accidents in oil storage tanks using the PHAST technique and to propose improvement measures for their prevention. Through an analysis of major domestic cases, it was found that such accidents often result from equipment defects, poor management practices, and legal or institutional shortcomings.

Common issues identified in the 2018 Goyang oil depot fire, the 2021 Yeosu industrial complex chemical plant explosion, and the 2025 Ulsan Onsan oil tank explosion included failures in vapor control, defects in vent pipes, and inadequate maintenance of flame arresters. These incidents suggest that the root causes are not limited to simple managerial negligence but are closely related to design-stage errors and insufficient maintenance of aging facilities.

To address these issues, the following improvement measures were proposed:

Strengthening of Equipment Monitoring Systems:
By actively utilizing monitoring systems such as automatic level gauges and oil level alarms installed inside tanks, it is possible to detect and block leakage sources at an early stage.

Enhancement of Management Systems:
Establishing systematic regular inspection processes and emergency response manuals can help ensure rapid responses to vapor leakage and fire incidents.

Regular Emergency Response Training:
Periodic emergency drills conducted by on-site self-firefighting teams and the use of simulation-based training can improve practical response capabilities in the event of an accident.

Through these improvements, it is expected that large-scale fires and explosions in oil storage tanks can be effectively prevented and potential damage minimized.

Future research should focus on building a proactive risk management system through the adoption of new technologies and the development of big data-based predictive risk models. These efforts will contribute to the continuous improvement of oil tank safety and the fundamental prevention of accident recurrence.

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