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FIRE SAFETY OF OIL AND OIL PRODUCTS TANKS AND ANALYSIS OF COST AVOIDANCE

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Annotation. This paper investigates the issues of fire safety in the operation of tanks for storage of oil and petroleum products, as well as analyzes the prevention of fire costs. Oil and oil products produced in Kazakhstan are produced, processed and stored in tank farms. In the state register of hazardous production facilities there is information about thousands of oil depots and storage facilities of oil and oil products.

Currently, the theoretical analysis of oil products combustion uses various approaches based on some modeling ideas about the combustion mechanism as a complex phenomenon. Detailed information on the regularities of the combustion process can be obtained by numerical solution of systems of equations for liquid and gaseous reactants. In this regard, the development of approximate analytical methods for calculating the combustion of petroleum products, allowing to determine the main characteristics of the combustion process, is of great importance.

The problem of improving industrial safety of tanks has become more acute due to a number of situations that have arisen in Kazakhstan under new economic conditions. Currently, 90% of the used tank farms have exceeded the normative service life. Review of emergency situations resulting from tank explosion and subsequent ignition of oil product in a free surface tank with rupture of the tank roof has shown that consideration of oil product combustion processes in a tank is currently an actual direction of science development.

Keywords: oil tank; hazard; fire safety; hazardous production facilities; analytical analysis; cost avoidance.

Introduction. Oil and oil products produced in Kazakhstan are refined, processed and stored in tank farms. The state register of hazardous production facilities contains information on thousands of oil depots and storage facilities for oil and oil products. In accordance with the Law of the Republic of Kazakhstan dated April 11, 2014 «On Civil Protection» [1] tank farms and oil storage facilities are classified as hazardous production facilities. The problem of improving industrial safety of tanks has become more acute due to a number of situations that have arisen in Kazakhstan under the new economic conditions. Currently, 90% of the tank farms in use have exceeded their normal service life. Review of emergency situations resulting from an explosion in the tank and subsequent ignition of oil products in the tank with a free surface, with the rupture of the tank roof showed that the consideration of combustion processes of oil products in the tank is currently an urgent direction of scientific development.

Burning of oil products by the free surface of the tank often leads to irreversible consequences. The study of the combustion process has an important scientific and applied significance related to the problems of fire extinguishing, oil spills in tank accidents.

Currently, the theoretical analysis of oil products combustion uses various approaches based on some modeling ideas about the combustion mechanism as a complex phenomenon. Detailed information on the regularities of the combustion process can be obtained by numerical solution of systems of equations for liquid and gaseous reactants. At the same time, in the study of turbulent combustion of petroleum products there are difficulties of physical nature, which are due to the establishment of turbulent exchange coefficients in the free convective flow of reactive gas of variable density.

In this connection, it is especially important to develop approximate analytical methods for calculating the combustion of petroleum products, which make it possible to establish the main characteristics of the combustion process. Considering that the solution of the problem of

predicting the conditions and consequences of tank fires is related to the preservation of human life and reduction of material damage, it is highly relevant.

In order to isolate tank fires to avoid material damage and human casualties, it is recommended to develop the following analytical methods for calculating the combustion of petroleum products with the free surface of the tank:

1. Assessment of the technical condition of tank farms, as well as analysis of statistical data on tank accidents, their area, features and consequences.

2. Investigation of the basics of oil products combustion with the free surface of the tank. Development of analytical methods to establish the main characteristics of the oil products combustion process.

3. Study of the main characteristics of the combustion process in connection with the structural and technological parameters of the tank.

Research materials and methods: Brief review of fire safety in the operation of oil product storage tanks in oil depots and oil warehouses. According to the state register of hazardous production facilities, there is information about thousands of oil depots and oil and oil products storage facilities. Of these, there are more than 50 facilities, for which the legislation in the field of industrial safety establishes mandatory development of industrial safety declaration. Ensuring industrial safety of hazardous production facilities suggests using the procedure of accident risk analysis to justify and make effective management decisions based on the most «dangerous places» identified in the technological system of the facility.

When assessing the scale of possible technogenic threats in the controlled facility, the following main accident development scenarios were established:

- the most dangerous - complete destruction of a surface tank with oil with spreading of oil vapor cloud, fire, explosion, fire spill; explosion of oil vapor in the ATB tunnel (length 3.5 km, diameter 5 m);

- the most probable - partial failure of the pump unit; local leakage from process equipment, wells. In case of accidents under these scenarios a fire due to ignition and oil (petroleum product) spillage is possible.

The main damaging factors of these accidents are: thermal radiation, impact of shock wave, getting into open flame, damage by splinters. When assessing the zones of possible damage (destruction):

- Methodology for assessing the consequences of accidental explosions of fuel-air mixtures - to determine the damage zones during combustion and explosion of fuel-air mixture clouds [2];

- Guidelines for Industrial Risk Assessment;

- Calculation of heavy gas dispersion to determine the mass of the substance involved in combustion (explosion);

-GOST 12.3.047-98. «Fire safety of technological processes. General requirements. Methods of control» - to determine the zones of thermal radiation damage during spill combustion [3].

In accidents with particularly severe consequences, the damage (destruction) zones may reach several hundred meters; in case of fire, the size of hazardous zones is limited to several tens of meters from the edge of the spill. In case of foreseen emergencies there is a breakdown of neighboring equipment, which can lead to further destruction of the accident. Accordingly, this condition may increase the area of affected areas. The occurrence of fires and explosions at oil storage facilities depends on many conditions related to the properties of oil products, production organization and external conditions [4, 5, 6]. Its main causes are:

- use of open flames during repair and inspection of equipment;
- use of leaky lighting devices and fittings;
- faulty electrical wiring;
- gas discharges;
- spontaneous combustion of combustible substances;

- electrification of fuel.

A special danger during operation of tanks, pipelines is electrification of fuel, which can cause fire. Petroleum products are dielectrics, i.e. conductors of electricity. When rubbing them on another dielectric or conductor static electric charges arise. The petroleum products are negatively charged, while the metal bonded to them will be positively charged. The higher the potential difference, the higher the danger of discharges (electric sparks), which may cause an explosion or fire.

When oil is stored under operational conditions, the fuel is electrified:

- pumping through hoses and pipes;
- passing through filters;
- jet impact on hard surfaces;
- splashing in the air when falling from a height.

The largest charges of static electricity are generated, which are dug out of rubber and rubberized hoses. The potential value can reach tens of thousands of volts. Dangerous charges are formed when pumping petroleum products in pumps, pipelines and valves. To avoid static electricity discharges it is necessary to ground all tanks, pipelines, injection units, hoses and other equipment related to storage, pumping and transportation of petroleum products. The greatest danger is the filling of tanks, automobile and railroad tanks with a filling hose with 1 m or more from the bottom of the container. In all cases, the filling of containers must be carried out under the product layer. Fire hazard for different petroleum products is not the same. It is characterized by ignition and temperature limits of ignition, vapor concentration in the air and the tendency of petroleum products to accumulate static electrical charges.

Results and their discussion. Current state of tanks at oil depots and oil storage facilities. Currently in Kazakhstan and CIS countries more than 40 thousand vertical and horizontal cylindrical tanks with capacity from 100 to 50000 m for storage of oil, oil products and aggressive chemicals are functioning [7]. Almost each of them is a hazardous object for the employees of the enterprise and the environment. Over the last 30 years in Kazakhstan several dozens of reservoirs have been destroyed with fires and sometimes human casualties.

In Table 1. the data of the analysis of the causes of accidents are given on the example of 65 accidents with tanks for oil and oil products, as well as with other tanks during the given year) [8].

Table 1 – Data for analyzing the causes of accidents

№	Causes of accidents	%
1	Metal brittleness	63,1
2	Explosion and fire	12,3
3	Corrosion wear of metal	7,7
4	Settlement of the tank base	4,6
5	Hurricane wind	1,5
6	Other causes	10,8
	Total	100

The degree of danger (responsibility) of tanks is taken into account by special requirements to materials, scope of control during design and is specified in the working documentation, as well as determined by the reliability coefficient for the purpose of calculation. Such classification of tanks reflects the degree of hazard of tank disasters to the public and the environment [8, 9].

Especially relevant are the issues related to the inspection of operating tanks based on effective methods of technical diagnostics. Based on risk assessment, diagnostics provides a significant increase in the reliability of the equipment in use, including tanks, reducing the number of failures and reducing the time spent on their regular inspection and maintenance [10].

The levels of risk associated with different tanks are not the same, so risk-based monitoring concentrates efforts to diagnose and maintain tanks with higher risk and possible consequences. For each tank diagnosed, a risk matrix is calculated and constructed with respect to the defects it contains.

The main objectives of risk-based diagnostics are:

* focusing on identifying and mitigating business and safety risks;

* achieving a high availability factor by taking tanks out of service only to perform the most necessary inspection programs;

* improving safety by preventing hazards associated with preparing tanks for inspection.

At present, new design solutions are offered by refiners, by means of which the technology of storage and transportation of petroleum products after preparation or overhaul is changed in the direction of reduction of product evaporation, acceleration of transportation, elimination of «funnel formation», removal of «dead» sediments, which leads to an increase in tank operation. At the same time, its convenience in use is ensured and a significant economic effect per 1m3 of stored product is achieved [9].

Recently, a considerable amount of theoretical studies of the combustion process related to the problems of fire extinguishing, chemical technology, development of effective methods of oil recovery enhancement have been carried out. Based on the results of these studies, many issues related to combustion under conditions of natural and forced convection have been considered. A quasi-dimensional model is used to describe free convective combustion of a liquid. On the basis of this model, a number of important questions of fluid combustion theory have been solved.

A brief review of the state of the theory of combustion of oil products with a free surface shows that a large number of works have been carried out on the experimental study of the characteristics of the processes, their dependence on various factors. Methods of mathematical description of this phenomenon have been developed, which allow, on the basis of numerical integration of the system of transport equations, to obtain information about the nature of the process, about the dependence of characteristics on various parameters. In addition, approximate analytical methods are important, allowing to calculate with sufficient accuracy the main characteristics of the process for technical applications.

Experimental study of the occurrence of hazardous risk factors of accidents with horizontal tanks. Petroleum products are flammable substances. Careless handling of fire, sparks from impact or electrical discharges of metal objects can cause them to explode or catch fire. Fires result in large losses of petroleum products, damage to structures and equipment. However, the degree of fire hazard is not the same for different petroleum products. It is characterized by temperature limits of ignition, vapor concentration in the air, and the propensity of petroleum products to accumulate static electric charges [11].

Characterization of explosion and fire hazardous properties of petroleum products [12]:

- ignition temperature;
- auto-ignition temperature;
- ignition zone (temperature and concentration limits of explosion hazard).

Ignition temperature is the lowest temperature of a substance (under standard test conditions) at which vapors or gases are formed from ignition sources on Earth that are capable of igniting in air, but the rate of vapor or gas formation is insufficient for prolonged combustion. Depending on the method of detection, a distinction is made between flash point in a closed crucible and flash point in an open crucible.

The flash point allows the assessment of the temperature conditions under which a substance ignites. This is important for classifying petroleum products and other combustibles by fire hazard. Flash point is the temperature at which a liquid (flammable substance) heated under normal conditions ignites when a flame falls on it and burns for at least 5 seconds. This temperature is a few degrees above the flash point.

Self-ignition temperature is the lowest temperature at which a substance can ignite without an open flame under standard conditions. Ignition occurs as a result of an increase in the rate of exothermic oxidation reactions of combustible vapors (or other oxidizing agent) in air, culminating in the formation of a flame. The ignition temperature is considered in the following cases:

- classification of gases and vapors of flammable liquids into explosion hazard groups;
- selection of the type of electrical equipment;
- determining the temperature limits of safe use of a substance when it is heated to a high temperature;
- when investigating the causes of fire.

Liquids with a low flash point have a higher ignition rate than liquids with a high flash point. This is due to the different mechanisms of the flame propagation process.

With an ignition source (flame) in a closed crucible, only a minimum concentration of combustible vapors capable of burning in air, the pre-formed front of the flame and most rapidly formed in volatile liquids (gasoline) is required for its propagation.

In the case of ignition of liquids from hot surfaces, critical conditions of ignition and flame propagation are more rapidly created in heavy hydrocarbons, which are thermally less resistant to the processes of AUTO-catalytic oxidizer decomposition. For this reason, heavy hydrocarbons self-ignite at lower temperatures than light thermally stable gasoline hydrocarbons. The ignition zone of gases (vapors) in air is characterized by the limits within which a mixture of gases (vapors) with air is capable of ignition from an external ignition source with subsequent flame propagation. The limits of the ignition zone are often expressed in terms of the volume percentage of the combustible substance in the mixture with air - concentration limits of ignition or temperature limits of ignition (explosion). Explosion concentration limits are expressed as the concentration of a combustible substance in a mixture with air; in given cases, no flame spreads through the mixture.

As indicated below, the concept of «explosion hazard» and «flame propagation» are used to describe the same process - rhenium - and differ only in the speed of the process.

Lower explosive concentration limit of combustible gases of substances is the minimum concentration of a substance in air at atmospheric pressure at which the mixture can be ignited by an external ignition source, after which the flame spreads throughout the entire volume of the mixture with an accompanying explosion. The upper explosive concentration limit of combustible gases is the maximum concentration of a substance in air at atmospheric pressure at which the mixture loses its ability to be ignited by an external ignition source and the flame can then spread.

A concentration of gas or vapor in air (inside a process apparatus) not exceeding 50% of the lower explosive limit or exceeding 50% of the upper explosive limit is considered explosive. Temperature limits of explosiveness are expressed by the temperature of the combustible substance, under given conditions saturated vapor of the state air (maximum possible vapor pressure of the liquid at a given temperature) is not ignited in a mixture with air.

Explosives are substances capable of exploding under the action of a powerful beginning. Explosive transformation is a process of rapid physical or chemical transformation accompanied by the conversion of potential chemical energy into thermal energy, which is converted into mechanical work of the resulting gases. The ability to explosive transformation is determined by their exothermic, high degree and rate of gassing.

Petroleum products are not explosives. They are not detonated by the detonator capsule under the action of a shock wave and friction. However, when mixing vapors with air, the formation of explosive, fire hazardous mixtures is possible, ignition and combustion of which, especially in a closed volume, is explosive in terms of the rate of flame propagation and pressure. The greatest evaporation is observed in gasoline with the highest vapor flow and the highest evaporation, which is ten times higher than in diesel fuel. Special attention should be given to control the losses due to evaporation of gasoline.

Experimental study is carried out in order to reveal the facts of horizontal tanks danger (actual evaporation of petroleum products from «big breath» and «back out») (Figure 1 - 4).

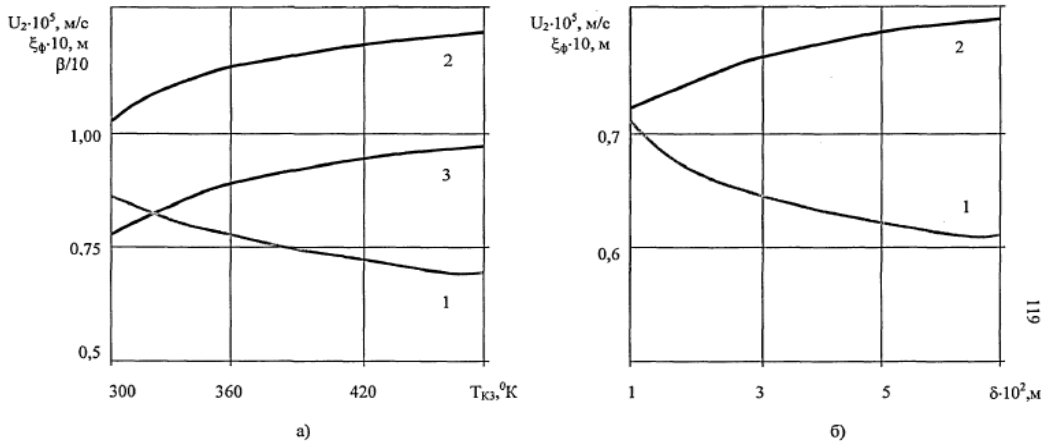

Figure 1 –
a) dependence of the process characteristics on the substrate boiling temperature;
b) dependence of the process characteristics on the thickness of the liquid layer
1- combustion velocity; 2- flame front coordinate; 3- β parameter

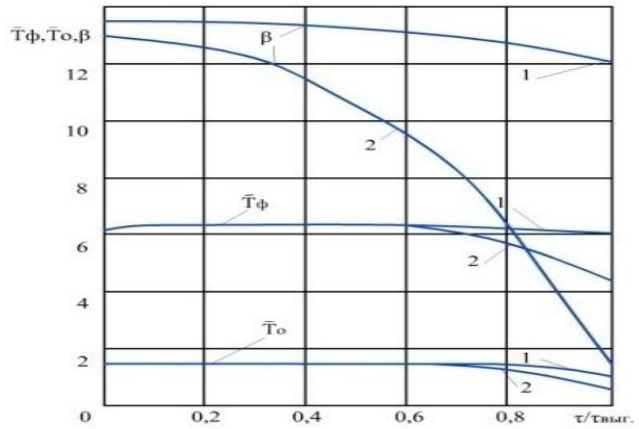

Figure 2 – Variation of flame temperature, free surface temperature and vapor concentration during combustion of a layer of finite thickness:
λ3=0.138 w/m*k; 1-ω3=1.1; 2- ω3 = 0.933

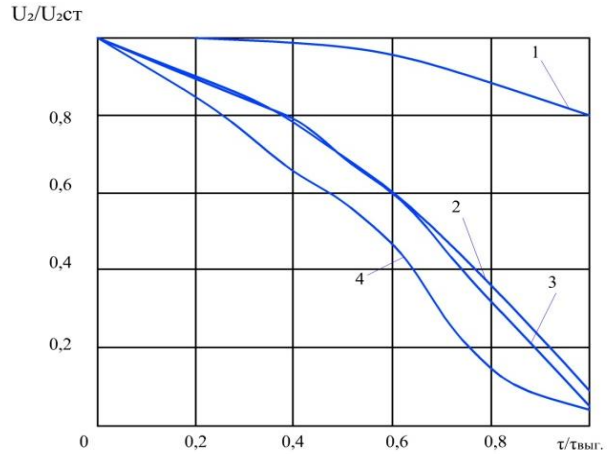

Figure 3 – Dependence of the liquid layer combustion rate on time
λ3=0.138 (1,3); 10-2 (2); 102 (4) W/(m*k),

ω=1,1 (1); 0,933 (2-4), U2ST is the steady-state combustion rate

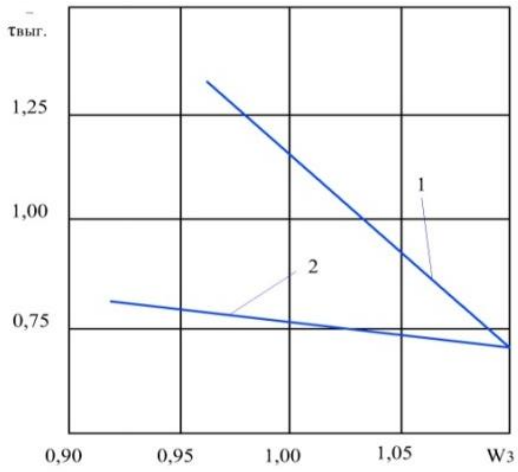

Figure 4 – Dependence of the layer combustion time on the parameter ω3
1- unsteady calculation; 2- stationary combustion

Conclusion. This paper has considered the issues of fire safety in the operation of oil and petroleum products storage tanks. In order to timely isolate fires in tanks to reduce material damage and human casualties, the development of analytical methods for calculating the combustion of oil products with the free surface of the tank is proposed.

According to the results of the analysis of accident rate in tank farms it is established that the most dangerous scenario of emergency situation development is the tank rupture with roof rupture and subsequent ignition of oil product (12.3% of the total number of accidents in the tank). The theoretical bases of stationary combustion of oil products with empty surface of tanks were analyzed and an analytical method for determining the characteristics of the oil products combustion process was developed, which allows increasing the reliability of fire development forecasting by 30%.

The dependence of the main characteristics of the combustion process on the structural and technological parameters of tanks has been obtained. It is established that the increase in tank diameter by 0.2 m leads to a 2.5-fold decrease in combustion rate and a 1.2-fold increase in flame height. A mathematical model of oil product burnout on a heat-conducting substrate is developed. It is shown that at known thermal conductivity of the substrate and certain critical values of the free surface and flame temperature there cannot be a constant combustion mode, which leads to damping of the combustion process. Taking into account that the solution of the problem of predicting the conditions and consequences of fires in tanks is related to the preservation of human lives and reduction of material damage, it is very relevant [13-15].

In addition, the technical condition of tank farms has been assessed, and statistical data on tank accidents, their scale, features and consequences have been analyzed. The fundamentals of stationary combustion of petroleum products with a free surface of the tank have been investigated and analytical methods have been developed to determine the main characteristics of the petroleum products combustion process. According to the results of statistical review the tank farm is recognized as the most fire and explosion hazardous object of the transshipment oil depot (TDP). Possible causes and nature of emergencies were identified. To improve the reliability of fire development prediction, the most important characteristics of the combustion process were identified. Their dependence on technological and structural parameters of the tank was investigated. To estimate the attenuation of the combustion process, the dependence of the change in the combustion rate in tanks with empty surface during the combustion of a layer of oil products was obtained.

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МҰНАЙ ЖӘНЕ МҰНАЙ ӨНІМДЕРІ САҚТАЛАТЫН РЕЗЕРВУАРЛАРДА ӨРТТІҢ АЛДЫН АЛУ МЕН ШЫҒЫНДАРДЫ АЗАЙТУ ТӘСІЛДЕРІН ТАЛДАУ

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Аңдатпа. Бұл мақалада мұнай және мұнай өнімдерін сақтауға арналған резервуарларды пайдалану кезіндегі өрт қауіпсіздігі мәселелері қарастырылып, өртке байланысты шығындарды болдырмау жолдары талданады. Қазақстанда өндірілетін мұнай және мұнай өнімдері резервуарлық парктерде дайындалып, өңделіп және сақталады. Қауіпті өндірістік объектілердің мемлекеттік тізілімінде мыңдаған мұнай базалары мен мұнай және мұнай өнімдерін сақтау орындары туралы мәліметтер тіркелген.

Қазіргі уақытта мұнай өнімдерінің жануын теориялық тұрғыдан талдау жану механизмін күрделі құбылыс ретінде сипаттайтын әртүрлі модельдік тәсілдерге негізделеді. Жану процесінің заңдылықтары туралы толық ақпарат сұйық және газ тәрізді реагенттерге арналған теңдеулер жүйесін сандық шешу арқылы алынады. Сондықтан жану процесінің негізгі сипаттамаларын анықтауға мүмкіндік беретін мұнай өнімдерінің жануын есептеудің жуық аналитикалық әдістерін әзірлеу маңызды болып табылады.

Қазақстандағы жаңа экономикалық жағдайларда орын алған бірқатар оқиғаларға байланысты резервуарлардың өнеркәсіптік қауіпсіздігін арттыру мәселесі өзектене түсті. Қазіргі қолданыстағы резервуарлық парктердің 90%-ы нормативтік қызмет мерзімінен асып кеткен. Резервуардағы жарылыс пен одан кейінгі жану салдарынан туындаған авариялық жағдайларды талдау мұнай өнімдерінің жану процестерін зерттеу ғылымның маңызды бағыттарының бірі болып отырғанын көрсетті.

Тірек сөздер: мұнай резервуары; қауіп; өрт қауіпсіздігі; қауіпті өндірістік объектілер; аналитикалық талдау; шығындарды болдырмау.

ПОЖАРНАЯ БЕЗОПАСНОСТЬ РЕЗЕРВУАРОВ ДЛЯ НЕФТИ И НЕФТЕПРОДУКТОВ И АНАЛИЗ СПОСОБОВ ПРЕДОТВРАЩЕНИЯ ЗАТРАТ

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Аннотация. В данной работе рассмотрены вопросы пожарной безопасности при эксплуатации резервуаров для хранения нефти и нефтепродуктов, а также проведён анализ способов предотвращения затрат, связанных с пожарами. Нефть и нефтепродукты, производимые в Казахстане, подготавливаются, перерабатываются и хранятся в резервуарных парках. В государственном реестре опасных производственных объектов содержатся сведения о тысячах нефтебаз и объектов хранения нефти и нефтепродуктов.

В настоящее время теоретический анализ горения нефтепродуктов использует различные подходы, основанные на модельных представлениях о механизме горения как сложного процесса. Подробную информацию о закономерностях горения можно получить путём численного решения систем уравнений для жидких и газообразных реагентов. В связи с этим важное значение имеет разработка приближённых аналитических методов расчёта горения нефтепродуктов, позволяющих определять основные характеристики процесса.

Проблема повышения промышленной безопасности резервуаров обострилась в связи с рядом ситуаций, возникших в Казахстане в условиях новых экономических реалий. В настоящее время 90% эксплуатируемых резервуарных парков превысили нормативный срок службы. Анализ аварийных ситуаций, возникших вследствие взрыва резервуара и последующего возгорания нефтепродукта с разрывом крыши, показывает, что изучение процессов горения нефтепродуктов в резервуарах является актуальным направлением научных исследований.

Ключевые слова: нефтяной резервуар; опасность; пожарная безопасность; опасные производственные объекты; аналитический анализ; предотвращение затрат.