Petroleum and Coal

Article **Open Access**

Health Threat for Fire-Fighters in The Fire of a Large-Capacity Tank Containing the Crude Oil

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Received December 14, 2020; Accepted April 21, 2021

Abstract

Among the characteristic phenomena accompanying the combustion of flammable liquids (crude oil) belongs the radiant heat. It is an integral part of such a fire. The emerging heat radiation can cause severe burns and serious damage to the respiratory tract of the intervening fire-fighters in such fires. In order to reduce the risk of damage to their health, it is necessary to know and predict the conditions around the burning high-capacity tanks. The paper deals with the prediction of the conditions around a selected large-capacity tank with the crude oil, focusing the radiant heat especially. The fulfillment of the stated objective has been progressively carried out, beginning with the calculation of the rate of heat (energy) release during the fire, mean height of the flame, the calculation of the density of heat flow and finished in calculation of heat flow density in various distances and levels of the burning tank surroundings. On the basis of the results obtained in the calculations, it was found that the zone with the highest density of heat flow in the levels on the surface of the ground, in the case of the analyzed large-capacity tank ranged between 25 and 35 m from the wall of the fire affected tank. Performed calculations in the paper can be applied to flammable liquids storing tanks of various sizes and designs, but the results can also be utilized in the practice of fire-fighting forces.

***Keywords**: Large-capacity tank, Radiant heat, Density of the heat flow.*

1. Introduction

Storage capacity of large-capacity tanks is today in comparison to tanks built decades ago, five to ten times larger. In the fires of crude oil stored in the large-capacity tanks, the radiant heat is generated, which spreads to the surrounding area, in which the other tanks, pipelines, buildings, infrastructure, persons, and not least the fire-fighters themselves, are located.

The potential risk of such a fire, we can never completely eliminate, even applying the most strictly requirements, measures defined in standards. The threats, such as some of the natural phenomena, or global terrorism, cannot be completely eliminated.

Fire risk arises mainly in the crude oil lifting stations, where there are multiple storage tanks situated side by side. The actual storage tanks are placed at intervals based on their diameter, but in some cases even less. In the fires of crude oil stored in the large-capacity tanks, there arises the density of the heat flow in order of 10^5 W·m^{-2}. The decrease in the density of heat flow with increasing distance is soft and the values that can be considered safe are at distances of hundreds of meters away from the fire scene. In the formation of a large fire and explosion at the industry workplaces or the oil lifting stations, it is possible that the fire will affect also the other tanks and the facilities in their surroundings and the fire will continue to expand. This situation is called a "domino" effect. An example is also a fire that occurred in Czechowice-Dziedzice (Poland) in 1971, see in Figure 1 [1].

Figure .1 Situation after the fire in Czechowice-Dziedzice (1971) (Source: www.bielskobiala.pl)

Crude oil viscosity is an important physical property that controls and influences the flow of oil through porous media and pipes. The viscosity, in general, is defined as an internal resistance of the fluid to flow. The evaluation of viscosity of crude oil is an important step in the design of various operations in oilfield and refineries. Therefore, the viscosity of crude oil, which is pressure and temperature dependent, must be evaluated for both reservoir engineering and operation design. The variation in viscosity with temperature and pressure changes is usually predicted empirically. Despite the importance of viscosity in engineering design, our understanding of such property is inferior to that of equilibrium properties [2].

2. Effect of thermal radiation on a man

In the fires, the thermal effect of a fire on the surrounding area is constantly changing. This change is affected by the course of fire, weather conditions and human activities during the fire extinguishing. Persons, who are presented during a fire are exposed to thermal radiation. Therefore, it is necessary to leave this dangerous area. When the heat generated by the fire affects the man`s skin, the skin is gradually heated up and after reaching the temperature of 45°C the pain threshold is exceeded. If the heat exposure of the skin continues, there gradually occurs the skin burns. According to the results of tests implemented in the past, in which people were exposed to heat and there their feelings and reactions on their skin were analyzed at the same time, different results have been achieved [1].

Recorded effects and feelings are introduced in Tables 1, 2 and 3. The differences in those values are likely to be caused by the different conditions during the tests and more complex specifications of description of other feelings by observed persons.

Table 1 Values of the heat flux density depending on the time of exposure and the feeling of pain [3]

Density (W.m^{-2})	Operating time (s)
280 – 550	Unlimited
625 – 1,050	180 – 300
1,100 – 1,600	40 – 60
1,680 – 2,200	20 – 30
2,200 – 2,800	12 – 14
2,800 – 3,100	7 – 10
> 3,500	2 – 5

Table 2. Values of the density depending on the sense of a man [15]

Density (W.m^{-2})	Observed effect
6,400	Pain after 8 s
10,400	Pain after 3 s
16,000	Blisters on the skin after

Table 3. Values of the density depending on the feeling of a man [4]

Density (W.m^{-2})	Man`s feeling
60 – 100	Perception of the heat
200 – 600	Feeling the warm
1,000 – 2,300	Feeling the heat
3,000 – 5,000	Feeling the pain

Permissible value of the heat flux density in the short exposure to human is 1,050 W·m^{-2}, in the long exposure is 540 W m^{-2} [4]. For the mobile fire-fighting technique, in which the fire-fighters are wearing the protective cloth, there are referred the critical flows ranged from 12,600 to 12,800 W·m^{-2} [1].

With the tank oil fire modelling for purposes of emergency planning dealt also Glatz, Gorzas and Hovanec [5]. In their work, they focused modelling of crude oil storage tank fire, in which they considered three scenarios. At a pool fire calculations, heat flux boundaries were considered for surrounding technology and intervening personnel. Using graphic representation (using maps), they determined the boundaries for the intervening team as well as for the location of fixed and mobile monitors.

Ghasemi and Nourai [6] introduced a framework minimizing domino effect through optimum spacing of storage tanks to serve in land use planning risk assessments. The novel framework to determine the water application rate for protection of storage tanks against thermal radiation from an external non-contacting fire through first principles modelling.

3. Large-capacity tank with a capacity of 30,000 m³

Large-capacity tank is all-metal, welded tank, with cylindrical shape. It is standing, overground tank. It has a floating roof that floats on the surface of the stored liquid. The maximum height of stored crude oil volume in the tank is of 20.2 m, the tank diameter is of 42.8. The diameter of the emergency tank is of 53.6 m and height of 14.5 m. The useful capacity of the tank with crude oil is of 29,062 m³. The tank is equipped with fire-fighting equipment for the delivery of fire-extinguishing foam on the surface of the burning liquid, into the sealing of the roof. On the outer perimeter of the shell is equipped with fittings, tanks for cooling of the tank shell. In Figure 2 is a sketch of the profile of the tank and on Figure. 3 is a view of the large-capacity tank with a capacity of 30,000 m^3.

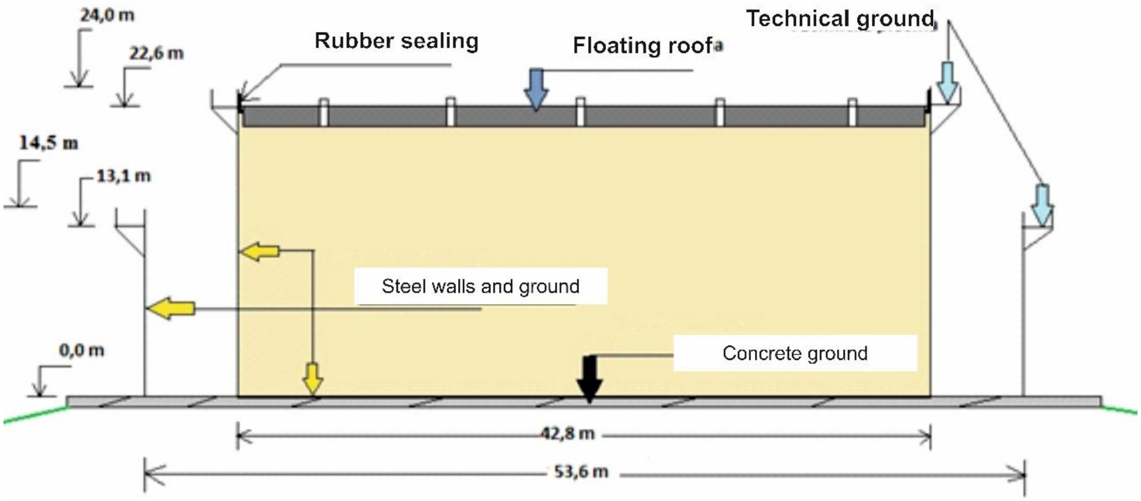


Figure 2. Profile of a large-capacity tank with capacity of 30,000 m^3 [13]

Floating roof with an area of 1 439 m² has around the perimeter the two thermo-sensitive cables for the detection of fire, which are brought out to the Operating Center of the Enterprise Fire Brigade.

Around the tank is built the emergency tank, which is also all-metal and cylindrical shape. It is also capable to capture the entire capacity of the storage tank. Emergency tank is fitted with a fire extinguishing and cooling device and also the thermo-sensitive cables for the detection of fires [7].

Figure 3. Storage tank with a capacity of 30,000 m^3 [8]

In the case of two-shell over-ground storage tanks, where is a space between the emergency and storage tank to capture the total capacity of crude oil, it is necessary to take into account a number of possible scenarios. In the case of damage of the storage tank is the most difficult scenario, in which there is a sum of the annulus area and the area of the storage tank. For simplification, it is possible to use the calculation of the horizontal diameter of the emergency tank. This is calculated as the sum of the storage tank area and the annulus.

Fire scenarios, which are theoretically possible:

- Fire in the space between the roof of the tank and the tank shell – **scenario S1**.
- Fire of the emergency tank and the space between the roof and the shell of the tank – **scenario S2**.
- Fire of the storage tank – allover (after floating roof tank immersion) – **scenario S3**.
- The current fire of the storage tank and emergency tank (immersed floating roof of the storage tank and damaged shell of the storage tank) – **scenario S4**.
- Fire in an emergency tank (the fire of the annulus) – **scenario S5**.

As the most complicated scenarios the S3 and S4 seem to be. These scenarios were selected for further calculations.

4. Calculation of parameters in case of a fire

4.1. Heat release rate in case of a fire

It is the heat released per unit of time (kJ·s^{-1}), varies with time, while:

- In the case of natural fire of the tank the heat release rate becomes a constant.
- It depends on the diameter of the tank (D).
- With a diameter of the tank over 0.2 m, the mass burning rate increases up to a certain value, then it is constant (m"∞),
- It depends on the constant (k. β) – i.e., a product of radiation flow characterizing the fuel, which values are available for liquids and thermoplastics.

When the crude oil in a large-capacity tank is burning, it is assumed that there will be a fire driven by fuel, since the access of air to the combustion zone should be not limited.

The energy release rate in case of fire is calculated from equation (1):

$$Q^{\bullet} = A_f \cdot m''_{\infty} \cdot (1 - e^{-k\cdot\beta\cdot D}) \cdot \chi \cdot \Delta H_C \tag{1}$$

here: A_f -horizontal burning surface (m^2); m''_{∞} – mass burning rate (kg.m^{-2}.s^{-1}); $k.\beta$ – product of the constants of radiation flow from a flame to the flammable liquid surface; D – tank diameter (m); χ – efficiency of burning (%); ΔH_c– total combustion heat (kJ.kg^{-1}) [9].

The values of the energy release rate are necessary for the calculation of mean height of the flame in the fire.

4.2. Mean height of flame in case of a fire

It provides experimental video – compliance with the freedom of the optical sense. The correlation of the height of the flames, the reason for this is the turbulent nature of the link with the area of burning D and Q a.

The real fires must take into account the fuel geometry (vertical and horizontal fuel distribution), the effect of the walls, the ceiling, holes [9].

The mean height of the flame $(L)_{(f)}$ (m) shall be calculated from equation (2):

$$\boldsymbol{L_f = 0{,}235 \cdot Q^{\bullet\frac{2}{5}} - 1{,}02 \cdot D} \tag{2}$$

The mean height of the flame in the fires of selected large-capacity tanks can be calculated by adding the energy release rate in a fire, calculated from the equation (1) into the equation (2). The calculated parameters are then used in the determination of the separation distances according to STN. The values of the mean height of the flame are also necessary for the calculation of the density of heat flux.

Storage tank with a capacity of 30,000 m^3 – input data:

tank diameter (D) 42.8 m; emergency tank diameter (D_h) 53.6 m; horizontal burning area (Af) 1,439 m^2; horizontal burning area of the emergency tank ($A_{f\,h}$) 2,256 m^2; m''_{∞} – mass burning rate 0.02833 kg.m^{-2}.s^{-1}; product of the constants of radiation flow from a flame to the flammable liquid surface ($k.\beta$) = 2.8 m^{-1}, efficiency of the crude oil burning (χ) 70 % i.e. 0.7; total crude oil combustion heat (ΔH_c) 42.5 MJ.kg^{-1} = 42,500 kJ.kg^{-1}

$Q^{\cdot}$ = 1,439 · 0.02833 · (1 – e$^{-2.8\,\cdot\,42.8}$)· 0.7 · 42,500 = 1,212,814.4 kJ·s^{-1} = 1,212.8144 MW

In the fire of the large-capacity tank with capacity of 30,000 m^3 the energy release rate will be of 1,213 MW. The mean height of the flame L_f (m)is of: L_f = 0.235 · 1,212,814.4 $^{2/5}$ – 1.02 · 42.8 = 20.1 m

The energy release rate and the mean flame height values are introduced also in Table 4. Those are introduced for two the most difficult fire scenarios (S3 and S4). Those parameters are mutually compared. From the energy release values comparison is evident the direct proportion between the energy release rate and the fire area. When comparing the mean flame height in both the scenarios, the difference of 1.55 m is evident.

Table 4. Parameters for fire scenarios S3 and S4

Tank	30,000 m^3	
Calculated volume	29,062 m^3	
Scenario	S3	S4
Diameter (m)	42.8	53.6
Area (m^2)	1 439	2 256
Q (MW)	1 213	1 901
L_f (m)	20.10	21.65

4.3. The heat flux density

The heat flux density q (kW.m^{-2}) is calculated based equation (3), taking into account the equivalent time of fire duration τ_e or τ_{em}, i.e. the virtual time of fire duration, when the fire propagation in a specific fire section would be corresponding with the standardized temperature curve and would evolve the equivalent effects as the real fully developed fire, or taking into account calculated fire loading p_v or p_{vm} and gas temperature, which is for the equivalent time of fire duration expressed (equation 4) by the standardized temperature curve T_N (°C) [16].

$$q = (T_N + 273)^4 \cdot 5{,}67 \cdot 10^{-11} \tag{3}$$

$$T_N = 20 + 345\, log(8t + 1) \tag{4}$$

where: q – heat flux density (kW.m^{-2}); T_N – standardized gas temperature in burning space (°C); t – equivalent time of fire duration (τ_e or τ_{em} (min), p_v or p_{vm} (kg.m^{-2}), from Table 2 of the STN 92 0201-4, [16] max. value 180).

The density of the heat flux in the crude oil fire was calculated as follows: t = 180 min

$T_N = 20 + 345 \log(8 \cdot 180 + 1) = 1{,}110°C$

$q = (1{,}110 + 273)^4 \cdot 5.67 \cdot 10^{-11} = 207.4$ kW·m^{-2}

In the next calculations, there was used the above calculated value of the heat flux density. The values of the heat flux density of the flame, depending on its temperature, are demonstrated in Table 5. There are compared the values of the heat flux density for the individual temperatures of the flame, which for the crude oil fires reported Michejev [10] in 1960 and Olšanský in 1976 [11]. Those were specified in the range of 1,000 – 1,300°C. Olšanský [11] specified also the value after boil over the crude oil, which increased up to 1,500°C.

Tab. 5 Densities of heat flux of the flame for the various temperatures of the flame

T (°C)	1,000	1,110	1,200	1,300	1,500
q (kW·m^{-2})	148.9	207.4	266.9	347.1	560.3

4.4. Heat flux density in a specified distance

The heat flux density in a specified distance can be calculated using the position factor – coefficient ϕ (-). The position factor is a part of an overall radiant heat radiated from the radiant surface, which is falls on the surface of the heat receiving area. Its value is dependent on the extent of the radiant surface, the distance of the receiving area from the radiant surface and also on their mutual orientation. The simplest is a parallel orientation. Partial position factor is expressed in equation (5) published by Kadlec [12], which was modified by specifying the marked tank parameters and the mean height of the flame.

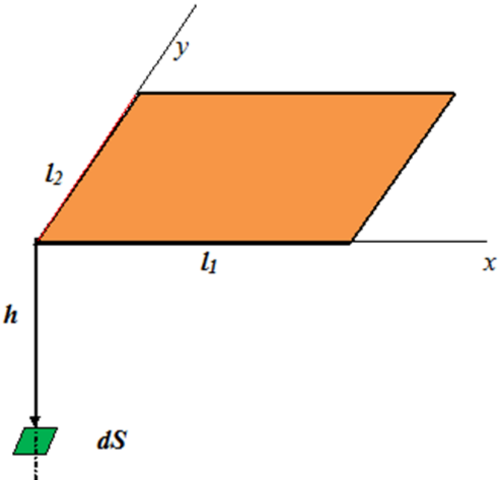


Figure 4. Elementary surface on the normal to the S surface peak

$$\varphi dS, S = \frac{1}{2 \cdot \pi}\left(\frac{l_1}{\sqrt{h^2+l_1^2}} \cdot arctg\frac{l_2}{\sqrt{h^2+l_1^2}} + \frac{l_2}{\sqrt{h^2+l_2^2}} \cdot arctg\frac{l_1}{\sqrt{h^2+l_2^2}}\right) \tag{5}$$

The resulting value of the heat flux density (after calculation of coefficient - position factor) can be obtained by the equation (7), which is a modification of the equation (6).

$$\varphi_{cr} = \frac{q_{cr}}{q} \tag{6}$$

where: q_{cr} – selected value of critical flux (kW.m^{-2}); q – density of radiant flux (kW.m^{-2}).

$$q_L = \varphi \cdot q \tag{7}$$

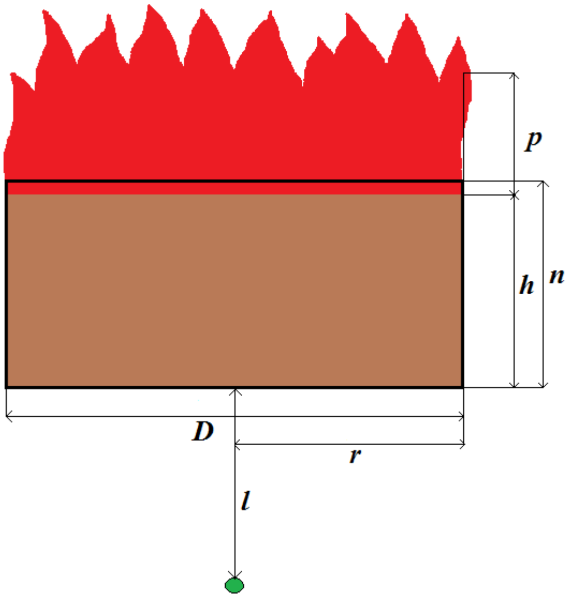
where: q_L – heat flux density in a specified distance (kW.m^{-2}); ϕ – position factor (coefficient) (-); q – flame heat flux density (kW.m^{-2}).

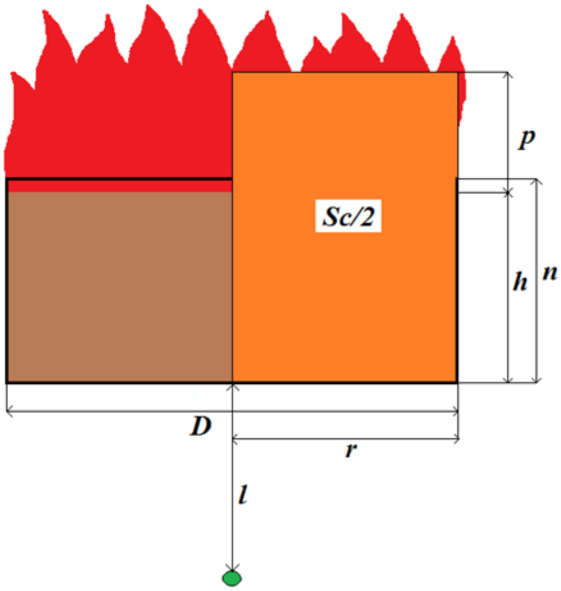
Figure 5 Mobile monitor Ambassador [11]

In Figure 6, there are marked the basic data required to calculate the heat flux in a specific distance from the fire affected large-capacity tanks. Heat flux density at selected distances from the fire affected tank was calculated for the three height levels: 0 m – surface of the ground, 1.5 m above the ground a 2.5 m above the ground. The height of 1.5 m above the ground represented the height of a fire-fighter`s face and the height of 2.25 m represented the height of the fire-fighter`s face, when extinguishing the fire from the Ambassador operational platform (Figure 5).

The resulting position factor represent a difference between the radiation coefficient *ϕdSc* and radiation coefficient *ϕdS*n, in calculation of the heat flux in the above mentioned three height levels.

The half of the overall coefficient *ϕdSc* is shown in Figure 7, marked as *Sc/2*. We calculate it from the modified equation (8). Then the radiation coefficient *ϕdSn/2* is calculated, using the modified equation (10). Coefficient Sn/2 is indicated in Figure 8. Coefficient *Sc* is calculated using the equation (9), multiplying the *Sc/2* value by 2. Similarly, Sn coefficient is calculated, applying the equation (11). Consequently, using the equation (12), the *Sn* coefficient is subtracted from the overall *Sc* coefficient and the result is the value of a position factor *ϕ*.





where*:* *h* – Height of the crude oil level in the tank (maximum level); *l* – Distance from the tank wall; *D* – Tank diameter; *r* – Tank radius; *p* – Flame height (L_f mean flame height calculated.

Sc/2 (rad) is calculated based on the equation (8):

$$\varphi dS,Sc/2=\frac{1}{2\cdot\pi}\left(\frac{r}{\sqrt{l^2+r^2}}\cdot arctg\,\frac{(p+h)}{\sqrt{l^2+r^2}}+\frac{(p+h)}{\sqrt{l^2+(p+h)^2}}\cdot arctg\,\frac{r}{\sqrt{l^2+(p+h)^2}}\right) \qquad (8)$$

$$\varphi dS,Sc=2\cdot Sc/2 \qquad (9)$$

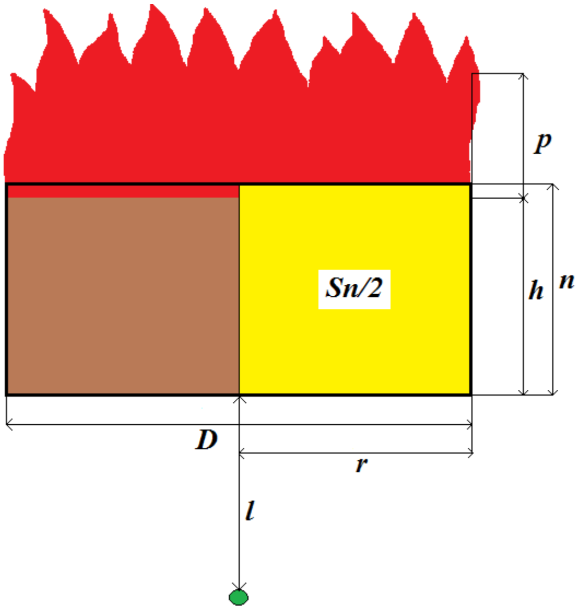


Figure 8 A half of the tank profile area *Sn/2* [7]

Sn/2 (rad) is calculated as follows:

$$\varphi dSn/2=\frac{1}{2\cdot\pi}\left(\frac{r}{\sqrt{l^2+r^2}}\cdot arctg\,\frac{n}{\sqrt{l^2+r^2}}+\frac{n}{\sqrt{l^2+n^2}}\cdot arctg\,\frac{r}{\sqrt{l^2+n^2}}\right) \qquad (10)$$

$$\varphi dS,Sn=2\cdot Sn/2 \qquad (11)$$

$$\varphi=\varphi dSc-\varphi dSn \qquad (12)$$

In the modified equation (7) is specified the resulting value of position factor in selected distance and flame heat flux density value (207,4 kW.m^{-2}) according to equation (3). The result of the product of these parameters is the density of heat flux at a specific distance from the fire affected tank shell.

Calculation of a heat flux density for a specific scenario

Calculation of the heat flux density at a distance of 20 m from the tank with capacity of 30,000 m^3 in the ground level (0 m) for the scenario S3 (in table S3/0 m).

Height of the crude oil level in the tank (maximum level) (h) 20.2 m; distance from the tank wall (l) 20.0 m; tank diameter (D) 42.8 m; tank radius (r) 21.4 m; height of the tank wall (n) 22.6 m; flame height (L_f mean flame height calculated) (p) 20.1 m.

$$\varphi dS,Sc/2=\frac{1}{2\cdot\pi}\left(\frac{21.4}{\sqrt{20^2+21.4^2}}\cdot arctg\,\frac{(20.1+20.2)}{\sqrt{20^2+21.4^2}}+\frac{(20.1+20.2)}{\sqrt{20^2+(20.1+20.2)^2}}\cdot arctg\,\frac{21.4}{\sqrt{20^2+(20.1+20.2)^2}}\right)=0.17286$$

$$\varphi dS,Sc=2\cdot Sc/2=2\cdot 0.17286=0.34572$$

$$\varphi dSn/2=\frac{1}{2\cdot\pi}\left(\frac{21.4}{\sqrt{20^2+21.4^2}}\cdot arctg\,\frac{22.6}{\sqrt{20^2+21.4^2}}+\frac{22.6}{\sqrt{20^2+22.6^2}}\cdot arctg\,\frac{21.4}{\sqrt{20^2+22.6^2}}\right)=0.14992$$

$$\varphi dS,Sn=2\cdot Sn/2\quad=2\cdot 0.14992=0.29985$$

$$\varphi=\varphi dSc-\varphi dSn\quad=\quad 0.34572\;-\;0.29985=0.04587$$

$$q_L=\varphi\cdot q=0.04587\cdot 207.4=9.51\ \ \mathrm{kW}\cdot m^{-2}$$

5. Results for the large-capacity tank with capacity of 30,000 m^3

The basic data for the calculation of the density of heat flux in specific distances from the large-capacity tank with a capacity of 30,000 m^3 are:
For S3 scenario: D = 42.8 m, r = 21.4 m, n = 22.6 m, h = 20.2 m, p = 20.1 m,
For S4 scenario: D_h = 53.6 m, r_h = 26.8 m n_h = 14.5 m, h_h = 12.9 m, p_h = 21.65 m.

Table 6 shows the calculated density of heat flux for large-capacity tank (30,000 m^3) in the specified distances and levels on the surface of the ground and above the ground. It has seven columns. In the first column is specified the distance (l) in m from the wall of the fire affected tank. Heat flux density values in the table are introduced in the intervals starting from 5 up to 300 m, while the interval from 5 to 70 m is separated to smaller 5 m distance intervals. These distances are interesting in terms of the threat to fire-fighters when intervening in this area. The distances in interval starting from 100 to 300 m are divided to intervals of 50 m. For scenario S3 is the distance calculated from the wall of the storage tank, in the case of scenario S4 is calculated from the walls of an emergency tank. In the second and up to the seventh column, there is introduced the calculated value of the heat flux density (q_L) in a specified distance as at level of the surface of the ground and above the ground (at height of 1.5 and 2.25 m). for scenario S4 in relationships (8) and (10) shall appoint the value for emergency tank marked with the index $_{(h)}$.

For each level, as on the surface of the ground and above the ground, there are submitted the below introduced values, specific for each scenario. For scenario 4, there were submitted the values indicated with index for emergency tank "$_h$", in equations (8) and (10).

For S3/0 m – at the surface of the ground height, in equation (8) is applied the following formula (p + h) = (20.10 + 20.20) = 40.30 m

For S3/1.5 m – at height of 1.5 m above the ground, in equation (8) is $(p + h)$ substituted by $(p + h) - 1.5$ = (20.10 + 20.20) – 1.50 = 38.80 m and the in equation (10) n value is substituted by $(n - 1.5)$ = (22.60 – 1.50) = 21.10 m

For S3/2.25 m – at height of 2.25 m over the ground, the equation (8) is substituted by (p + h) – 2.25 = (20.10 + 20.20) – 2.25 = 38.05 m and equation (10) is substituted by (n – 2.25) = (22.60 – 2.25) = 20.35 m

For S4/0 m – at height of the surface of the ground, applying equation (8) is calculated as follows: $(p_h + h_h)$ = (21.65 + 12.90) = 34.55 m

For S4/1.5 m - at height of 1.5 m above the ground, in equation (8) is $(p_h + h_h) - 1.5$ = (21.65 + 12.90) – 1.50 = 33.05 m and in equation (10): $(n - 1.5)$ = (14.50 – 1.50) = 13.00 m

For S4/2.25 m – at height of 2.25 m above the ground, in equation (8) is applied the substitution of $(p_h + h_h) - 2.25$ = (21.65 + 12.90) – 2.25 = 32.30 m an in equation (10): (n – 2.25) = (14.50 – 2.25) = 12.25 m

For S3 scenario: D = 42.80 m, r = 21.40 m, n = 22.60 m, h = 20.20 m, p = 20.10 m,
For S4 scenario: D_h = 53.60 m, r_h = 26.80 m, n_h = 14.50 m, h_h = 12.90 m, p_h = 21.65 m.

Tab. 6. Resulting values for the large-capacity tank with capacity of 30,000 m^3

l (m)	q_L (kW.m^{-2}) S3/0 m	q_L (kW.m^{-2}) S3/1.5 m	q_L (kW.m^{-2}) S3/2.25 m	q_L (kW.m^{-2}) S4/0 m	q_L (kW.m^{-2}) S4/1.5 m	q_L (kW.m^{-2}) S4/2.25 m
5	1.17	1.41	1.56	4.05	5.16	5.87
10	3.99	4.74	5.17	12.21	14.89	16.50
15	7.10	8.24	8.89	18.94	22.17	24.00
20	9.51	10.81	11.53	22.54	25.54	27.17
25	10.94	12.19	12.87	23.55	26.05	27.35
30	11.48	12.59	13.18	22.95	24.91	25.93
35	11.41	12.34	12.83	21.51	23.03	23.80
40	10.96	11.72	12.11	19.73	20.89	21.47
45	10.30	10.91	11.22	17.88	18.76	19.21
50	9.40	10.04	10.29	16.10	16.78	17.12
55	8.79	9.18	9.38	14.47	15.00	15.26

l (m)	q_L (kW.m^{-2}) S3/0 m	q_L (kW.m^{-2}) S3/1.5 m	q_L (kW.m^{-2}) S3/2.25 m	q_L (kW.m^{-2}) S4/0 m	q_L (kW.m^{-2}) S4/1.5 m	q_L (kW.m^{-2}) S4/2.25 m
60	8.05	8.36	8.52	13.00	13.41	13.62
65	7.36	7.61	7.74	11.70	12.02	12.18
70	6.72	6.93	7.03	10.54	10.80	10.93
100	4.02	4.09	4.12	6.02	6.10	6.14
150	2.01	2.03	2.03	2.92	2.94	2.95
200	1.18	1.19	1.19	1.70	1.70	1.71
250	0.77	0.77	0.77	1.10	1.11	1.11
300	0.54	0.54	0.54	0.77	0.77	0.77

In Figure 9 is visualized the dependence of the density of heat flux on the distance from the wall of the fire affected large-capacity tank in scenario S3. Distinguished by color curves demonstrate the differences in the density of heat flux at three levels: on the surface of the ground, at height of 1.5 and 2.25 m above the ground. From the curves, it is possible to see that the heat flux density values are increasing with increasing value of the height. The highest density of heat flux was at a distance of approximately 30 m from the wall of the storage tank. From this distance the density of heat flux decreased. It is a so-called zone of maximum heat flux density q_{max}.

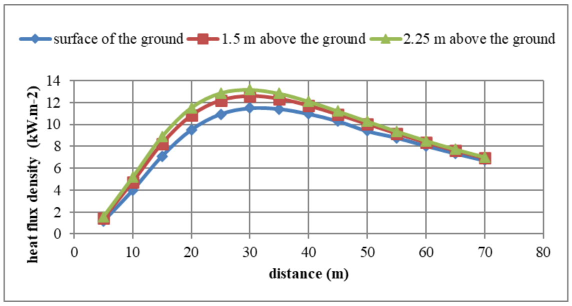


Figure 9. Heat flux density values at selected distances and height levels above the ground – S3 scenario

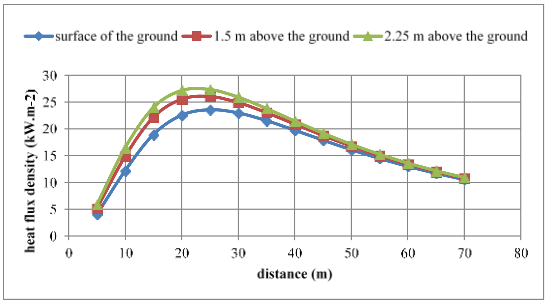


Figure 10. Heat flux density values in selected distances and height levels above the ground – S4 scenario

In Figure 10, there is a graph representing the heat flux densities for scenario S4. The q_{max} zone is in the distance of just under 25 m from the wall of an emergency tank. From the data introduced in Figure 9 and 10 is evident that the heat flux densities are higher in scenario S4 as from the distance as from the height level point of view.

6. Conclusions

The impact of the enormous radiant heat when there is a fire of large-capacity tank, it is a threat, that the fire-fighters in tactical training may not be aware of or in are not able to reproduce it any way. The radiant heat intensity and its effect at a certain distance from the fire affected tank depend on several factors.

The calculated parameters of the fire of large-capacity tank with a crude oil, in the selected scenarios, allow you to create a better idea of the potential risk, hidden in those storage tanks. They point to the need to fully realize the very high risk, invisible to the naked eye, related to the presence of radiant heat, when the fires of substances with high combustion heat occur in larger quantities. In the calculations, it was found that the density of the heat flux at the surface of the surrounding terrain is not the largest in the wall of the affected tank, but at some distance from it. In the calculations, the zone with a maximum density of heat flux for the storage tank ranged between 25 and 35 m from the wall of the affected tank.

In the end, the value of the heat flux density in the vicinity of the fire affected tank depends at the same time from a number of factors. If we do not take into account weather conditions, so they are, in particular: the diameter of the tank, the height of the walls of the tank, the amount of the crude oil level in the tank, distance from the tank, position against the tank, the height above the surface of the ground, the mean height of flames in case of fire, the temperature of the flame and emissivity and shielding the flame with smoke.

Acknowledgment

The paper was created with the support of the KEGA agency, project no. 001TU Z-4/2020.

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