UDC 614.8

A. Basmanov, DSc, Prof., chief researcher, NUCPU,
Y. Kulik, teacher, NUCPU

IDENTIFYING THE CONVECTIVE HEAT TRANSFER COEFFICIENT OF THE TANK WALL IN THE CASE OF DIKE FIRE

The convective heat transfer coefficient of the tank wall in the case of forced convection caused by wind and turbulent plume above a spill fire in the tank dike was found with using the similarity theory.

Keywords: tank, fire in the tank dike, convective heat transfer, spill fire, forced convection.

Problem formulation. Fire in the oil tank storage is one of the most difficult emergencies due to threat of spreading the fire to the next tanks. In particular it takes place in the case of spill fire in the tank dike. Building the effective plan of fire-fighting in tank storage is impossible without evaluating the influence of a spill fire to the tank. It includes the convective heat transfer from ambient air and plume above spill fire to the tank wall.

***Analysis of recent researches and publications*.** The model of thermal influence of a fire in an oil tank to the next tank has been built in the [1]. It includes thermal radiation and convection. The model of spill fire in the tank dike has been built in the [2]. It assumes that tank wall is in contact with gas which temperature is equal to the fire temperature or the ambient temperature. The case of hot turbulent plume above a spill fire hasn't been considered. The model of velocity and temperature distribution in the plume above a spill fire has been built in the [3].

***Statement of the problem and its solution*.** The main goal of the work is obtaining the convective heat transfer coefficient of oil tank wall in the case of forced convection caused by wind and plume above spill fire in the tank dike.

In general, there are three possibilities of forced convective heat transfer from environment to the tank wall:

- forced convection due to plume above a spill fire when there is no wind;
- forced convection due to wind when vertical component of the air flow is insignificant;
- forced convection due to superposition of wind and plume above a spill fire.

In the case of forced convection caused only by plume above a spill fire the Nusselt number can be obtained from the expression for convective heat transfer from gas to vertical plate [4]

$$Nu = 0{,}032\,\mathrm{Re}^{0,8},$$

where thermal conductivity coefficient of air λ_f and its dynamic viscosity ν

contained in the Nusselt $Nu = \frac{\alpha L}{\lambda_f}$ and Reynolds $\mathrm{Re} = \frac{w_f L}{\nu}$ numbers are taken at airflow temperature; characteristic length $L = z$ is the distance from point on the wall surface to the ground.

Thus the estimation of the heat transfer coefficient with fire plume takes the form

$$\alpha_{21} = 0{,}032 \lambda_f \nu^{-0,8} w_f^{0,8} z^{-0,2}.$$

To simplify the expression let's replace the function

$$f_1(T_f) = \lambda_f(T_f)\nu^{-0,8}(T_f) \quad (1)$$

by approximated value

$$\tilde{f}_1(T_f) = 4581{,}5 T_f^{-0,5626} \quad (2)$$

based on the table data [5] of air thermal conductivity and viscosity dependences on temperature.

The analysis of (1), (2) indicates that approximation error doesn't exceed 3% for the airflow temperature ranging in $T_f = (273 \div 1273)K$. After substituting the approximation the convective heat transfer coefficient can be estimated as follows

$$\alpha_{21} = 146{,}6 T_f^{-0,5625} w_f^{0,8} z^{-0,2}, \quad (3)$$

where all values have to be presented in the SI system due to dimensional coefficients in the (2), (3).

For typical vertical steel tanks ($D = (10 \div 60)m$ – RVS-700 and more) used for storage of oil and oil products wind velocity $w_f = (1 \div 10)m/s$ the Nusselt number belongs to the range $\mathrm{Re} = (6 \cdot 10^5 \div 4 \cdot 10^7)$. It means the turbulent nature of the airflow past the tank.

For the specified range of Reynolds number values, the value of the Nusselt number averaged along the tank circumference is described by expression [6]

$$\overline{Nu} = 0{,}3 + \frac{0{,}62\,\mathrm{Re}^{0,5}\,\mathrm{Pr}^{1/3}}{\left[1 + \left(\frac{0{,}4}{\mathrm{Pr}}\right)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{\mathrm{Re}}{2{,}82 \cdot 10^5}\right)^{5/8}\right]^{4/5}.$$

Therefore the convective heat transfer coefficient averaged along circumference takes the form

$$\overline{\alpha}_{22} = \frac{\lambda_f}{D}\left[0{,}3 + \frac{0{,}62\,\mathrm{Re}^{0{,}5}\,\mathrm{Pr}^{1/3}}{\left[1+\left(\frac{0{,}4}{\mathrm{Pr}}\right)^{2/3}\right]^{1/4}}\left[1+\left(\frac{\mathrm{Re}}{2{,}82\cdot 10^5}\right)^{5/8}\right]^{4/5}\right]. \qquad (4)$$

To simplify the expression (4) let's use the approximated representation of the

$$f_2(\mathrm{Re}) = \mathrm{Re}^{0{,}5}\left[1+\left(\frac{\mathrm{Re}}{2{,}82\cdot 10^5}\right)^{5/8}\right]^{4/5}$$

as power function

$$\tilde{f}_2(\mathrm{Re}) = 7{,}3\cdot 10^{-3}\,\mathrm{Re}^{0{,}9227}. \qquad (5)$$

The error of the approximation doesn't exceed 6% for the Reynolds number ranging in $\mathrm{Re} = \left(6\cdot 10^5 \div 4\cdot 10^7\right)$ – fig. 1.

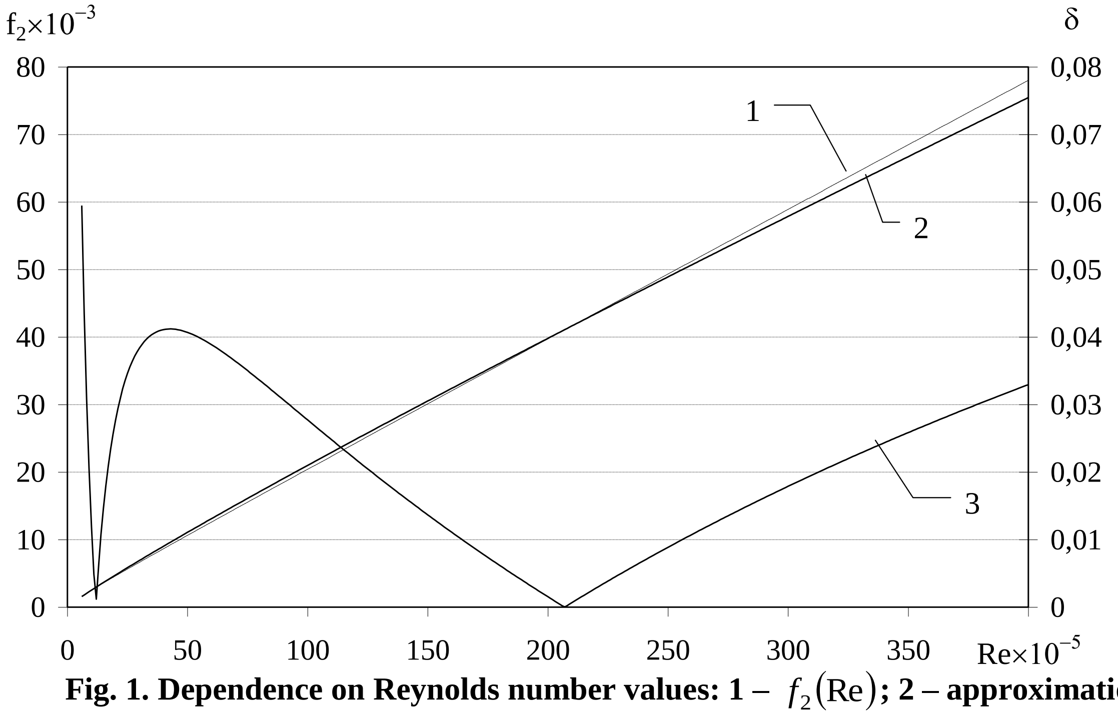

Fig. 1. Dependence on Reynolds number values: 1 – $f_2(\mathrm{Re})$; 2 – approximation $\tilde{f}_2(\mathrm{Re})$; 3 – relative error of approximation (the right axis)

Substituting the (5) into the (4) gives

$$\overline{\alpha}_{22} \cong \frac{\lambda_f}{D}\left[0{,}3 + 0{,}62\,\mathrm{Pr}^{1/3}\left[1+\left(\frac{0{,}4}{\mathrm{Pr}}\right)^{2/3}\right]^{-1/4} 7{,}3\cdot 10^{-3}\,\mathrm{Re}^{0{,}9227}\right] =$$

$$=\frac{\lambda_f}{D}\left[0{,}3+\frac{0{,}62\,\mathrm{Pr}^{1/3}}{\left[1+\left(\frac{0{,}4}{\mathrm{Pr}}\right)^{2/3}\right]^{1/4}}7{,}3\cdot10^{-3}\left(\frac{w_f D}{\nu}\right)^{0{,}9227}\right].$$

The value of the second term in square brackets of the last expression is ranging in $\left(83\div4\cdot10^{4}\right)$ for the airflow temperature $T_f=\left(273\div1273\right)K$, velocity $w_f=\left(1\div10\right)m/s$ and tank diameter $D=\left(10\div60\right)m$. Therefore the first term is insignificant and can be removed. Then the estimation of convective heat transfer coefficient takes the form

$$\overline{\alpha}_{22}\cong\frac{\lambda_f}{D}\frac{0{,}62\,\mathrm{Pr}^{1/3}}{\left[1+\left(\frac{0{,}4}{\mathrm{Pr}}\right)^{2/3}\right]^{1/4}}7{,}3\cdot10^{-3}\left(\frac{w_f D}{\nu}\right)^{0{,}9227}.$$

Taking into account the dependences of thermal conductivity and Prandtl number on air temperature allows to approximate the expression

$$f_3\left(T_f\right)=\lambda_f\frac{0{,}62\,\mathrm{Pr}^{1/3}}{\left[1+\left(\frac{0{,}4}{\mathrm{Pr}}\right)^{2/3}\right]^{1/4}}7{,}3\cdot10^{-3}\nu^{-0{,}9227} \qquad (6)$$

by power function

$$\tilde{f}_3\left(T_f\right)=198T_f^{-0{,}7655}. \qquad (7)$$

The analysis of the (6), (7) indicates that error of approximation (7) does not exceed 2% for temperature values ranging in $T_f=\left(273\div1273\right)K$. Thus the estimation of convective heat transfer coefficient averaged along tank circumference takes the form

$$\overline{\alpha}_{22}=198T_f^{-0{,}7655}w_f^{0{,}9227}D^{-0{,}0773}, \qquad (8)$$

where all values have to be presented in the SI system due dimensional coefficients. The function (8) is shown in the fig. 2 for the tank RVS-1000 ($D=28{,}5\,m$).

The analysis of the expression (8) indicates that convective heat transfer coefficient rises almost linearly with increasing the wind velocity (fig. 2), decreases with increasing the airflow temperature and insignificant depends on tank diameter: increasing the tank diameter from 10 m to 60 m leads to 15% reduction in the coefficient $\bar{\alpha}_{22}$.

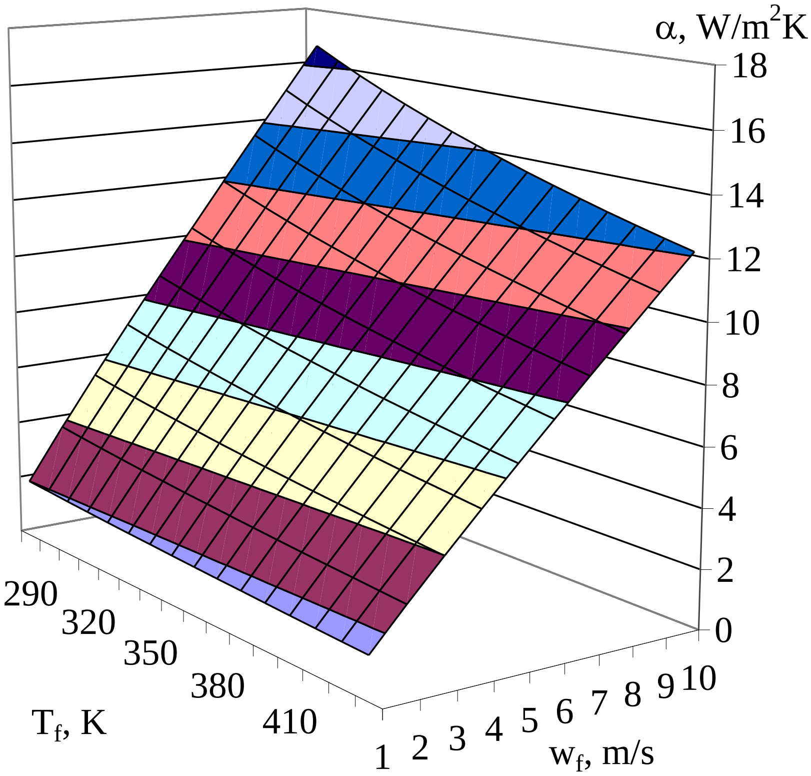

Fig. 2. Convective heat transfer coefficient averaged along the circumference of the tank RVS-10000 depending on airflow temperature and velocity

Local coefficient of the convective heat transfer α_{22} (value in the specified point along the circumference of the tank) can be obtained from expression

$$\alpha_{22} = u(\varphi)\bar{\alpha}_{22}, \tag{9}$$

where φ is the angle measured from the front stagnation point. Function $u(\varphi)$ is evaluated empirically [4, 5].

If the vertical component w_{f1} of the airflow, caused by plume above a spill fire, is not insignificant compared to horizontal component w_{f2} and vise versa then local coefficient of convective heat transfer will be evaluated by combining the expressions (3), (8), (9). Dependence of the convective heat transfer coefficient on the airflow velocity in (3), (8) is close to linear, total airflow velocity is a vector sum of the vertical and horizontal components

$$w_f = \sqrt{w_{f1}^2 + w_{f2}^2}. \tag{10}$$

Therefore the local coefficient of convective heat transfer will be assumed in the form similar to (10)

$$\alpha_2 = \sqrt{\alpha_{21}^2 + \alpha_{22}^2} =$$
$$= \sqrt{\left(146{,}6T_f^{-0{,}5625} w_{f1}^{0{,}8} z^{-0{,}2}\right)^2 + \left(198u(\varphi)T_f^{-0{,}7655} w_{f2}^{0{,}9227} D^{-0{,}0773}\right)^2} =$$
$$= \left(21491 T_f^{-1{,}125} w_{f1}^{1{,}6} z^{-0{,}4} + 39204 u^2(\varphi) T_f^{-1{,}531} w_{f2}^{1{,}8454} D^{-0{,}1546}\right)^{0{,}5}, \quad (11)$$

where all values have to be presented in the SI system.

Fig. 3 illustrates the dependence of the convective heat transfer coefficient on the horizontal w_{f2} and vertical component w_{f1} of the airflow velocity at the front stagnation point of the tank RVS-10000 ($D = 28{,}5\,m$). The height of the point is $z = 3\,m$, the temperature of the airflow is $T_f = 300\,K$.

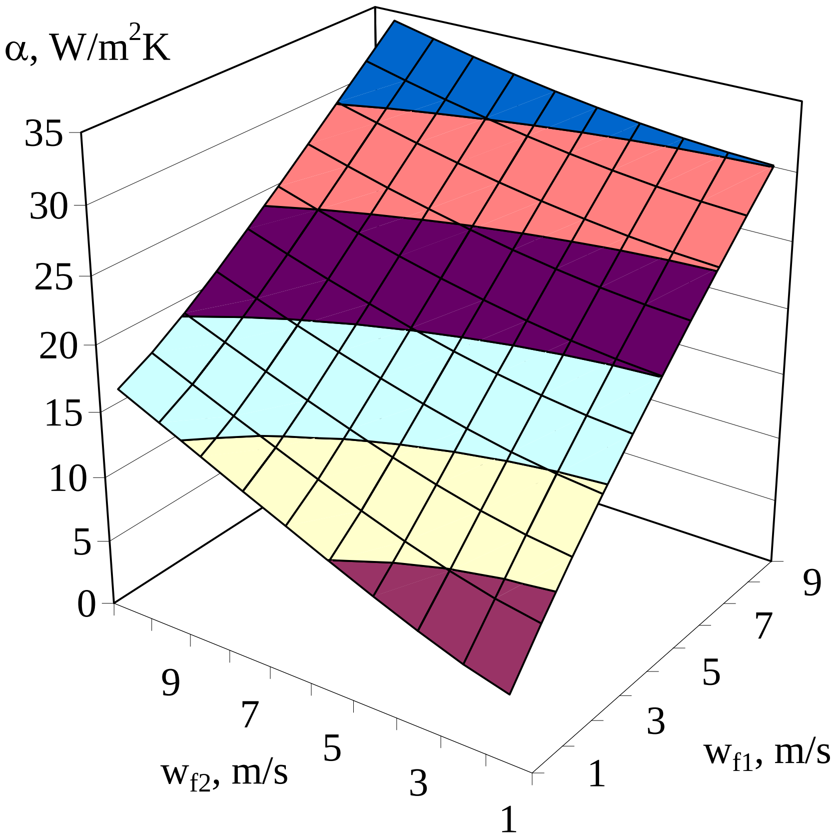

Fig. 3. The dependence of the convective heat transfer coefficient on the horizontal and vertical component of the airflow velocity

Conclusions. Coefficient of convective heat transfer from environment to the tank wall is evaluated for the case of forced convection caused by wind and plume above a spill fire in the tank dike. It is shown that convective heat transfer coefficient caused either by wind or fire plume can be approximated by power function (3) or (9) respectively. The estimation of convective heat transfer coefficient for the case of superposition of wind and fire plume is proposed. The results can be used to simulate the thermal effects of fire to the tank.

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Received by editorial Board 15.03.2017

А.Е. Басманов, Я.С. Кулик

Идентификация коэффициента конвективного теплообмена стенки резервуара при пожаре в обваловании

Методами теории подобия проведена идентификация коэффициента конвективного теплообмена стенки резервуара для случая вынужденной конвекции, обусловленной ветром и восходящими потоками над очагом горения горючей жидкости в обваловании резервуара.

Ключевые слова: резервуар, пожар в обваловании, конвективный теплообмен, вынужденная конвекция.

О.Є. Басманов, Я.С. Кулик

Ідентифікація коефіцієнта конвекційного теплообміну стінки резервуара при пожежі в обвалуванні

Методами теорії подібності проведено ідентифікацію коефіцієнта конвекційного теплообміну стінки резервуара для випадку вимушеної конвекції, обумовленої вітром і висхідними потоками над осередком горіння горючої рідини в обвалуванні резервуара.

Ключові слова: резервуар, пожежа в обвалуванні, конвекційний теплообмін, вимушена конвекція.