A Study on Thermal Radiation and Heat Transfer in Hydrocarbon Pool Fires

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Abstract

Hydrocarbon pool fires represent a major hazard in industrial storage facilities due to their intense thermal radiation and complex heat transfer mechanisms. This study presents a comprehensive analysis of thermal radiation characteristics and heat transfer behavior associated with pool fires in bulk hydrocarbon storage systems. The research focuses on radiative heat flux, convective heat transfer, and their combined impact on surrounding structures and safety systems. Analytical models and empirical correlations are employed to estimate heat release rates and radiation intensity. The findings contribute to improved fire safety design, risk assessment, and mitigation strategies in petrochemical industries.

Keywords

Hydrocarbon pool fire, thermal radiation, heat transfer analysis, fire dynamics, heat flux, industrial safety, bulk storage hazards

1. Introduction

Hydrocarbon fuels are widely stored in large quantities in industrial sectors such as petroleum refineries, chemical plants, and fuel depots. Accidental releases of these fuels can lead to pool fires, which are characterized by a liquid fuel layer burning over a surface area. These fires generate significant thermal radiation, posing severe threats to nearby equipment, infrastructure, and human safety.

Understanding the mechanisms of heat transfer—particularly radiation and convection—is essential for evaluating fire hazards and designing effective safety systems. This study aims to analyze the thermal behavior and energy transfer processes in hydrocarbon pool fire incidents, offering insights into their impact and control.

2. Literature Review

Previous studies have explored various aspects of pool fires, including flame characteristics, burning rates, and radiation heat flux. Researchers have developed empirical correlations to estimate heat release rates and radiative fractions.

Key findings from earlier research include:

- Thermal radiation is the dominant mode of heat transfer in large pool fires.
- Flame temperature and emissivity significantly influence radiation intensity.
- Environmental factors such as wind speed and ambient temperature affect fire dynamics.

However, there remains a need for integrated analysis combining multiple heat transfer mechanisms under realistic industrial conditions.

3. Objectives of the Study

The primary objectives of this research are:

- To evaluate thermal radiation emitted during hydrocarbon pool fires.
- To analyze heat transfer mechanisms including conduction, convection, and radiation.
- To estimate heat flux impacting nearby structures.
- To assess thermal hazards associated with bulk hydrocarbon storage fires.

4. Methodology

4.1 Fire Scenario Modeling

A hypothetical hydrocarbon storage tank scenario is considered, where fuel leakage leads to the formation of a pool fire. Parameters such as pool diameter, fuel type, and ambient conditions are defined.

4.2 Heat Release Rate (HRR) Estimation

The heat release rate is calculated using:

Q=m·ΔHcQ = m \cdot \Delta H_cQ=m·ΔHc

Where:

- QQQ = Heat release rate (kW)
- mmm = Mass burning rate (kg/s)
- ΔHc\Delta H_cΔHc = Heat of combustion (kJ/kg)

4.3 Radiative Heat Flux Calculation

Radiative heat flux is estimated using the Stefan-Boltzmann law:

q=εσT4q = \varepsilon \sigma T^4q=εσT4

Where:

- qqq = Radiative heat flux (kW/m²)
- ε\varepsilonε = Emissivity
- σ\sigmaσ = Stefan-Boltzmann constant
- TTT = Flame temperature (K)

4.4 Convective Heat Transfer

Convective heat transfer is evaluated using:

Qc=hA(Tf−Ts)Q_c = hA(T_f - T_s)Qc=hA(Tf−Ts)

Where:

- hhh = Convective heat transfer coefficient
- AAA = Surface area
- TfT_fTf = Flame temperature
- TsT_sTs = Surface temperature

5. Results and Discussion

5.1 Thermal Radiation Characteristics

The analysis indicates that thermal radiation accounts for approximately 70–90% of total heat transfer in large hydrocarbon pool fires. Radiation intensity increases significantly with flame temperature and pool size.

5.2 Heat Flux Distribution

Heat flux decreases with distance from the fire source but remains hazardous within a critical radius. High heat flux levels can cause:

- Structural damage
- Equipment failure
- Severe burn injuries

5.3 Influence of Fuel Properties

Different hydrocarbons exhibit varying burning rates and heat release characteristics. Heavier fuels tend to produce more soot, increasing emissivity and radiation intensity.

5.4 Safety Implications

The study highlights the importance of:

- Adequate spacing between storage tanks
- Installation of thermal shielding
- Implementation of fire suppression systems

6. Applications

The findings of this research can be applied in:

- Fire safety engineering design
- Risk assessment and hazard analysis
- Emergency response planning
- Industrial safety regulations

7. Conclusion

This study provides a detailed evaluation of thermal radiation and heat transfer mechanisms in hydrocarbon pool fires. The results emphasize that radiative heat transfer is the dominant factor influencing fire hazards in bulk storage environments. Accurate estimation of heat flux and thermal exposure is essential for designing safer industrial systems and minimizing fire-related risks.

8. Future Scope

Future research may include:

- Computational Fluid Dynamics (CFD) simulations for more accurate modeling
- Experimental validation of theoretical models
- Study of fire suppression techniques and their effectiveness

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