ISSN: 2414-1895 DOI: 10.6919/ICJE.202505_11(5).0015

Study on Cold Venting Characteristics of High-Sulfur Gas on Offshore Oil Platforms

Ying Liu[1], Zhen Shen[2], Shijia Zhang[1], Beibei Zheng[3], Shuai Liu[3]

[1] CNOOC EnerTech Equipment Technology Co., Ltd.Design & R&D Center, Tianjin 300451, China

[2] CNOOC EnerTech Equipment Technology Co., Ltd. Zhanjiang Branch, Zhanjiang 524057, China

[3] CNOOC (China) Co., Ltd, Tianjin Branch, Tianjin 300459, China

Abstract

This study investigates the dispersion characteristics of cold venting gas containing hydrogen sulfide on an offshore platform in the western South China Sea using PHAST software. The maximum downwind distances of gas clouds under different atmospheric stabilities and venting rates were analyzed for both flammability and toxicity. For H2S toxicity analysis (minimum concentration threshold: 7 ppm), the maximum downwind distance initially increased and then decreased with rising wind speed. The optimal distance of 176.7 m occurred at a venting rate of 18 kg/s and wind speed of 4 m/s. This phenomenon arises from the dual effects of wind-driven horizontal transport and turbulence-induced dilution. For flammability analysis, the maximum downwind distance exhibited a continuous growth trend at a venting rate of 18 kg/s, reaching 52 m at 20 m/s wind speed. Here, horizontal transport dominated over dilution effects. These findings provide critical guidance for operational safety and accident prevention on offshore platforms.

Keywords

Cold Venting; PHAST; Toxic Gas; Dispersion Analysis; Maximum Downwind Distance.

1. Introduction

The western South China Sea hosts substantial reserves of oil and natural gas. In certain blocks, associated gas inevitably contains hydrogen sulfide due to geological and operational factors. For instance, gas produced from some offshore platforms in the Weizhou area has been measured to contain H_2S at concentrations as high as 8,000 ppm by volume. During offshore oil and gas field development, surplus gas that cannot be economically utilized or emergency releases from safety valves are directed to flare knockout drums. The separated gas is then discharged and combusted via flare systems [1]. When designing flare boom lengths, engineers must not only mitigate thermal radiation risks but also evaluate the impact of unignited "cold venting" scenarios (e.g., flare outages) on platform safety. According to Section 11 of the Offshore Oil and Gas Field Process Design Guidelines, gases with a calorific value below 7.5 MJ/m³ (insufficient for combustion) or intermittent low-volume flammable releases should be routed through cold venting systems, necessitating dispersion analysis and risk assessments.

Numerous studies have addressed gas dispersion. For example, Liu Moshan from the China University of Geosciences simulated H_2S leakage in Sichuan-Chongqing sulfur-bearing gas pipelines using PHAST software, proposing optimized valve placement to limit accident consequences [2]. Mao Huizong investigated natural gas leakage on offshore platforms, revealing migration patterns of

ISSN: 2414-1895 DOI: 10.6919/ICJE.202505_11(5).0015

flammable clouds under varying scenarios [3]. Yuan Jing compared gas dispersion models, highlighting the suitability of the Unified Dispersion Model (UDM) for sensitive, densely populated areas [4].

2. PHAST Software Overview

PHAST, developed by DNV Norway, is a professional quantitative risk assessment (QRA) software. Its Unified Dispersion Model (UDM) integrates the Gaussian plume model, BM model, and P-G model to simulate gas dispersion by analyzing time and distance as foundational parameters, thereby predicting post-dispersion concentration distributions [5]. The simulation results align closely with experimental data, making PHAST a widely adopted tool in the global petrochemical industry for risk analysis and safety evaluations.

3. Flare System Parameters and H_2S Evaluation Criteria

The simulated offshore platform flare system has a maximum venting rate of 78,100 Sm^3/d (0.927 kg/s) with a vertically oriented flare tip. The release type is continuous venting at maximum capacity. The flare knockout drum operates at 70 kPaG and 68°C. The flare boom measures 28.8 m in length, angled at 45° to the horizontal plane, with the flare tip positioned 41 m above sea level. Ambient conditions include an air temperature of 30°C, humidity of 85%, and a gas mixture with a relative molecular weight of 24.5.

Table 1. Composition of Associated Gas

Component	CO_2	N_2	C_1	C_2	C_3	IC_4	NC_4	IC_5	NC_5	H_2O
Mole (%)	2.94	2.47	63.73	13.00	10.21	1.42	3.50	0.61	0.41	1.72

Note: H_2S content = 5000 ppm.

The vented gas exhibits both toxicity and flammability [6][7]. Toxicity is evaluated against the Chinese national standard GB Z2.1-2007 (Occupational Exposure Limits for Hazardous Agents in the Workplace), which stipulates a maximum permissible H_2S concentration of 10 mg/m^3 (~7 ppm). For flammability, Q/HS 3155-2022 (Section 6.13) mandates a minimum safety distance of 3 m between platform structures and the boundary of 20% of the lower explosive limit (LEL) concentration.

Atmospheric stability, defined as the resistance of air layers to vertical motion, critically influences gas dispersion patterns[8]. The PHAST software employs the Pasquill-Gifford classification (Classes A–G), where Class G denotes the most stable conditions and Class D represents neutral stability (applicable to all wind speeds). For the western South China Sea, Class D stability is representative and was selected for this simulation.

Table 2. Pasquill-Gifford Stability Classes and Corresponding Conditions

Stability Class	**Description**	**Weather Conditions**	**Wind Speed Range (m/s)**
C (Moderately Unstable)	Moderate instability	Sunny/cloudy with light wind	2–5.9
D (Neutral)	Neutral stability	Overcast or windy nights	Any wind speed
E (Moderately Stable)	Moderate stability	Less overcast/windy than Class D	≤4.9
F (Stable)	High stability	Clear skies with light/moderate wind	≤2.9

ISSN: 2414-1895 DOI: 10.6919/ICJE.202505_11(5).0015

4. Dispersion Analysis

Fluid flow adheres to the fundamental physical conservation laws: mass conservation, momentum conservation, and energy conservation [9].

(1) Concentration Distribution Formula for Continuous Leakage Model

$$C(x,y,z) = c_0(x)\exp\left\{\left|\frac{z}{\sqrt{2}\,\sigma_z}\right|^n\right\}\exp\left\{\left|\frac{y}{\sqrt{2}\,\sigma_y}\right|^m\right\} \tag{1}$$

C(x,y,z,H)-- Mass concentration at any point, kg/m3

c0(t)-- Centerline concentration of gas cloud at time t, kg/m3

c0(x)-- Centerline concentration of gas cloud , kg/m3

m(x)-- Gas parameter

n(x)-- Meteorological parameter

Rx(t)-- Downwind diffusion coefficient at time, t

Ry(t)-- Crosswind diffusion coefficient at time, t

xcld(t)-- Downwind propagation distance of gas cloud center at timet, m

σy-- Lateral diffusion coefficient, m

σz -- Vertical diffusion coefficient, m

ζ-- Height difference between specified elevation and gas cloud center , m

(2) Mass Conservation Equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial u_x}{\partial x} + \frac{\partial u_y}{\partial y} + \frac{\partial u_z}{\partial z} = 0$$

(3) Momentum Conservation Equation:

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial(\rho u_i u_i)}{\partial x_j} = -\frac{\partial p}{\partial x_j} + \frac{\partial}{\partial x}\left(\mu \frac{\delta u_i}{\delta x_j}\right) - \frac{\partial}{\partial x_j}\left(\overline{\rho u_i' u_j'}\right)$$

(4) Energy Conservation Equation

The energy conservation law reflects the preservation of energy in fluid flow, embodying the first law of thermodynamics. It states that the net heat flux into a control volume plus the work done by surface forces equals the rate of energy increase within the volume:

$$\frac{\partial(\rho T)}{\partial t} + div(\rho \bar{u} T) = div\left(\frac{k}{c_{\mathrm{p}}} grad\ T\right) + S_{\mathrm{t}}$$

Where, c_p is Specific heat capacity (J/kg • K) , k is Thermal conductivity of fluid (W/m·K), t is Temperature (K), S_T is Viscous dissipation term 。

4.1 Toxic Dispersion Characteristics Analysis

This section investigates the toxic dispersion characteristics of vented gas under environmental wind speeds of 1, 3, 5, 7, 10, 15, and 20 m/s, with an H_2S threshold concentration of 7 ppm.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202505_11(5).0015

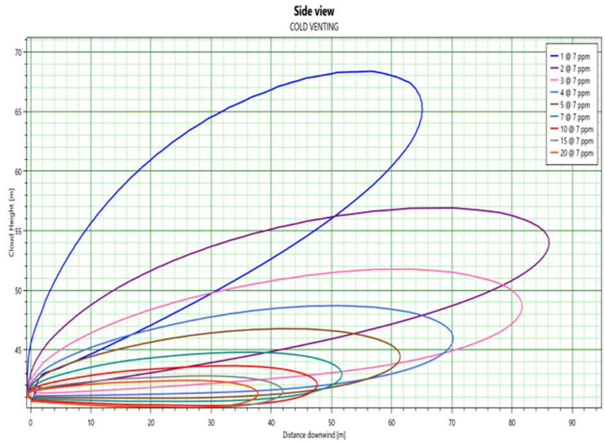

Figure 1. Maximum downwind distance of H_2S dispersion at 0.927 kg/s venting rate (Stability class D)

From Figure 1, it can be concluded that as the wind speed increases, the overall height of the H_2S gas cloud decreases. The analysis attributes this to the initial diffusion in the form of turbulent jet dispersion. Higher wind speeds enhance the entrainment effect, which dilutes the cloud, leading to lower concentrations and a gradual decrease in the overall height of the cloud. Under different wind speeds, the maximum downwind distance of the cloud first increases and then decreases, reaching the farthest distance of 86.2 m at a wind speed of 3 m/s.

The analysis is as follows: On one hand, as the wind speed increases, H_2S is carried farther by the wind. On the other hand, increased wind speed leads to greater dilution of H_2S due to turbulent diffusion. In other words, the maximum downwind distance of the cloud is determined by the combined effects of horizontal wind transport and turbulent diffusion. This manifests as an increase in the maximum downwind distance between wind speeds of 1 m/s and 3 m/s, followed by a decreasing trend from 3 m/s to 20 m/s.

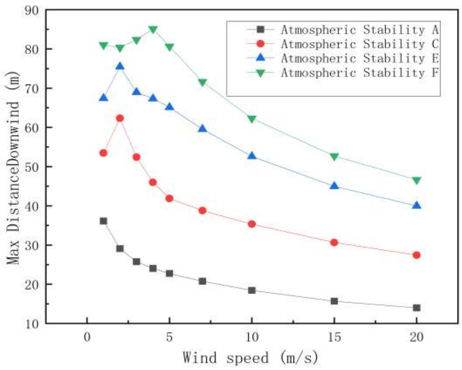

Figure 2. Maximum Downwind Diffusion Distance Under Different Atmospheric Stability Conditions at a Release Rate of 0.927 kg/s

From Figure 2, it is observed that when the atmospheric stability conditions are A, C, E, and F, the maximum downwind distance also follows a trend of first increasing and then decreasing.

- Under atmospheric stability A, the maximum downwind distance occurs at a wind speed of 1 m/s, reaching 36.1 m.
- Under atmospheric stability C, the maximum downwind distance occurs at a wind speed of 2 m/s, reaching 62.3 m.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202505_11(5).0015

- Under atmospheric stability E, the maximum downwind distance occurs at a wind speed of 2 m/s, reaching 75.5 m.

- Under atmospheric stability F, the maximum downwind distance occurs at a wind speed of 4 m/s, reaching 85.2 m.

The more stable the atmosphere, the farther the cloud diffuses at the same wind speed. Additionally, as atmospheric stability increases, the wind speed corresponding to the maximumdownwind distance also increases.

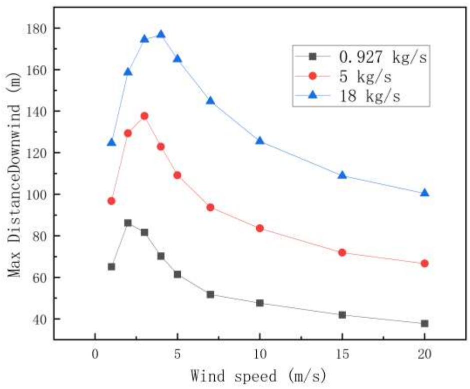

Figure 3. Maximum Downwind Diffusion Distance Under Different Release Rates at Atmospheric Stability D

From Figure 3, it is observed that for different release rates, the maximum downwind distance also follows a trend of first increasing and then decreasing.

At a mixed gas release rate of 0.927 kg/s, the maximum downwind distance occurs at a wind speed of 2 m/s, reaching 36.1 m.

At a mixed gas release rate of 5 kg/s, the maximum downwind distance occurs at a wind speed of 3 m/s, reaching 137.6 m.

At a mixed gas release rate of 18 kg/s, the maximum downwind distance occurs at a wind speed of 4 m/s, reaching 176.7 m.

The analysis indicates that within the wind speed range of 0–20 m/s, the focus is on hydrogen sulfide (H_2S) in the mixed gas, with a minimum concentration of 7 ppm set as the threshold for cloud simulation. For different release rates, there exists an optimal wind speed corresponding to the maximum downwind distance, which is determined by the balance between horizontal wind transport and turbulent dilution.

4.2 Analysis of Flammable Gas Dispersion Characteristics

This section examines the dispersion characteristics of flammable gas. Environmental wind speeds considered are 1 m/s, 3 m/s, 5 m/s, 7 m/s, 10 m/s, 15 m/s, and 20 m/s. The flammable limits of the associated gas are:

Upper Flammable Limit (UFL): 139,095 ppm

Lower Flammable Limit (LFL): 38,332.6 ppm

20% of LFL (safety threshold): 7,666.5 ppm

The simulation focuses on a flammable gas concentration of 7,666.5 ppm.

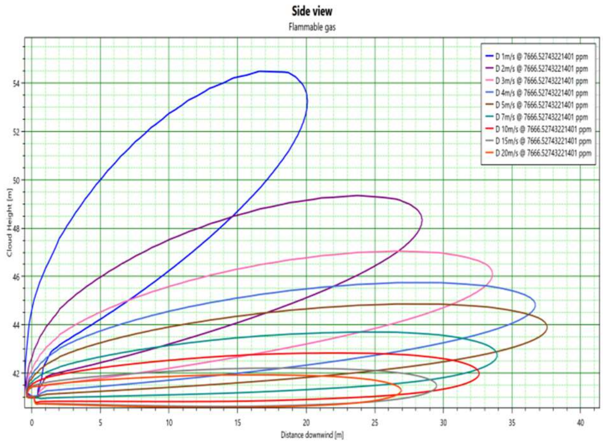

Figure 4. Downwind Distance of Gas Cloud at Different Atmospheric Stability Conditions (Release Rate: 0.927 kg/s)

From Figure 4, it is observed that as wind speed increases, the overall height of the flammable gas cloud decreases. The initial dispersion occurs in a turbulent jet pattern. Higher wind speeds enhance entrainment, diluting the cloud and reducing its height.

The maximum downwind distance first increases and then decreases with wind speed, peaking at 37.5 m (5 m/s). This trend occurs because:Higher wind speeds carry the gas farther downwind.Increased turbulence dilutes the gas, reducing its concentration.The interplay between horizontal wind transport and turbulent diffusion determines the maximum downwind distance, leading to an increase from 1 m/s to 5 m/s and a decrease from 5 m/s to 20 m/s.

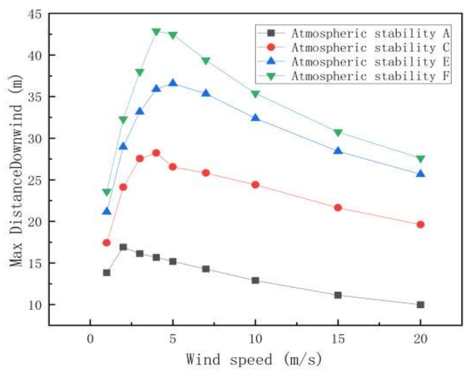

Figure 5. Maximum Downwind Diffusion Distance Under Different Atmospheric Stability Conditions (Release Rate: 0.927 kg/s)

From Figure 5, under atmospheric stability classes A, C, E, and F, the maximum downwind distance follows the same increasing-then-decreasing trend:

Stability A: Max distance at 2 m/s (16.9 m)

Stability C: Max distance at 4 m/s (28.2 m)

Stability E: Max distance at 5 m/s (36.6 m)

Stability F: Max distance at 4 m/s (42.9 m)

More stable atmospheric conditions lead to greater diffusion distances at the same wind speed.

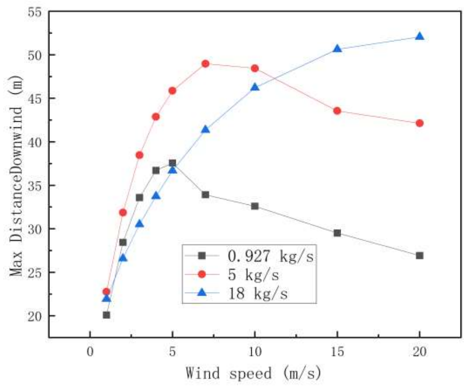

Figure 6. Maximum Downwind Diffusion Distance Under Different Release Rates at Atmospheric Stability D

When other conditions remain constant but the release rate changes:At 0.927 kg/s, the maximum downwind distance occurs at 5 m/s (37.5 m), then decreases with higher wind speeds.

At 5 kg/s, the peak occurs at 7 m/s (48.9 m), followed by a decline.At 18 kg/s, the maximum downwind distance continuously increases with wind speed (0–20 m/s).Analysis for 18 kg/s case: At such a high release rate, horizontal wind transport dominates over turbulent dilution effects. Even though turbulence causes some dilution, the massive release rate (18 kg/s) outweighs the dilution impact, allowing the cloud to spread farther as wind speed increases.

5. Conclusion

For this platform, with a focus on the minimum H_2S dispersion concentration of 7 ppm, dispersion analysis must account for the combined effects of horizontal wind transport and turbulence. The maximum dispersion distance occurs within a relatively low wind speed range.

Under identical constraints, within a wind speed range of 1–20 m/s, the dispersion distance of H_2S follows an initial increase followed by a decrease under varying atmospheric stability conditions and release rates.

For flammable gas dispersion analysis, within a wind speed range of 1–20 m/s, the dispersion distance also exhibits an initial increase followed by a decrease under different atmospheric stability conditions.

For flammable gas dispersion analysis, when the release rate reaches 18 kg/s, the maximum downwind distance within 0–20 m/s shows a continuous increasing trend with rising wind speed. This is because, at such a high release rate, horizontal wind transport dominates the dispersion process, while the dilution effect caused by turbulence becomes negligible.

References

[1] Chen R Q. Determination of flare system design discharge rates for offshore platforms[J]. *China Offshore Oil and Gas*, 1997, 9(5): 4-7.

[2] Liu M S. Consequence simulation of H_2S leakage in Sichuan-Chongqing gas pipelines[D]. *China University of Geosciences (Beijing)*, 2010.

[3] Mao H Z. Numerical simulation of natural gas leakage on offshore platforms[D]. *Hebei University of Engineering*, 2022. DOI:10.27104/d.cnki.ghbjy.2022.000735.

[4] Yuan J, Zhao D F, Meng Y F. Comparative analysis of gas dispersion models for engineering applications[J]. *Petrochemical Safety and Environmental Technology*, 2016, 32(01): 16-19.

[5] Huang W H, et al. Review of heavy gas leakage and dispersion models[J]. *Zhejiang Chemical Industry*, 2009, 40(07): 18-22.

[6] Cheng Y, et al. Hazards, origins, and mitigation of H_2S in offshore oilfields[J]. *Petrochemical Technology*, 2022, 29(12): 194-196.

[7] Tang P. Height optimization for emergency atmospheric discharges[J]. *Petrochemical Safety and Environmental Technology*, 2023, 39(02): 22-24.

[8] Yao J J, et al. Dispersion simulation of H_2S-containing flammable gas in enclosed ground flares[J]. *Refining Technology and Engineering*, 2016, 46(08): 16-19.

[9] Du J M. Risk assessment of LNG leakage and vapor cloud dispersion[D]. *Harbin Institute of Technology*, 2020. DOI:10.27061/d.cnki.ghgdu.2020.005253.