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Effect of Inorganic Components of Fire Foaming Agents on the Aquatic Environment

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Abstract: Impact on the aquatic medium of the number of inorganic additives that are part of the foaming agents for firefighting is investigated in paper. The influence of the most widespread inorganic components on aquatic organisms was analyzed. Significant variability of data was noted. It is proved that the magnesium and sodium chlorides are the safest for the environment and the most dangerous ones are aluminum compounds and sulfamic acid. Inorganic additives based on aluminum, sulfamic acid, and sodium bicarbonate are the most dangerous for aquatic living organisms, in the short and long term, and the safest compounds are magnesium and sodium chlorides.

Keywords: Fire foaming agents, inorganic additives, aquatic environment.

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INTRODUCTION

Today's environment is often subject to anthropogenic impact. Apart from the work of industrial enterprises, agricultural facilities, housing and communal sector, the influence of various types combustion that turn into fires is also negative. Fires often acquire catastrophic scale affecting individual technogenic objects (1) and the planet as a whole (2, 3) despite the preventive measures (4, 5, 6).

Today, one of the most effective means for localizing and extinguishing fires of various types, including oil products, is foam. During the fire both firemen (7) and environmental objects are exposed to dangerous thermal effects. At the same time, the environment is negatively affected both by the fire itself (8) and the ingress of combustion products and components of fire extinguishing mixtures into the air, water, and soil (9, 10). As the latter ones, apart from foams (11), the water (12) and fire extinguishing powders (13) often act.

According to the composition, foaming agents are divided into synthetic, protein, fluorosynthetic, and fluoroprotein ones (14). They are a mixture of organic and inorganic compounds of natural or artificial origin. In addition to identifying (15, 16) and evaluating the content of these compounds and their decomposition products in the environment using various laboratory (17) and express physical and chemical methods of analysis (18, 19), it is important to study their ecological properties.

Detergents (20), alkyl sulfonates (21), fatty acids (22), natural compounds (23), and fluorinated derivatives (24) are used as the main active ingredients.

The influence of the main substances, which are present in the foaming agents, on the environment, mainly, aquatic environment, has been sufficiently studied (25, 26). As ecological and ecotoxicological characteristics, experimental or calculated bioindication parameters appear in this case.

On the contrary, it should be noted that in addition to the main substance, various additives are also included in the foams, which affect on the properties of the foams such as multiplicity, viscosity, stability, frost resistance, etc. These additives are organic (alcohols, acids, and their salts) or inorganic compounds. When extinguishing the fires, these additives also enter the environment and have a negative impact on it.

The policy of developers and manufacturers to replace the precise composition of the foaming agent with a trade name, brand or generic name, including the Safety Data Sheets (27), greatly complicates the assessment of the environmental characteristics and environmental impact of individual components of the foaming agents. The information about the environmental impact of individual components of the foaming agents can be useful while developing new, more environmentally friendly compounds of the foaming agents. It will also allow potential buyers to make more environmentally conscious choices when purchasing these products.

The aim of this paper is a comparative study of the impact on the environment, in particular, the aquatic environment of the individual inorganic components of the foaming agents.

MATERIAL AND METHODS

The well-known analytical methods of processing the data are used in the paper by applying the information about chemicals presented in the literature and on the website of European Chemicals Agency (28). As the parameters of research, the values PNEC - predicted no effect concentration, LC - Lethal concentration, NOEC - no observed effect concentration, LOEC - lowest observed effect concentration, ECx the effect concentration associated with x% response (27, 29) are selected.

RESULTS AND DISCUSSION

In the paper, the approach proposed in (13, 30) was used. The essence of the proposed assessment is to study the environmental characteristics of inorganic salts which are used to improve the extinguishing properties of foaming agents. Their composition can vary from a few thousandths to tens of percent of the total mass of the substance (0.005 - 40%).

The best known (31-40) additives are compounds such as magnesium chloride and its natural analogue, bischofite ($MgCl_2$), basic aluminum chloride ($Al_2(OH)_5Cl$), sulfamic acid (NH_2SO_3H), sodium bicarbonate ($NaHCO_3$), calcium chloride ($CaCl_2$), sodium chloride (NaCl), sodium carbonate (Na_2CO_3), ammonium sulfate ($(NH_4)_2SO_4$), aluminum sulfate ($Al_2(SO_4)_3$), sodium hydroxide (NaOH), and sodium hexametaphosphate ($Na_6P_6O_{18}$).

With the temperature factor (since extinguishing the fires involves a high ambient temperature) and the presence of several components in the mixture, for example (36, 37, 39), some products may also be released into the environment:

$$3Al_2(OH)_5Cl \rightarrow AlCl_3 + 5Al(OH)_3 \quad (1)$$

in turn, when exposed to heat:

$$2Al(OH)_3 \rightarrow Al_2O_3 + 3H_2O_{(g)} \quad (2)$$

Also, the temperature factor can lead to the formation of such products for the mixture:

$$3Al_2(OH)_5Cl + 6(NH_4)_2SO_4 \rightarrow 2Al_2(SO_4)_3 + Al_2O_3 + 12NH_{3\,(g)} + 3HCl_{\,(g)} + 12H_2O_{(g)} \quad (3)$$

In the composition of foams, these compounds can be found mainly in aquatic and soil ecosystems. The paper examined the effect of inorganic components of foaming agents on aquatic ecosystems. Since sodium hexametaphosphate is a more branched structure of sodium metaphosphate, the main analysis can be done by using EXA data on sodium metaphosphate.

The data on the predicted safe concentration (PNEC) of a substance for organisms living in marine and freshwater ecosystems are presented in Table 1.

It was concluded that the lower the PNEC value, the unsafer the substance for organisms, so aluminum and ammonium sulfates are more dangerous to get into fresh water, and aluminum sulfate and sulfamic acid to get into the sea water, periodic discharges, containing in the fresh water, sulfamic acid and ammonium sulfate are unsafer. In sediments, the accumulation of ammonium sulfate (fresh water) and sulfamic acid (seawater) is unsafe. That is, as seen from the presented PNEC values, sulfonated inorganic compounds have a greater negative effect on aquatic organisms.' Thus, the comparative analysis of the environmental hazard of the tested inorganic additives of foaming agents showed that the most dangerous for the environment are aluminum compounds and sulfamic acid, and the safest are magnesium and sodium chlorides.

To assess the environmental hazard to aquatic organisms data, obtained in the same conditions, were used.

For a comparative analysis of inorganic additives of foaming agents according to their short-term toxicity the parameter LC50 (4 days) is the most suitable for fish. Table 2 shows sodium, calcium and magnesium chlorides, as well as sodium bicarbonate in the short term are the least toxic for fish. It is difficult to name the most toxic substance for fish, since there is data variability. If we accept that in the case of variable data, we follow the lowest value, then the most dangerous compounds are aluminum-based compounds for fish. If we take the maximum values of LC50 (4 days), then sulfamic acid, ammonium sulfate, and sodium hexametaphosphate are more toxic in the short term for fish.

Values of long-term toxicity of substances for fish also vary greatly, and the data themselves are incomplete. So, NOEC for the studied compounds is presented to the fullest extent possible (Table 2). It can be noted that sodium chloride is the safest for freshwater fish in terms of long-term toxicity, and the most dangerous is basic aluminum chloride and, as a possible reaction product, aluminum sulfate.

Table 1. PNEC for Aquatic Organisms, mg/L (mg/kg sediment dw)

Substance	**PNEC**					
	Freshwater	**Intermittent releases (freshwater)**	**Marine water**	**Sewage treatment plant**	**Sediment (freshwater)**	**Sediment (marine water)**
Magnesium chloride	3.21 mg/L	5.48 mg/L	320 μg/L	90 mg/L	288.9 mg/kg sediment dw	28.89 mg/kg sediment dw
Sodium chloride	5 mg/L	No data	aquatic toxicity unlikely	aquatic toxicity unlikely	No exposure of sediment expected	No exposure of sediment expected
Calcium chloride	No data	No data	No data	No data	No data	No data
Basic Aluminum chloride	No hazard identified	No hazard identified	No hazard identified	No hazard identified	No hazard identified	No hazard identified
Sodium hydroxide	No data	No data	No data	No data	No data	No data
Sulfamic acid	1.8 mg/L	480 μg/L	180 μg/L	No data	8.36 mg/kg sediment dw	840 mg/kg sediment dw
Ammonium sulfate	312 μg/L	530 μg/L	31.2 μg/L	16.18 mg/L	63 mg/kg sediment dw	No data
Sodium bicarbonate	No data	No data	No data	No data	No data	No data
Sodium carbonate	aquatic toxicity unlikely	aquatic toxicity unlikely	aquatic toxicity unlikely	aquatic toxicity unlikely	No data	No data
Sodium hexametaphosphate	No hazard identified	No hazard identified	No hazard identified	No hazard identified	No hazard identified	No hazard identified
Aluminum chloride	No hazard identified	No hazard identified	No hazard identified	No data	No data	No data
Aluminum sulfate	300 – 4 500 000 ng/L	30.11 mg/L	30 – 64 000 000 ng/L	No hazard identified	10 mg/kg sediment dw	31.4 mg/kg sediment dw
Aluminum oxide	aquatic toxicity unlikely	aquatic toxicity unlikely	aquatic toxicity unlikely	aquatic toxicity unlikely	No data	No data
Aluminum hydroxide	No hazard identified	No hazard identified	No hazard identified	No hazard identified	No data	No data

Table 2. Data on toxicity of test substances for aquatic organisms

Substance	**Short–term toxicity to fish**	**Long–term toxicity to fish**	**Short–term toxicity to aquatic invertebrates**	**Long–term toxicity to aquatic invertebrates**	**Toxicity to aquatic algae and cyanobacteria**	**Toxicity to microorganisms**
1	**2**	**3**	**4**	**5**	**6**	**7**
Magnesium chloride	LC50 (4 days) 541 – 2 119.3 mg/L Summaries:	No data	LC50 (48 h) 140 - 548.4 mg/L Summaries:	EC10 (21 days) 82 - 321 mg/L Summaries:	EC50 (72 h) 100 mg/L NOEC (72 h) 100 mg/L	EC50 (3 h) 900 mg/L Summaries:

	LC50 for freshwater fish 2,119 g/L LC50 for marine water fish 10,968 g/L		EC50/LC50 for freshwater invertebrates 548,4 mg/L EC50/LC50 for marine invertebrates 3,259 g/L	EC10/LC10 or NOEC for freshwater invertebrates 321 mg/L	Summaries: EC10 or NOEC for freshwater algae 100 mg/L	EC10 or NOEC for microorganisms 900 mg/L
Sodium chloride	LC50 (4 days) 5.84 g/L Summaries: LC50 for freshwater fish 5.84 g/L	NOEC (33 days) 252 - 533 mg/L LOEC (33 days) 352 - 734 mg/L Summaries: EC10/LC10 or NOEC for freshwater fish 252 mg/L	LC50 (48 h) 4.136 g/L LC50 (24 h) 874 mg/L Summaries: EC50/LC50 for freshwater invertebrates 1.9 g/L	NOEC (21 days) 314 mg/L LOEC (21 days) 441 mg/L Summaries: EC10/LC10 or NOEC for freshwater invertebrates 314 mg/L	EC50 (5 days) 2.43 g/L Summaries: EC50 for freshwater algae 2.43 g/L	EC50 (4 days) 6.87 g/L Summaries: EC10 or NOEC for microorganisms 5 g/L

1	2	3	4	5	6	7
Calcium chloride	LC50 (4 days) 4.63 g/L LC50 (48 h) 6.56 g/L LC50 (24 h) 6.66 g/L	No data	LC50 (48 h) 2.4 - 2.77 g/L NOEC (48 h) 2 g/L	EC50 (21 days) 610 mg/L LC50 (21 days) 330 - 920 mg/L	EC50 (72 h) 2.9 - 27 g/L EC20 (72 h) 1 g/L	No data
Basic aluminum chloride	LC50 (4 days) 1.39 - 186 mg/L LC10 (4 days) 580 - 142 000 µg/L EC50 (4 days) 156 µg/L NOEC (4 days) 156 - 1 000 000 µg/L	NOEC (60 days) 13 - 26 µg/L NOEC (7 days) 752 - 56 480 µg/L LOEC (7 days) 831 - 91 420 µg/L LC50 (42 days) 15 µg/L LC50 (28 days) 19 µg/L	EC50 (48 h) 214 - 200 000 µg/L EC10 (48 h) 2.8 - 42 mg/L NOEC (48 h) 160 mg/L	NOEC (7 days) 15 mg/L LOEC (7 days) 15 mg/L	EC50 (72 h) 75 - 14 000 µg/L NOEC (72 h) 20 - 1 000 µg/L EC10 (72 h) 15 - 3 100 µg/L	EC50 (3 h) 4.4 - 1 000 mg/L EC10 (3 h) 4.4 – 1 000 mg/L
Sodium hydroxide	No data	No data	EC50 (48 h) 40.4 mg/L	No data	No data	No data
Sulfamic acid	LC50 (4 days) 70.3 mg/L Summaries: LC50 for freshwater fish	NOEC (65 days) 25 µg/L NOEC (34 days) 60 mg/L	EC50 (48 h) 71.6 mg/L EC50 (24 h) 71.6 mg/L	NOEC (35 days) 150 µg/L NOEC (21 days) 19 mg/L	EC50 (72 h) 33.8 - 48 mg/L NOEC (72 h) 18 mg/L	EC50 (3 h) 200 mg/L NOEC (3 h) 200 mg/L

	70.3 mg/L	Summaries: EC10/LC10 or NOEC for freshwater fish 60 mg/L	Summaries: EC50/LC50 for freshwater invertebrates 71.6 mg/L	LOEC (21 days) 34 mg/L EC50 (21 days) 60 mg/L Summaries: EC10/LC10 or NOEC for freshwater invertebrates 19 mg/L	EC10 (72 h) 13.3 - 29.5 mg/L Summaries: EC50 or freshwater algae 48 mg/L EC10 or NOEC for freshwater algae 18 mg/L	Summaries: EC50 for microorganisms 200 mg/L EC10 or NOEC for microorganisms 200 mg/L
1	**2**	**3**	**4**	**5**	**6**	**7**
Ammonium sulfate	LC50 (4 days) 53 - 57.2 mg/L Summaries: LC50 for freshwater fish 53 mg/L	EC10 (30 days) 5.29 mg/L Summaries: EC10/LC10 or NOEC for freshwater fish 5.29 mg/L	EC50 (48 h) 121.7 - 169 mg/L Summaries: EC50/LC50 for freshwater invertebrates 169 mg/L	EC10 (70 days) 3.12 mg/L Summaries: EC10/LC10 or NOEC for freshwater invertebrates 3.12 mg/L	EC50 (18 days) 2.7 g/L EC50 (5 days) 1.605 g/L	EC50 (30 min) 1.618 g/L
Sodium bicarbonate	LC50 (4 days) 7.1 g/L NOEC (4 days) 5.2 g/L Summaries: LC50 for freshwater fish 7.1 g/L	No data	EC50 (48 h) 4.1 g/L NOEC (48 h) 3.1 g/L Summaries: EC50 / LC50 for freshwater invertebrates 4.1 g/L	NOEC (21 days) 576 mg/L	No data	No data
Sodium carbonate	LC50 (4 days) 300 mg/L Summaries: LC50 for freshwater fish 300 mg/L	No data	EC50 (48 h) 200 - 227 mg/L Summaries: EC50/LC50 for freshwater invertebrates 200 mg/L	No data	No data	No data

1	2	3	4	5	6	7
Sodium hexametaphosphate	LC50 (4 days) 100 mg/L NOEC (4 days) 100 mg/L Summaries: LC50 for freshwater fish 100 mg/L	No data	EC50 (48 h) 485 mg/L Summaries: EC50/LC50 for freshwater invertebrates 100 mg/L	No data	EC50 (72 h) 100 mg/L NOEC (72 h) 32 mg/L LOEC (72 h) 100 mg/L Summaries: EC50 for freshwater algae 100 mg/L	EC50 (3 h) 1 g/L NOEC (3 h) 1 g/L Summaries: EC50 for microorganisms 1 g/L EC10 or NOEC for microorganisms 1 g/L
Aluminum chloride	LC50 (16 days) 430 - 3 910 μg/L LC50 (8 days) 22.4 mg/L LC50 (4 days) 78 - 218 640 μg/L LC50 (72 h) 10 - 19.3 mg/L LC50 (48 h) 11.5 mg/L	NOEC (60 days) 88 - 350 μg/L NOEC (30 days) 57 - 88 μg/L NOEC (28 days) 4.7 - 23.1 mg/L NOEC (7 days) 160 - 56 480 μg/L LOEC (60 days) 169 - 350 μg/L	EC50 (48 h) 1.5 - 27.3 mg/L LC50 (4 days) 22 - 30.6 mg/L LC50 (48 h) 71 - 99 600 μg/L NOEC (4 days) 22.6 mg/L NOEC (48 h) 5 - 672 μg/L	NOEC (28 days) 1.89 mg/L NOEC (21 days) 76 - 137 μg/L NOEC (8 days) 4.9 mg/L NOEC (7 days) 1.1 - 1.4 mg/L NOEC (6 days) 340 - 1020 μg/L	EC50 (4 days) 24 - 570 μg/L EC50 (72 h) 200 - 4 980 μg/L NOEC (72 h) 4 - 600 μg/L LOEC (72 h) 1 mg/L EC10 (72 h) 51 - 3 155 μg/L	No data

1	2	3	4	5	6	7
Aluminum sulfate	LC50 (8 days) 122.17 - 161.4 mg/L LC50 (7 days) 430 – 4 270 μg/L LC50 (6 days) 560 – 6 650 μg/L LC50 (5.833 days) 22.74 mg/L LC50 (5 days) 1.05 - 20.8 mg/L Summaries: LC50 for freshwater fish	NOEC (60 days) 13 - 1 670 μg/L NOEC (33 days) 71.5 - 558.1 μg/L NOEC (30 days) 250 - 1 670 μg/L NOEC (28 days) 29.8 - 44.9 mg/L NOEC (15 days) 1.67 mg/L Summaries: EC10/LC10 or NOEC for freshwater fish 44.9 mg/L	EC50 (4 days) 5.9 - 58.2 mg/L EC50 (72 h) 27.7 mg/L EC50 (48 h) 1.4 - 200 mg/L LC50 (7 days) 11.2 mg/L LC50 (72 h) 1.52 - 19.5 mg/L Summaries: EC50/LC50 for freshwater	NOEC (42 days) 232.6 - 453.8 μg/L NOEC (30 days) 1.092 - 2.099 mg/L NOEC (28 days) 53.1 - 12 000 μg/L NOEC (17 days) 962.5 μg/L NOEC (10 days) 1.1 - 4.282 mg/L Summaries: EC10/LC10 or NOEC for freshwater invertebrates	EC50 (30 days) 1.767 g/L EC50 (5 days) 3.011 - 19.091 g/L EC50 (4 days) 460 - 570 μg/L EC50 (72 h) 40 - 100 000 μg/L EC50 (22 h) 25 mg/L Summaries: EC50 for freshwater	EC50 (1.084 years) 500 - 3 100 μg/L EC50 (22 days) 114 - 512 μg/L EC50 (5 days) 3.011 - 19.091 g/L EC50 (24 h) 6 mg/L EC50 (3 h) 200 - 1 000 mg/L Summaries:

	122.17 mg/L LC50 for marine water fish 12.2 mg/L	EC10/LC10 or NOEC for marine water fish 4.5 mg/L	invertebrates 242 mg/L EC50/LC50 for marine invertebrates 19.5 mg/L	12 mg/L EC10/LC10 or NOEC for marine invertebrates 41.2 mg/L	algae 3.011 g/L EC50 for marine algae 302 mg/L EC10 or NOEC for freshwater algae 602 mg/L EC10 or NOEC for marine algae 30 mg/L	EC50 for microorganisms 3.011 g/L EC10 or NOEC for microorganisms 200 - 602 mg/L
1	**2**	**3**	**4**	**5**	**6**	**7**
Aluminum oxide	LC50 (16 days) 430 - 3 910 µg/L LC50 (8 days) 22.4 mg/L LC50 (4 days) 78 - 218 644.1 µg/L LC50 (4 days) 2.9 µmol/L LC50 (72 h) 10 - 19.3 mg/L	NOEC (60 days) 88 - 350 µg/L NOEC (33 days) 71.5 - 558.1 µg/L NOEC (30 days) 57 - 88 µg/L NOEC (28 days) 4.7 - 23.1 mg/L NOEC (7 days) 25.1 - 56 480 µg/L	EC50 (48 h) 1.5 - 2.56 mg/L LC50 (4 days) 22 - 30.6 mg/L LC50 (48 h) 5.7 - 99 600 µg/L NOEC (4 days) 22.6 mg/L NOEC (48 h) 5 - 672 µg/L	NOEC (42 days) 232.6 - 453.8 µg/L NOEC (30 days) 1.092 - 2.099 mg/L NOEC (28 days) 53.1 - 4 281.8 µg/L NOEC (21 days) 76 - 600 µg/L NOEC (17 days) 962.5 µg/L	EC50 (4 days) 5.4 - 570 µg/L EC50 (72 h) 16.9 - 4 980 µg/L NOEC (72 h) 4 - 600 µg/L LOEC (72 h) 400 - 1 000 µg/L EC10 (72 h) 203 - 3 155 000 ng/L	No data
Aluminum hydroxide	LC50 (16 days) 430 - 3 910 µg/L LC50 (8 days) 22.4 mg/L LC50 (4 days) 570 - 218 644.1 µg/L LC50 (4 days) 2.9 µmol/L LC50 (72 h) 10 - 19.3 mg/L	NOEC (60 days) 88 - 350 µg/L NOEC (33 days) 71.5 - 558.1 µg/L NOEC (30 days) 57 - 88 µg/L NOEC (28 days) 4.7 - 23.1 mg/L NOEC (7 days) 25.1 - 56 476.6 µg/L	EC50 (48 h) 1.5 - 2.56 mg/L LC50 (4 days) 22 - 30.6 mg/L LC50 (48 h) 5.7 - 99 600 µg/L NOEC (4 days) 22.6 mg/L NOEC (48 h) 5 - 671.2 µg/L	NOEC (42 days) 232.6 - 453.8 µg/L NOEC (30 days) 1.092 - 2.099 mg/L NOEC (28 days) 53.1 - 4 281.8 µg/L NOEC (21 days) 76 - 600 µg/L NOEC (17 days) 962.5 µg/L	EC50 (4 days) 5.4 - 570 µg/L EC50 (72 h) 16.9 - 1 799 µg/L NOEC (72 h) 4 - 600 µg/L LOEC (72 h) 400 - 1 000 µg/L EC10 (72 h) 203 – 3 155 000 ng/L	No data

For invertebrates, the smallest effect of short-term toxicity is sodium bicarbonate, and the greatest one is chloride, oxide and aluminum hydroxide.

Analysis of the long-term toxicity of substances for aquatic invertebrates shows a significant variation in data and the difficulty in evaluating them. The most fully presented are the final values of EC10 / LC10 or NOEC for freshwater invertebrates. As one can see, the most dangerous compound is ammonium sulfate. At the same time, the lowest NOEC values, obtained for a different period (6-42 days) (Table 2), are characteristic of aluminum compounds. However, these data have a significant scatter, which complicates the objectivity of their comparison.

The toxicity of the tested compounds for algae and cyanobacteria is most fully characterized by EC50 values (72 h). As can be seen, toxicants such as aluminum compounds are the most dangerous for these organisms.

When analyzing the toxic effects of the tested inorganic compounds on aquatic microorganisms, the EC50 parameter was used (3 h). As can be seen (Table 2), the most dangerous compounds are sulfonic compounds and aluminum compounds, in particular sulfamic acid, basic aluminum chloride and aluminum sulfate. Based on scattered data, it can be assumed that magnesium and sodium chlorides, as well as ammonium sulfate, have the least toxic effect on aquatic microorganisms.

It can be said that in the short and long term, inorganic compounds based on aluminum, sulfamic acid and sodium bicarbonate are the most dangerous for aquatic living organisms. And the safest ones are magnesium and sodium chlorides. Incomplete data and their significant variability greatly complicate data processing.

Thus, despite the fragmentation and incompleteness of the available data, and their significant variability, including the parameters themselves and the conditions for obtaining them, for aquatic living organisms in the short and long term, the most dangerous are inorganic compounds based on aluminum, sulfamic acid and sodium bicarbonate, and the safest are magnesium and sodium chlorides.

CONCLUSIONS

It is advisable to analyze the effect of inorganic additives of foaming agents on the environment by studying the ecological, ecotoxicological and toxicological characteristics of inorganic salts, which are used to improve the extinguishing properties of foaming agents, taking into account their effect on living organisms and the environment.

A comparative analysis of the environmental hazards of the tested inorganic additives of foaming agents showed that the most dangerous for the environment are aluminum compounds and sulfamic acid, and the safest are magnesium and sodium chlorides.

Despite the fragmentation and incompleteness of the available data, and their significant variability, including the parameters themselves and the conditions for obtaining them, for aquatic living organisms in the short and long term, the most dangerous are inorganic compounds based on aluminum, sulfamic acid and sodium bicarbonate, and the safest are magnesium and sodium chlorides.

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