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EXPERIMENTAL VERIFICATION OF THE MODEL OF HEATING THE TANK IN CASE OF POOL FIRE

The model of heating the dry tank wall under thermal influence of burning spilled liquid has been verified experimentally. The estimation of dispersion of tank wall temperature has been built. It is shown that theoretical data match the experimental data.

Keywords: spilled flammable liquid, fire, tank, emissive power.

Problem formulation. Fires in tank storages are very dangerous. Their liquidation is difficult due to hazard of spreading the fire to next tanks. The efficient method of liquidation the fire is using the automatic fire distinguishing system which allow liquidate fire at the early stage. For constructing the system it is necessary to build the model of fire thermal influence to fuel tank and fire detector. Particularly, it applies to the pool fires of flammable liquids.

Analysis of recent researches and publications. The mathematical model of the thermal influence of fire inside the tank embankment to the fuel tank is proposed in [2, 3]. The feature of the model is considering the spill of an arbitrary form (not only round spill). The model hasn't been verified experimentally. The verification is difficult due to stochastic nature of emissive power from fire and, therefore, stochastic nature of heated object. In [1] stochastic model of heating the tank under thermal influence of fire was built. It was shown that temperature of radiating surface of fire and square of its transverse section are stationary normal processes.

Statement of the problem and its solution. The main goal of the work is verification the model heating the tank under thermal influence of burning oil spill by experimental determining the temperature of tank wall and comparing with theoretical data.

Pool fire of motor oil AK-10 (flammable viscous liquid, density is 930 kg/m^3, emissivity of flame is 0,85 [4]) was studied experimentally. The burning of liquid took place in a steel tray. The dimensions of the tray are 1 m and 1,5 m (fig. 1, 2). The height of tray walls is 0,2 m, wall thickness is 2 mm. Cylindrical model of tank (height is 0,6 m, diameter is 0,3 m, wall thickness is 1 mm) was located at a distance of $l = 0{,}65\,m$ from the longest side of tray.

The thermocouple was located on the side surface of the tank model. The thermocouple was connected to the digital temperature sensor. It was used for determining the temperature at the tank side in front of the flame.

Changing the temperature of elementary area of the tank surface in the presence of fire thermal influence is described by differential equation [2, 3]

$$\frac{dT}{dt} = \frac{c_0 \varepsilon_f \varepsilon_w}{\rho \delta c}\left[\left(\frac{T_f}{100}\right)^4 - \left(\frac{T}{100}\right)^4\right]\psi_f +$$

$$+\frac{c_0 \varepsilon_w}{\rho \delta c}\left[\left(\frac{T_0}{100}\right)^4 - \left(\frac{T}{100}\right)^4\right]\left(1-\psi_f\right) + \frac{\alpha\left(T_a - T\right)}{\rho \delta c}, \qquad (1)$$

where $c_0 = 5{,}67\ \mathrm{W/m^2K^4}$; ε_f is emissivity of fire ($\varepsilon_f = 0{,}85$); T_f is the fire surface temperature ($T_f = 800^o\mathrm{C}$); T_0 is the ambient temperature; T is the temperature of elementary area on the tank surface; ε_w is its emissivity ($\varepsilon_w = 0{,}8$); ρ, c are density and heat capacity of the tank wall material; δ is the wall thickness; T_a is the air temperature near the elementary area; α is the convective heat transfer coefficient; ψ_f is the mutual flame radiation coefficient

$$\psi_f = \iint_{S_f} \frac{\left(\vec{r}, \vec{n}_f\right)\left(\vec{r}, \vec{n}\right)}{r^4} dS_f ,$$

$\vec{r}$ is radius vector connecting the current point at the elementary area with point on the flame surface; $\vec{n}_f$ is normal vector to the flame surface; $\vec{n}$ is normal vector to the current point at the elementary area; S_f is flame surface.

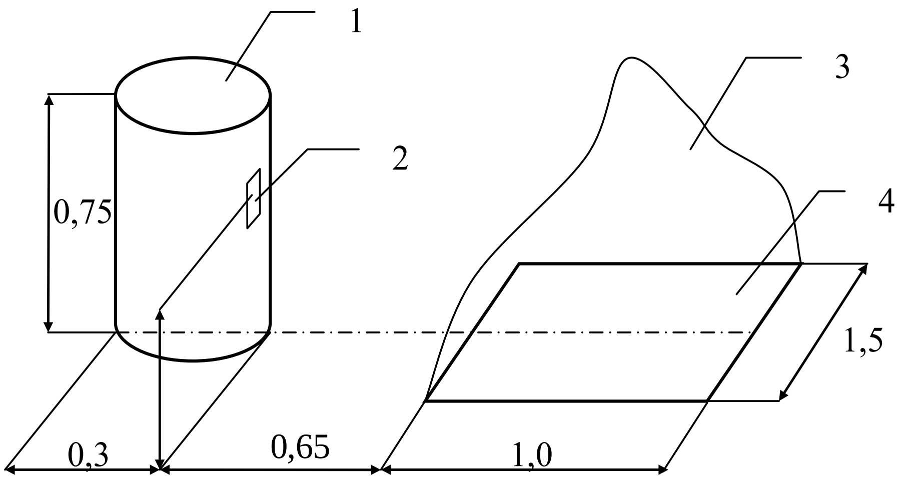
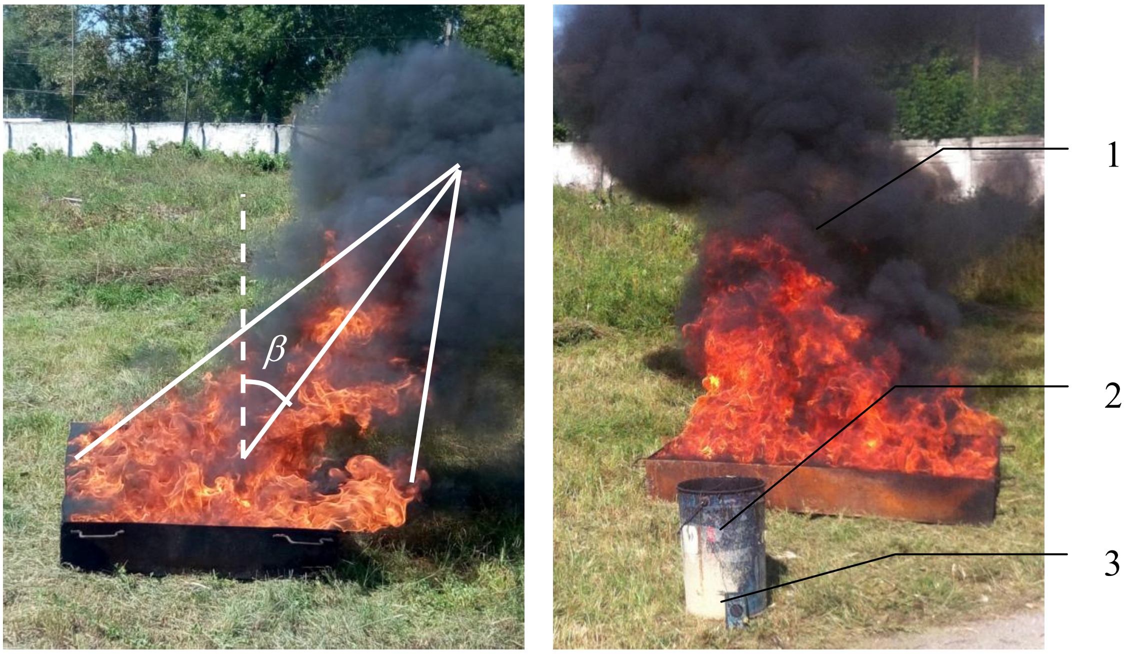


Fig. 1. Scheme of the experiment: 1 – tank model; 2 – thermocouple; 3 – flame; 4 – tray with flammable liquid

The radiating surface of pool fire was determined by model from the work [2]. It is described by parametrical form

$$\begin{cases} x = u + r \cdot c \cdot \sin\alpha \cdot \cos\varphi, \\ y = v + r \cdot c \cdot \sin\alpha \cdot \sin\varphi, \\ z = r \cdot c \cdot \cos\alpha, \end{cases}$$

where $(u, v) \in \Omega$ is a point in the area of spill Ω; r is distance between the point (u,v) and spill boundary; $(\cos\varphi, \sin\varphi)$ is the vector of wind direction; β is the angle between flame axis and vertical axis ($\beta = 45^o$, fig. 2a); c is the constant depended on liquid type. It is $c = 2{,}4$ for the motor oil.



a) b)

Fig. 2. Burning fuel in the tray: 1 – fuel; 2 – tank model; 3 – digital sensor connected to the thermocouple

The dynamics of thermocouple temperature on the tank model in front of the fire (line 4) and temperature obtained from equation (1) (line 1) are shown at the fig. 3.

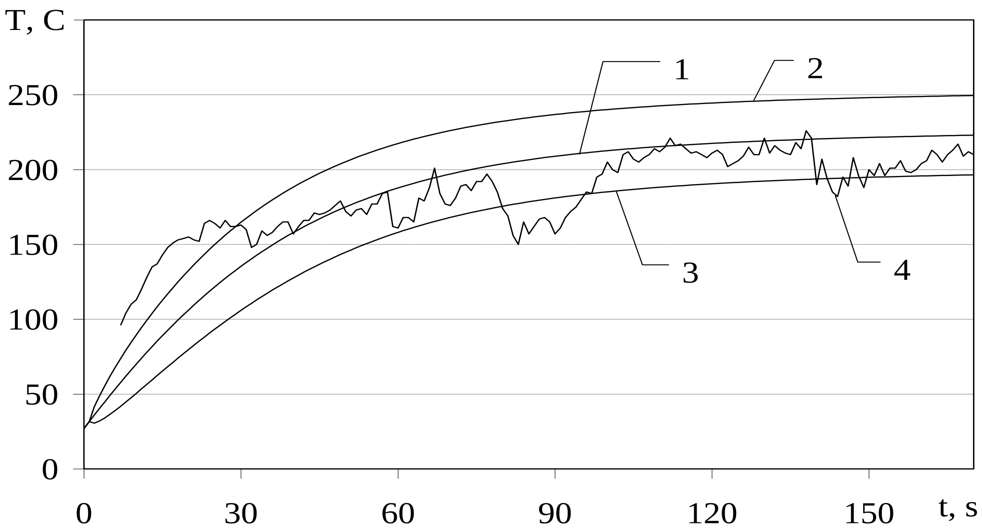


Fig. 3. The dynamics of the thermocouple temperature at the wall of the tank model in front of the fire: 1 – the expected value; 2, 3 – upper and lower boundaries of the interval $\pm 3\sigma$; 4 – experimental data

The stochastic model of heating the dry tank wall under the thermal influence of fire in case when temperature of radiating surface of flame and square of its transverse section are stationary normal processes had been built in the work [1]. It had been shown that temperature distribution of dry tank wall is normal and expected value of the temperature $\overline{\mathrm{T}}(\mathrm{t})$ agrees with the deterministic solution $\mathrm{T}(\mathrm{t})$ of the equation (1). The system of differential equations of the dispersion of the tank wall temperature has been obtained by transformations similar to [1]:

$$\frac{d\sigma^2}{dt}=\frac{2\varepsilon_w c_0}{\rho\delta c}\left[\varepsilon_f\psi_f\left(\frac{A}{100^4}-\frac{T^4K_{\xi w}+4T^3\sigma^2}{100^4}\right)-\right.$$
$$\left.-\psi_f\left(\frac{K_{\xi w}T_0^4}{100^4}-\frac{T^4K_{\xi w}+4T^4\sigma^2}{100^4}\right)-\frac{4T^3\sigma^2}{100^4}\right]-2\sigma^2\frac{\alpha}{\rho\delta c},$$
$$\frac{dK_{\xi w}}{dt}=\frac{\varepsilon_w c_0}{\rho\delta c}\left[\varepsilon_f\psi_f\left(\frac{B_f}{100^4}-\frac{B}{100^4}\right)-\right.$$
$$\left.-\psi_f\left(\sigma^2\left(\frac{T_0}{100}\right)^4-\frac{B}{100^4}\right)-\frac{4T^3K_{\xi w}}{100^4}\right]-K_{\xi w}\frac{\alpha}{\rho\delta c}-\alpha_\xi K_{\xi w},$$
$$\frac{dK_{\theta w}}{dt}=\frac{\varepsilon_w c_0}{\rho\delta c}\left[\varepsilon_f\psi_f\left(\frac{C_f}{100^4}-\frac{C}{100^4}\right)-\right.$$
$$\left.-\psi_f\left(K_{\xi\theta}\left(\frac{T_0}{100}\right)^4-\frac{C}{100^4}\right)-\frac{4T^3K_{\theta w}}{100^4}\right]-K_{\theta w}\frac{\alpha}{\rho\delta c}-\alpha_\theta K_{\theta w},$$

where

$$B_f=T_f^4\sigma_\xi^2+4T_f^3K_{\xi\theta}+6T_f^2\left(\sigma_\xi^2\sigma_\theta^2+2K_{\xi\theta}^2\right)+$$
$$+3\sigma_\theta^2\left(4T_\phi K_{\xi\theta}+\sigma_\xi^2\sigma_\theta^2+4K_{\xi\theta}^2\right),$$
$$B=T^4\sigma_\xi^2+4T^3K_{\xi k}+6T^2\left(\sigma_\xi^2\sigma^2+2K_{\xi w}^2\right)+3\sigma^2\left(4TK_{\xi w}+\sigma_\xi^2\sigma^2+4K_{\xi w}^2\right),$$
$$C_f=T_f^4K_{\xi\theta}+4T_f^3\sigma_\theta^2+18T_f^2K_{\xi\theta}\sigma_\theta^2+12T_f\sigma_\theta^4+15K_{\xi\theta}\sigma_\theta^4,$$
$$C=T^4K_{\xi\theta}+4T^3K_{\theta w}+12T^2K_{\xi w}K_{\theta w}+3\sigma^2\left(\sigma^2K_{\xi\theta}+4K_{\xi w}K_{\theta w}\right),$$
$$A=T_f^4K_{\xi w}+4T_f^3K_{\theta w}+6T_f^2\left(\sigma_\theta^2K_{\xi w}+2K_{\xi\theta}K_{\theta w}\right)+12T_f\sigma_\theta^2K_{\theta w}+$$
$$+3\sigma_\theta^2\left(\sigma_\theta^2K_{\xi w}+4K_{\xi\theta}K_{\theta w}\right),$$

$\xi(t)$ is the square of transverse section (normal stationary process); $\theta(t)$ is the temperature of the radiating surface of fire (normal stationary process); $\sigma^2(t)$ is the dispersion of the temperature of the elementary heated area; $K_\xi(t)$, $K_\theta(t)$ are the correlation functions of the stochastic processes $\xi(t)$ and $\theta(t)$; $\sigma_\xi^2=K_\xi(0)$; $\sigma_\theta^2=K_\theta(0)$; $K_{\xi\theta}(t)$ is the correlation function between $\xi(t)$ and $\theta(t)$; $K_{\xi w}(t)$, $K_{\theta w}(t)$ are correlation functions between the temperature of the elementary heated area and stochastic processes $\xi(t)$ and $\theta(t)$ respectively [1].

Upper and lower boundaries of the interval $T(t)\pm 3\sigma(t)$ are shown by lines 2 and 3 (fig. 3). Analysis of graphical dependences in the fig. 3 shows, that experimental data satisfactorily fit into the interval $\pm 3\sigma$ and solution of the equation (1) may be used as expected value of the temperature.

Conclusions. The model of thermal influence of pool fire at the fuel tank has been verified experimentally. It has been shown, that expected value of the temperature of tank dry wall may be approximated by solution of the differential equation (1). The estimation of dispersion of its temperature has been built. It has been shown, that experimental values of temperature satisfactorily fit into the interval $\pm 3\sigma$. Results may be used for estimating the thermal influence of pool fire inside the embankment at the fuel tank.

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Експериментальна перевірка моделі нагріву резервуару від пожежі розливу горючої рідини

Проведено експериментально перевірку моделі нагріву сухої стінки резервуара під тепловим впливом пожежі розливу горючої рідини. Побудовано оцінку дисперсії температури стінки і показано відповідність розрахункових даних результатам експерименту.

Ключові слова: розлив горючої рідини, пожежа, резервуар, тепловий потік випромінюванням.

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Экспериментальная проверка модели нагрева резервуара от пожара разлива горючей жидкости

Проведена экспериментальная проверка модели нагрева сухой стенки резервуара под тепловым воздействием пожара разлива горючей жидкости. Построена оценка дисперсии температуры стенки и показано соответствие расчетных данных результатам эксперимента.

Ключевые слова: разлив горючей жидкости, пожар, резервуар, тепловой поток излучением.