Evaluation of the Thermal Radiation Intensity During a Fire in the Oil Tank Farm Dike

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Abstract. Petroleum product storage facilities are explosion and fire hazard systems. The occurrence of an accident with oil spillage followed by a fire creates the danger of exposure of humans and the environment to thermal radiation. The most typical emergency is a fire of spills in the dike. This paper proposes a technical solution aimed at reducing the fire and explosion hazard for oil tanks. The thermal radiation intensity during a fire of spills in the dike has been calculated. The need to protect the oil storage tank farm with a fence wall with a wave deflector baffle has been proposed and mathematically justified. Along with reducing the likelihood of oil spills at the destruction of a vertical steel tank, this appliance will reduce the environmental consequences of a man-made accident.

1. Introduction

Oil and petroleum product storage facilities, where significant volumes of raw materials are concentrated in a relatively small area, are not only explosive and fire hazardous but also life support systems. Storing large volumes of oil poses a potential risk of various emergencies. The most typical emergency is a fire of spills in the dike [1].

In the event of an accident with oil spillage followed by a fire creates the danger of exposure of neighboring objects and the staff to thermal radiation and the likelihood of injury of humans staying at a certain distance from the epicenter of the accident by thermal radiation.

2. Research objective and calculations

The technical parameters of the oil tank destruction consequences should be determined.

The thermal radiation intensity has been calculated for the most dangerous substance stored at the facility - oil. The tank farm - 4 RVS-5000 (vertical steel tanks) with oil - is surrounded by an 80×80 m dike (area of 6,400 m²). The total volume of a single tank is 5,000 l, the tank diameter is 22.804 m, the tank height is 12.345 m. The tank filling degree is 0.8. In the case of an accident, one of the end tanks is destroyed with the spillage of 4,000 liters of oil into the dike. The ambient temperature is 20 °C.

The thermal radiation intensity during a fire has been calculated according to Appendix B. [2]. Additional calculation conditions are the spillage of 6,400 m² of oil into the dike to a distance of 40 m and exposure of firefighters to radiant heat.

The thermal radiation intensity q, kW/m², is calculated by the formula:

$$q = E_f \cdot F_q \cdot \tau,$$  \hspace{1cm} (1)

where $E_f$ is the average thermal irradiance of the flame, kW/m², $F_q$ is the effective irradiance,
τ is the atmospheric transmittance.
The fire seat area for the tank with a diameter of 22,804 m:

$$F_3 = \frac{\pi d^2}{4} = \frac{3.14 \times 22,804^2}{4} = 408,22 \text{ m}^2$$  \( (2) \)

The effective spill diameter d, m, is calculated by the formula (3):

$$d = \sqrt{\frac{4F_3}{\Pi}}$$  \( (3) \)

where \(F_3\) is the spill area, m².

$$d = \sqrt{\frac{4 \times 408,22}{4}} = 22,804 \text{ m}^2$$

The flame height \(N\), m, is calculated by the formula (4):

$$H = 42d \left( \frac{m}{\rho_{av}g d} \right)^{0.61}$$  \( (4) \)

Where

\(m\) is the specific mass burning rate of oil (table, \(m = 0.04 \text{ kg/(m}^2 \cdot \text{s})\)),
\(\rho_{av}\) is the ambient air density (1.15 \text{ kg/m}^3),
\(g\) is the gravity acceleration (9.81 m/s²).

$$H = 42 \times 22,804 \times \left( \frac{0.04}{1.15 \times \sqrt{9.81 \times 22,804}} \right)^{0.61} \approx 23.7 \text{ m}$$

The effective irradiance \(F_q\):

$$E_q = \sqrt{F_V^2 + F_H^2}$$  \( (5) \)

where

$$F_V = \frac{1}{\pi} \left[ \frac{1}{S} \cdot \arctg \left( \frac{h}{\sqrt{S^2 - 1}} \right) - \frac{h}{S} \cdot \{ \arctg \left( \frac{S-1}{(S+1)A} \right) - \frac{A-1}{\sqrt{A^2-1}} \cdot \arctg \left( \frac{(A+1)(S-1)}{(A-1)(S+1)} \right) \} \right],$$

$$F_H = \frac{1}{\pi} \left[ \frac{(B-1/S)}{\sqrt{B^2-1}} \cdot \arctg \left( \frac{(B+1)(S-1)}{(B-1)(S+1)} \right) - \frac{(A-1)}{\sqrt{A^2-1}} \cdot \arctg \left( \frac{(A+1)(S-1)}{(A-1)(S+1)} \right) \right],$$

\(A = \frac{h^2 + S^2 + 1}{2 \times S} = \frac{2,08^2 + 2,07^2 + 1}{2 \times 2,75} = 2,34\)

\(B = (1+S^2) / (2S), B = (1+2,75^2)/(2 \times 2,75) = 1,56\)

$$S = \frac{2 \times \sqrt{r}}{d} = \frac{2 \times 31,402}{22,804} = 2,75$$

$$h = \frac{2 \times H}{d} = \frac{2 \times 23,7}{22,804} = 2,08$$

$$F_V = \frac{1}{3,14} \left[ \frac{1}{2,75} \cdot 0,68 + 0,76 \{ 0,44 - 1,1 \cdot 0,82 \} \right] = 0,19$$
\[ F_H = \frac{1}{3.14} \left[ \frac{1.2 \cdot 1.13 - 0.93 \cdot 0.86}{1.2} \right] = 0.11 \]

The average thermal irradiance of the flame \( E_f \) is adopted according to Table P 3.4 of Appendix 4 [3].

Considering the spill (fire seat) diameter of 22.804 m, \( E_f \) can be found by linear interpolation of the table values in the fire seat diameter values of 20 and 30 m: \( E_f = 19.2 \text{ kW/m}^2 \).

Thus, the thermal radiation intensity for a fire of oil spills with an area of \( F_q \) (effective irradiance) at a point located at a distance of 20 m from the fire seat boundary will be:

\[ F_q = \sqrt{0.19^2 + 0.11^2} = 0.22 \]

The atmospheric transmittance \( \tau \) is determined by the formula (6)

\[ \tau = \exp[-7.0 \cdot 10^{-4} (r - 0.5 d)] \quad (6) \]

\[ \tau = \exp[-7.0 \cdot 10^{-4} (31.402-0.5\cdot22,804)] = 0.986 \]

The thermal radiation intensity \( q \) is calculated by the formula (7), assuming \( E_f = 12 \text{ kW/m}^2 \) according to Table A.3.4 [3]:

\[ q = E_f \cdot F_q \cdot \tau, \quad (7) \]

The \( q \) value is calculated by values of \( F_q \) and \( \tau \):

\[ q = 12 \cdot 0.22 \cdot 0.986 = 2.6 \text{ kW/m}^2 \]

The obtained \( q = 2.6 \text{ kW/m}^2 \) characterizes the intermediate value between the safe consequences for humans and the need to use heavy-duty clothing as a means of protection from thermal radiation.

3. Technical solution

As a technical solution to reduce the oil spill, it is proposed to install a vertical fence wall that will allow retaining the entire oil volume within the dike and prevent further spillage over a large area when the tank is destroyed. Then, the height of the oil tank farm fence wall should be determined [4, 5].

At the facility studied, 4 RVS-5000 tanks are located in two rows, see Fig. 1.

The calculation is performed according to SNiP 2.11.03-93 Storage of Oil and Petroleum Products. Fire safety standards [6].

\[ V = 5000 \text{ m}^3, \ D = 22.804 \text{ m}, \ H = 12.345 \text{ m}. \]
Figure 1. The RVS-5000 Dike Scheme.

The calculation is relevant if the below condition is met:

\[ 100 \leq V_t \leq 30000 \]
\[ 3 \leq L \leq 30 \]

Where \( L \) is the distance from the vertical wall to the tank wall, 6.75 m
\( V_t \) is the tank volume, m³.

The diked area can be found by the below formula, considering the dike width \((a)\) and length \((b)\):

\[ S_{dike} = a \cdot b \]

\[ S_{dike} = 80 \cdot 80 = 6,400 \text{ m}^2 \] (8)

Let us predict the diked area for the case of one of the four reservoirs destroyed.

Area of the intact tanks:

\[ S_{tanks}^{int} = \pi \frac{d^2}{4} \]

where \( d \) is the tank diameter.

\[ S_{tanks}^{int} = 3,14 \cdot \frac{22,804^2}{4} = 408.22 \text{ m}^2 \]

Let us calculate the dike height:

\[ h_{dike} = \frac{V_{tank}}{S_{dike} - S_{tanks}^{int}} \]

where: \( V_{tank} \) is the volume of a single tank, m³
\( S_{tanks}^{int} \) is the area of the intact tanks, m²
\( S_{dike} \) is the dike area, m²

\[ h_{dike} = \frac{5,000}{6,400 - (408.22 \times 3) + 0.2} = 1.17 \text{ m}^2 \]
Figure 2. Proposed Scheme of Fence Wall with a Wave Deflector Baffle.
1 - fence wall; 2 - wave deflector baffle; 3 – flux reflection plate; 4 - wall base.

\[ \alpha_1 = 15.2 \cdot \left( \frac{b}{H_{liq}} \right) + 0.485 \]
\[ \alpha_2 = f_2 \cdot \left( \frac{L_1}{R_{tank}} \right) = \log \left( \frac{L_1}{R_{tank}} \right) \]

Where \( H_w \) is the fence wall height, m,
\( b \) is the length of the wave deflector baffle outreach, 1 m,
\( L_1 \) is the distance from the tank center to the wall, 16.2 m,
\( H_{liq} \) is the maximum liquid level in the tank, 12 m,
\( R_{tank} \) is the damaged tank radius, 9.49 m.

\[ \alpha_1 = 15.2 \cdot \frac{1}{12} + 0.485 = 1.72 \]
\[ \alpha_2 = \log \left( \frac{18.402}{6} \right) = \log 1.707 = 0.4867 \]

Let us calculate the fence wall height:

\[ \frac{H_w}{K_s H_{liq}} = -0.0664 \cdot \left( \frac{a_1^2}{a_2^2} \right) + 0.0871 \cdot \frac{a_1}{a_2} + 0.0639 \cdot \frac{a_1}{a_2} \]
\[ H_w = K_s H_{liq} \cdot 0.1081 \]

Subject to the recommended safety factor \( K_s = 1.1 \):

\[ H_w = K_s H_{liq} \cdot 0.1081 \]
\[ H_w = 1.1 \cdot 12.345 \cdot 0.1081 = 1.47 \text{ m} \]

The required fence wall height is 1.47 m.

4. Conclusions
Arrangement of the fence wall proposed in the tank farm will ensure the required fire safety level of the protected facility and significantly reduce the damage caused by the accident. For the oil tank farm, the fence wall is assumed to be 1.47 m high.
The proposed fence wall with a wave deflector baffle can not only restrain the outburst wave and the entire volume of liquid spilled from a destroyed tank but also minimize the consequences of environmental damage.

5. References
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