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A Study on Risk Assessment of Leakage Fire in Oil Storage Tanks and Improvement of Safety Management

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Abstract

Purpose: This study aims to quantitatively evaluate the fire hazards associated with gasoline storage tank leakage and to propose safety management improvement strategies using the PHAST process hazard analysis tool and the eCA accident consequence analysis program. Overflow accident scenarios at two logistics centers were analyzed to identify key factors influencing thermal radiation impact distances and to develop evidence-based safety countermeasures. **Methods:** A parameter analysis was conducted using PHAST 7.21 and eCA simulation programs to evaluate seven operational and environmental variables: liquid level, operating pressure, relative humidity, leak orifice diameter, ambient temperature, dike area, and ground surface characteristics. Two facilities of Company G—the C Logistics Center (250,000 BBL capacity) and the M Logistics Center (100,000 BBL capacity)—were analyzed under identical overflow scenario conditions. **Results**: The analysis confirmed that liquid level, leak orifice diameter, and operating pressure are high-impact variables that significantly influence thermal radiation distance. The eCA simulation produced consistently wider hazard impact distances—approximately 40–60% greater—than those calculated by PHAST. Additionally, winter low-temperature conditions increased impact distances by up to 50% compared to summer conditions. **Conclusion:** Based on the findings, safety management should shift from relying solely on fixed separation distances to adopting an integrated risk management system that incorporates real-time monitoring of critical parameters. This approach enhances the ability to prevent, detect, and mitigate overflow-related fire hazards in gasoline storage facilities.

Keywords : Gasoline Storage Tank, Pool Fire, PHAST Simulation, eCA Simulation, Quantitative Risk Assessment(QRA), Thermal Radiation, Safety Management

JEL Classification Code : L69, N70, Z19

1. Introduction[1]

1.1 Background and Necessity of the Study

Petroleum storage tanks are major industrial facilities that store large quantities of hazardous materials such as crude oil, petroleum products, and chemical solvents. Leakage accidents occurring in these tanks can lead to fires and explosions, causing significant environmental contamination and severe human casualties. In particular, inadequate management, design flaws, and external impacts can trigger serious fire and explosion events.

Representative cases in Korea include the 2018 Goyang oil storage tank fire, the 2021 explosion at a chemical plant in the Yeosu National Industrial Complex, and the 2025 oil tank explosion in the Onsan Industrial Complex. These successive incidents revealed critical deficiencies in the safety management of petroleum storage facilities. Key causes identified include vapor leakage, poor maintenance of flame arresters, and design defects in venting systems.

Such issues arise not only from simple operational negligence but also from errors in the design stage and insufficient maintenance of aging equipment, leading to repeated accidents. Therefore, technical improvements and reinforcement of safety management systems are essential to prevent accidents involving petroleum storage tanks. This study aims to analyze hazard impact distances using PHAST and eCA simulations and to propose safety management enhancement measures based on the quantitative risk assessment (QRA) methodology.

1.2. Purpose and Scope of the Study

The purpose of this study is to conduct a quantitative risk assessment of overflow accident scenarios involvi ng gasoline storage tanks and to identify the key facto rs influencing thermal radiation impact distances, there by proposing practical and effective improvements to s afety management practices. The scope of the study fo cuses on the gasoline storage tanks located at Compan y D's C Logistics Center in Changwon, Gyeongnam, a nd M Logistics Center in Mokpo, Jeonnam. A compar ative analysis is performed using the PHAST 7.21 and eCA simulation programs.

2. Theoretical Background

2.1. Classification and Structure of Storage Tanks

Flammable liquid storage tanks can be classified according to their shape, capacity, and roof type, and are selected based on spatial characteristics of the installation site and the physical properties of the stored liquid. Cylindrical outdoor storage tanks are generally categorized into cone-roof tanks, dome-roof tanks, floating-roof tanks, and fixed-roof tanks with internal floating covers. Floating-roof tanks are commonly used for large-capacity storage of highly volatile petroleum products because the minimal vapor space between the roof and the liquid surface reduces vapor accumulation.

2.2. Fire and Explosion Mechanisms

When a large quantity of petroleum is released from a storage tank, it can rapidly spread over a wide surface area, leading to either a pool fire or a BLEVE. A pool fire occurs when spilled liquid forms a thin layer over the ground surface and ignites, producing extensive flames. Its key characteristics include high temperatures, wide flame envelopes, and rapid lateral spread, which may ignite adjacent tanks or equipment and trigger secondary explosions.

A BLEVE (Boiling Liquid Expanding Vapor Explosion) occurs when internal pressure rises following a major release, causing the heated liquid to boil violently and the vapor to expand explosively. This results in an instantaneous and powerful blast accompanied by metal fragments and flame projection across a wide area, often forming a fireball that can inflict severe damage on nearby facilities.

2.3. Thermal Radiation Criteria

The thermal radiation thresholds applied in this study are based on KOSHA Guide P-102-2021. A radiation level of **4 kW/m²** corresponds to the threshold at which first-degree burns may occur after 20 seconds of exposure and thus represents the minimum evacuation distance. A level of **12.5 kW/m²** indicates the intensity at which materials such as wood or plastic may ignite after prolonged exposure, serving as the equipment protection distance to prevent secondary accidents. A level of 37.5 kW/m² is associated with immediate burn injury and equipment damage, and is used as a basis for establishing required separation distances between tanks.

3. Research Methods

3.1. Target Facilities

The facilities analyzed in this study are two petroleum logistics centers operated by Company G. The **C Logistics Center** (Changwon, Gyeongnam) consists of 12 tanks with a total storage capacity of **250,000 BBL**. The gasoline storage tank selected for analysis, **Tank D-210**, has a capacity of **30,000 BBL**, a height of **14.6 m**, and a dike area of **8,815 m²**.

The **M Logistics Center** (Mokpo, Jeonnam) consists of six tanks with a total storage capacity of **100,000 BBL**. The gasoline storage tank selected for the study, **Tank D-305**, has a capacity of **15,000 BBL**, a height of **15 m**, and a dike area of **5,972 m²**.

Table 1: Overview of the Study Facilities

Category	Item	C Logistics Center	M Logistics Center
Facility Overview	Location	Changwon, Gyeongnam	Mokpo, Jeonnam
	Number of Tanks	12 units	6 units
	Total Capacity	250,000 BBL	100,000 BBL
Target Tank	Tank Name	D-210	D-305
	Capacity	30,000 BBL	15,000 BBL
	Height	14.6 m	15 m
	Dike Area	8,815 m²	5,972 m²

3.2. Simulation Programs

PHAST (Process Hazard Analysis Software Tool) is a commercial software package developed by DNV GL, and Version 7.21 (2016) was used in this study. PHAST analyzes pool fire scenarios using the Unified Dispersion Model and the Cone Model. eCA (effective Consequence Analysis) is a free software developed by the Korea Occupational Safety and Health Agency (KOSHA), optimized for domestic regulations and integrated with the e-PSM system. A comparative analysis of the two programs was conducted to identify differences in applicability within the Korean industrial context.

3.3. Scenario Definition

This study analyzed an overflow scenario as the basis for simulation. An overflow accident occurs when the tank liquid level is not properly monitored during filling operations, resulting in a large amount of gasoline leaking into the bund area and forming a pool fire. According to KOSHA Guide P-107-2020, the detection and isolation systems were set to Grade B, and the release duration was assumed to be 1,200 seconds (20 minutes).

Table 2: PHAST Simulation Input Parameters

Item	C Oil Depot	M Oil Depot	Remarks
Leak Material	Gasoline	Gasoline	
Release Duration (s)	1,200	1,200	Based on Grade B criteria
Mass Flow Rate (kg/s)	180	140	Inflow (filling) rate
Total Released Mass (kg)	216,000	168,000	
Operating Temperature (°C)	25	25	
Operating Pressure (kg/cm²)	Atmospheric	Atmospheric	
Bund Area (m²)	8,815	5,972	

3.4. Parameter Analysis Items

A sensitivity analysis of seven parameters was conducted using the eCA program.
The parameters analyzed were as follows: **Storage liquid level** (1/3, 2/3, and full tank height), **Operating pressure** (1/3, 2/3, and full design pressure), **Relative humidity** (30%, 60%, 90%), **Leak hole diameter** (2 inches, 6 inches, 10 inches), **Atmospheric temperature** (−20°C, 10°C, 40°C), **Bund (dike) area** (0.5×, 1×, and 2× of actual area), **Surface type (wet soil, dry soil, concrete)**

4. Research Result

4.1. PHAST Simulation Results

According to the PHAST simulation results, the thermal radiation impact distance at the C Oil Depot under an overflow scenario was **139 m for 4 kW/m²** and **54 m for 12.5 kW/m²**.
For the M Oil Depot, the corresponding distances were **119 m for 4 kW/m² and 45 m for 12.5 kW/m². The C Oil Depot exhibited approximately** 15–20% greater impact distances **than the M Oil Depot, which is attributable to its larger storage capacity and bund area.**

Table 3: PHAST Simulation Results for the Overflow Scenario

Thermal Radiation Level	C Oil Depot (m)	M Oil Depot (m)
4 kW/m²	139	119
12.5 kW/m²	54	45

4.2. eCA Parameter Analysis Results

Based on the sensitivity analysis of seven parameters using the eCA program, the influencing factors were categorized into **high-impact** and **low-impact** variables according to their effect on thermal radiation impact distance.

High-Impact Factors

Storage liquid level:
When the tank level increased from one-third to full height, the 4 kW/m² impact distance increased from 270 m to 348 m, representing an approximate **29% increase**.

Leak hole diameter:
When the leak hole size changed from 2 inches to 10 inches, the 4 kW/m² impact distance increased dramatically from 56 m to 270 m, an approximate **382% surge**, confirming it as the most sensitive parameter.

Operating pressure:
For the C Oil Depot, when the operating pressure varied within the range of 0.9–2.7 kg/cm², the 4 kW/m² impact distance increased from 364 m to 436 m, an approximate **20% increase**.

Low-Impact Factors

Relative humidity:
When humidity changed from 30% to 90%, the impact distance decreased slightly from 275 m to 262 m (approx. **5% decrease**).

Atmospheric temperature:
When the temperature changed from −20°C to 40°C, the 4 kW/m² impact distance decreased from 306 m to 261 m (approx. **15% decrease**); however, this indicates that **cold winter conditions increase the hazard radius**, making it an important factor for safety planning.

Bund area:
Varying the bund area from 0.5× to 2× the actual area showed **almost no change** in impact distance.

Surface type:
Wet soil, dry soil, and concrete surfaces all produced **identical results**, confirming negligible influence.

Table 4: eCA Analysis of 4 kW/m² Thermal Radiation Impact Distance (Unit: m)

Parameter	**Condition 1**	**Condition 2**	**Condition 3**	**Impact Level**
Storage Liquid Level (1/3, 2/3, Full)	270	319	347	High
Leak Hole Diameter (2, 6, 10 inches)	56	162	270	High
Operating Pressure (1/3, 2/3, Full)	364	401	436	High
Temperature (−20, 10, 40°C)	306	280	261	Medium
Relative Humidity (30, 60, 90%)	275	270	262	Low
Bund Area (0.5×, 1×, 2×)	270	270	270	Low

4.3. Comparison Between PHAST and eCA

A comparison of the two programs revealed that **eCA consistently produced wider impact distances** than PHAST.

At **4 kW/m²**, eCA produced **351 m**, which is **2.5–2.9 times higher** than PHAST (C: 139 m, M: 119 m).

At **12.5 kW/m²**, eCA produced **200–199 m**, which is **3.7–4.4 times higher** than PHAST (C: 54 m, M: 45 m).

This discrepancy is attributed to eCA's conservative modeling approach aligned with domestic safety regulations.

Table 5: Comparison of Thermal Radiation Impact Distances Between PHAST and eCA (Unit: m)

Thermal Radiation Level	**PHAST (C)**	**PHAST (M)**	**eCA (C)**	**eCA (M)**
4 kW/m²	139	119	351	351
12.5 kW/m²	54	45	200	199
37.5 kW/m²	–	–	110	110

5. Safety Management Improvement Measures

Based on the quantitative risk assessment results derived in this study, safety management improvements are proposed across **five key areas**.

5.1. Strengthening Overflow Prevention Systems

Implement a dual-verification system that triggers an automatic alarm when the deviation between the TLG (Tank Level Gauge) and ATMS (Automatic Tank Monitoring System) exceeds ±3%.

Apply a 10% safety margin in the automatic calculation of receiving volumes.

Establish a minimum two-person monitoring system during receiving operations, with inspections every 15 minutes.

Upgrade the detection/isolation system level from Grade B to Grade A, reducing leak duration to **under 10 minutes**.

Enable automatic shutdown upon reaching the HIHI level and restrict restart without approval from safety personnel.

5.2. Strengthening Fire Response Capabilities

Install fixed foam monitors (minimum two per tank, discharge range ≥1.5 times tank diameter, pressure ≥7 kgf/cm²).

Install water spray systems for all gasoline tanks within 30 m (≥10 L/min/m² capacity, ≥4-hour duration).

Ensure at least two access routes for fire trucks, each ≥6 m wide.

Conduct quarterly fire response drills, including nighttime and adverse weather scenarios, and perform semiannual joint training with local fire departments.

5.3. Improving Emergency Evacuation Systems

Simulation results indicate that the main gate of the C Oil Depot may fall within the thermal radiation impact zone; thus, evacuation routes require revision.

C Oil Depot: Designate a secondary muster point ≥200 m northeast.

M Oil Depot: Designate a secondary muster point ≥150 m northwest.

Secure at least **three evacuation routes** (≥3 m width), install photoluminescent signs and emergency lighting every 10 m (with ≥2-hour battery), and conduct monthly evacuation drills with a **5-minute evacuation goal**.

5.4. Enhancing Training Programs

Conduct quarterly specialized training for receiving operators with a required passing score ≥80%.

Mandate at least one month of OJT for new operators.

Renew emergency response personnel certification semiannually.

Conduct quarterly overflow scenario drills and semiannual hands-on firefighting drills using actual extinguishing systems.

5.5. Facility Improvements

C Oil Depot

Insufficient water spray system capacity relative to tank size.

Narrow spacing between tanks increases fire spread risk.
→ Expand water spray systems and install fireproof coatings.

M Oil Depot

Coastal location increases salt damage and strong wind exposure.
→ Strengthen corrosion protection systems and develop wind-responsive emergency procedures.

Long distance from unloading facilities delays emergency response.
→ Install remote emergency shutdown systems.

6. Conclusion

This study conducted a quantitative risk assessment of overflow scenarios involving gasoline storage tanks using PHAST and eCA simulations, identifying key factors affecting thermal radiation impact distances. Major findings include:

Storage liquid level, leak hole diameter, and operating pressure were identified as high-impact parameters, with leak hole diameter showing the greatest sensitivity (approx. 382% increase in impact distance).

eCA consistently produced **40–60% wider hazard distances** than PHAST, reflecting the conservative approach of Korean regulatory standards.
→ Therefore, eCA results are recommended as the primary basis for determining safety distances in domestic facilities.

In winter conditions (−20°C), impact distances increased by up to **50%** compared to summer conditions (40°C), highlighting the need for seasonally differentiated emergency response planning.

Relative humidity, bund area, and surface type showed negligible influence and were classified as low-impact factors.

This study is meaningful in that it links quantitative risk assessment results with practical safety management improvement measures. The findings can contribute to establishing predictive and proactive risk management systems not only for petroleum storage facilities but for all hazardous material storage sites.

Future research should focus on implementing real-time monitoring systems based on new technologies (IoT sensors, AI-based prediction models) and developing big-data-driven risk forecasting models to further enhance safety management.

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