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COMPARATIVE ASSESSMENT OF ENVIRONMENTAL PARAMETERS OF FOAMING AGENTS BASED ON SYNTHETIC HYDROCARBON USED FOR EXTINGUISHING THE FIRES OF OIL AND PETROLEUM PRODUCTS

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Abstract

The paper examines in detail the environmental impact of foaming agents used for extinguishing Class B fires, which include oil and petroleum product fires. There is a significant negative impact on the environment of long-chain fluorine-containing foaming agents and the search for alternatives of their use for firefighting. The advantages of calculation methods for determining the environmental parameters of foaming agents to extinguish fires, taking into account their chemical structure, are noted. The method «Quantitative Structure - Property Relationships» was used for obtaining BCF, LC_{50} (Fathead Minnow, Daphnia Magna), IGC_{50} (Tetrahymena Pyriformis) for a number of foaming agents with a carbon chain length C_8-C_{14}, containing fluorine and fluorine-free. It is shown that according to BCF the safest is sodium lauryl sulfate, according to LC_{50} (Daphnia Magna) the safest of the studied are foaming agents based on alkyl compounds Sodium decyl sulfate, Sodium lauryl sulphate, Triethanolamine salt of decyl sulfate (third class of acute toxicity), whereas fluorine-containing compounds (6:2 fluorotelomers) according to LC_{50} (Daphnia Magna) belong to the first class of acute toxicity (the most dangerous of the studied compounds).

Keywords:
Fluorine-free foaming agent;
Fluorotelomer;
Oil;
Petroleum products;
Extinguishing the fires;
Environmental parameter;
Calculation method.

Introduction

Today, the environment is more and more susceptible to changes associated with anthropogenic activities. Particularly, oil being extracted of and petroleum products being produced, there may be different options for environmental disturbance [1, 2]. Additional factors influencing the environment are emergencies and their consequences [3, 4]. One of the common types of emergencies is fires. They can occur both in natural ecosystems and at man-made objects despite using preventive approaches [5-7], methods [8] and fire-retardant materials [9]. At the same time, both fires and combustion products and fire extinguishing agents have a significant negative impact on the natural and man-made environment, as well as living organisms [10, 11].

Today there are innovative approaches for fighting the fires, such as the use of low-frequency and medium-frequency acoustic effects [12, 13] for identifying the nature of a burning substance [14], with the development of separate methods [15, 16], devices [17-19] and systems [20] used on their basis, including the use of neural networks [21]. Gel forming systems [22] and gel forming systems with foam glass [23], early response sensors are also offered to use [24, 25]. Nevertheless, water, powders and foaming agents are currently the most common means of extinguishing fires of various classes [26].

Water as a universal natural solvent has minimal negative impact on the environment, but it can also act as a means of transporting anthropogenic products to various natural sources and soils [27].

Used in large quantities, chemical extinguishing agents can decompose, interact with combustion products or get directly into water, soil and air. The ingress of these substances into the soil and water bodies may be accompanied by their accumulation and long-term impact on individual living organisms and ecosystems in general. The impact of fire

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fighting foams on the environment has been studied in details [28, 29]. As for fire extinguishing powders, environmental information is presented mainly in special documents [30], and it is not always complete. They are certified as inorganic chemical compounds, taking into account the danger of their impact on the environment and humans [10].

Further in the work the impact on the environment of foaming agents (foams) used for extinguishing class B fires, which also include fires of oil and petroleum products, is considered in more detailed way.

Review of impact of foaming agents for extinguishing fires of oil and petroleum products on the environment

Fire fighting foam is today one of the most common means used for extinguishing liquid materials. Its main characteristics are multiplicity, dispersion, viscosity, etc. Foams are aqueous solutions of foaming agents, of which the main component are surfactants. The aqueous foams, containing fluorine and forming a film, including their mixtures with hydrocarbon foaming agents, are widely used, as a separate class, for extinguishing fires of oil and petroleum products. The protein-based foaming agents can also be used [26]. Some researchers suggest using natural substances, such as soap root, to produce an environmentally friendly foaming agent [31].

The foams being used, the threat to the environment can be either the foams themselves, or their decay products, which affect mainly the aquatic environment and soils.

As already mentioned, one of the most effective agents for extinguishing the burning oil and petroleum products is fluorine-containing film-forming foam. However, the use of aqueous film forming foams, containing fluorine, allows perfluorooctanoic acid (PFOA), perfluorooctanesulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride to go into the environment, which is classified as resistant by the Stockholm Convention on Persistent Organic Pollutants. They are dangerous because they are not biodegradable, they can accumulate in living organisms and adversely affect them [32].

Many works have been devoted to the direct impact of perfluorooctanoic acid and perfluorooctanoic sulfonic acid on the environment. Further researches in this direction revealed additional negative factors in the use of compounds containing fluorine in the process of anthropogenic activity. Thus, the author warns of the danger of the presence of a large number of different perfluoroalkyl compounds with fully or partially fluorinated hydrocarbons in the environment in addition to the known perfluorooctanesulfonic acid and perfluoroalkyl acids [33]. The author identified more than four hundred new compounds that were found in natural and anthropogenic objects, including aqueous foams forming the film. These compounds can also lead to the formation of perfluorooctanesulfonic acid and perfluoroalkyl acids.

It is reported that [34] there are new aqueous foaming agents containing fluorine, based on fluorotelomers with short-chain fluorinated carbon, whose impact on the environment is less than conventional foaming agents, containing fluorine. Since the early 2000s, the Persistent Organic Pollutants Review Committee (The Stockholm Convention on Persistent Organic Pollutants) and the US Environmental Protection Agency have recommended abandoning the production and the use of compounds containing fluorine which lead to PFOA and PFOS. As a result, many European and American manufacturers have voluntarily stopped producing the long-chain fluorine-containing foaming agents for fire fighting which has dramatically limited their availability. However, some manufacturers of foaming agents did not respond positively to this transition. In particular, there is a decrease of the fire-extinguishing characteristics in such compounds, and, as a consequence, the need for more of them to eliminate the source of ignition. Accordingly, there is a need to revise permits for their use for fire fighting [11].

The use of short-chain fluorinated carbon-containing compounds for manufacturing of foams to extinguish the fires, recommended by the Persistent Organic Pollutants Review Committee, has led to further research into their effects on the environment. As a result, it is noted that the so-called fluorotelomers 8:2 can cause the appearance of PFOS, perfluoroalkyl compounds and their derivatives in the environment [35]. According to the results of the Persistent Organic Pollutants Review Committee, a number of alternative compounds for extinguishing class B fires, in particular, fluorotelomers 6:2, fluorine-free foams, silanes, protein-based foams have been offered to use [36]. However, the subsequent use of 6:2 fluorotelomers for fire fighting has shown their distribution in surface waters [37] and danger to the environment [38], whereas manufacturers and users in different countries have focused on fluorine-free foams [39-41].

The authors [42], in turn, propose to move away from use of the perfluorinated surfactants and modified surfactants with a length of perfluorinated carbon radical 6 4 towards the use of surfactants based on alkyl sulfates, sodium oleinsulfonates, noting less negative environmental effects of synthetic surfactants, including two-component fast-curing compositions in comparison with modified perfluorinated surfactants used for quenching of flammable liquids. Characteristics such as phytotoxicity and biodegradation were used for comparison.

At the same time, it is noted that the release of a significant amount of non-fluorinated hydrocarbon surfactants into the environment also has a negative effect on living organisms [43].

It should be noted that the task of determining the environmental parameters of these compounds is complicated by the lack or shortage of clear requirements in the regulations and standards of different countries regarding the environmental properties of these foams [11].

To date, the general criteria of the hazards of a substance are set out in European document REACH [44], which deals about the hazards of a substance in terms of environmental or human impact. The criteria of danger, defined in this document, are accumulation, toxicity, stability, and influence on a human body [44].

Various approaches are used for determining the environmental impact of foaming agents on the environment for quenching the fires. Thus, the acute and long-term effects of these substances on living organisms were determined by modeling natural aquatic and semi-aquatic biotypes. There is a more toxic effect of synthetic detergents compared to soap [45].

Depending on the nature of fire extinguishers, the ways to determine their environmental parameters may vary. The economic parameter is used for fire extinguishing substances consisting of gel forming systems [46], their impact on living organisms [22]. According to the impact on terrestrial and aquatic organisms, it is also possible to determine the environmental friendliness of powders extinguishing the fires [10]. In the United States there is an international standard NFPA 11:2016 [47], which uses environmental risks as criteria for assessing the impact of foams on the environment. In the Safety Data Sheets of foaming agents, manufacturers indicate such environmental characteristics of these solutions as biodegradability, impact on soil, aquatic organisms, etc., although there is no specific acceptable criterion of their environmental friendliness.

Thus, there is a refusal to use of long-chain fluorine-containing foaming agents for extinguishing the fires of oil and petroleum products and transition to the use of short-chain fluorotelometers, fluorine-free foaming agents. There is a further search for alternative approaches for extinguishing the fires of class B.

Chemical composition and structure of foaming agents for fire fighting

The impact of chemicals, including those coming with fire extinguishing agents, on the environment can be assessed both experimentally and by calculation [48].

Foaming agents for fire fighting are a complex mixture of chemicals of organic and inorganic nature. Foaming components provide such important characteristics as foam multiplicity, freezing temperature, pH of the solution, ability to extinguish the fires of a certain class (A, B, etc.), foam resistance, its corrosion properties, shelf life, etc. [26]. They can be included as the main active substances [49] or in the form of special additives [50, 51]. In both cases, their content and composition vary.

In addition, it should be noted that the organic components of the foaming agents may be a mixture of different organic compounds, which complicates the assessment of their impact on the environment. In some cases, the foaming agent may contain a mixture of isomers with the same structural formula, but different properties.

Difficulties in the experimental study of the properties of organic substances which are part of foaming agents, including their impact on the environment, are due to a number of factors. Among them, first of all, it is necessary to highlight the following: a large and constantly growing quantity of synthetic compounds; the need for sufficient funding and time for research; complexity of the structure of organic molecules (polymers; molecules containing cyclic or branched structures, multi-element composition, the presence of isomers). All these factors complicate greatly the provision of quality and a reliable experiment.

Given the above, it becomes more attractive to use approaches related to obtaining the calculated characteristics. In particular, the impact of chemical compounds on the environment can be assessed using the methods of «Quantitative Structure Activity Relationships» (QSARs). Thus, it is possible to estimate the bioaccumulation potential presented by the octanol/water partition coefficient logKow, as well as the bioconcentration factor BCF or bioaccumulation factor BAF [48, 49].

To date, there are different approaches for determining the BAF and the BCF. Thus, empirical models, models of mass balance are used. However, the most common methods are the «structure-activity» dependencies SAR (Structure Activity Relationships). SAR is an approach designed to find relationships between the chemical structure and characteristics (properties) of the studied chemical compounds. There are qualitative and quantitative SAR which together are referred to as QSAR. Today, the most used methods are 2D QSAR and 3D QSAR. Within 2D QSAR a two-dimension representation allows identifying molecular 2D descriptors. There are two main types of 3D QSAR methods: the use of lattice-based descriptors and surface-based descriptors [49].

The use of QSAR methods is recommended by various international instruments and organizations, including the European Chemicals Agency, the Organization for Economic Cooperation and Development and a number of others. The use of these methods has made it attractive to be able to predict the various properties of chemicals used in various fields, including the firefighting. In addition, they allow evaluating the already existing effect of known compounds at relatively low costs [48].

Thus, the development of production of foaming agents for extinguishing the fires of oil and petroleum products stimulated the development of calculation methods for studying their properties, based on the characteristics of the chemical structure of these compounds.

Analysis of environmental parameters of separate components of foaming agents used for extinguishing the fires of oil and petroleum products

It should be noted that in many cases the exact structural formula of the active compound used in the firefighting is a trade secret.A known substance is often the final compound which is in the environment. Therefore, an assumption in the form of an assessment of the ecological properties of related isomeric substances and (or) their decomposition products is made later in the paper. The environmental characteristics of a number of synthetic foaming agents containing synthetic hydrocarbon compounds as components, alkyl-containing surfactants or fluorine-containing compounds were determined in the process of analysis. Since the primary composition of film-forming foaming agents despite different manufacturers is almost always closed by a trademark, of which the name does not contain information about its components, we assume that long-chain fluorine-containing surfactants decompose to form the final products PFOS and (or) PFOA.

The environmental characteristics of typical synthetic surfactants, which are the main components of foaming agents for extinguishing the fires, were determined in the work. The length of the carbon chain was 8 to 14 C atoms.

Environmental parameters of surfactants that do not contain fluorine were determined by the example of individual representatives of alkyl sulfates Sodium decyl sulfate (fig. 1), Triethanolamine salt of decyl sulfate (fig. 2), Triethanolamine salt of tetramethyldecyl sulfate (fig. 3), Sodium lauryl sulphate (fig. 4), Sodium 4,5,6,7-tetramethyldecyl sulfate (fig. 5); fluorotelomers 6:2 Perfluorohexane ethyl sulfonyl betaine (fig. 6) and 6:2 fluorotelomer sulfonamidamine oxide (fig. 7). For comparison, the ecological parameters of fluorine-containing compounds (PFOA (fig. 8) and PFOS (fig. 9)) were studied [49].

The paper determines the environmental characteristics of these compounds using QSAR approaches. To do this, the capabilities of existing databases of known chemical compounds, in particular, PubChem are used [52]. The research was carried out using the GUSAR application software package, which allows evaluating the ecological properties of compounds for extinguishing the fires according to their 2D structure [50]. This approach is more expressive compared to the assessment of the 3D structure, less time and resource-intensive, which makes it attractive for the initial assessment of the environmental performance of foaming agents.

Environmental parameters such as 96-hour Fathead Minnow 50% lethal concentration (LC_{50}), BCF, 48-hour Daphnia Magna LC_{50}, Tetrahymena Pyriformis 50% growth inhibition concentration (IGC_{50}) were used for analysis.

The presence of structural formulas (fig. 19) allowed calculating by using the 2D QSAR approaches the environmental characteristics of individual representatives of foaming agents for extinguishing the fires or their decomposition products. The results of the calculation are presented in table 1.

As we can see from the obtained data (Table 1) of the studied substances there are fluctuations in the values of the parameters of the Fathead Minnow LC_{50} (log10 (mmol/l)) in the range (-1.85) – (-3.724), while the highest values of IGC_{50} are observed for Tetrahymena pyriformis for PFOA and PFOS [49].

Further, the study of environmental parameters for these components of foaming agents by Bioaccumulation factor log10 (BCF) and Daphnia

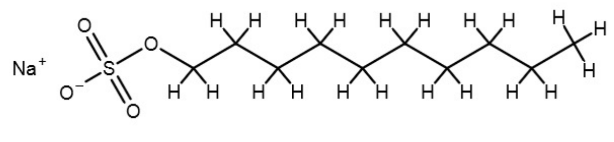

Fig.1. 2D structure Sodium decyl sulfate

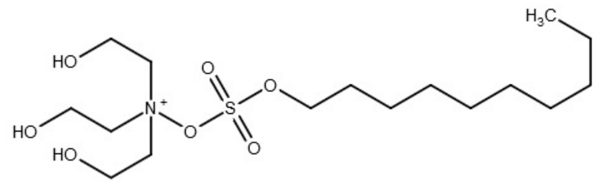

Fig.2. 2D structure Triethanolamine salt of decyl sulfate ({[(decyloxy)sulfonyl]oxy}tris(2-hydroxyethyl)azanium)

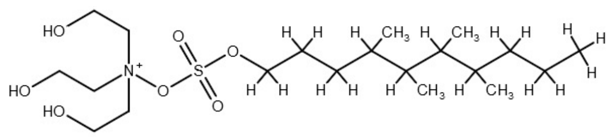

Fig.3. 2D structure Triethanolamine salt of tetramethyldecyl sulfate (tris(2-hydroxyethyl)({[(4,5,6,7-tetramethyldecyl)oxy]sulfonyl}oxy)azanium)

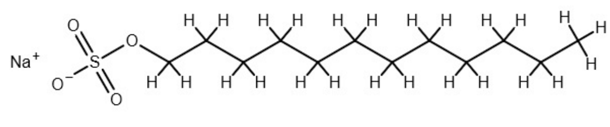

Fig.4. 2D structure Sodium lauryl sulphate

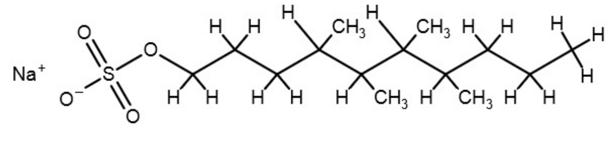

Fig.5. 2D structure Sodium 4,5,6,7-tetramethyldecyl sulfate

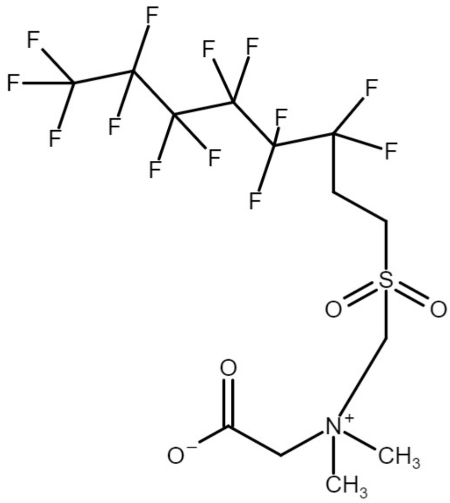

Fig.6. 2D structure Perfluorohexane ethyl sulfonyl betaine (2-{dim ethyl[(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctanesulfonyl)methyl]azaniumyl}

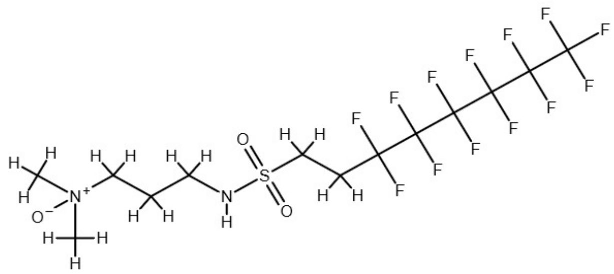

Fig.7. 2D structure 6:2 fluorotelomer sulfonamidamine oxide (N-[3-(dimethyl-oxo-λ⁵-azanyl)propyl]-3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctane-1-sulfonamide)

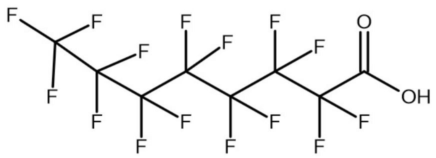

Fig.8. 2D structure PFOA

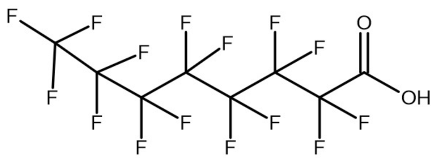

Fig.9. 2D structure PFOS

magna LC_{50} allowed obtaining the data shown in figures 10 and 11, respectively.

As we can see from figure 10, the most environmentally friendly substance by Bioconcentration factor (BCF is Perfluorohexane ethyl sulfonyl betaine, and the

Table 1

Ecological characteristics of the components of foaming agents

№	Substance	Activity	Predicted value
1	PFOS	Fathead minnow LC_{50} log10 (mmol/l)	-2.712
		Tetrahymena pyriformis IGC_{50} -log10(mol/l)	1.841
2	PFOA	Fathead minnow LC_{50} log10 (mmol/l)	-2.915
		Tetrahymena pyriformis IGC_{50} -log10(mol/l)	2.009
3	Sodium decyl sulfate	Fathead minnow LC_{50} log10 (mmol/l)	-1.850
		Tetrahymena pyriformis IGC_{50} -log10(ml/l)	1.325
4	Sodium lauryl sulphate	Fathead minnow LC_{50} log10 (mmol/l)	-2.526
		Tetrahymena pyriformis IGC_{50} -log10(mol/l)	1.769
5	Triethanolamine salt of decyl sulfate	Fathead minnow LC_{50} log10 (mmol/l)	-3.060
		Tetrahymena pyriformis IGC_{50} -log10(mol/l)	1.600
6	Triethanolamine salt of tetramethyldecyl sulfate	Fathead minnow LC_{50} log10 (mmol/l)	-3.724
		Tetrahymena pyriformis IGC_{50} -log10(mol/l)	1,360
7	Perfluorohexane ethyl sulfonyl betaine	Fathead minnow LC_{50} log10 (mmol/l)	-2.773
		Tetrahymena pyriformis IGC_{50} -log10(mol/l)	0.932
8	6:2 fluorotelomer sulfonamidamine oxide	Fathead minnow LC_{50} log10 (mmol/l)	-3.238
		Tetrahymena pyriformis IGC_{50} -log10(mol/l)	1.392
9	Sodium 4,5,6,7-tetramethyldecyl sulfate	Fathead minnow LC_{50} log10 (mmol/l)	-2.426
		Tetrahymena pyriformis IGC_{50} -log10(mol/l)	1.407

most dangerous one is PFOS, for which there is also an excess of regulatory values under the European document REACH, which acts as a standard.

In the study of the effect of substances on Daphnia magna (fig.11) LC_{50} values (log10, mol/l) are obtained, which, later, taking into account the molar mass transferred into more convenient concentration values (mg/l), allowed them to compare with the criteria for toxicity [30]. As we can see from these data, the most environmentally friendly substances are Sodium decyl sulfate, Sodium lauryl sulphate,

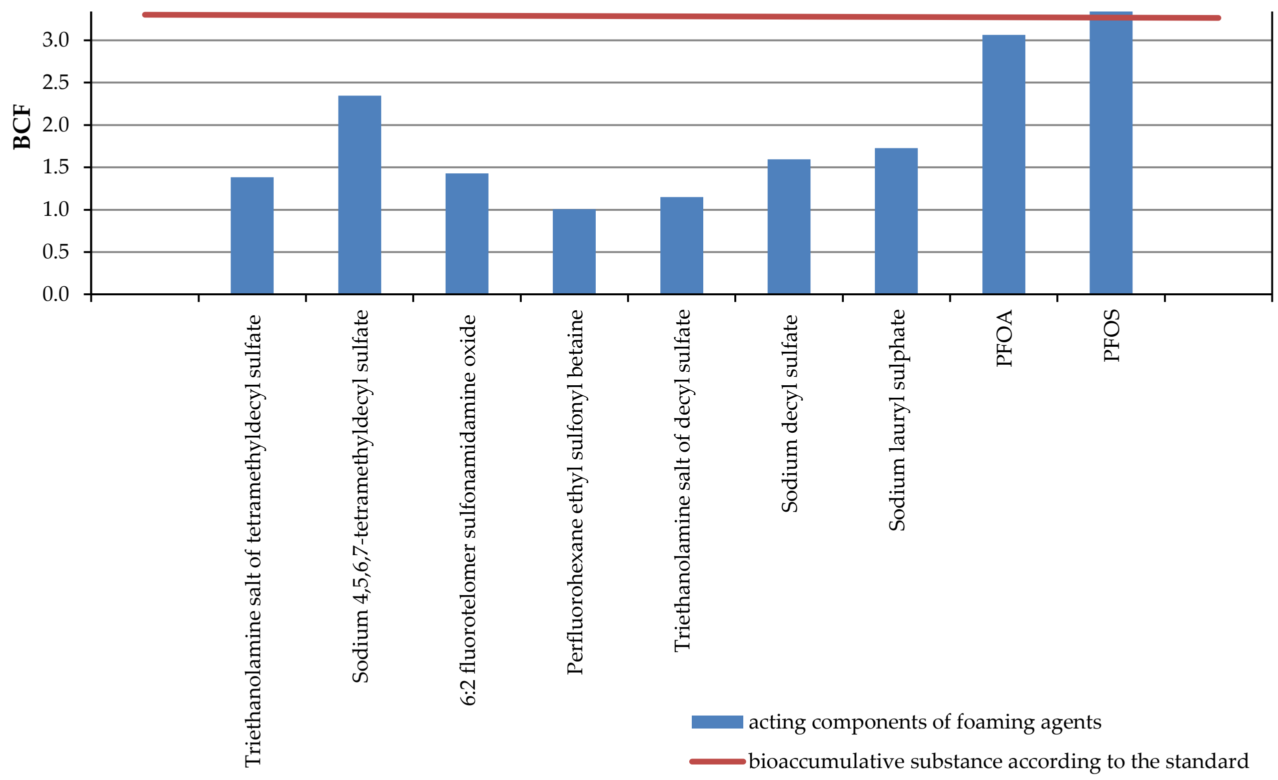

Fig. 10. The value of the calculated BCF test substances and the value of the standard

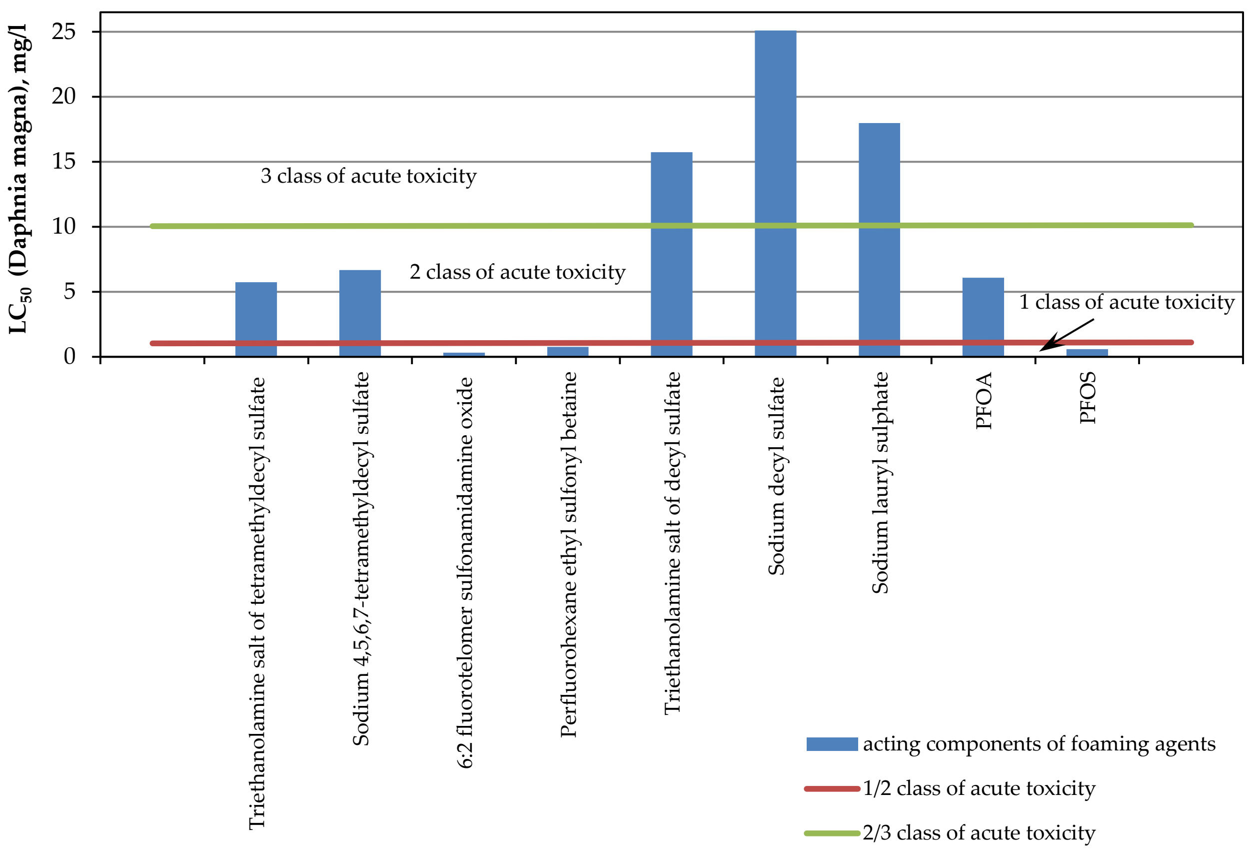

Fig. 11. The value of LC_{50} (mg/l) on the effect of substances on Daphnia magna

Triethanolamine salt of decyl sulfate, belonging to the third class of acute toxicity, and the most dangerous ones are PFOS and 6:2 fluorotelomers (first class of acute toxicity).

Accordingly, the significant danger of long-chain fluorine-containing foaming agents to living organisms and their accumulation in the environment is confirmed, and 6:2 fluorotelomers, despite low BCF values, also have a negative effect on living organisms.

Thus, it should be noted that in addition to the clearly high characteristics in the firefighting of oil and petroleum products today, the extinguishing agent must also have high environmental performance indicators. For a number of fluorine-containing foaming agents and fluorine-free foaming agents based on synthetic hydrocarbons, environmental parameters have been determined according to Fathead Minnow LC_{50}, BCF, Daphnia Magna LC_{50},Tetrahymena Pyriformis IGC_{50}. It was found that among the investigated foaming agents the safest compounds for the environment in terms of BCF and Daphnia magna LC_{50} can be fluorine-free compounds based on synthetic hydrocarbon, in particular, Sodium decyl sulfate, Sodium lauryl sulphate, Triethanolamine salt of decyl sulfate (Sodium decyl sulfate, Sodium lauryl sulphate, Triethanolamine salt of decyl sulfate (third class of acute toxicity). The most dangerous compounds studied in Daphnia magna LC_{50} are PFOS and 6:2 fluorotelomers (first class of acute toxicity).

Conclusions

Today, much attention in the world is paid to both fire extinguishing and environmental characteristics of substances used in the firefighting.

There is a refusal to use the long-chain fluorine-containing foaming agents in the firefighting of oil and petroleum products and transition to the use of short-chain fluorotelometers, fluorine-free foaming agents. There is a further search for alternative approaches for extinguishing the Class B fires.

The development of the production of foaming agents for extinguishing the fires of oil and petroleum products stimulated the development of calculation methods for studying their properties, based on the peculiarities of the chemical structure of these compounds.

It should be noted that in addition to the clearly high characteristics in the firefighting of oil and petroleum products today, the extinguishing agent must also have high environmental performance. For a number of fluorine-containing foaming agents and fluorine-free foaming agents based on synthetic hydrocarbons, environmental parameters have been determined according to Fathead Minnow LC_{50}, BCF, Daphnia Magna LC_{50}, Tetrahymena Pyriformis IGC_{50}. It was found that among the investigated foaming agents the safest compounds for the environment in terms of BCF and Daphnia magna LC_{50} can be fluorine-free compounds based on synthetic hydrocarbon, in particular, Sodium decyl sulfate, Sodium lauryl sulphate, Triethanolamine salt of decyl sulfate (third class of acute toxicity). The most dangerous compounds studied in Daphnia magna LC_{50} are PFOS and 6:2 fluorotelomers (first class of acute toxicity).

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Сравнительная оценка экологических параметров пенообразователей на синтетической углеводородной основе, применяемых для тушения пожаров нефти и нефтепродуктов

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Реферат

В работе подробно рассмотрено влияние на окружающую среду пенообразователей, используемых в тушении пожаров класса Б, к которым относятся пожары нефти и нефтепродуктов. Отмечается значительное негативное влияние на окружающую среду длинноцепочечных фторсодержащих пенообразователей и поиск альтернатив их применения в пожаротушении. Отмечаются преимущества расчетных методов для определения экологических параметров пенообразователей для пожаротушения с учетом их химической структуры. Использован метод «Quantitative Structure - Property Relationships» для получения BCF, LC_{50} (Fathead Minnow, Daphnia Magna), IGC_{50} (Tetrahymena Pyriformis) для ряда пенообразователей с длиной углеродной цепи C_8-C_{14}, содержащих фтор и безфторных. Показано, что согласно BCF наиболее безопасным является лаурилсульфат натрия, согласно LC_{50} (Daphnia Magna) наиболее безопасными из исследуемых является пенообразователь на основе алкилсоединений -децилсульфата натрия, лаурилсульфата натрия, триэтаноламиновой соли децилсульфата (третий класс острой токсичности), тогда как фторсодержащие соединения (6:2 фтортеломеры) согласно LC_{50} (Daphnia Magna) относятся к первому классу острой токсичности (наиболее опасные из исследуемых соединений).

Ключевые слова: не содержащий фтора пенообразователь, фтортеломер, нефть, нефтепродукты, тушение пожара, экологический параметр, расчетный метод.

Neft və neft məhsullarının yanğınlarının söndürülməsi üçün istifadə olunan sintetik karbohidrogen əsaslı köpükəmələgətiricilərin ekoloji parametrlərinin müqayisəli qiymətləndirilməsi

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Xülasə

Məqalədə neft və neft məhsullarının yanğınlarına aid edilən B sinif yanğınların söndürülməsində istifadə olunan köpükəmələgətiricilərin ətraf mühitə təsiri ətraflı şəkildə nəzərdən keçirilmişdir. Uzun zəncirli ftor tərkibli köpükəmələgətiricilərin ətraf mühitə mənfi təsiri və onların yanğınların söndürülməsi üçün istifadə alternativlərinin axtarışları göstərilmişdir. Yanğınların söndürülməsi üçün köpükəmələgətiricilərin kimyəvi quruluşlarının nəzərə alınması ilə ekoloji parametrlərinin müəyyənləşdirilməsi üçün hesablama metodlarının üstünlükləri qeyd olunmuşdur. Tərkibində ftor olan və olmayan bir sıra C_8-C_{14} uzun karbon zəncirli köpükəmələgətiricilər üçün BCF, LC_{50} (Fathead Minno, Daphnia Magna), IGC_{50}-nin (Tetrahymena Pyriformis) alınması üçün «Quantitative Structure - Property Relationships» metodundan istifadə edilmişdir. Göstərilmişdir ki, ftor tərkibli birləşmələr (6:2 ftortelomerlər) LC_{50}-yə (Dhnapna) əsasən kəskin toksikliyin birinci sinfinə (tədqiq olunan birləşmələr arasınada ən təhlükəli) aid olduğu halda, BCF-yə əsasən ən təhlükəsizi natrium laurilsulfat, LC_{50}-yə (Daphnia Magna) əsasən isə tədqiq olunanlar arasında ən təhlükəsizləri alkil birləşmələri – natrium decilsulfat, natrium lauril sulfat, dekilsülfat trietanolamin duzları əsasında hazırlanmış köpükəmələgətiricilərdir (kəskin toksikliyin üçüncü sinfi).

Açar sözlər: tərkibində ftor olmayan köpükəmələgətirici; ftortelomer; neft; neft məhsulları; yanğının söndürülməsi; ekoloji parametr; hesablama metodu.