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Thermal Radiation and Noise Safety Assessment of an Offshore Platform Flare Stack as Sudden Emergency Relief Takes Place

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***Abstract*—**To study the potential hazards of the sudden emergency relief of flare stack, the thermal radiation and noise calculation of flare stack is carried out by using Flaresim program 2.0. Thermal radiation and noise analysis should be considered as the sudden emergency relief takes place. According to the Flaresim software simulation results, the thermal radiation and noise meet the requirement.

***Keywords*—**Flare stack, thermal radiation, noise, safety assessment.

I. Introduction

THIS flare stack emergency assessment method is based on the pressure-relieving and de-pressuring systems guidelines (API RP 521 [1]) recommended by United States Petroleum Association. By using Flaresim 2.0, the thermal radiation and noise values of flare stack are calculated. As the sudden emergency relief takes place, the safety assessment of thermal radiation and noise of an offshore platform flare stack is necessary. The thermal radiation and the noise are released when the flare stack is burning. According to the platform general layout, few key points are selected. As long as the point of thermal radiation and noise value are lower than the allowed values, all other positions on the platform of the thermal radiation and noise will also be lower than the allowed value. So personnel on the platform is safe.

II. Calculating Model

According to API RP 521, flare stack calculation includes thermal radiation, surface temperature, and noise models.

A. Mach Number Calculation

According to the pressure-relieving and de-pressuring systems guidelines (API RP 521 [1]), [2], the isothermal outlet Mach number is given by (1).

$$Ma = 3.23 \times 10^{-5}\left(\frac{q_m}{p \cdot d^2}\right)\left(\frac{Z \cdot T}{M}\right)^{0.5} \tag{1}$$

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where: q_m is the gas mass flow, showed in kg/h; Z is the gas co mpressibility factor; T is the absolute temperature, showed in K; M is the gas relative molecular mass; d is the pipe inside dia meter, showed in m.

Ma value: under normal conditions, $Ma \leq 0.2$; emergency vent conditions, $Ma \leq 0.5$; as the offshore platform at the fire emergency conditions, $Ma = 0.5$ tends to be conservative, it is usually preferable to use 0.75 [3].

B. Thermal Radiation Intensity

A common way to determine the flame radiation for the interest point is to consider the flame having a single radiant epicenter and to use the following empirical equation by Hajek and Ludwig [4]. Equation (2) may be used for both subsonic and sonic flares when the correct F factor is used.

$$D = \sqrt{\frac{\tau F Q}{4\pi K}} \tag{2}$$

where: D is the minimum distance from the epicenter of the flame to the object being considered, showed in m. τ is the fraction of the radiated heat transmitted through the atmosphere; According to [5], [6], τ=1.0; F is the fraction of heat radiated, and according to API, RP521, F= 0.1911; Q is the heat release (lower heating value), showed in kW; K is the radiant heat intensity, showed in kW/m^2; According to API RP521, Permissible design levels for personnel are showed in Table I. Solar thermal radiation intensity is 0.790～1.04 KW/m^2. Thermal radiation intensity is 4.73 KW/m^2 as the emergency relief takes place.

C. Surface Temperature [5]

The equilibrium surface temperature of metal surfaces exposed to the thermal radiation is calculated from the heat balance between the thermal radiation from the flame incident at the specified point and the heat losses from the same point. Equation (3) may be used for the surface temperature.

$$\alpha K = (h_c + h_f) \cdot (T_m - T_\infty) \tag{3}$$

where: K is thermal radiation at receptor (W/m^2); α is metal surface absorptivity, α=0.7. h_c is the convective heat transfer coefficient which is calculated from a series of empirical correlations that are a function of air velocity.

$$h_c = \begin{cases} 0.8 + 0.22u_\infty & 0 \le u_\infty \le 15m/s \\ 0.56u_\infty^{0.75} & u_\infty \rangle 15m/s \end{cases} \quad (4)$$

This heat balance equation assumes that heat losses by convection and radiation occur only from the surface exposed to the radiation. The overall heat loss from the point is the sum of the radiation from the point and the forced/free convection from the point. The radiative heat transfer coefficient is given by:

$$h_f = \sigma E \frac{(T_m^4 - T_\infty^4)}{(T_m - T_\infty)} \quad (5)$$

where, E is the metal surface emissivity, E=0.7; σ is Stephan Boltzman constant, 5.67×10^{-8} W/m$^2\cdot$K^4; u_∞ is the wind velocity, m/s; T_m is the metal surface temperature, K; T_∞ is the atmospheric temperature, K.

TABLE II
RECOMMENDED DESIGN THERMAL RADIATION FOR PERSONNEL [1]

Permissible design level K (KW/m^2)	Conditions
1.58	Maximum radiant heat intensity at any location where personnel with appropriate clothing* can be continuously exposed
4.73	Maximum radiant heat intensity in areas where emergency actions lasting 2 to 3 min can be required by personnel without shielding but with appropriate clothing*.
6.31	Maximum radiant heat intensity in areas where emergency actions lasting up to 30s can be required by personnel without shielding but with appropriate clothing*.
9.46	Maximum radiant heat intensity at any location where urgent emergency action the personnel is required reach to. When personnel enter or work in an area with the potential radiant heat intensity is greater than 6.31 KW/m^2, then radiation shielding and/or special protective apparel (e.g. a fire approach suit) should be considered. SAFETY PRECAUTIO---It is important to recognize that personnel with appropriate cloth*cannot tolerate thermal radiation at 6.31KW/m^2 for more than a few seconds.

* Appropriate cloth consists of hard hat, long-sleeved shirts with cuffs, work gloves, long-legged pants and work shoes. Appropriate cloth can minimize personnel' s body skin direct exposure to thermal radiation.

D. Flare Noise [7]

Flare noise is mainly composed of the combustion noise and the nozzle noise. Although the flare noise can be represented in average value, it was constituted by different frequencies of noise, and each frequency noise contributing to the average value depends on the noise which is caused by the flare combustion noise in a duct or which is caused by the noise of sonic flare nozzle. Flare noise spectrum is usually caused by 63~8000 Hz, usually indicated by a sound power level and sound pressure level:

$$PWL = 10\log\left(\frac{W}{W_0}\right) \quad (6)$$

$$SPL = 10\log\left(\frac{P}{P_0}\right)^2 \quad (7)$$

where: PWL is sound power level, dB; SPL is sound pressure level, dB; W_0 is the reference value, W_0=10^{-12} W; P_0 is the reference value, P_0=2×10^{-6} Pa.

When the flare device is positioned in the surrounding empty environment, sound pressure level and sound power levels of noise are as:

$$SPL = PWL - 20\log D - 0.49 - SPL_A \quad (8)$$

where: D is the minimum distance from the flare midpoint to receptor, m; SPL_A is the attenuation of the sound pressure level of noise in the atmosphere, dB.

The attenuation is a function of the noise frequency, with higher frequencies being more readily attenuated than lower ones. PWL is associated with the noise of the flare nozzle. SPL is associated with the combustion noise.

III. CALCULATION

The above-mentioned models are calculated by using Flaresim 2.0 software. Calculated parameters include platform environment and flare stack data, vent gas compositions data, and the location of the assessment point information. Platform environment and flare stack data are showed in Table II. Vent gas compositions data are showed in Table III. Location of the assessment point information is showed in Table IV.

Calculation conditions include:

- Wind direction is always towards the check point;
- Max Wind speed is 38 m/s.

TABLE II
ENVIRONMENT AND FLARE STACK DATA

Air average temperature	22.9 □
Vent gas temperature	62 □
Maximal vent gas flow rate	4.85×104 Sm^3/d
Height of vent pipe	12 m
Diameter of vent pipe	3" (76.2 mm)
Humidity (%)	81
Low wind speed	1 m/s
Maximal wind speed	38 m/s
The most dangerous direction of wind	SSW

TABLE III
VENT GAS COMPOSITIONS TATA

Compositions	Chem. formula	Mole fraction
Nitrogen	N_2	0.0145
Carbon-dioxide	CO_2	0.0388
Water-vapor	H_2O	0.0034
Methane	CH_4	0.8639
Ethane	C_2H_6	0.0388
Propane	C_3H_8	0.0295
i-Butane	C_4H_{10}	0.0033
n-Butane	C_4H_{10}	0.0061
i-Pentane	C_5H_{12}	0.001

IV. EMERGENCY FIRE CASE ANALYSIS

Vent pipeline emergency fire may be caused by thunderbolt when the platform emergency relieving. So the thermal radiation analysis and noise analysis should be considered when vent pipeline emergency fire takes place. Flaresim calculation program 2.0 is used to analyze all conditions mentioned above. The wind direction and speed should be based on the operation experience of offshore platform and offshore oil engineering design guides.

TABLE IV
ASSESSMENT POINT INFORMATION

Assessment point	Description	Coordinate (m) x	y	z
1	Vent pipe inlet	-25.3	-16.01	13.05
2	CO_2 snuffing system	8	-14.94	0.9
3	Helideck	28	0	4.2
4	Living quarter (up)	15	-14.94	-3.3
5	Material room	6.37	-14.94	0.9
6	Central air conditioning sets	22.8	-14.94	0.9
7	Foam bladder vessel	26	-14.94	0.9

A. Radiation Criteria

Radiation limit shall be as per API RP 521 recommendation. Since emergency relief is typically infrequent and short duration, meanwhile, the CO_2 snuffing system can work and the worker can escape within several seconds, so we chose 4.73 KW/m^2 as radiation level.

TABLE V
THE DISTRIBUTION OF RADIATION INTENSITY IN ASSESSMENT POINT WITH V=1M/S AND V=38M/S

Assess. Point	Description	Radiation Intensity (KW/m^2) v=1m/s	v=38m/s	Remarks (KW/m^2)	Temp. (□) v=1m/s	v=38m/s
1	Vent pipe inlet	2.942	3.037	<4.730	93.95	31.55
2	CO_2 snuffing system	0.213	0.2564	<4.730	28.65	23.65
3	Helideck	0.1082	0.1166	<1.893	25.85	23.25
4	Living quarter (up)	0.1471	0.174	<4.730	26.95	23.35
5	Material room	0.2267	0.2759	<4.730	29.05	23.65
6	Central air condition sets	0.1259	0.1412	<4.730	26.35	23.35
7	Foam bladder vessel	0.1136	0.126	<4.730	26.05	23.25

The radiation intensities at the assessment points with wind velocity v= 1 m/s and v=38 m/s case are showed in Table V. According to calculation results, the radiation intensities meet the requirements when emergency fire condition occurs.

B. Noise Analysis

Noise and vibration requirements shall be limited to those noted in this specification, except that where the governing laws of the People's Republic of China are more stringent they shall apply. The following codes and standard regulations (latest edition if existing) are part of this specification and shall be complied.

1. Industry Standards and Codes for Noise

1) API 615 Sound control of mechanical equipment for refinery service.
2) 29 CFR 1910 Occupational Safety & Health Standard.

2. Industry Standards and Codes for Vibration

1) API 670 Vibration, axial position and bearing temperature monitoring system.
2) API 678 Accelerometer-based vibration monitoring system.

3. Results and Analysis

Since emergency relief is typically infrequent and short duration, the noise might not be subjected to regulation. According to "Safety Rules for Offshore Fixed Platforms", open machinery spaces mean that the equipment is located in open spaces. The noise value for such spaces shall not exceed 115 dB(A). Permissible worker noise level is showed in Table VI. The noises at the assessment points with wind velocity v=1 m/s and v=38 m/s are showed in Table VII. According to the results, wind velocity has no effect on assessment point noise. Every assessment point noise is below to the remarked value. But, the outdoor noise is exceeding the indoor noise level, so if people want to take rest, he/she will be inside.

TABLE VI
PERMISSIBLE WORKER NOISE LEVEL

Permissible Exposure	Level dB(A)
12 hours per day	88
8 hours per day	90
Less than 8 hours per day	94 (max.)
* 45 minutes per day	100
Control room, office, and lab.	60
Service area	65
Public area	55
Communication room, bedroom, clinic etc.	45

*Only in special condition, 45 minutes per day criteria shall be applied.

TABLE VII
THE NOISES IN ASSESSMENT POINT WITH V=1M/S AND V=38M/S

Assessment point	Description	Noise results dB(A) v=1m/s	v=38m/s	Remarks dB(A)
1	Vent pipe inlet	87.0	87.0	<115
2	CO_2 snuffing system	70.7	70.7	<115
3	Helideck	67.1	67.1	<115
4	Living quarter (up)	69.0	69.0	<90
5	Material room	71.1	71.1	<115
6	Central air conditioning sets	68.0	68.0	<115
7	Foam bladder vessel	67.5	67.5	<115

V. CONCLUSION

According to the data in Tables V and VII, the thermal radiation and noise meet the safety requirements. To ensure platform security, CO_2 extinguishing system should be installed beside the cold vent pipe [8]-[12].

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