# Optimizing Flare Stack Performance and Radiation Impact Analysis in Onshore Facilities: A Simulation Based Study Using FLARESIM and PHAST Software

**Umesh Banker[1], Dr. Kiran D. Bhuyar[2]**

[1]M. Tech. 2nd year, Dept. of Chemical Engineering, Priyadarshini College of Engineering, Nagpur. Maharashtra, India
[2]Assistant Professor, Dept. of Chemical Engineering, Priyadarshini College of Engineering, Nagpur. Maharashtra, India

Email: umeshbanker[at]gmail.com

**Abstract:** ***Flare stacks are critical safeguards in oil and gas and petrochemical facilities for safe disposal of excess hydrocarbons. This paper presents a concise, simulation-based investigation of flare performance and thermal radiation impacts using FLARESIM (for ignited releases) and PHAST (for unignited dispersion). Site-representative compositions, flow rates, and meteorological categories were modelled for two onshore stacks: a High-Pressure (HP) flare and a Tank Vapor (TV) flare. Design acceptance criteria were aligned with API 521 radiant heat thresholds and company standards. Results indicate that a 25 m HP flare and a 15 m TV flare meet personnel and equipment protection criteria, with sterile-area radii of ~39 m and ~23 m respectively, and fence-line distances of ~90 m and ~50 m. Unignited toxic (H2S) and flammable dispersion remained buoyant above tip elevation for the assessed weather categories. The study demonstrates that targeted adjustments to stack height and tip sizing, validated via radiation isopleths, can achieve compliance while minimizing footprint.***

**Keywords:** Flare system, Radiation Impact analysis, Hydrocarbon Flare, Flaresim, Sterile area

## 1.Introduction

In industrial facilities, particularly within the oil and gas sector, flare stacks are crucial components designed to safely burn off excess gases and hydrocarbons that cannot be processed or utilized. Their primary function is to mitigate risks associated with over pressurization, accidental releases, and emergency situations by ensuring that volatile compounds are combusted in a controlled manner. However, the operation of flare stacks has implications for both performance and environmental impact, with radiation from the flare plume being a significant concern. Sometimes it is necessary to get rid of excess gas, and occasionally liquids from a facility. The safest way to do that is with the Flare System.

With increasingly stringent environmental regulations, optimizing flare stack performance is more important than ever. Stack height plays a pivotal role in emission dispersion and radiation exposure. Industrial flare systems combust waste and relief gases during normal operation, upsets, and emergencies, thereby preventing overpressure and uncontrolled releases. While indispensable for process safety, flares can generate significant thermal radiation and pollutants if poorly configured. Consequently, optimizing height, tip design, assist systems, and operating envelopes is central to maintaining high destruction efficiency alongside acceptable radiation at grade and at occupied boundaries. This paper condenses a broader thesis into a journal-length study focused on an onshore HP flare and TV flare, summarizing literature, problem framing, approach, and results suitable for design decision-making and publication. This paper focuses on optimizing stack height and configuration to enhance operational efficiency while minimizing radiation impact, ensuring compliance with both safety and environmental standards.

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## 2.Literature Review

Flare stacks play a critical role in industrial safety by combusting excess hydrocarbon gases during normal operations and emergencies. However, the performance and environmental implications of flaring-especially related to combustion efficiency and thermal radiation exposure-remain areas of ongoing research and industrial concern. This chapter reviews relevant studies and technologies related to flare stack performance optimization and radiation impact assessment, with an emphasis on simulation tools such as Flaresim.

Flare Stack Systems and Combustion Efficiency: Flare stacks are designed to ensure complete combustion of waste gases to reduce the release of pollutants such as methane, carbon monoxide, volatile organic compounds (VOCs), and soot. El-Halwagi (2012) emphasized the importance of air-to-fuel ratio and turbulence in promoting complete combustion. Flare efficiency, often defined by hydrocarbon destruction efficiency (DE), is sensitive to flow rate, wind speed, tip design, and assist gas type.

EPA (1995) defines a minimum destruction efficiency of 98% for industrial flare systems, which has become a benchmark in environmental regulations. However, Kostiuk et al. (2004) found that in windy or low-flow conditions, combustion may be incomplete, leading to visible smoke and pollutant emissions.

Thermal Radiation and Safety Analysis: Radiation from flare stacks poses significant risks to human safety and nearby equipment. The API 521 standard defines acceptable radiation limits for occupied and unoccupied areas. Research by Zhang et al. (2009) demonstrated that stack height and tip design have a significant influence on radiation intensity.

Yousef and Abu-Qudais (2013) modeled radiation using empirical correlations, showing that increased stack height reduces ground-level radiation but may require structural reinforcements. Moreover, Ahmad and Khan (2015) emphasized the importance of accurately modeling flame shape and heat release rate to predict radiation dispersion accurately.

Use of Simulation Tools for Flare Analysis: Simulation tools such as Flaresim, FLACS, and CFD-based ANSYS Fluent have been widely used for flare modeling. Flaresim, developed by Softbits Consultants, is tailored for flare system design and includes modules for calculating radiation, noise, and flame stability. Hamid et al. (2018) used Flaresim to model offshore flare systems and validated simulation results with field data, demonstrating acceptable error margins (<10%).

Unlike CFD tools that require intensive computation and detailed geometry, Flaresim provides quicker results with built-in algorithms and empirical data. However, Ghorbani et al. (2020) note that while Flaresim is user-friendly and reliable for standard configurations, it lacks the flexibility of full CFD tools for non-standard flame behavior or dynamic conditions.

Flare Optimization and Multi-Objective Approaches: Studies by Chakrabarti et al. (2016) introduced optimization methods to balance combustion efficiency and safety risks, often involving multi-objective genetic algorithms. Parameters such as flare diameter, stack height, and assist medium flow rates were varied to meet both environmental and operational constraints.

Regulatory and recommended practices emphasize combustion efficiency (often ≥98%) and radiant exposure limits for personnel and equipment, with API 521 providing widely adopted guidance on acceptable heat flux thresholds for continuous and emergency exposures. Empirical and semi-empirical models (e.g., Brzustowski/Sommer, Chamberlain, Hajek/Ludwig) implemented in design tools such as FLARESIM enable rapid estimation of flame geometry, heat release, and radiation isopleths. Studies report strong sensitivity of ground-level radiation to stack height, tip exit velocity/Mach number, gas composition, and assist media, and recommend systematic parameter studies rather than ad hoc sizing. For unignited releases, dispersion modelling with PHAST is used to evaluate toxic (e.g., $H_2S$) and flammable clouds against TLV/IDLH and LFL/UFL criteria, including buoyancy and stability-class effects.

## 3.Problem Definition

Flaresim software, a specialized tool for modeling flare systems, offers a valuable platform for simulating combustion behavior and predicting radiation intensities under various design and operating scenarios. However, its full potential remains underutilized in many industrial applications.

This paper addresses the gap by using Flaresim to simulate and optimize flare stack performance, with a particular emphasis on analyzing and minimizing radiation impacts, thereby enhancing both safety and environmental compliance in industrial operations. Given an onshore facility with two flare stacks (HP and TV), determine whether existing heights-25 m (HP) and 15 m (TV)-are adequate to: (i) keep 9.46 kW/m² radiation from impinging at grade, (ii) satisfy sterile-area and fence-line criteria (4.73 and 1.58 kW/m² contours), and (iii) prevent toxic/flammable clouds from reaching ground level during flame-out, including simultaneous flaring under a General Power Failure (GPF) scenario.

## 4.Methodology / Approach

The methodology for the paper on "Optimizing Flare Stack Performance and Radiation Impact Analysis in Industrial Facilities" should encompass several key phases, including data collection, performance calculation, radiation analysis, and optimization. Here's a structured approach to the methodology:

1. Data Collection:

- Flare Stack Specifications:

Design Data: Gather detailed design specifications of the flare stack, including height, diameter, flare tip configuration, and materials used.

Operational Data: Collect information on operating conditions such as gas flow rates, gas composition, and combustion temperatures.

- Site-Specific Information:

Meteorological Data: Obtain local weather conditions, including wind speed, wind direction, and ambient temperature.

Geographical Data: Map the surrounding area to identify nearby buildings, facilities, and other potential radiation receptors.

- Regulatory and Compliance Data:

Standards and Guidelines: Review relevant environmental and safety regulations related to flare stack operations and radiation exposure.

2. Flare Stack Performance Calculation:

- Capacity and Efficiency Calculations: Use established models and software tools to calculate flare stack capacity, heat release, and combustion efficiency.
- Performance Modeling: Employ simulation tools (e.g., Aspen HYSYS, FLARESIM) to model flare stack performance under various scenarios.

3. Radiation Impact Analysis:

- Radiation Dispersion Modeling: Estimate radiation dispersion using point source models and empirical correlations.
- Impact Assessment: Assess radiation levels and their potential impact on personnel and the environment.
- Compliance Evaluation: Ensure calculated radiation levels meet regulatory standards.

4. Optimization:

- Stack Height and Configuration: Analyze the effects of different stack heights and configurations on performance and radiation levels. Use optimization techniques to determine the ideal balance.
- Integrated Design Recommendations: Develop best practices for flare stack design and operation, focusing on optimizing performance while minimizing radiation impact.

5. Validation and Verification:

- Model Validation: Cross-validate simulation results with real-world data and perform sensitivity analysis to test robustness.
- Documentation: Compile a detailed report, including methodology, results, and recommendations, prepare presentations.

Flare dispersion, vent gas dispersion and thermal radiation modelling has been carried out using the following software:

1. FLARESIM Version 5.0: To determine thermal radiation and exhaust gas dispersion of ignited releases from the flares.
2. PHAST, Version 8.11: to determine the unignited gas dispersion (flammable and toxic).

PHAST and FLARESIM define flaring and venting cases using the following input parameters:

- Inventory: Composition; Flow rate.
- Release Scenario:

i. Flare stack height, type and tip diameter (flares).
ii. Weather conditions (wind speed and other ambient conditions).
iii. Design limits in terms of thermal radiation and flammable gas dispersion.

FLARESIM v5.0 was used to model ignited releases and compute thermal radiation contours using the Brzustowski radiation method and generic pipe tips sized for maximum Mach ~0.5. PHAST v8.11 was used for unignited dispersion (toxic and flammable). Inputs: Process data included HP and TV compositions and flowrates (HP ~99,950 kg/h; TV ~17,570 kg/h), tip diameters (~488.9 mm HP; ~202.7 mm TV), ambient temperature (~30°C), humidity (~70%), wind/stability categories 2F, 3C, 4D, and 7D, and prevailing wind from ~330°. Acceptance Criteria: Thermal radiation thresholds considered were 1.58, 4.73, 6.31, and 9.46 kW/m² per company/API guidance; toxic dispersion assessed 10/100/300 ppm $H_2S$; flammable dispersion assessed UFL/LFL, 1/2 LFL, and 1/4 LFL clouds.

## 5.Results & Discussion

Thermal Radiation - HP Flare (25 m): Radiation of 9.46 kW/m² did not reach grade; 1.58 kW/m² contour extended to ~90 m; sterile-area (4.73 kW/m²) radius ~39 m; 6.31 kW/m² at ~24 m. Thermal Radiation - TV Flare (15 m): Radiation of 9.46 kW/m² did not reach grade; 1.58 kW/m² contour extended to ~50 m; sterile-area radius ~23 m; 6.31 kW/m² at ~16 m. Simultaneous Flaring: Radiation contours overlaid on plot plan remained within acceptable limits given the proposed heights and sterile-area fencing. Toxic Dispersion (Flame-out): For $H_2S$, the eight-hour TWA (10 ppm) plumes remained above tip elevation; max downwind distances ~375 m (HP, 2F) and ~145 m (TV, 2F). Flammable Dispersion (Flame-out): 1/4 LFL downwind distances were ~44 m (HP, 7D) and ~23 m (TV, 7D), remaining above tip elevation and unlikely to encounter ignition sources. Discussion: The studied heights and tip sizings balance radiation control with combustion stability. Fence-line and sterile-area placements derived from isopleths are compatible with the current layout. These results support design adequacy for GPF and routine scenarios, subject to vendor verification in detailed design.

## 6.Conclusion

A 25 m HP flare and a 15 m TV flare-sized with tip Mach ~0.5 and evaluated via FLARESIM/PHAST-meet thermal radiation, toxic, and flammable dispersion acceptance criteria for the assessed conditions. Sterile-area radii (~39 m HP; ~23 m TV) and fence-line distances (~90 m HP; ~50 m TV) provide adequate personnel protection and layout compliance. The approach demonstrates that simulation-driven sizing and verification can minimize radiation footprint without sacrificing combustion performance.

## 7.Future Scope

- Field validation of radiation and dispersion with instrumented campaigns and remote sensing (e.g., IR cameras, $SO_2$ monitoring).
- Transient and emergency flaring dynamics, pilot reliability, and auto-ignition modelling under variable wind/gust scenarios.
- Integration with flare gas recovery systems (FGRS) and ESG reporting to reduce routine flaring.

- CFD-backed sensitivity studies for non-standard tips, multi-jet ground flares, and shielding (water curtains/solid barriers).
- Multi-objective optimization (height, tip diameter, assist rates) under cost, noise, and constructability constraints.

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