UDK 614.8

A.E. Basmanov, DSc, Prof., chief researcher, NUCDU,
Y.S. Kulik, adjunct, NUCDU

MODELING AN EMERGENCY HAZARD IN THE PRESENCE OF WIND

Model of the impact of emergency hazard in the presence of wind is built for example of thermal impact of oil pool fire.

Keywords: emergency, detector of the emergency hazard.

Problem formulation. Oil spill near the tank and its inflammation is a dangerous emergency at oil tank storage. The main causes of this situation are tank overflow and depressurization of tank product lines. The danger of this emergency is threat of fire spreading to the tank with oil due to thermal fire impact to the tank and product lines. So, preventing the fire spreading to the tank with oil is one of the problems. It requires to build the model of thermal impact of pool fire.

Analysis of recent researches and publications. Mathematical model of evaluating the place of emergency source by response from emergency hazard detectors (for example of pool fire and fire detectors) is built in [1]. However flame deformation in the presence of wind isn't accounted. It is the course of an additional error of evaluating the fire source.

Statement of problem and its solution. The main goal of the work is to build a model of an emergency hazard in the presence of wind (for example of thermal impact of pool fire to the oil tank).

Following [1] we divide the inner space of embankment to separate areas using straight lines with same distances between their and parallel to embankment edges. We will approximate spill area by the rectangles (fig. 1).

It is supposed that combustion area is a simply connected domain, the area boundary is simply connected if oil tank is out of the spill and doubly connected if the tank is in the spill. It means the spill is solid and there is no non-burning area inside it.

The polygon approximating the oil spill is denoted as Ω. Flame height at a point of spill $(x,y)\in\Omega$ is equal to [2]

$$z(x,y)=r\cdot c, \tag{1}$$

where r is the distance between the point $(x,y)\in\Omega$ and the boundary $\partial\Omega$ of the spill area; c is the constant depending from oil type: $c=2{,}8$ for highly flammable liquids and $c=2{,}4$ for flammable liquids. In particular, formula (1) for round spill of diameter D gives a cone of the height $1{,}4D$ for highly flammable and $1{,}2D$ for flammable liquids.

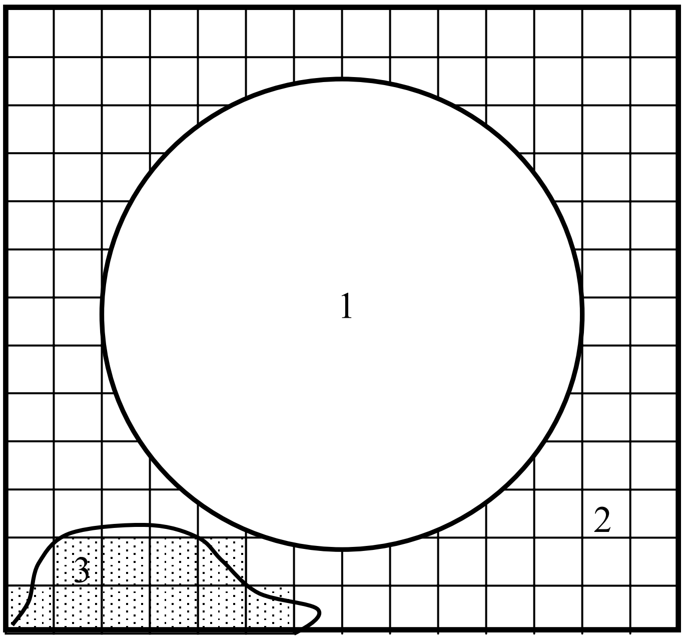

Fig. 1. Dividing inner space of embankment to the separate areas: 1 – oil tank; 2 – inner space of embankment; 3 – spill area and its approximation

Wind with velocity up to 10 m/s leads to flame tilt from vertical axis by the angle α [2]

$$\alpha = \operatorname{arctg}\frac{w}{2},$$

where w is the wind velocity, m/s. In this case fire length is still described by the formula (1) and the fire height h at the point $(x, y) \in \Omega$ is

$$h = z\cos\alpha. \qquad (2)$$

It allows to introduce radiating surface of the flame in parametric form

$$\begin{cases} x = u + r \cdot c \cdot \sin\alpha \cdot \cos\varphi, \\ y = v + r \cdot c \cdot \sin\alpha \cdot \sin\varphi, \\ z = r \cdot c \cdot \cos\alpha, \end{cases} \qquad (3)$$

where $(u, v) \in \Omega$; r is the distance between the point (u, v) and the spill boundary $\partial\Omega$; $(\cos\varphi, \sin\varphi)$ is the vector of wind direction.

Parametric form of fire radiating surface allows to determine the normal vector to the surface. Unit normal vector $\vec{n}$ to the surface S given by equation (3) in the point $(x, y, z) \in S$ is equal to

$$\vec{n} = \left(\frac{A}{\sqrt{A^2 + B^2 + C^2}}, \frac{B}{\sqrt{A^2 + B^2 + C^2}}, \frac{C}{\sqrt{A^2 + B^2 + C^2}} \right), \qquad (4)$$

where $A = \frac{\partial y}{\partial u}\frac{\partial z}{\partial v} - \frac{\partial z}{\partial u}\frac{\partial y}{\partial v}$; $B = \frac{\partial z}{\partial u}\frac{\partial x}{\partial v} - \frac{\partial x}{\partial u}\frac{\partial z}{\partial v}$; $C = \frac{\partial x}{\partial u}\frac{\partial y}{\partial v} - \frac{\partial y}{\partial u}\frac{\partial x}{\partial v}$. If $(u, v) \notin \Omega$ then $x(u, v) = y(u, v) = z(u, v) = 0$.

Differential equation describing heating of an elementary area on the surface by heat impact of fire [1] is

$$\frac{dT}{dt} = \frac{c_0 \varepsilon_f \varepsilon_s}{\rho \delta c} \left[\left(\frac{T_f}{100} \right)^4 - \left(\frac{T}{100} \right)^4 \right] \psi_f + \frac{c_0 \varepsilon_s}{\rho \delta c} \left[\left(\frac{T_0}{100} \right)^4 - \left(\frac{T}{100} \right)^4 \right] (1 - \psi_f) + \\ + \frac{\alpha (T_a - T)}{\rho \delta c}, \qquad (5)$$

where T is elementary area temperature; $c_0 = 5{,}67\ W/m^2K^4$; ε_f, ε_s are emissivities of flame surface and elementary area; T_f is temperature of the radiating surface of fire; ρ, c are density and heat capacity of tank wall; δ is wall thickness; T_a is air temperature at the point of contact with the sensor; α is convective heat transfer coefficient; ψ_f is fire local radiation coefficient

$$\psi_\phi = \frac{1}{\pi} \iint_S \frac{\cos\theta_1 \cos\theta}{r^2} dS,$$

$\vec{r}$ is the radius vector connecting the elementary area and point on the flame surface; θ_1 is the angle between the normal vector $\vec{n}_1$ to elementary area and the radius vector $\vec{r}$; θ is the angle between the normal vector to the flame surface $\vec{n}$ and the radius vector. The integral is taken only at those points of the flame surface where both angles θ_1 and θ are sharp corners. Replacing cosines by scalar products gives

$$\psi_\phi = \frac{1}{\pi} \iint_S \frac{(\vec{n}_1, \vec{r})(\vec{n}, \vec{r})}{|\vec{n}_1| r^4} dS, \qquad (6)$$

where integration is performed over the area where both scalar products are positive.

In the Cartesian coordinate system with the origin at the center of the tank bottom the unit normal vector to an elementary surface on the reservoir wall is

$$\vec{n}_1 = (x_0, y_0, 0), \tag{7}$$

where (x_0, y_0, z_0) is point on the tank surface. Surface element dS also can be represented in parametric form

$$dS = \sqrt{A^2 + B^2 + C^2}\,dudv. \tag{8}$$

Substituting expressions (4), (7), (8) in the (6) gives

$$\psi_ф = \frac{1}{\pi} \times$$
$$\times \iint_\Omega \frac{\left[A(x - x_0) + B(y - y_0) + C(z - z_0)\right]\left[x_0(x - x_0) + y_0(y - y_0)\right]}{\sqrt{x_0^2 + y_0^2}\left[(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2\right]^2} dudv \quad ,(9)$$

where integrating is performed only on that part of the area Ω where both of factors in numerator are positive

$$A(x - x_0) + B(y - y_0) + C(z - z_0) > 0,$$
$$x_0(x - x_0) + y_0(y - y_0);$$

(x, y, z) – the point on the flame surface in the parametric form (3).
The maximum of temperature achieved by elementary area due to heat impact of the fire can be evaluated from (5) with additional condition $\frac{dT}{dt} = 0$.
Then the maximum of elementary area temperature is the solution of equation

$$c_0 \varepsilon_ф \varepsilon_д \left[\left(\frac{T_ф}{100}\right)^4 - \left(\frac{T}{100}\right)^4\right]\psi_ф + c_0 \varepsilon_д \left[\left(\frac{T_0}{100}\right)^4 - \left(\frac{T}{100}\right)^4\right](1 - \psi_ф) +$$
$$+ \alpha(T_в - T) = 0. \tag{10}$$

Value of the temperature can be used for evaluating the danger of heat flow impact to tank wall and probability of triggering the thermal fire detectors located on the tank.

Conclusions. Model of an emergency hazard in the presence of wind (on example of thermal impact of pool fire to the oil tank) is built. The model can be used for the automatic systems of emergency mitigation. In particular, using it for evaluating the placement of pool fire inside of tank embankment allows to reduce the consumption of extinguishing agent.

LITERATURE

1. Basmanov A.E. Algorithm of evaluating parameters of emergency source based on response from emergency hazard detectors / A.E. Basmanov, Y.S. Kulik // Problems of emergencies. – Kharkiv: NUCDU, 2015. – Vol. 21. – P. 7-10.

2. Ulinets E.M. Wind impact to the form of radiating surface of oil pool fire / E.M. Ulinets // Scientific bulletin of construction. – 2008. – Vol. 48. – P. 268–272.

О.Є. Басманов, Я.С. Кулик

Моделювання небезпечного фактора надзвичайної ситуації в умовах вітрового навантаження

Побудовано модель впливу небезпечного фактора надзвичайної ситуації в умовах вітрового навантаження на прикладі теплового впливу розливу нафтопродукту в обвалуванні резервуара.

Ключові слова: осередок надзвичайної ситуації, датчик небезпечного фактору надзвичайної ситуації.

А.Е. Басманов, Я.С. Кулик

Моделирование опасного фактора чрезвычайной ситуации в условиях ветровой нагрузки

Построена модель воздействия опасного фактора чрезвычайной ситуации в условиях ветровой нагрузки на примере теплового воздействия разлива нефтепродукта в обваловании резервуара.

Ключевые слова: очаг чрезвычайной ситуации, датчик опасного фактора чрезвычайной ситуации.