In the cases where there is a need to quickly move large volumes of water over a distance of hundreds of meters, firefighting equipment is used. In such cases, hose lines formed from fire hoses are usually used. An attempt was made to determine the effect of microdoses of foaming agents on the level of fluid consumption transported by fire hoses. It has been experimentally established that the fluid consumption during its transportation by fire hoses increased when foaming agents were added to it. The foaming agents Pirena-1, Sofir, Alpen, and Bars, which are used in firefighting in Ukraine, were selected for the experiments. Each of the foaming agents was used in two versions – one that meets and one that does not meet the guaranteed shelf life. The maximum increase in flow rate (11.5 %) was recorded when adding 0.021 % of the Bars foaming agent to water. The results of the experiments depended on the brand of foaming agents used and were almost independent of the "age" of the foaming agents. It is important that the results of the study showed that "overdue" foaming agents can be used to increase the efficiency of fire-fighting equipment. Latex-coated pressure fire hoses with a diameter of 51 mm were randomly selected (from those available in the fire department). The length of the hose line was 200 m (500 m for hoses with a diameter of 77 mm), the ambient temperature was about 20 °C, the pressure at the pump was 4...6 bar. The facts of the increase in liquid flow rate established in the study could be used in practice to increase the amount of liquid transportation (pumping) without changing other parameters of the fire-fighting equipment, for example, when eliminating the consequences of floods or landslides

Keywords: fire hose, hose line, water transportation, liquid flow rate, surfactants

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ESTABLISHING THE EFFECT OF LOW-PERCENTAGE DOSES OF FOAMING AGENTS ON INCREASING FLUID CONSUMPTION AT ITS TRANSPORTATION BY FIRE HOSES

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1. Introduction

One of the most important tasks resolved by firefighting equipment is the supply of water and aqueous solutions of foaming agents to fire sites and the pumping (transportation) of liquids. For this purpose, fire trucks, motor pumps, and now also unmanned ground robotic firefighting support systems are used.

There are several main options for pumping liquids with firefighting equipment. If the distance from the fire truck to the water intake point is small horizontally, then water is taken using an extended suction line. Such a line usually consists of three or four hoses, each 4 m long. If it is difficult to drive a fire truck to the water source, then water can be taken using portable or trailer motor pumps. In the case of difficult access to reservoirs, when the water level is 7–20 m lower than the pump axis, water is taken using hydraulic elevator systems.

It is generally believed that the amount of water supplied by motor pumps installed at water sources depends on the performance and pressure of the pump, the type of hoses, the length of the main line, and the elevation difference of the terrain (1).

For example, the maximum amount of water Q supplied by motor pumps installed at water sources is determined from the following formula:

$$Q=\sqrt{\frac{H_M}{\left(N_H \cdot S\right)}}, \tag{1}$$

where Q is the water supply from the motor pump, l/s; H_M is the pressure loss in the hoses of the main hose line, m; N_H is the number of hoses in the main hose line taking into account the coefficient of 1.2 for uneven terrain, pcs.; S is the hydraulic resistance of one fire hose of the main hose line with a length of 20 m.

It is important that the hydraulic resistance of a fire hose significantly depends on its diameter. For a fire hose with a diameter of 77 mm and a length of 20 m, the hydraulic resistance *S* is ten times smaller than for a diameter of 51 mm (it is 0.015).

Water pumping by fire-fighting equipment pumps is used when the distance to the water source from the fire site is significant. In this case, the pressure developed by one fire pump is insufficient either to overcome the pressure loss in the hose lines or to create working fire-extinguishing jets.

The distance recommended for pumping water usually does not exceed 2 km. At the same time, an important condition for effective liquid transportation is the diameter of the fire hoses. In order to transport water and working solutions of foaming agents to the fire site, fire hoses of various lengths, diameters, and types can be used. Fire trucks are equipped with pressure fire hoses of the T type.

One of the most important characteristics of the operation of fire-fighting equipment is the intensity of water supply (fire extinguishing agent). It depends on the power of the means of transporting liquids, the diameters and hydraulic resistance of fire hoses, the characteristics of the pumped (transported) liquid, etc. Usually, after laying the hose lines, it is impossible to change the power of the means of pumping liquids and the diameter of the hoses. It is possible to increase the flow rate (intensity of liquid supply), for example, by influencing the characteristics of the transported liquid.

Hydraulic resistance arises due to the influence of various factors, primarily frictional resistance, and local resistances. Since the Reynolds numbers characteristic of the processes of pumping liquids by fire-fighting equipment are inherent in turbulent flows, the influence of roughness on the hydraulic resistance increases. It depends on the Reynolds number, and on the material and average height of the irregularities of the inner surface of the hoses. In the case of a significant increase in the Reynolds number, the pumped liquid is characterized by a turbulent flow regime, in which the viscous sublayer is completely destroyed, and the friction created depends only on the roughness of the fire hoses. It is important that rubberized fire hoses have a significantly lower hydraulic resistance than non-rubberized ones.

It can be assumed that an increase in the intensity of liquid transportation can be ensured by changing the characteristics of the transported liquid or reducing the hydraulic resistance of the fire hoses. Therefore, the topic of determining the influence of low-percentage doses of foaming agents on increasing liquid flow is relevant when transporting water over long distances.

2. Literature review and problem statement

The process of transporting liquids by fire-fighting equipment is carried out using hose lines. The pressure along the hose line can significantly decrease due to the action of hydraulic resistance forces. Part of the energy losses during the transportation of liquid goes to the elongation and thickening of fire hoses. Experimental studies on the processes of changing the length and diameter of fire hoses during the transportation of fire-extinguishing liquids are described in detail in [1]. In [2], the factors influencing the change in the geometric parameters of fire hoses after hydraulic tests of fire hoses and fire nozzles were determined. The experiments showed that the flow rates obtained using Pitot tube measurements are somewhat higher than the real values. Thus, the results of real full-scale experiments on determining fluid flow rates may differ from the results obtained by "classical" laboratory methods [3]. But the question of the influence of the extension of the length of the fire hose and the change in its diameter on the fluid flow rate remains unresolved.

In [4], the friction loss characteristics of fire hoses were determined, which is one of the reasons for the extension of the length of the fire hose. In total, three fire organizations conducted 86 tests on 82 fire hose samples with a diameter of 1–5 inches (pressure fire hoses of 51 mm and 77 mm are in the specified range). Data on the dimensions of the fire hoses, pressure, flow, and friction losses were used to calculate three different friction coefficients. It was found [4] that the friction loss characteristics for individual sections of the fire hose are a factor of the inner diameter and roughness. The inner diameter was not an indicator of the magnitude of the friction loss for all the samples studied. However, it is not clear from study [4] why most of the obtained coefficient values are lower than the values obtained by other researchers. The use of three different friction coefficients [4] complicates the understanding of the process of transporting fluid through fire hoses.

It is important to consider that substances that reduce the surface tension of the extinguishing liquid can be used in fire extinguishing, facilitating its spreading in the fire site. Due to the special structure of molecules or ions of long-chain surfactants, they are easily dissolved in a polar medium – water. The main components of foaming agents used in fire extinguishing are surfactants. In [5] it is stated that the use of fluorine-containing short- and long-chain surfactants in fire extinguishing can have a negative impact on the environment. However, the addition of small amounts of inorganic and organic compounds is considered an inexpensive and effective method of increasing the fire-protective properties of water. That is why it is possible and necessary to determine whether the addition of these compounds will have an effect on the process of their transportation over long distances or to the jet-forming device – a fire hose.

Among the options for overcoming the difficulties in determining the hydraulic resistance of fire hoses are not only "mechanical" approaches. Thus, in work [6], when testing the hydraulic resistance of a fire hose, it was proposed to use computer modeling technology. First of all, the authors investigated the maximum stresses of the fire water gun, which is only the final element of the fire extinguishing agent supply system and the formation of a liquid jet. The authors point to the "narrow" structural places of the fire hose, although the hose line can also have an impact on the characteristics of the transported fire extinguishing liquid.

An increase in the speed of liquid transportation by fire hoses with unchanged values of other flow characteristics leads to an increase in liquid flow rate. To determine the speed of liquid movement in the hoses, various technical means are used, the functioning of which is based on the use of different techniques. The structure of the integrated electronic piezoelectric accelerometer proposed in [7] is designed as a sensor for measuring the flow rate based on the vibration caused by the movement of water flowing through the fire hose. It is important that the device has a small size and weight, is easily attached and removed anywhere along the fire hose, without interfering with the flow of water. In [7], such a fire hose is called "smart", which contributes to awareness of the transportation (flow) of liquid during fire extinguishing. However, it is not clear from the results of study [7] whether the designed device could make it possible to accurately determine the flow velocity and flow rate if water with additives is transported.

The increase in the flow rate of the liquid transported by the fire hoses affects the reaction force of the hose. This allows for fundamentally new engineering solutions that differ from traditional approaches to the creation of fire hoses and nozzles. Thus, in works [8, 9], the design of a hose-type robot with a special nozzle module was proposed. It was demonstrated that by controlling the directions of the liquid release through two nozzles, the resulting reaction force can be controlled. The authors experimentally showed that robots approximately 2 meters long [8] and 4 meters [9] can stably "fly" in the air due to the action of a water jet moving in the fire hose. A fire extinguishing demonstration was successfully carried out at the opening ceremony of the World Robot Summit 2020 in Fukushima, Japan. At the same time, stability control is provided by the design feature of the nozzle module, and it is not clear whether the flight stability of a hose-type robot can be ensured when the fluid flow rate changes.

Hydraulic studies on fire hoses conducted at the Lawrence Radiation Laboratory in the middle of the last century made it possible to derive simple equations of pressure loss depending on flow rate [1]. Interestingly, the pressure losses were noticeably lower than those given in the fire flow tables of that time.

Increasing the efficiency of liquid transportation by fire hoses, without changing either the scheme or the means of transportation, can be achieved in various ways. For example, by reducing the hydraulic resistance of the hose line, the energy flow rate for its transportation will also decrease. Thus, it is advisable to conduct a study aimed at determining the prospects of using low-percentage doses of foaming agents for liquid flow rates when transporting it by fire hoses.

3. The study materials and methods

The purpose of our study is to identify the patterns of influence of low-percentage doses of foaming agents on the increase in liquid flow. This will make it possible to ensure an increase in liquid flow by adding a small amount of foaming agents to the transported liquid.

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

– to determine the water flow without adding foaming agents at a temperature of 20–25 °C and a pressure of 4, 5, and 6 bar;

– to determine the liquid flow when adding 0...0.5 % of foaming agents to water at a temperature of 20–25 °C and a pressure of 4, 5, and 6 bar (without further obtaining air-mechanical foam);

– to determine the water consumption when transporting it through hose lines with the addition of expired foaming agents.

4. The study materials and methods

4. 1. The object and hypothesis of the study

The object of our study is the change in the flow rate of liquid when transported by fire hoses due to the addition of small doses of foaming agents. The term "small amount" of foaming agent refers to 0...0.05 % of the amount of water. When using such an amount of foaming agent, there is no increase in the extinguishing agent, but only a change in the flow rate of liquid during its transportation. To create a hose line that will transport water, pressure latex fire hoses with diameters of 51 mm and 77 mm should be used.

One of the types of applications of a hose line is the transportation of liquid in the required amount with the required head. Ensuring the required amount (flow rate) of liquid or the required head at its end requires energy costs for its transportation. The hydraulic resistance of the hose line affects the energy costs, which leads to a decrease in the hydraulic head. Among the causes of head losses are the mode of movement of the liquid and the viscosity of the transported liquid. Adding small doses of foaming agents (surfactants) to water affects the hydraulic characteristics of the fluid flow, which affects transportation costs.

4. 2. Methodology for determining water flow rate when transporting it by hose lines (without adding foaming agents)

Our study involved latex-coated fire hoses with a diameter of 51 mm, which are the most commonly used in Ukraine. All pressure fire hoses used in the experiments were previously in use, passed standard tests, and were randomly selected from those available in the training fire and rescue unit. The average length of one FHs was 20 m. Initially, a study was conducted to determine water flow rate when transporting it by two hundred and five hundred meter hose lines. The ambient temperature was 20–25 °C, the pressure at the pump was 4–6 bar, and the height difference between the initial and final pumping points did not exceed 1 m.

The experiment was conducted using a setup (Fig. 1), part of which was a bench for studying free hydraulic jets [10]. In Fig. 1, the arrow on the hose line indicates the direction of fluid movement. Water was transported by two hundred and five hundred meter hose lines, which were laid on a horizontal surface (Fig. 2).

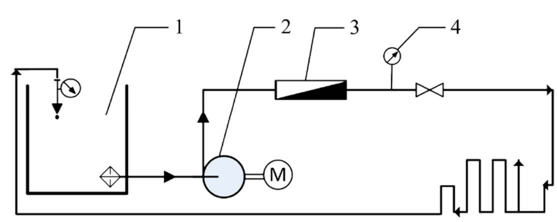

Fig. 1. Hydraulic diagram of the experimental setup: 1 — water tank; 2 — centrifugal pump; 3 — flow meter; 4 — pressure gauge; 5 — hose line

Using the control unit of the power module of the bench for the study of free hydraulic jets [11], the frequency F (Hz), current I (A), and power P (kW) consumed by the experimental installation for transporting liquids were recorded.

Fig. 2. Laying a hose line of pressure fire hoses with a diameter of 51 mm

4. 3. Methodology for determining water flow rate when transporting it by hose lines with the addition of foaming agents

Similar experiments were then conducted, but small doses (0...0.05 %) of foaming agents Pirena-1, Sofir, Alpen, and Bars were added to the water. In some experiments, fire hoses Protek-366 and RS-70 were used at the end of the hose line. For all foaming agents, the use of fire hoses led to the absence of the effect of increasing fluid flow rate.

To establish the fact of changing the flow rate of the transported fluid, empirical research methods were used, namely observation, measurement, and experiment.

5. Results of investigating water flow rate during its transportation by hose lines

5. 1. Determining water flow rate during its transportation by hose lines (without adding foaming agents)

At the first stage of the study, the measurement of water flow rates and power module indicators that provided these flows was carried out with a gradual increase in the inlet pressure from 4 to 6 bar in increments of 1 bar. The results are given in Table 1.

Table 1

Indicators of the power module that provided water flow rate (length of hose line L=200 m and L=200 m)

Q, bar	I, A	P, kW	F, Hz	L, m
4	22.1	13.2	52.6	200
5	31.1	19.2	61.0	200
6	38.0	24.5	69.1	200
4	23.9	14.2	55.3	500
5	33.0	20.4	63.3	500
6	39.9	26.4	70.0	500

The water flow rate values and power module indicators (Table 1) were taken as a basis for comparison with similar data in the case of using low-percentage doses of foaming agents.

5. 2. Determining water flow rate during its transportation by hose lines with the addition of foaming agents

At the next stage of research, general-purpose foaming agents of Ukrainian origin were used in the experiments: Pirena-1 (Scientific and Production Enterprise "Pirena"), Sofir (TOV "Firma "SOYUZ, LTD"), Alpen (TOV "Alkhim"), and Bars (TOV "Scientific and Production Enterprise "Vogneborets").

To obtain air-mechanical foam, these foaming agents are usually used with a working solution concentration of about 6 %, while the ambient temperature should be above 0 °C.

The use of surfactants, and any foaming agent consists of surfactants, makes it possible to radically change the surface and interfacial properties of the aqueous solutions they form [12]. Pseudoplastic liquids (pseudoplastics) do not exhibit a yield point. For them, a dependence in the form of a power law (2) was established. The dependence takes the form:

$$\tau = k\dot{\gamma}^n, \qquad (2)$$

where τ is the shear stress, γ is the shear rate, k is a measure of the consistency of the liquid; n is a quantity characterizing the degree of non-Newtonian behavior of materials.

The higher the viscosity value, the greater k, and the more n differs from unity, the more non-Newtonian properties are manifested.

Dilatant liquids are somewhat similar to pseudoplastic liquids since they also have no yield point. Dilatant liquids can also be described using the Oswald de Wiel equation, but for them the value $n>1$ [12].

According to Oswald de Wiel's law, the foaming agents Pirena-1 and Sofir selected for the study behave as dilatant liquids, and the foaming agent Alpen behaves as a pseudoplastic liquid. Comparative analysis of the obtained rheological characteristics of foaming agents gives the right to assert their fundamental similarity with most other foaming agents, which indicates the possibility of their use by existing fire-fighting equipment under similar fire-fighting conditions. Mixing of the Alpen foaming agent with other biologically "soft" general-purpose foaming agents made from surfactants of similar chemical nature is allowed.

It is known that sometimes, when additives are added to water in small concentrations, it is possible to provide the ability to reduce the frontal resistance of the liquid movement by up to 80 % [13]. However, although there are many attempts to explain the mechanisms of resistance reduction, it cannot be said that there is a single generally accepted opinion on this subject.

The bench for studying free hydraulic jets [11] makes it possible to record the change in pressure to ensure an increase in liquid flow rate, or a change in liquid flow rate if low-percentage doses of foaming agents are added to it.

Since the pattern of liquid transportation at hose line lengths of 200 m and 500 m was similar, subsequent studies were conducted only at L=200 m (Table 2). In addition, we note that liquid transportation at L=500 m and pump pressure P=6 bar occurred at the limit of the technical capabilities of the experimental installation and was more effective when using fire hoses of larger diameter. Therefore, further analysis of the results of our research concerned the liquid transportation system with parameters L=200 m and P=4 bar.

According to the data indicated by the manufacturers, the shelf life of the foaming agents Pirena-1, Sofir, Alpen is 36 months, for the foaming agent Bars S1 – 60 months. At the time of the experiments, all the foaming agents used in the second stage had a production date of no more than 12 months. The results are given in Table 2.

From Table 2, the most informative indicator is the power W (kW) consumed by the experimental unit for transporting liquids.

Table 2

Indicators of the power module that provided water flow rate with low-percentage doses of foaming agents (length of hose line L=200 m, foaming agent concentration P_c=0...0.05 %)

Brand of foaming agent	P, bar	P_c, %	I, A	P, kW	F, Hz
Pirena-1	4	0.01	22.0	13.0	51.6
		0.02	22.1	13.1	51.7
		0.03	22.0	13.0	51.6
		0.05	22.7	13.4	52.0
	5	0.01	31.0	19.1	61.0
		0.02	31.0	19.1	61.1
		0.03	31.0	19.1	61.0
		0.05	31.2	19.2	61.2
	6	0.01	37.8	24.2	68.3
		0.02	37.6	24.1	68.3
		0.03	37.6	24.1	68.3
		0.05	37.6	24.1	68.3
Sofir	4	0.01	22.1	13.1	52.0
		0.02	22.0	13.0	51.6
		0.03	22.1	13.1	51.2
		0.05	22.8	13.5	52.2
	5	0.01	31.1	19.2	61.0
		0.02	31.1	19.2	61.0
		0.03	31.2	19.3	61.2
		0.05	31.1	19.2	61.0
	6	0.01	37.9	24.3	68.3
		0.02	37.4	24.0	67.2
		0.03	37.3	23.8	66.9
		0.05	38.0	24.4	68.4
Alpen	4	0.01	22.1	13.4	52.1
		0.02	22.4	13.3	51.2
		0.03	22.4	13.2	51.0
		0.05	22.1	13.4	52.3
	5	0.01	31.1	19.2	61.0
		0.02	31.0	19.1	61.1
		0.03	31.1	19.2	61.1
		0.05	31.2	19.2	61.2
	6	0.01	38.0	24.5	69.0
		0.02	38.1	24.6	69.4
		0.03	38.0	24.5	69.1
		0.05	38.1	24.6	69.4
Bars	4	0.01	21.5	12.6	52.2
		0.02	19.8	11.9	50.8
		0.03	21.4	12.3	51.2
		0.05	22.3	13.2	52.6
	5	0.01	29.9	18.4	60.4
		0.02	28.6	17.7	60.4
		0.03	29.9	18.3	60.9
		0.05	31.1	19.1	61.4
	6	0.01	36.5	23.5	68.7
		0.02	35.8	23.0	68.4
		0.03	36.7	23.6	68.7
		0.05	37.9	24.5	68.9

The data for the foaming agent Bars from Table 2 were used to draw Fig. 3. As can be seen from Fig. 3, the power consumption P (kW) of the experimental unit depends on the percentage of foaming agent added to the water.

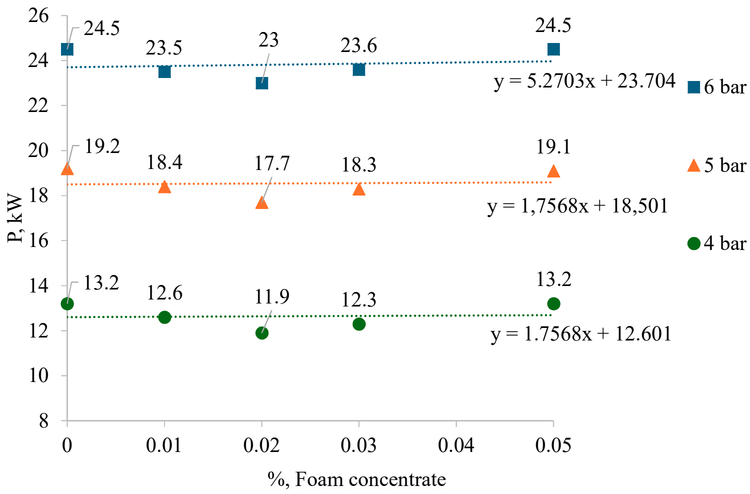

Fig. 3. Dependence of power consumption P (kW) of the experimental installation for transporting liquids on the percentage value of the foaming agent Bars

5. 3. Determining water flow rate when transporting it by hose lines with the addition of expired foaming agents

In the third stage of the research, foaming agents were used, which, according to their technical characteristics, cannot be used for their intended purpose (without additional measures). All of them had an expiration date overdue by at least 12 months. That is, their use is not allowed to obtain low and medium-multiplicity foam and wetting solutions when mixed with water in the appropriate proportions. All other conditions for conducting the third stage of the research were identical to the second stage. Fire hoses were washed after the second stage before the start of the experiment.

Similar to the second stage of the research, the transportation of liquid at L=500 m and pump pressure P=6 bar occurred at the limit of the technical capabilities of the experimental installation. That is why a liquid transportation system with parameters L=200 m and P=4 bar was used for the research.

The results are given in Table 3.

The power consumption P (kW) of the experimental installation for transporting liquids depends on the percentage value of the expired foaming agent Bars (Table 3).

It was established that the liquid flow rate increased (up to a maximum of 11.5 %) for the foaming agent Bars.

A decrease in the power consumption P (kW) of the experimental installation was observed when using the Bars foaming agent. For the Pirena-1, Sofir, Alpen foaming agents, the pattern of dependence of power consumption P (kW) of the experimental installation for transporting liquids on percentage value of the foaming agent was similar. The upper green curve II (Fig. 4) is constructed for the Alpen foaming agent but is also characteristic of the Pirena-1 and Sofir foaming agents.

Table 3

Indicators of power module that provided water flow rate with low percentage doses of foaming agents with an expired shelf life

Brand of foaming agent	P, bar	P_c, %	I, A	P, kW	F, Hz
1	2	3	4	5	6
Pirena-1	4	0.01	22.1	13.1	51.8
		0.02	22.2	13.2	51.9
		0.03	22.0	13.0	51.6
		0.05	22.4	13.2	51.7
	5	0.01	30.8	18.9	61.0
		0.02	30.8	18.9	61.1
		0.03	31.0	19.1	61.0
		0.05	31.4	19.3	61.2
	6	0.01	37.7	24.1	68.2
		0.02	37.6	24.1	68.3
		0.03	37.6	24.1	68.3
		0.05	37.7	24.1	68.2
Sofir	4	0.01	22.2	13.2	52.1
		0.02	22.0	13.1	51.5
		0.03	22.1	13.1	51.2
		0.05	22.7	13.5	52.1
	5	0.01	31.3	19.3	61.2
		0.02	31.2	19.2	61.1
		0.03	31.2	19.3	61.2
		0.05	31.1	19.1	61.1
	6	0.01	37.7	24.1	68.1
		0.02	37.2	24.2	67.1
		0.03	37.3	23.8	66.9
		0.05	38.2	24.2	68.1

Continuation of Table 3

1	2	3	4	5	6
Alpen	4	0.01	22.1	13.4	52.1
		0.02	22.4	13.3	51.2
		0.03	22.4	13.2	51.0
		0.05	22.1	13.4	52.3
	5	0.01	31.3	19.3	61.2
		0.02	31.1	19.0	61.0
		0.03	31.1	19.2	61.1
		0.05	31.2	19.2	61.2
	6	0.01	38.4	24.3	69.3
		0.02	38.4	24.3	69.3
		0.03	38.2	24.4	69.2
		0.05	38.3	24.8	69.6
Bars	4	0.01	21.4	12.7	52.0
		0.02	19.5	11.7	50.6
		0.03	21.0	12.1	51.0
		0.05	22.0	13.1	52.6
	5	0.01	29.5	18.2	60.0
		0.02	28.3	17.5	60.2
		0.03	29.5	18.1	60.8
		0.05	30.8	19.0	61.0
	6	0.01	36.1	23.3	68.4
		0.02	35.3	22.8	68.1
		0.03	36.1	23.3	68.5
		0.05	37.6	24.3	68.7

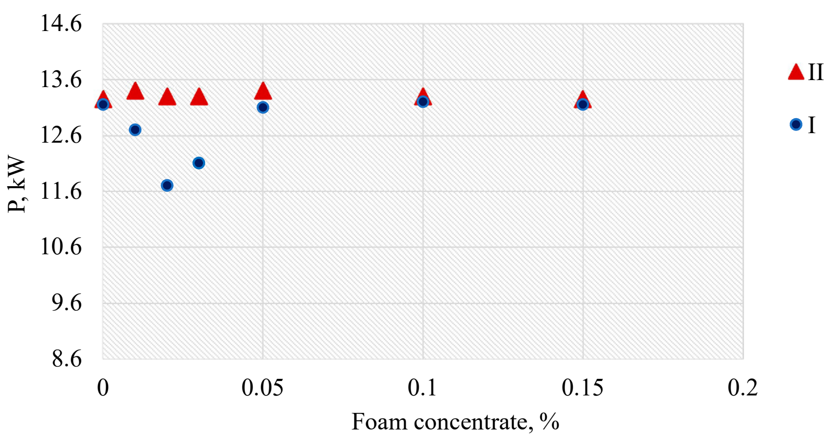

Fig. 4. Dependence of power consumption *P* (kW) of the experimental installation for transporting liquids on the percentage of foaming agent added to water. Curve I, blue — Bars foaming agent, curve II, red — Alpen foaming agent

6. Discussion of results based on the use of low-percentage doses of foaming agents when transporting water by fire hoses

Fig. 3, 4 demonstrate the dependence of power consumption *P* (kW) of the experimental installation for transporting liquids on percentage value of a foaming agent and are constructed in different graphical formats. The abscissa axis in Fig. 4 demonstrates a wider range of the percentage value of the foaming agent (0…0.16 %). Figure 3 highlights the range of percentage value of the foaming agent (0…0.05 %), at which the dependence of power consumption *P* (kW) of the experimental installation decreased. In addition, in Fig. 4, the scale of the ordinate axis has been changed for better visualization of the dependence of power consumption *P* (kW) of the experimental installation.

As a result of our experiments, the dependences of the liquid flow rate when transporting it by fire hoses were established when using (Tables 2, 3) and without using (Table 1) low-percentage doses of foaming agents.

The water transportation modes were typical for fire engines most commonly used in Ukraine. The pump pressure was 4, 5, and 6 bar, foaming agents were added in the range of 0…0.05 % of the amount of water, the experiments were carried out at a temperature of 20–25 °C. Pressure latex fire hoses with a diameter of 51 mm were used to assemble the hose line.

The change in the flow rate of the transported liquid when using some of the foaming agents was insignificant and was within the error range of the experimental results. However, when using the foaming agent "Bars" with an expired shelf life, the power consumption *P* (kW) of the experimental installation for transporting liquids was 11.7 kW, and when using a new foaming agent 11.9 kW (P_c=4 bar, P=0.02 %).

As expected, for most of the foaming agents used in the study, it was not possible to obtain changes in the flow rate of the transported liquid. That is, for typical modes of liquid transportation by hose lines (4–6 bar) when using 0–0.05 % doses of foaming agents, no increase in liquid flow rate was recorded, or the increase in flow rate was within the error range caused by the accuracy of the measuring equipment used. However, a slightly different picture was observed when adding Bars foaming agent to water, when the maximum increase in flow rate was recorded at 0.02 % of the specified foaming agent. After that, studies were conducted to determine the flow rate when using 0.019...0.023 % (in increments of 0.001 %) of the specified foaming agent. After conducting clarifying experiments, the extremum of flow rates (an increase of 11.5 %) was recorded when adding 0.021 % of the foaming agent while the pump pressure was 6 bar.

The actual increase in water flow was recorded when the frequency F (Hz), current I (A), power consumption P (kW) of the experimental installation for transporting liquids increased. Also, a change in liquid flow was recorded in some cases when foaming agents were added to water. Thus, under certain conditions of adding microdoses of foaming agents, it is possible to achieve an increase in the amount of pumped liquid without changing the modes and parameters of the liquid transportation system.

It is important that the increase in the flow rate of the transported liquid was recorded both for the foaming agent Bars permitted for use and for the one with an expired service life. Such a result, after conducting additional studies, may allow the use of foaming agents not only for their intended purpose but also to increase liquid flow even after the end of the permitted terms of use of foaming agents. To explain the obtained results of the increase in flow, there is a need to establish the reasons for such an increase. There is currently insufficient data to state whether our results are due to an error inherent in the measurement process itself, the equipment used, the composition of the foaming agent, or anything else. If it is possible to achieve a steady increase in liquid flow rates when adding low percentage doses of some foaming agents, it will be possible to transport liquids over long distances more efficiently or to pump large volumes of liquids more quickly.

It can be assumed that the obtained results of the increase in water flow are explained by the physicochemical features of specific foaming agents, the physicotechnical features of the structure of the liquid transportation system, as well as the influence of the conditions and modes of their operation. Each of the above reasons should be studied in detail and the magnitude of their influence on the increase in liquid flow should be determined.

In general, the established fact of the increase in liquid flow (up to 11.5 %) can be taken as a basis for further research related to the transportation of fire-extinguishing liquids by fire hoses or flexible pipelines.

At the same time, as a result of our experiments, the level of dependence of the liquid flow in a fairly narrow range (0...0.05 %) of the concentrations of foaming agents added to water was established. It remains unclear how to evenly add the required amount of foaming agent to stably ensure the increase in the flow rate of water transported by hose lines identified in the study.

In this way, it will be possible to devise new approaches to reducing dissipative losses when transporting liquids to jet-forming devices [14]. The identification of substances that allow increasing the flow rate of the transported liquid and the determination of their effective concentrations makes it possible to create a basis for ensuring an increase in the flow rate of the liquid without changing the output pressure at the fire pump.

In contrast to [5], which noted the negative environmental impact of using fluorinated short- and long-chain surfactants, our study discusses the benefits of using foaming agents. Adding small amounts of inorganic and organic compounds is considered an inexpensive and effective method for increasing the fire-retardant properties of water [5]. However, the results of the study show that adding low-percentage doses of foaming agents to water can contribute to an increase in fluid flow rate. The result may be not only an increase in the volume of transported fluid, but also an increase in the amount of extinguishing agent supplied to the fire.

That is why the practical application of our results may prove useful when using firefighting equipment while pumping large volumes of liquids over significant distances (for example, when eliminating the consequences of the natural-technological process of raising the groundwater level, floods, etc.). In addition, the use of additional devices at the end of the hose line, for example a fire hose, will change the conditions for transporting the liquid primarily due to the increase in the value of hydraulic resistance. In such cases, the feasibility of using microdoses of foaming agents when transporting fire extinguishing agents to the fire site is quite questionable.

Among the limitations on the use of the reported results, it is necessary to highlight the environmental component. Pumping large volumes of water using foaming agents may in some cases negatively affect the microflora of reservoirs and rivers. Thus, the presence of anionic, nonionic, and cationic surfactants in the composition of foaming agents requires ensuring their biological decomposition.

It should be noted that the use of the established effect of increasing fluid flow rate requires the development of mechanisms and means for dosing foaming agents. In addition, it is necessary to determine which types of foaming agents are appropriate to use.

7. Conclusions

1. It has been established that an important factor influencing the ability to change the flow rate of a liquid is the use of foaming agents as an additive to the liquid transported by pressure fire hoses. It is important that in the cases where the change in flow rate was significant (up to 11.5 %), that is, it exceeded the experimental error limit, the function of the flow rate dependence on the percentage of foaming agent added to water contained a growth zone, an extremum, and a decline zone. In the cases when an increase in the flow rate was recorded, it was a question of using microdoses of foaming agents, namely 0...0.05 % of the total volume of the liquid. In fact, the results of our experiments indicate the influence of small doses of surfactants on the process of transporting liquids by fire hoses. The value of power W, which ensures the transportation of liquids by pressure fire hoses with and without the addition of individual types of foaming agents when using the experimental installation, has been experimentally determined.

2. When transporting water by pressure fire hoses for the studied types of foaming agents, it was experimentally established that an increase in liquid flow rate can occur when using small doses of foaming agents. At the same time, for most of the studied foaming agents (Pirena-1, Sofir, Alpen), the increase in liquid flow rate is not significant. The maximum increase in flow rate (11.5 %) was recorded when adding 0.021 % of the Bars foaming agent to the transported water. The results obtained can contribute to the improvement of systems for transporting large volumes of liquids over

long distances when eliminating the consequences of floods. In all cases, when adding more than 0.2 % of foaming agents, the flow rate began to decrease compared to the case without adding foaming agents.

3. The use of overdue foaming agents is not permitted for low and medium foam production. However, they could be used to increase water flow rates when transporting water through hose lines.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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