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ASSESSMENT OF EXCESS PRESSURE DURING ACCIDENTS AT OIL REFINERIES

Assessed the excess explosion pressure during an accident on oil tanks. In the studies, three cases of accidents were considered: local depressurization of the oil tank, full depressurization of the oil tank without the formation of a breakthrough wave and full depressurization with the formation of a breakthrough wave of the oil. The study was conducted for tanks with a volume of 10.000 m³. The paper considers a mathematical model of the overpressure of the explosion of vapors evaporated from a oil spill in the event of these accidents. According to this mathematical model, graphs of the dependence of excess explosion pressure on the radius were built. From the analysis of these graphs, numerical values of the radii of buildings damage degreewere determined. In case of full depressurization of the oil tank with the formation of a breakthrough wave, the radii of buildings damage degreewill be significantly larger than in the case of full depressurization without the formation of a breakthrough wave, which is due to a significant increase in the area of evaporation of the oil. It is determined that the presence of a serviceable dike can significantly reduce the consequences of accidents that can occur when damaged oil tanks. The radii on which a person will suffer damage of various degrees of complexity from the explosion of oil product vapors during their spill as a result of an accident on oil tanks are determined. It was established that for the case of local and full depressurization of a tank with an oil product without the formation of a breakthrough wave, a person will not receive too severe affections from a shock wave. In this case, for the case of full depressurization of the oil tank with the formation of a breakthrough wave, this distance will be at least 535 meters. The obtained results allow to assess the consequences of accidents on oil tanks and can be used to determine the distances of personnel and their special protective clothing.

Keywords: excess explosion pressure, oil spill, oil tanks, consequences of accidents

1. Introduction

Fire hazard of petrochemical industry facilities must meet the requirements of fire, energy, economic, environmental safety. The issues of fire and explosion safety of oil refining industry enterprises are very relevant. This is explained by: the presence of potential dangers that cause material and human losses; concentration of chemical energy carriers, oil and oil products, their ability to burn, explode and pollute the atmosphere with hazardous emissions, extremely high energy saturation of oil refining industry facilities.

Modern enterprises of the oil refining industry are a constant source of threats that have a global social character and require adequate measures for the safety of the population and the environment. A significant number of hazards occur in the petrochemical and oil refining industries. Tank farms are the main place of storage of crude oil and petroleum products at oil refineries, transshipment and distribution depots, enterprises of automobile, railway, water, air transport. Accumulation of flammable and combustible liquids in a relatively small area of the tank farm leads to increased fire hazard of such facilities. The spill and ignition of petroleum products is one of the most dangerous emergencies that can lead not only to significant material losses, but also to human casualties. In terms of complexity, the fire in the tank farm is one of the largest, you have to think about the location of communications passing nearby and the location of adjacent rooms.

The situation is complicated by the war on the territory of Ukraine, since most objects of the petrochemical industry are constantly shelled by the aggressor country. Before the war, the number of fires over the past 30 years remained virtually unchanged: during the year on the territory of Ukraine there are on average 2 fires for 3 years at large oil refineries or oil depots. Over the last two years, the number of accidents at side facilities has sharply increased. At what oil tanks can be damaged directly by shells, their fragments, and so the shock wave caused by the hit of missiles near the tank. Based on this, the assessment of the consequences of emergencies that may occur at petrochemical facilities is relevant.

2. Analysis of literature data and problem statement

The fire hazard of petrochemical industry facilities must meet the requirements of fire, energy, economic and environmental safety. The issues of ensuring fire and explosion safety of enterprises of the oil refining industry are very relevant. This is explained by: the presence of potential dangers causing material and human losses; the concentration of chemical energy carriers, oil and oil products, their ability to burn, explode and pollute the atmosphere [1], underground and river waters due to seepage of liquid deep into the soil [2] with dangerous emissions, extremely high saturation energy of oil refining industry capacities. Spreading over considerable distances, they significantly affect the state of the air [3]. The shortcoming of the works [1–3] is that they consider the consequences of accidents at the facilities of the petrochemical industry from the point of view of impact on the environment, while the consequences of direct impact on people and buildings remain undefined.

About 60 % of fire emergencies are fires involving flammable liquids [4]. Accidents of vertical steel tanks, as a rule, are accompanied by oil spills and fires caused by it, which leads to man-made disasters, violations of normal operation and significant environmental pollution [5]. In works [4–5] models of spill area of various oil products depending on various factors are considered, while the conditions for the formation of a fire-hazardous environment during the formation of such spills are not defined.

In [6], the main causes of accidents at tanks with oil products are considered, the most common of which are violations of the technological conditions of operation, defects and violations during installation, damage by debris and shock waves during shelling of oil tanks, corrosion, etc.

The paper [7] investigated the thermal effect of a fire in a tank with petroleum products on the neighboring tank. Using the thermal conductivity equation, the temperature distribution inside the tank wall is determined. However, this research paper does not consider the consequences of an oil spill. In [8], a model of the thermal effect of a flame on a container with oil products located nearby is proposed, but this model does not take into account the different temperatures on the outer and inner surfaces of the container. In the paper [9], the authors analyze the impact of a fire in a nearby tank and a collapse fire on a tank with petroleum products.

In [10], a model of the burning of an oil spill on a horizontal surface in the shape of a circle is presented. The disadvantage of the model is that the slope of the surface is not taken into account, which leads to the stretching of the spill area along the direction of the slope [11]. In [12], the method of experimentally determining the parameters of infiltration into the soil is given, but the parameters of the flame above the burning and spreading liquid are not taken into account. In [13], a model of the convection component of the heat flow from a spill fire of arbitrary shape is described. This model takes place during the formation of a spill of petroleum products and their ignition without the formation of an explosion. The article does not consider the case when, due to the spread of oil products, an explosive vapor-air concentration is formed over them, which, in the presence of an ignition source, is capable of exploding and the consequences to which this can lead.

Thus, the unsolved part of the considered problem is the lack of research on the consequences of accidents caused by the explosion of a vapor-air mixture formed as a result of the evaporation of an oil spill and their impact on people and buildings.

3. The purpose and tasks of the research

The purpose of the work is to evaluate the impact of the overpressure of the explosion on people and buildings during various accidents on oil tanks.

To achieve the goal, the following tasks must be solved:

– to determine the dependence of the excess pressure of the explosion on the distance in various accidents on tanks with oil products;

– to determine the degree of damage to people and buildings under the action of excess pressure of the explosion, which was formed as a result of accidents.

4. Research materials and methods

The object of the study is the consequences of accidents during the destruction of tanks with petroleum products.

The subject of the study is the assessment of the degree of damage to people and buildings by the shock wave of the explosion of a vapor-air cloud over an oil spill. The hypothesis of the study is that the formation of a shock wave of an explosion of a steam-air cloud over an oil spill can lead to the death or injury of people and the destruction of buildings and structures.

Tabl. 1. Initial data

Parameter	Value
Oil tank volume, m^3	10000
Height, m	12.0
Radius, m	17.1
Oil density, kg/m^3	850
Coefficient of spillage during spreading, f_p/m	20
Oil temperature, $^\circ C$	39
Lower flame propagation concentration limit, %	0.9
Molecular weight, $kg/kmol$	50
Acceleration of gravity, m/s^2	9.8
Air pressure, kPa	101.325
Degree of filling of oil tank, %	90
Block time, s	3600
Saturated oil vapor pressure, kPa	60
Saturated oil vapor concentration, %	59.215
Diameter of hole formed during depressurization, m	0.05

In the study were estimated the consequences of emergency situations at oil depots. For research were chosen three possible scenarios of fire occurrence and development:

– local depressurization with the occurrence of an oil spill fire in the diking;

– full oil tank depressurization without wave with the occurrence of an oil spill fire throughout all the dike area;

– full oil tank depressurization with wave which burns and goes through the dike area.

The data were used for the studies presented in Tabl. 1. For research were used 10.000 cubic meter oil tanks were, as are the most common in Ukraine. Calculations will be carried out by computing equipment using the Maple program.

5. Mathematical model oil spill fire thermal influence size zones estimation

Value of excess pressure determined by the formula:

$$\Delta p = p_x \cdot p_0, \tag{1}$$

where the value of dimensionless excess pressure is:

$$p_x = \begin{cases} \left(\dfrac{u^2}{C_0^2}\right)\cdot\left(\dfrac{\sigma-1}{\sigma}\right)\cdot\left(\dfrac{0{,}83}{r_x}-\dfrac{0{,}14}{r_x^2}\right), \text{if } \ r_x > 0{,}34 \\ \left(\dfrac{u^2}{C_0^2}\right)\cdot\left(\dfrac{\sigma-1}{\sigma}\right)\cdot\left(\dfrac{0{,}83}{0{,}34}-\dfrac{0{,}14}{0{,}34^2}\right), \text{if } \ r_x \le 0{,}34 \end{cases}, \tag{2}$$

the value of dimensionless distance from center of the cloud:

$$r_x = \frac{r}{\left(E/p_0\right)^{1/3}} \tag{3}$$

and E – effective energy reserve of combustible mixture.

Visible flame speed determined by the formula:

$$u = \begin{cases} u_p, \text{if } \ u_p > 300; \\ 300, \text{if } \ u_p \le 300. \end{cases} \tag{4}$$

where estimated flame speed is:

$$u_p = k_1 m_п^{1/6}, \tag{5}$$

the mass of evaporated oil product vapors:

$$m_п = 0{,}15\rho V_s, \tag{6}$$

where V_s – volume of spill oil, ρ – oil density.

For a scenario with full depressurization of the tank without creating a break-through wave, the volume of oil flowing out is determined by the formula:

$$V_s = h_d \frac{\pi D_p^2}{4}. \tag{7}$$

For a scenario with complete depressurization of the tank with the formation of a breakthrough wave, the volume of oil spilled will be determined by the formula:

$$V_s = \varepsilon H_t \frac{\pi D_p^2}{4}. \quad (8)$$

Tabl. 2. Oil spill area for different emergency scenarios

Emergency scenarios	Oil spill area, m²
Local depressurization	1267
Full oil tank depressurization without wave	17564
Full oil tank depressurization with wave	297637

The area of the oil spill for various emergency scenarios, which was calculated based on the data in Tabl. 1, is presented in Tabl. 2.

6. Assessment of damage degree to people and buildings from explosion

Using formula (1), the graphs of the excess explosion pressure during combustion of the explosive hazardous steam-air mixture against the distance for various accidents of oil tanks were plotted and shown in Fig. 1.

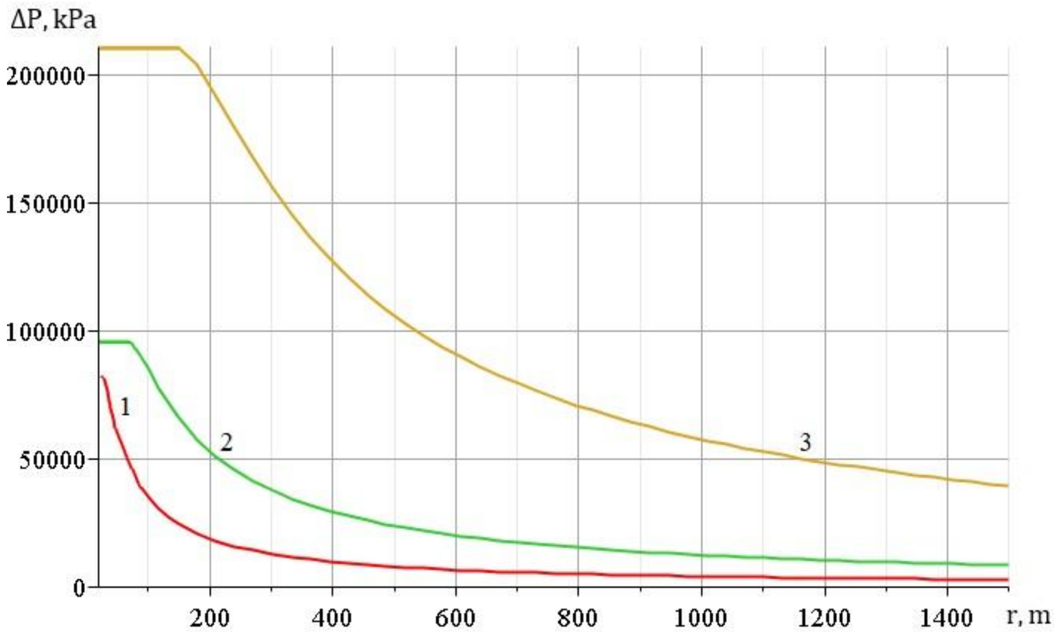

Fig. 1. Dependence of excess pressure on the distance for oil tank when it has: 1 – local depressurization; 2 – full depressurization, without wave; 3 – full depressurization, with wave

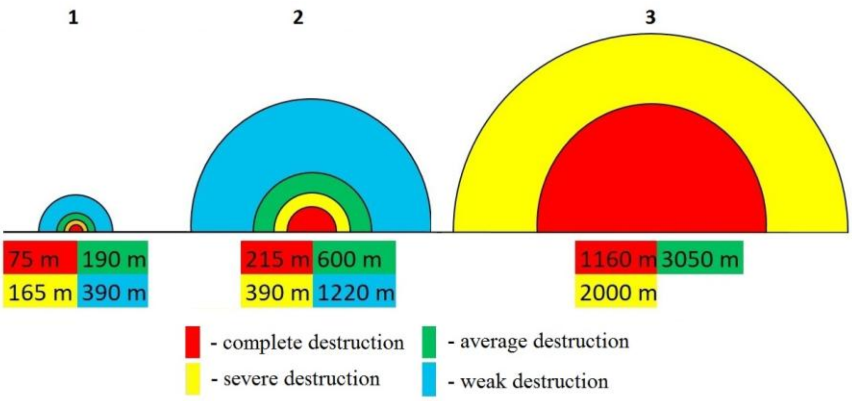

Fig. 2. Radii of Buildings Damage Degree in an Oil Spill Explosion: 1 – local depressurization; 2 – full depressurization, without wave; 3 – full depressurization, with wave

From the analysis of the graphs presented in Fig. 1, the distances at which a person will receive different degrees of shock wave damage resulting from local depressurization of the oil tank, full oil tank depressurization without wave and full oil tank depressurization without for oil tanks with a volume of 10.000 m³ are determined are presented respectively in Tabl. 3.

Tabl. 3. Humans Damage Degrees (Oil tank V=10000 m³)

Damage Degrees	Radius, m
Local depressurization	
Light affections	84–180
Average affections	50–84
Severe affections	<50
Too severe affections	–
Full depressurization, without wave	
Light affections	280–600
Average affections	170–280
Severe affections	<170
Too severe affections	–
Full depressurization, with wave	
Light affections	1470–3000
Average affections	950–1470
Severe affections	535–950
Too severe affections	>535

Also, the radii of destruction of buildings during the explosion of the steam-air mixture formed as a result of local depressurization of the tank, complete depressurization of the tank without the formation of a breakthrough wave and complete depressurization of the tank with the formation of a breakthrough wave were determined, which are presented in Fig. 2.

7. Discussion of the results of the overpressure assessment of the explosion

The assessment of the consequences of an accident at petrochemical enterprises, namely an explosion of a vapor-air mixture on a spill of a petroleum product, which was formed when a reservoir with a petroleum product was damaged, was studied. When conducting the research, it was assumed that the oil product was spilled on a flat asphalted surface, and the spilled substance was oil.

Tabl. 2 shows oil spill zones with various damage to oil tanks. From the analysis of this table, it can be stated that the presence of a technically sound dike can significantly reduce the area of oil spill. At the same time, under the condition of complete depressurization of the tank with the formation of a breakthrough wave, the area of oil spill will increase by no less than 16.84 times compared to the complete depressurization of the tank without the formation of a breakthrough wave. This is due to the fact that when the reservoir is fully depressurized without a breakthrough wave, the spill zone will be limited to the dam area.

From the analysis of the graphs presented in fig. 1, the radii of destruction of buildings during the explosion of a vapor-air mixture are determined, as shown in Fig. 2. From this figure, it can be seen that with local depressurization of the oil tank, the radius of complete destruction of buildings will be 75 meters, with complete destruction of the tank without the formation of a breakthrough wave, 215 meters, and with complete destruction with the formation of a breakthrough wave – 1160 meters. Based on this, it can be argued that the presence of collapse can reduce the radius of the lesion by at least 5.39 times.

It follows from table 3 that with local depressurization and full depressurization without the formation of a wave, a person will not receive too severe injuries. And with complete depressurization by wave formation, this distance will be 535 meters. At the same time, a person will receive severe damage in the case of local depressurization of the tank at a distance of up to 50 meters, in the case of full depressurization without the formation of a breakthrough wave, this distance will be 3.4 times greater, and in the case of full depressurization due to the formation of a wave, this distance will be 10.7 times. This is due to the fact that the area of oil spillage when the tank is completely depressurized with the formation of a breakthrough wave is much larger, and accordingly, the area of evaporation is also larger.

The disadvantages of this study are the narrow area of obtaining results. This is due to the fact that when applying this method, the physical characteristics of the spreading substance are taken into account, so separate calculations must be made for each substance. Evenness of the surface and its material can also play a significant role in obtaining results. Future research will be directed to the construction of mathematical models of oil product spreading that take into account the topography of the area. Such studies require the use of mathematical apparatus, which involves the solution of integral equations and the use of mathematical software.

Based on these data, it can be argued that the presence of a functional collapse can significantly reduce the consequences of accidents at oil storage facilities. In general, the data given in the work can be used by fire extinguishing managers for the placement of personnel and equipment during the liquidation of accidents at such facilities. For example, the data in Tabl. 3 can be used to determine the distances of personnel and special equipment.

8. Conclusions

1. The dependence of the excess explosion pressure on the distance in various accidents on oil tanks was determined and graphs of these dependencies were plotted. Numerical values of radii of destruction of buildings and structures of different degrees are determined. It was determined that with local depressurization of the oil tank, the radius of damage will be 75 meters, with full depressurization it will increase by 2.86 times, and with full depressurization with the formation of a wave by 15.46 times. Based on this, it can be argued that the presence of a serviceable dike can significantly reduce the consequences of accidents on oil tanks.

2. The degrees of damage to people by the shock wave, which was formed as a result of the explosion of a mixture of vapors of a petroleum product spill during accidents on tanks with oil of various nature, which are presented in the form of a table, are determined. It is established that in the case of local depressurization and full depressurization without wave, people will not receive too severe affections, and in the case of full depressurization with wave, this distance at which people will receive too severe affections will be 535 meters.

References

1. Kustov, M. V., Kalugin, V. D., Tutunik, V. V., Tarakhno, E. V. (2019). Physicochemical principles of the technology of modified pyrotechnic compositions to reduce the chemical pollution of the atmosphere. Voprosy khimii i khimicheskoi tekhnologii, 1, 92–99. doi: 10.32434/0321-4095-2019-122-1-92-99

2. Loboichenko, V., Strelec, V. (2018). The natural waters and aqueous solutions express-identification as element of determination of possible emergency situation. Water and Energy International, 61, 9, 43–50. Available at: https://www.indianjournals.com/ijor.aspx?target=ijor:wei&volume=61r&issue=9&article=008

3. Popov, O., Iatsyshyn, A., Kovach, V., Artemchuk, V., Kameneva, I., Taraduda, D., Sobyna, V., Sokolov, D., Dement, M., Yatsyshyn, T. (2020). Risk assessment for the population of Kyiv, Ukraine as a result of atmospheric air pollution. Journal of Health and Pollution, 10, 25. doi: 10.5696/2156-9614-10.25.200303

4. Fabiano, B., Caviglione, C., Reverberi, A. P., Palazzi, E. (2016) Multicomponent Hydrocarbon Pool Fire: Analytical Modelling and Field Application. Chemical Engineering Transactions, 48, 187–192. doi: 10.3303/CET1648032

5. Raja, S., Tauseef, S. M., Abbasi, T. (2018). Risk of Fuel Spills and the Transient Models of Spill Area Forecasting. Journal of Failure Analysis and Prevention, 18, 445–455. doi: 10.1007/s11668-018-0429-1

6. Vasilchenko, A., Otrosh, Yu., Adamenko, N., Doronin, E., Kovalov, A. (2018). Feature of fire resistance calculation of steel structures with intumescent coating. MATEC Web of Conferences, 230, 02036. doi: 10.1051/matecconf/201823002036

7. Semerak, M., Pozdeev, S., Yakovchuk, R., Nekora, O., Sviatkevich, O. (2018). Mathematical modeling of thermal fire effect on tanks with oil products. MATEC Web of Conferences, 247(00040). doi: 10.1 051/matecconf/201824700040

8. Espinosa, S. N., Jaca, R. C., Godoy, L. A. (2019). Thermal effects of fire on a nearby fuel storage tank. Journal of Loss Prevention in the Process Industries. 62(103990). doi: 10.1016/j.jlp.2019.103990

9. Ahmadi, O., Mortazavi, S. B., Pasdarshahri, H., Mohabadi, H. A. (2019). Consequence analysis of large-scale pool fire in oil storage terminal based on computational fluid dynamic (CFD). Process Safety and Environmental Protection, 123, 379–389. doi: 10.1016/j.psep.2019.01.006

10. Abramov, Y., Basmanov, O., Krivtsova, V., Salamov, J. (2019). Modeling of spilling and extinguishing of burning fuel on horizontal surface, Naukovyi Visnyk NHU 4, 86–90. doi: 10.29202/nvngu/2019-4/16

11. Oliinik, V., Basmanov, O. (2023). Model of spreading and burning the liquid on the soil, Problems of emergency situations, 1(37), 18–30. doi: 10.52363/2524-0226-2023-37-2

12. Abramov, Y., Basmanov, O., Khmyrov, I., Oliinik, V. (2022). Justifying the experimental method for determining the parameters of liquid infiltration in bulk material, Eastern-European Journal of Enterprise Technologies, 4/10(118), 24–29. doi: 10.15587/1729-4061.2022.262249

13. Abramov, Y., Basmanov, O., Oliinik, V., Khmyrov, I., Khmyrova, A. (2022). Modeling the convective component of the heat flow from a spill fire at railway accidence. EUREKA: Physics and Engineering, 6, 128–138. doi: 10.21303/2461-4262.2022.002702

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ОЦІНКА НАДЛИШКОВОГО ТИСКУ ВИБУХУ ПРИ АВАРІЯХ НА НАФТОПЕРЕРОБНИХ ПІДПРИЄМСТВАХ

Проведено оцінку надлишкового тиску вибуху при аварії на резервуарах з нафтопродуктом. У дослідженнях було розглянуто три випадки аварій: локальна розгерметизація резервуару з нафтопродуктом, повна розгерметизація резервуару без утворення хвилі прориву та повна розгерметизація з утворенням хвилі прориву нафтопродукту. Дослідження було проведено для резервуарів об'ємом 10000 м³. В роботі розглянута математична модель надлишкового тиску вибуху парів, що випаровуються з розливу нафтопродукту у випадку цих аварій. За цією математичною моделлю були побудовані графіки залежності надлишкового тиску вибуху від радіусу. Із аналізу цих графіків визначені численні значення радіусів ступенів руйнувань будівель і споруд. Встановлено, що у випадку повної розгерметизації резервуару з нафтопродуктом з утворенням хвилі прориву радіуси повних руйнувань будівель і споруд будуть значно більшими ніж у випадку повної розгерметизації без утворення хвилі прориву, що обумовлюється значним збільшенням площі випаровування нафтопродукту. Визначено, що наявність справного обвалування дозволяє у рази зменшити наслідки аварій, що можуть статися при пошкоджені резервуарів з нафтопродуктом. Визначені радіуси на яких людина отримає пошкодження різних ступенів складності від вибуху парів нафтопродукту при їх розливі внаслідок аварії на резервуарах з нафтопродуктами. Встановлено, що для випадку локальної та повної розгерметизації резервуару з нафтопродуктом без утворення хвилі прориву людина не отримає надважких ушкоджень від ударної хвилі. При цьому для випадку повної розгерметизації резервуару з нафтопродуктом з утворенням хвилі прориву ця відстань складе не менше 535 метрів. Отримані результати дозволяють оцінити наслідки аварій на резервуарах з нафтопродуктом та можуть бути використані керівниками гасіння пожеж для розміщення особового складу та техніки при виникненні аварій на цих об'єктах.

Ключові слова: надлишковий тиск вибуху, розлив нафтопродукту, резервуари з нафтопродуктом, наслідки аварій

Література

1. Kustov M. V., Kalugin V. D., Tutunik V. V., Tarakhno E. V. Physicochemical principles of the technology of modified pyrotechnic compositions to reduce the chemical pollution of the atmosphere. Voprosy khimii i khimicheskoi tekhnologii. 2019. № 1. P. 92–99. doi: 10.32434/0321-4095-2019-122-1-92-99

2. Loboichenko V., Strelec V. The natural waters and aqueous solutions express-identification as element of determination of possible emergency situation. Water and Energy International. 2018. № 61. 9. P. 43–50. URL: https://www.indianjournals.com/ijor.aspx?target=ijor:wei&volume=61r&issue=9&article=008

3. Popov O., Iatsyshyn A., Kovach V., Artemchuk V., Kameneva I., Taraduda D., Sobyna V., Sokolov D., Dement M., Yatsyshyn T. Risk assessment for the population of Kyiv, Ukraine as a result of atmospheric air pollution. Journal of Health and Pollution. 2020. Vol. 10. №. 25. P. 1–11. doi: 10.5696/2156-9614-10.25.200303

4. Fabiano B., Caviglione C., Reverberi A. P., Palazzi E. Multicomponent Hydrocarbon Pool Fire: Analytical Modelling and Field Application. Chemical Engineering Transactions. 2016. Vol. 48. P. 187–192. doi: org/10.3303/CET1648032

5. Raja S., Tauseef S. M., Abbasi T.: Risk of Fuel Spills and the Transient Models of Spill Area Forecasting. Journal of Failure Analysis and Prevention. 2018. Vol. 18. № 2. P. 445–455. doi: 10.1007/s11668-018-0429-1

6. Vasilchenko A., Otrosh Yu., Adamenko N., Doronin E., Kovalov A.: Feature of fire resistance calculation of steel structures with in tumes centcoating. MATEC Web of Conferences. 2018. № 230. 02036. P. 1–5. doi: 10.1051/matecconf/201823002036

7. Semerak M., Pozdeev S., Yakovchuk R., Nekora O., Sviatkevich O. Mathematical modeling of thermal fire effecton tanks with oil products. MATEC Web of Conferences. 2018. № 247(00040). P. 1–8. doi: 10.1051/matecconf/201824700040

8. Espinosa S. N., Jaca R. C., Godoy L. A. Thermal effects of fire on a nearby fuels to rage tank. Journal of Loss Prevention in the Process Industries. 2019. № 62(103990). P. 1–13. doi: 10.1016/j.jlp.2019.103990

9. Ahmadi O., Mortazavi S. B., Pasdarshahri H., Mohabadi H. A. Consequence analysis of large-scale pool fire in oil storage terminal based on computational fluid dynamic (CFD). Process Safety and Environmental Protection. 2019. Vol. 123. P. 379–389. doi: 10.1016/j.psep.2019.01.006

10. Abramov Y., Basmanov O., Krivtsova V., Salamov J. Modeling of spilling and extinguishing of burning fuel on horizontal surface. Naukovyi Visnyk NHU. 2019. № 4. P. 86–90. doi: 10.29202/nvngu/2019-4/16

11. Oliinik V., Basmanov O. Model of spreading and burning the liquid on the soil, Problems of emergency situations. 2023. № 1(37). P. 18–30. doi: 10.52363/2524-0226-2023-37-2

12. Abramov Y., Basmanov O., Khmyrov I., Oliinik V. Justifying the experimental method for determining the parameters of liquid in filtration in bulk material. Eastern-European Journal of Enterprise Technologies. 2022. Vol. 4. № 10(118). P. 24–29. doi: 10.15587/1729-4061.2022.262249

13. Abramov Y., Basmanov O., Oliinik V., Khmyrov I., Khmyrova A. Modeling the convective component of the heat flow from a spill fire a trail way accidence. EUREKA: Physics and Engineering. 2022. № 6. P. 128–138. doi: 10.21303/2461-4262.2022.002702

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