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CALCULATION OF HEAT FLUX DENSITY AT A LARGE OIL TANK FIRE AFFECTING NEIGHBORING TANKS

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Abstract

In general, the storage volume of the bulk tanks is five up to ten times bigger compared to the storage tanks built several decades ago. The potential risk of such a fire cannot be eliminated even by the most strict regulations or precautions. When there is an oil storage tank fire, radiant heat is formed which spreads further into an environment often containing other storage tanks. The paper presents the calculation of the heat flux density in a specified distance from the burning tank. The resulting value of the heat flux density in the surrounding of the tank depends simultaneously on several factors. The construction of bulk oil tanks is recommended to have, in the future, legislation regulations also considering the value oil radiant heat at a fire. Based on the calculation of the radiant heat values in a specific area, the minimum separation distance between storage tanks shall be stated.

Keywords: *Oil fire; Fire scenario; Bulk storage tank; Heat flux density.*

1. Introduction

In case oil catches on fire, the rapid spread of fire and intense burning can be assumed. The fire shall spread across the entire surface of the flammable liquid. Oil has high calorific value and the flame temperature achieves 1000 to 1300°C [1]. If a big fire or explosion occurs at an oil hub or a storage center it is rather likely that the fire shall strike also other tanks and adjacent facilities and that it shall spread farther. This situation is called a domino effect. The risk analysis of domino effect fires in storage areas was investigated by [2]. They claim that domino accidents account for the largest proportion (44%) in the causes of pool fires at storage areas and therefore it needs further thorough investigations. The example is presented by the fire in Čechovice (Poland) in 1971. The fire risk forms especially at pumping stations where there are more storage tanks within the proximity. The individual storage tanks are placed in the distance close to their diameter, rarely closer. At fires of large storage tanks, the heat flux density achieves in the order of 10^5 W.m^{-2}. The decrease in the density of the heat flux is rather moderate and the space considered safe is in the distance of hundreds of meters from the fire spot. The heat impact is constantly changing at crude oil fires as there are influences by the fire development, climatic conditions, and human interference during the fire suppression [3].

2. Objectives

The main objectives of the paper are to introduce the calculation of the heat flux at the selected distance of a large storage tank. This calculation shall then be applied on selected large capacity tanks and at various fire scenarios considering other neighboring tanks. The necessary parameters related to a fire and separation distances are described next.

2.1. The fire parameters calculation

Energy release rate:
It is energy released per unit of time (kJ s^{-1}); it changes with time, whereas:

- At a natural fire of tanks, the rate becomes the constant,
- depends on the tank diameter *D,*
- at the diameter over 0.2 m the burning rate per unit area increases until a certain diameter then it becomes constant m''_{∞},
- it depends on the constant $k.\beta$ – the product of radiation flux characteristic for fuel which is set for liquids and thermoplastic.

When a large storage tank is burning, it is assumed that it is a fuel limited fire as there should not be access of air into the fire limited by any means. Energy release rate at the fire is calculated from the equation (1):

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

where: A_f -horizontal burning area (m^2); m''_{∞} – burning rate per unit area (kg m^{-2} · s^{-1}); $k.\beta$– the product of flame heat flux constants against flammable liquid surface; D– tank diameter (m); χ–fuel efficiency (%); ΔH_c – total heat of combustion (kJ.kg^{-1}) [4].

The values of energy release at the fire are necessary to calculate the mean length of the flame at a fire.

2.1.1. Mean flame length

Averaging of the visible flame in time, *y* (flame appearance) 1.0 permanent visible flame length; 0.5 half of the flame in time; on the *x* axes distance from the flame *L* (m). It is stated experimentally based on the video records in harmony with subjective optical perception. The correlation of flame length is caused by the turbulent nature and relation to the area of combustion *D* and *Q*.

At real fires the fuel geometry must be also taken into account-vertical or horizontal layout of the fuel), the impact of shells, ceiling, openings [5].

The mean flame length L_f (m) is calculated from the equation (2):

$$L_f = 0{,}235 \cdot \sqrt[5]{Q^{\bullet 2}} - 1{,}02 \cdot D \qquad (2)$$

The mean flame length for large storage tanks can be calculated by substituting the energy release rate calculated from equation (1) into the equation (2). The mean flame length values are essential to calculate the heat flux density.

2.1.2. Calculation of flame heat flux density

Heat flux density *q* (kW · m^{-2}) (equation 3) is determined from the equivalent time of fire duration τ_e or τ_{em} (it is hypothetical time of fire duration during which a fire would last in the fire compartment according to the stated temperature curve and would pose equivalent impacts in the construction as a real fully developed fire), or possibly from the calculated fire load p_v or p_{vm} and gas temperature which is expressed by a standardized temperature curve T_N (°C), (STN 92 0201-4, 2000) for the equivalent time of fire duration (equation 4).

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

$$T_N = 20 + 345\, log(8t + 1) \qquad (4)$$

where: q–heat flux density (kW·m^{-2}); T_N–standardized gas temperature in a burning compartment (°C); t–the equivalent time of fire duration (τ_e or τ_{em} in minutes, p_v, or p_{vm} in $kg\ m^{-2}$, from Table No.2, STN 92 0201-4, max. value 180).

The flame heat flux density for crude oil fires is calculated from equation (3), where t = 180 min.

T_N = 20 + 345 log(8 180 + 1) = 1 110°C

q = (1110 + 273)^4 5.67 10^{-11} = **207.4 kW.m^{-2}**

The calculated value of 207.4 kW.m^{-2} shall be considered in further calculations.

The flame heat flux densities depending on its temperature are given in Table 1. The values of flame heat flux temperatures for specific flame temperatures are compared to those of stated by *Michejev* [6]; *Olšanský* [7] ranging from 1 000° to 1 300 °C, at crude oil boiling (stated by *Olšanský* [7]) up to 1 500°C.

Tab. 1 Flame heat flux densities for given flame temperatures

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

2.1.3. Heat flux density at the specific distance

The heat flux density at a specific distance can be calculated via a distance factor - coefficient φ (-). The distance factor affects the total radiant heat being emitted by a radiant surface which lands on the receiving surface. Its value depends on the size of the emitting surface, the distance of the receiving surface from the emitting surface and on their mutual orientation. The parallel position presents the simplest arrangement. A partial distance factor is expressed in equation (5). In Figure 1 the basic area presents the receiving area at the vector towards the *S* area, which presents the emitting area.

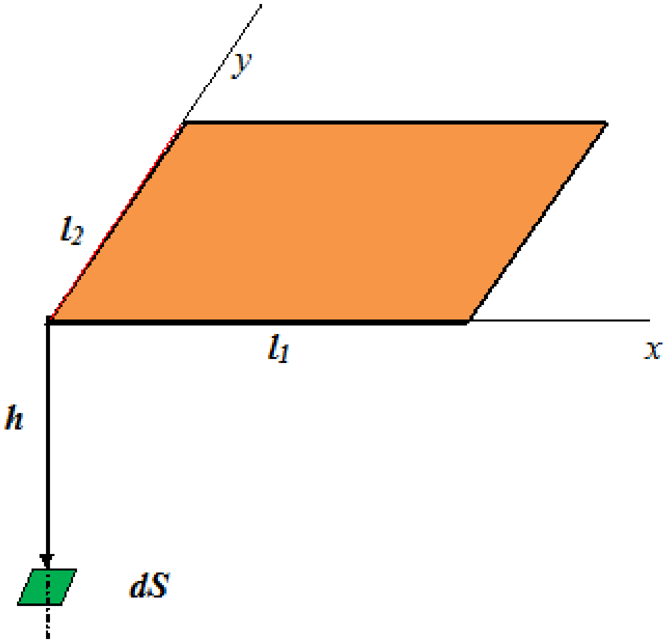

Fig.1. Basic area (dS) towards the top of the *S* area

To calculate the heat flux density in the specific area, the relation (5) according to Kadlec [8] was used. The relation was modified by inserting relevant tank parameters and the mean length of flames.

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

The final value of the heat flux density (having calculated the position factor) can be achieved via a modified relation (7) out of the relation (6),

$$\varphi_{cr} = \frac{q_{cr}}{q} \qquad (6)$$

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

$$q_L = \varphi \cdot q \qquad (7)$$

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

The final value of the position factor in the chosen distance and the calculated flame heat flux density of 207.4 kW.m^{-2} from (8) are inserted in the modified – derived relation (7) and the product of these parameters is the heat flux density in the given distance from the outer shell of the affected tank.

2.2. The energy release rate and mean flame length

In the world, there are several variants of the large storage tanks for crude oil. The comparison of the fire safety of the storage tanks and possibilities to extinguish the fires of such large storage tanks is devoted a minimal attention in the scientific community in European countries.

The calculations of the parameters are conducted for selected volumes of the large storage tanks. The tanks of two sizes–30 000 m^3 and 70 000 m^3 are currently in operation in Slovakia. The crude oil pump station in Tupá (Slovak Republic) comes as the fourth one in order from the east border from Ukraine. There are six tanks of the 30 000 m^3 volume and two of 70 000 m^3

volume in operation. The tank of 125 000 m^3 volume is used to store crude oil in the Central Crude Oil Tank Farm Nelahozeves of Mero Company (Czech Republic), where 16 crude oil tanks with the total storage capacity of 1 550 000 m^3 are located. The calculations of the energy release rate and mean flame length tanks of the mentioned capacities are described individually further.

The chosen tanks are of similar construction and make, however, they have different dimensions which shall be used in the investigation. When considering double layer aboveground storage tanks where there is free space between the storage tank layer and the outer safety shell, several fire scenarios should be taken into account. To simplify the issue, the horizontal area of the outer tank diameter, which is, in fact, the sum of the storage tank area and the ring towards the outer safety shell, is being used for calculations.

The fire scenarios which might occur:

1. A fire in the space between the tank roof and tank shell- **S1 scenario.**
2. A fire of the outer safety tank and the space between the roof and tank shell–**S2 scenario.**
3. A fire of the storage tank - full-area fire (the floating roof is immersed)–S3 scenario.
4. A simultaneous fire of the storage tank and safety tank (the floating roof of the storage tank is immersed and the outer shall of the safety tank is damaged)–**S4 scenario.**
5. A fire in the outer safety tank (a fire in the ring)–**S5 scenario**.

The S3 and S4 scenarios seem to be the most complicated. Therefore, they are used in the further study.

3. Calculations

3.1. Storage tank of 30.000 m^3 volume – energy release rate

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

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

During a fire of a large storage tank of 30,000 m^3 volume, the energy release rate shall be approximately **1 213 MW**.

3.1.1. Storage tank of 30.000 m^3 volume - the mean flame length L_f (m)

$$L_f = 0.235 \cdot \sqrt[5]{Q^{\cdot 2}} - 1.02 \cdot D$$

$$L_f = 0.235 \cdot \sqrt[5]{1\,212\,814.4^2} - 1.02 \cdot 42.8 = 20.1\ m$$

The mean flame length shall be approximately **20.1 m**.

3.2. The storage tank of 70,000 m^3 volume - energy release rate

D–tank diameter (66 m); D_h –diameter of the safety tank (80 m); A_f – horizontal burning surface area of the tank (3421 m^2); $A_{f\,h}$–horizontal burning surface area of the safety tank (5027 m^2); m''_{∞} – planar burning rate (0.02833 kg m^{-2} · s^{-1}); $k.\beta$ –the product of flame radiation flux constants against the flammable liquid surface (2.8 m^{-1}); χ – fuel of crude oil (70 % i.e. 0.7); ΔH_c – total crude oil combustion heat (42.5 MJ · kg^{-1} = 42 500 kJ ·kg^{-1})

Q = 3 421 0.02833 (1 – e$^{-2.8.\,66}$) 0.7 42 500 = 2 883 278.7 kJ s^{-1} = 2 883.2787 MW

During the fire of a large storage tank of 70 000 m^3, the energy release rate shall be approximately **2 883 MW**.

3.2.1. The storage tank of 70,000 m³ volume-the mean flame length

$L_f = 0.235 \cdot \sqrt[5]{2\,883\,278.7^{\,2}} - 1.02 \cdot 66 = 22.84\ m$. The mean flame length shall be **22.84 m**.

3.3. The large storage tank of 125 000m³ – energy release rate

D tank diameter (84.47 m); D_h–diameter of the safety tank (90.47 m); A_f –horizontal burning surface area of the tank (5 604 m²); $A_{f\,h}$–horizontal burning surface area of the safety tank (6 428 m²); m''_∞ – planar burning rate (0.02833 kg m^{-2} s^{-1}); *k.β*–the product of flame radiation flux constants against the flammable liquid surface (2.8 m^{-1}); *χ* – fuel of crude oil (70 % i.e. 0.7); ΔH_c – total crude oil combustion heat 42.5 MJ kg^{-1} = 42 500 kJ kg^{-1})

$\dot{Q} = 5\,604 \cdot 0.02833\,(1 - e^{-2.8\,\cdot\,84.47})\,0.7 \cdot 42\,500 = 4\,723\,149.3\ \text{kJ s}^{-1} = 4\,723.1493\ \text{MW}$

During a fire of a large storage tank of 125 00m³, the energy release rate shall be approximately **4 723 MW.**

3.3.1 The large storage tank of 125 000 m³ - the mean flame length

$L_f = 0.235 \cdot \sqrt[5]{4\,723\,149.3^{\,2}} - 1.02 \cdot 84.47 = 23.68\ m$

The mean flame length at the fire shall be approximately **23.68 m**.

The parameters of energy release rate at a fire and the mean flame length are stated in Table 2. These parameters are compared for large storage tanks in the most complicated scenarios. The comparison of the values of the energy release rate shows the direct proportionality in increasing the energy release rate with the increasing size of the fire area.

Tab. 2 Comparison of calculated parameters for the chosen fire scenarios

Tank calculated volume	30 000 m³ 29 062 m³		70 000 m³ 72 803 m³		125 000 m³ 124 968 m³	
Scenario	S3	S4	S3	S4	S3	S4
Diameter(m)	42.8	53.6	66	80	84.47	90.47
Area (m²)	1 439	2 256	3 421	5 027	5 604	6 428
$\dot{Q}$ (MW)	1 213	1 901	2 883	4 237	4 723	5 418
L_f (m)	20.10	21.65	22.84	23.57	23.68	23.76

3.4. Calculation of the heat flux density affecting the neighboring tanks

To calculate the heat flux density in a specific distance there was used the relation 8 modified from the relation 5 [8], which was modified by inserting selected parameters of the tank and the mean flame length.

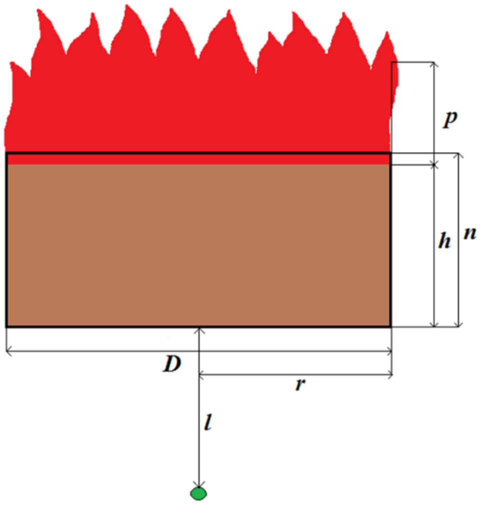

Figure 2 shows the basic parameters of the large crude oil storage tank, where: *h*–crude oil level height in the tank (maximum height considered); ℓ–the distance from the burning tank shell; *D* – tank diameter; *r* – radius of the tank; *n* – tank shell height; *p* – flame length (calculated mean flame length L_f), which were used to calculate the heat flux at a specific distance from the burning large oil storage tank.

Figure 2. The scheme of a burning tank and relevant parameters

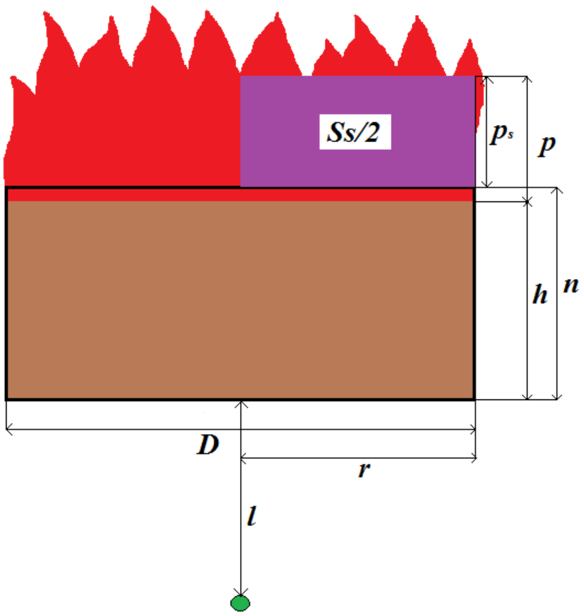

Figure 3 shows the half of the emitting flame surface (referred to as *Ss/2*) in purple color. This area of emitting flame is the basis for the calculation of the distance factor considering the effect of heat flux on the neighboring container. Referring to S3 scenario the calculations shall be projected for radiation on the neighboring tank of the same dimensions as the burning tank at the level of the upper edge of the neighboring tank shell. In case of the fire of the safety tank (S4 scenario) the final values of heat flux density projected at the height of the safety tank on the outer shell of the neighboring tank.

Fig. 3 Half of the cross section area of the ratiating flame Ss/2 ; *Ss/2* (radians) – half of the area of the radiating flame p_s

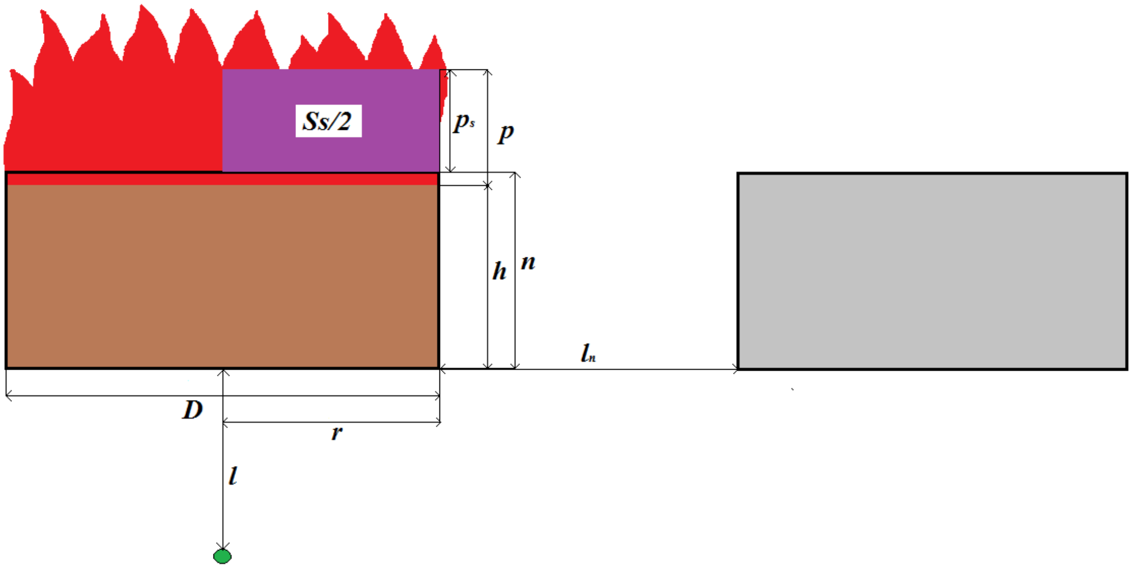

Fig. 4 Scheme of the heat flux effect on the neighboring tank with marked parameters

Figure 4 shows the distance between the tanks l_n.

$$\varphi dS,Ss/2=\frac{1}{2\cdot\pi}\left(\frac{r}{\sqrt{l_n^2+r^2}}\cdot arctg\frac{p_s}{\sqrt{l_n^2+r^2}}+\frac{p_s}{\sqrt{l_n^2+p_s^2}}.\,arctg\frac{r}{\sqrt{l_n^2+p_s^2}}\right) \tag{8}$$

$$\varphi dS,Ss=2\cdot Ss/2 \tag{9}$$

where: p_s – the length of the radiating flame – the length of the flame lowered by the difference between the height of the tank shell and height of the oil level in the tank; $p_s = p - (n - h) = (p - n + h)$; l_n – the distance of the neighboring tank shell from the shell of the burning tank.

4. Results

4.1. The large storage tank of 30 000 m³ volume

To calculate the heat flux density against the neighboring tanks the distance of 35 m to 70 m was used. Table 3 states the calculated values of the heat flux effect on the neighboring tanks in specified distances. The first column of Table 3 specifies the distance (marked as l_n) in meters for the heat flux density calculation q_L (kW m^{-2}) in the second column of S3 scenario in the second column and for S4 in the third column.

The basic data for further heat flux density calculations in specified distances between the storage tanks 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.

The length of the radiating flame p_s is calculated out of the basic data, whereas the data for the safety tank are indexed with $_h$.
For S3 scenario–in equation (8) there is used: $p_s = p-(n-h) = (p-n+h) = (20.1-22.6+20.2) = 17.7$ m.
For S4 scenario–in equation (8) there is used: $p_s = p_h-(n_h-h_h) = (p_h-n_h+h_h) = (21.65-14.5+12.9) = 20.05$ m.

Fig. 3 The heat flux of the 30 000 m^3 tank against the neighboring tanks – S3 and S4 tanks

l_n (m)	q_L (kW.m^{-2}) S3 scenario	q_L (kW.m^{-2}) S4 scenario	l_n (m)	q_L (kW.m^{-2}) S3 scenario	q_L (kW.m^{-2}) S4 scenario
35	28.91	36.38	55	14.15	18.87
40	23.74	30.46	60	12.17	16.36
45	19.75	25.74	65	10.56	14.29
50	16.62	21.94	70	9.24	12.58

The calculated values in Table 3 illustrate that the heat flux density is higher in the safety tank fire in all specified distances. The graph in Figure 5 presents the calculated values of heat flux densities from Table 3 for 30 000 m^3 tank and compares both scenarios for the particular tank.

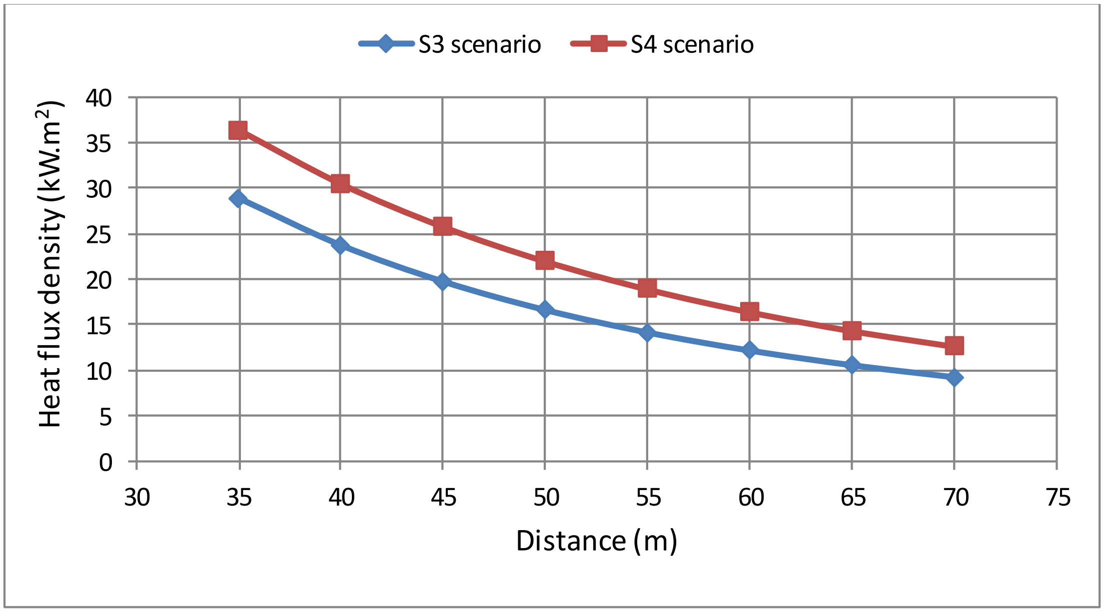

Fig. 5 Heat flux density effects on the neighboring tank at a fire of the large storage tank of 30 000 m^3 volume–S3 and S4 scenarios

4.2. The large storage tank of 70 000 m^3 volume

The basic data for the calculation of the heat flux in specified distances between large storage tanks of 70 000m^3 volume are:
For S3 scenario: D = 66 m, r = 33 m, n = 236 m, h = 21.28 m, p = 22.84 m.
For S4 scenario: D_h = 80 m, r_h = 40 m, n_h = 15.3 m, h_h = 14.5 m, p_h = 23,57 m.

Consequently, the length of the flame p_s is calculated:
S3 scenario – in the equation (8) the following values are used: $p_s = p - (n - h) = (p - n + h)$ = (22.84 – 23.6 + 21.28) = **20.52 m**
S4 scenario – in the equation (8) the following values are used: $p_s = p_h - (n_h - h_h) = (p_h - n_h + h_h)$ = (23.57 – 15.3 + 14.5) = **22.77 m**

Table 4 states the calculated levels of heat flux density in specified distances for a large storage tank of 70 000 m^3. Figure 6 shows the graph illustration of the calculated values for both fire scenarios.

Tab. 4 Heat flux of 70 000 m^3 tank against neighboring tanks – S3 and S4 scenarios

l_n (m)	q_L (kW m^{-2}) S3 scenario	q_L (kW m^{-2}) S4 scenario	l_n (m)	q_L (kW m^{-2}) S3 scenario	q_L (kW m^{-2}) S4 scenario
35	41.06	47.61	55	22.33	27.49
40	34.91	41.23	60	19.51	24.26
45	29.87	35.84	65	17.16	21.52
50	25.74	31.31	70	15.18	19.18

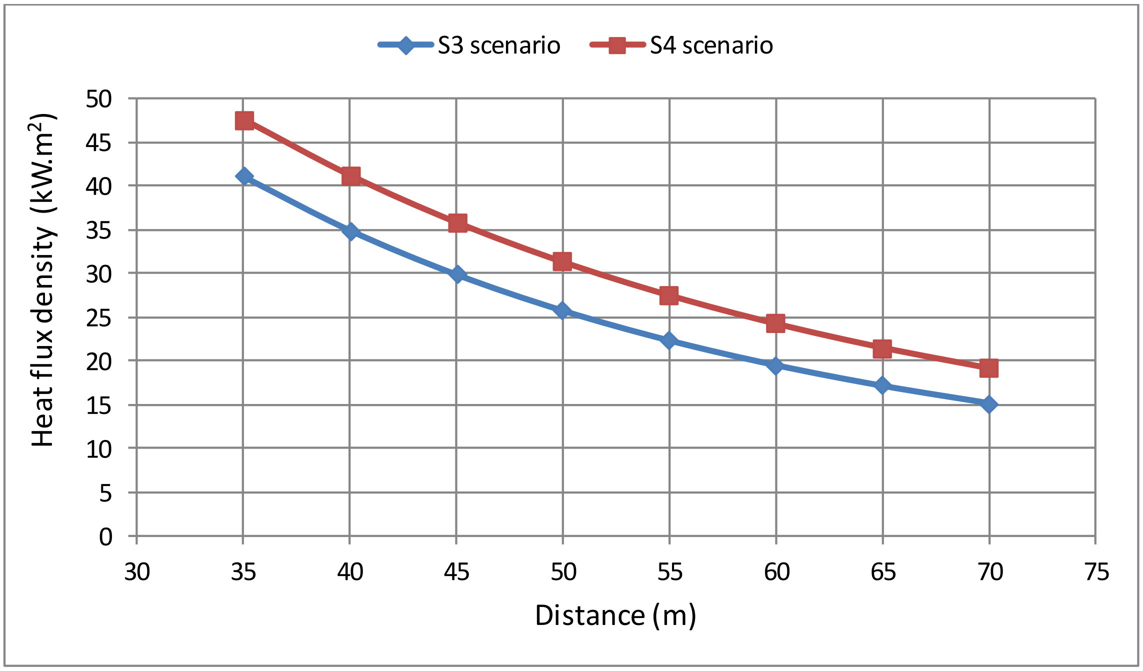

Fig. 6 Heat flux density effects of 70 000 m^3 storage tank on the neighboring tanks–S3 and S4 scenarios

4.3. The large storage tank of 125 000 m^3 volume

The values for heat flux density for the tank of 125 000m^3 volume were calculated for distances l_n ranging from 35 m to 75 m, which correspond to the real distances between the shells of safety tanks.

Table 5 states the calculated values for the storage tank of 125 000 m^3 volume. Basic data for further calculations of heat flux density in specified distances between the large storage tanks of 125 000 m^3 volume are:

- for S3 scenario: D = 84,47 m, r = 42,235 m, n = 24,1 m, h = 22,3 m, p = 23.68 m,
- for S4 scenario: D_h = 90,47 m, r_h = 45,235 m, n_h = 19,75 m, h_h = 19,44 m, p_h = 23,76 m.

The flame length p_s for particular scenarios is then calculated:

S3 scenario – in the equation (8) is inserted the value: $p_s = p - (n - h) = (p - n + h) = (23.68 - 24.1 + 22.3) =$ **21.88 m**.

S4 scenario – in the equation (8) is inserted the value $p_s = p_h - (n_h - h_h) = (p_h - n_h + h_h) = (23.76 - 19.75 + 19.44) =$ **23.45 m**.

Tab. 5 Heat flux of 125 000 m^3 storage tank against neighboring tanks – S3 and S4 scenarios

l_n (m)	q_L (kW m^{-2}) S3 scenario	q_L (kW m^{-2}) S4 scenario	l_n (m)	q_L (kW m^{-2}) S3 scenario	q_L (kW m^{-2}) S4 scenario
35	47.18	50.48	60	24.23	26.73
40	40.92	44.13	65	21.52	23.84
45	35.63	38.70	70	19.21	21.36
50	31.17	34.06	75	17.23	19.21
55	27.41	30.11			

The graph in Fig. 7 illustrates the calculated values for S3 and S4 scenarios for the 125 000 m^3 tank previously stated in Table 5.

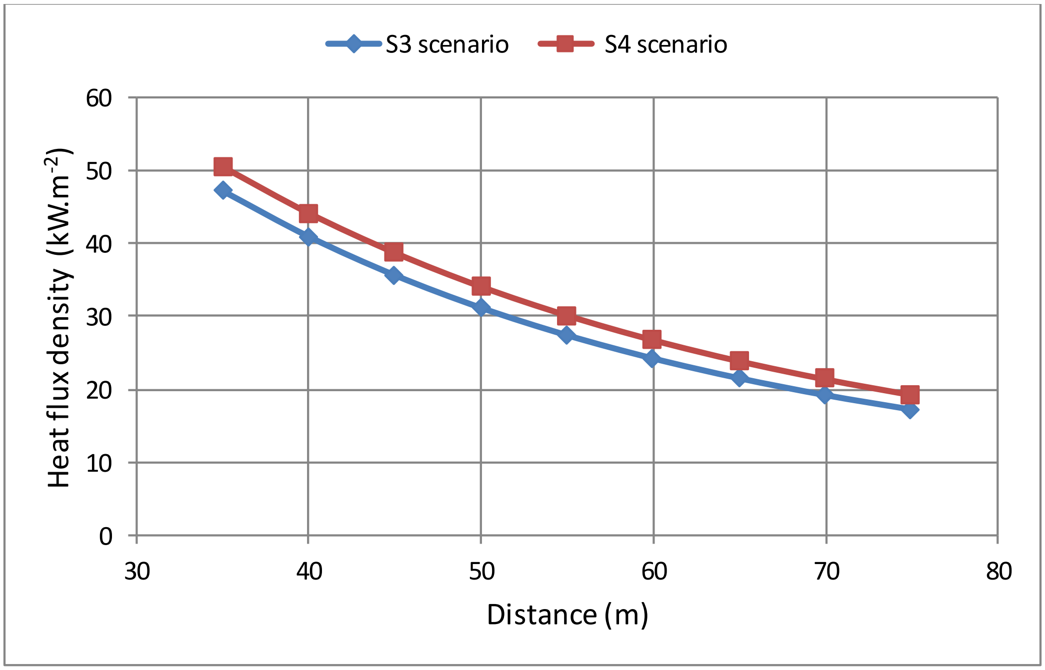

Fig. 7. Heat flux density affecting the neighboring tanks at a fire of 125 000 m^3 tank–S3 and S4 scenarios

The graph in Fig. 8 shows the curves of heat fluxes for the particular tanks for S3 scenario when heat flux affects a neighboring tank.

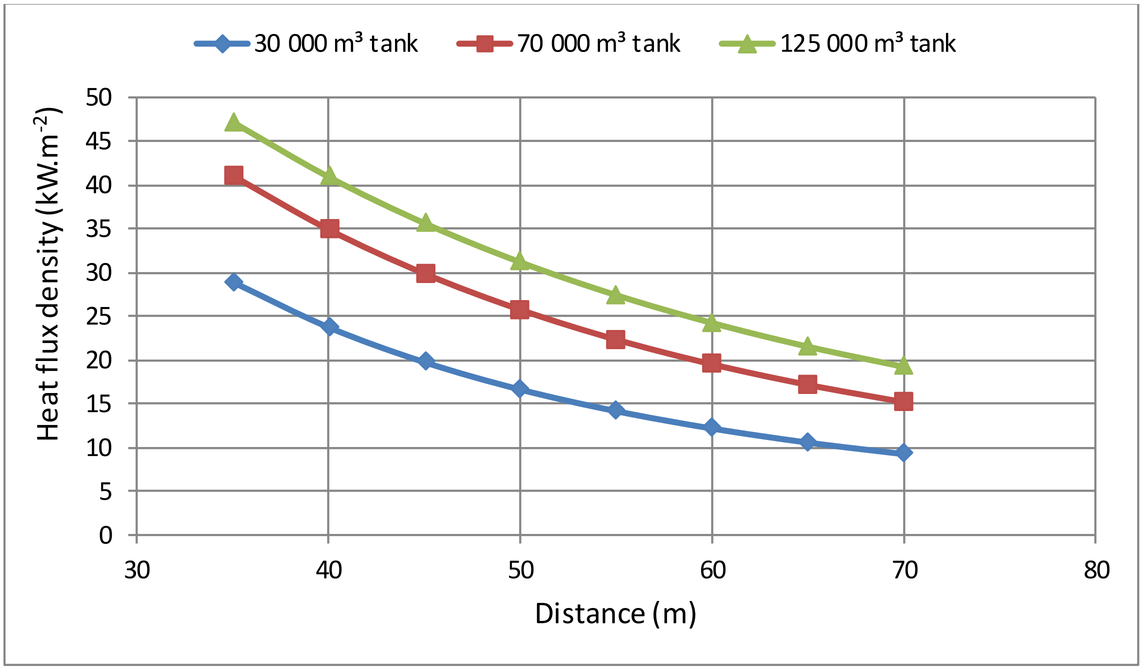

Fig. 8. Comparison of heat flux density against neighboring tanks – S3 scenario

The graph in Fig.8 clearly shows that the size of the heat flux density grows with the size of the storage tank at the same distance and at the same height of the storage tank shell. The graph in Fig.9 shows heat flux densities calculated for S4 scenario, the highest values appear for 125 000 m^3 tank.

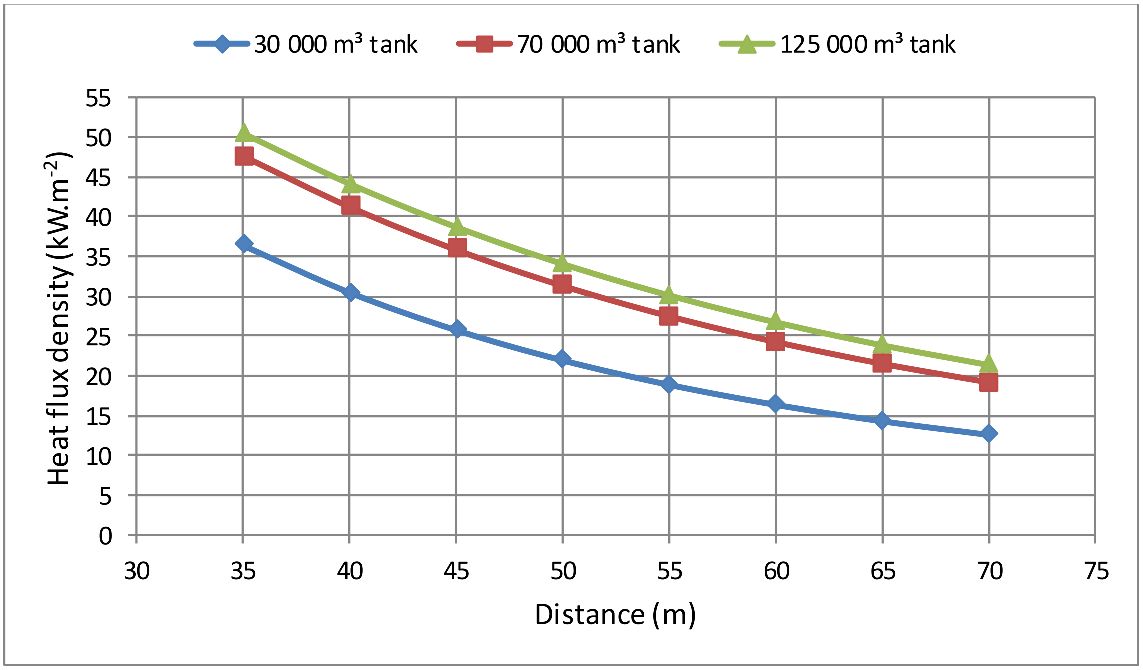

Fig. 9. Comparison heat flux density against neighboring tank – S4 scenario

We found out that the compared calculated rates of energy release at a fire are proportional to the area of a fire. In case of the fire of large storage tanks, the size of the area of the fire calculated is total horizontal area of stored crude oil.

There were four scenarios suggested, however, the calculations were conducted for two of them considered the most severe. Three different sizes were chosen and constant rate of energy release was calculated per time unit and per area unit i.e. areal energy release rate q_f''= 842.8 kJ s^{-1} m^{-2} (0.8428 MW m^{-2}) for crude oil based on the earlier described circumstances. Baum a McGrattan [9] claim that energy release rate for a large crude oil storage tank of 84 m diameter and 27 m height, was 4.7 GW; after recalculating this value into areal energy release rate, this presents approximately q_f''= 848 kW m^{-2} (0.848 MW m^{-2}). The conditions of the surroundings include wind 6 m s^{-1} at 27 meters above the terrain and outside temperature of 20°C. After deducting smoke absorbing radiation (10% referred smoke absorption), the areal energy release rate appears to be q_f''=900 kW m^{-2} (0.9 MW m^{-2}). The paper does not mention the crude oil characteristic.

The same authors [10] state the energy release rate for crude oil as q_f''= 1 900 kW m^{-2}, planar burning rate as m''_∞ = 0.045 kg m^{-2} s^{-1} and total combustion heat as ΔH_c=42 600 kJ kg^{-1} and fuel efficiency as χ = 1 (100 %).

The calculations in this paper employ planar burning rate of m''_∞ = 0.028 kg m^{-2} s^{-1}, total combustion heat of ΔH_c=42 500 kJ kg^{-1} and fuel efficiency of χ=0.7 (70 %). Considering that the burning rate used in this paper is substantially lower, the resulting planar energy release rate was 55% lower than the value referred to by the earlier mentioned authors [10].

5. Conclusions

Generally, it would be sufficient for large storage tanks from a certain diameter to substitute a constant energy release rate per unit of time and unit of area (areal energy release rate) and the area of stored crude oil with the same characteristic. Even for a different flammable liquid, the constant of energy release per a time unit and area unit would be proportional to the total combustion heat, areal burning rate, fuel efficiency and the product of the constants of flame radiation against the flammable liquid surface.

Considering the ratios of diameters and volumes of the selected tanks, there were recorded the differences only from a few centimeters to tens of decimeters among the calculated values of the mean flame length. The mean flame length was more than 20 m for every tank. These values apply only in case of a calm. However, wind or other unexpected situations such as blow, boilover explosion, tank deformation, floating roof failure, may expand the flame length several times.

In conclusion, it can be claimed that the heat flux density in the surrounding of a burning tank depends simultaneously on a few parameters. If the weather conditions are not the case, it concerns especially: tank diameter; tank shell height; crude oil level in the tank; distance from the tank; position against the tank; a level above the terrain; mean flame length; flame temperature; emission rate and smoke shadowing of the flame.

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