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Pump-hose systems with universal fire barrels for extinguishing buildings

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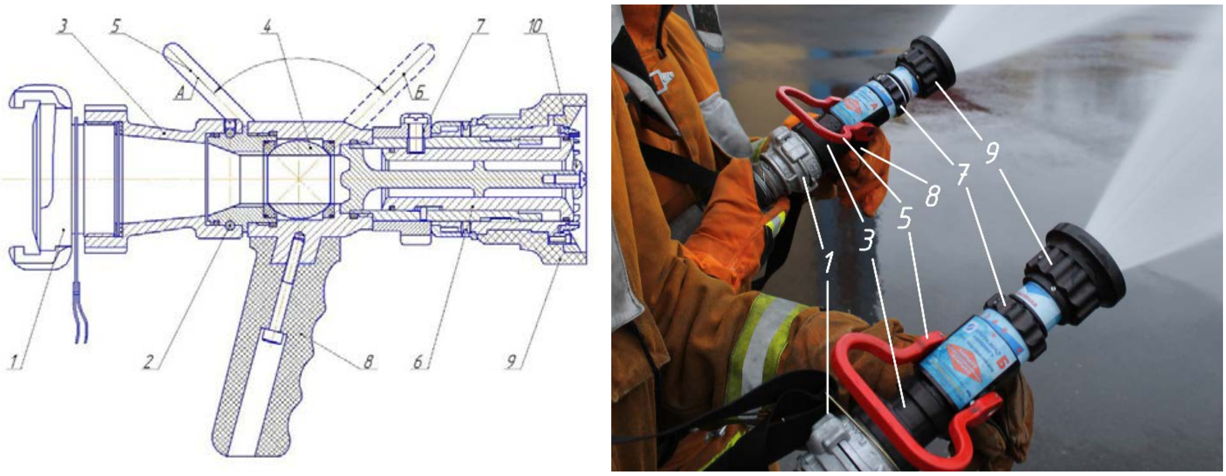
Abstract. The hydraulic calculation of pump-hose system was carried out, taking into account the influence of its elements on the performance of fire barrels. Corresponding dependences for mixed pump-hose systems consisting of one and three fire barrels are presented. Based on the hydraulic calculation of the pump-hose system, it was found that an increase in the number of hoses to 12 in the main and up to 3 in the working line leads to a decrease in barrel consumption by 1.5 %, which does not affect fire fighting process. As a result of the analysis of the pump-hose system with three fire barrels when changing the main parameters in one of them, we can conclude that a significant effect on the flow rate is exerted by a change in the position of the dispenser, the height of the barrel and the number of hoses in the working line (total line resistance). It was also established that the flow rate of the other two system trunks varies slightly (1.5 %), which in practice can be ignored. Based on the data obtained, recommendations are given to the operator working on the pump of a fire truck when feeding fire extinguishing substances to a height. The presented research results are obtained in the field of fire extinguishing agents and methods of their application and can be used in fire fighting and emergency response.

1. Introduction

According to the State Statistical Reporting, in the period from 2014 to 2019, more than 30000 fires occurred in the Republic of Belarus, in which 2856 people died (including 47 children) and 1668 were injured. At the same time, 91 % of the total number of fires falls on the housing stock [1–2]. A similar problem is encountered in many countries of the world, which is confirmed by studies by scientists from Russia [3], Japan [4], Spain [5], Sweden [6], USA [7], Netherlands [8], United Kingdom [9].

When extinguishing fires in residential buildings, a number of technical means are used: a car for water delivery, fire hoses, fire barrels. In this work, we studied the mutual influence of the elements of the pump-hose system (fire hoses in conjunction with one or more fire barrels) on its tactical and technical characteristics.

Currently, to extinguish such fires fire barrels with variable flow rate are used around the world. Unlike previously used, all of these barrels allow supplying water and aqueous solutions of extinguishing agents in a wide range of flow rates and head (form a spectrum of different types of jets and their combinations, while ensuring high quality spray with different torch angles), and if there is a nozzle, they generate air-mechanical foam of low multiplicity. TFT (USA) [10], POK (France) [11], Akron Brass Company (USA) [12], Yone Corporation (Japan) [13], R.PONS (France) [14], Delta Fire Ltd (England) [15], Rosenbauer (Austria) [16], Protek (Taiwan) [17]. In 2013, the Ministry of Emergency Situations of the Republic of Belarus began an import substitution of these foreign trunks with domestic counterparts SPRU-50/0.7 and SPRUK-50/0.7 “Viking” (Fig. 1) [18–19], manufactured by the Optron instrument-making plant.



a **b**

Figure 1. The appearance of the barrel:
a is the diagram; b is the photo of the barrel while water supplying
1 is the connecting head HZ 50; 2 is the fixing element; 3 is the rotating adapter; 4 is the overlapping device; 5 is the control handle; 6 is the mechanism for controlling the flow of extinguishing agent; 7 is the dispenser (5 positions); 8 is the holding handle; 9 is the nozzles; 10 is the deflector.

The main purpose of fire barrels is the remote effective supply of extinguishing agent to the fire, which allows for fire extinguishing at a distance from the fire front within the radius of the jet. Obviously, they have certain tactical and technical characteristics: operating head, flow rate and range of extinguishing agent. In this regard, the problems arising from the supply of extinguishing agent for extinguishing buildings can be divided into two categories. The first concerns issues related to the localization of fires in high-rise buildings and buildings with increased number of storeys, and the second concerns the localization of fires in several places at the same time when apartments on different floors or in neighboring entrances are burning in parallel. While questions of the first category are considered enough, for example, in [20–25], the questions of the second category need to be studied additionally. This is due to the fact that the performance characteristics directly depend on the head on the pump of the fire truck, therefore, it is important for the operator working on it to know what optimal head value must be maintained during firefighting. Since the fire departments are currently using domestic barrels with variable flow rates for emergency situations, for which the dependence of the performance characteristics on required head, taking into account the composition of the pump-hose system in unknown, is necessary to conduct experimental studies.

Thus, the calculation of the pump-hose system is reduced to determining the required head at the pump at a given flow rate, as well as the actual head and flow rates at barrels at a given head on the pump. To achieve this goal in the work it is necessary to solve the following tasks:

1. To get the formula for calculating the head at the fire truck pump, taking into account the influence of the characteristics of all elements of the pump-hose system when using fire barrels with a variable flow rate.

2. To carry out a hydraulic calculation of the pump-hose system with one fire barrel with a variable flow rate.

3. To study the effect of a fire barrel with a variable flow rate on a pump-hose system with several barrels.

All calculations in this research were carried out for the fire barrel SPRUK 50/0.7 Viking at the University of Civil Protection of the Ministry of Emergencies of Belarus. Moreover, all the obtained dependencies will be valid for other modern barrels with variable flow rate. The difference will only be in the resistance of the barrels, due to various geometric parameters and material of manufacture.

2. Methods

In general terms, the pump and hose system (Fig. 2) is a combined fire pump, hose line and fire barrel (extinguishing agent supply device).

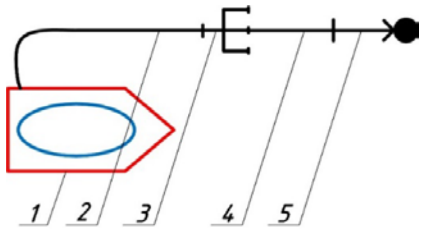


Figure 2. Scheme (general) of the pump-hose system
1 is the fire truck; 2 is the main hose line; 3 is the hose branching (dictating point); 4 is the working hose line; 5 is the fire barrel.

Depending on the method of connecting these elements, parallel, serial and mixed pump-hose systems are distinguished (Fig. 3).

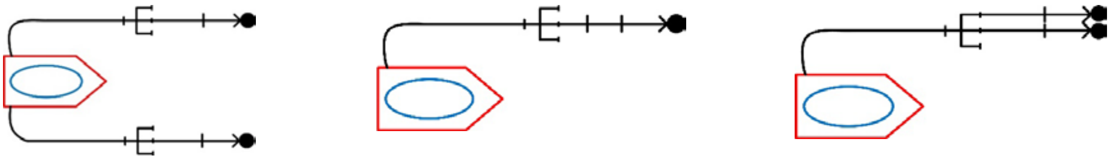


Figure 3. Types of pump-hoses systems: a is the parallel; b is the sequential; c is the mixed.

The basis for any hydraulic calculation of pump-hoses systems is the determination of flow head losses at a given flow rate. It is known that the total flow rate of the system in parallel connection of elements is equal to the sum of the flow rate in each of them, while in series – all flow rates are equal to each other. Moreover, the head losses in the parallel system are the same in all its elements, while in the serial system the losses on the elements are added up. Based on these rules, for a mixed pump-hose system, it can be written:

$$H_{p.} = H_{m.} + H_{w.}, \tag{1}$$

where $H_{p.}$ is head at the pump of the fire truck, m; $H_{m.}$ is head loss in the main hose line, m; $H_{w.}$ is head losses in the working hose lines or head in the dictating point, m.

In this case, the working hose lines are parallel, therefore the head losses in them are equal to each other.

Head loss are due to the presence of hydraulic resistance: linear and local. Linear resistances are caused by the friction of the fluid layers against each other, on the inner surface of the pipe (hose) and in practice causes head losses in the hose lines. Since the hose lines are cylindrical pipelines, and the fluid flow is turbulent [19], for calculating the head loss in them, one can use the Darcy-Weisbach formula:

$$h_{l.} = \lambda \frac{l}{d} \cdot \frac{\upsilon^2}{2g}, \tag{2}$$

where λ is the coefficient of hydraulic friction; l is the length of the plot, m; d is the diameter of the pipeline (hose), m; υ is the average flow velocity, m/s; g is acceleration of gravity, m/s^2.

Expressing from the condition of continuity

$$Q = \upsilon\omega, \tag{3}$$

where Q is the fluid flow rate, m^3/s; ω is area of water section, m^2,

the average flow velocity υ and, substituting in (2), we obtain:

$$h_{l.} = \lambda \frac{l}{d} \cdot \frac{Q^2}{2g\omega^2} = \lambda \frac{l}{d} \cdot \frac{16Q^2}{2g\pi^2 d^2} = \lambda \frac{8l}{g\pi^2 d^4} \cdot Q^2 = S_p Q^2,$$

$$S_p = \lambda \frac{8l}{g\pi^2 d^4} \cdot 10^{-6}. \tag{4}$$

where S_p is the hose resistance, m s^2/l^2.

Hose resistance was established experimentally as part of research work at the University of Civil Protection of the Ministry of Emergencies of Belarus and the Scientific Research Institute of Fire Safety and Emergencies (Table 1).

Table 1. Resistance of fire hoses.

Hose type	Resistance of fire hoses, m·s²/l², for a hose with a diameter, mm						
	38	51	66	77	89	110	150
Latexed	0.53	0.12	0.023	0.0117	–	–	–
Rubberized	–	0.15	0.035	0.0150	0.0046	0.002	0.0005

Local resistances are caused by a local change in flow velocity in magnitude and direction and cause head loss in the branches and fire barrels. The magnitude of such losses can be calculated by the empirical formula of Weisbach:

$$h_{loc.} = \xi_{loc.} \cdot \frac{\upsilon^2}{2g} = \xi_{loc.} \cdot \frac{Q^2}{2g\omega^2} = \frac{8\xi_{loc.}}{g\pi^2 d^4} \cdot Q^2 = S_{loc.} Q^2,$$

$$S_{loc.} = \frac{8\xi_{loc.}}{g\pi^2 d^4} \cdot 10^{-6}, \tag{5}$$

where $\xi_{loc.}$ is the coefficient of hydraulic resistance; d is the input diameter of local resistance, m; $S_{loc.}$ is local resistance, m s²/l².

We calculate the value of local resistance for branching and fire barrel.

According to [26], the coefficient of local resistance for hose branches of sizes RT-70 and RT-80 is 2 and 1.5, respectively. Knowing the input diameter of the branches (conditional passage of the inlet pipe), we can determine the local resistance value by the formula (5). The calculation results are presented in Table 2.

Table 2. Hose branch resistance.

Branch sizes	Conditional pass of an entrance branch pipe, m	Local resistance, m·s²/l²
RT-70	0.07	0.0052
RT-80	0.08	0.0030

The local resistance coefficient for the fire barrel SPRUK 50/0.7 Viking is not known. However, in [27], the flow rates for various positions of the dispenser are given for working heads at the entrance to the barrel. Since the resistance of the barrel does not depend on the head at the inlet and for each position of the flow controller remains constant regardless of the flow, then, knowing the head and flow, we can determine the resistance value for each position of the flow controller by the formula:

$$S_{loc.} = \frac{H_{barr.}}{Q^2}, \tag{6}$$

where $H_{barr.}$ is head on the barrel, m.

The calculation results are presented in Table 3.

Table 3. Resistance of a fire barrel SPRUK 50/0.7 "Viking".

Dispenser position	Parameter	Head, m				Average value of local resistance, m·s²/l²
		40	50	60	70	
1	The value of flow, l/s	0.53	0.58	0.67	0.69	142.93
	Resistance, m·s²/l²	142.40	148.63	133.66	147.03	
2	The value of flow, l/s	0.97	1.06	1.17	1.28	43.39
	Resistance, m·s²/l²	42.51	44.50	43.83	42.72	
3	The value of flow, l/s	1.83	2.06	2.28	2.42	11.81
	Resistance, m·s²/l²	11.94	11.78	11.54	11.95	
4	The value of flow, l/s	2.61	2.97	3.25	3.61	5.65
	Resistance, m·s²/l²	5.87	5.67	5.68	5.37	
5	The value of flow, l/s	3.15	3.45	3.73	4.17	4.14
	Resistance, m·s²/l²	4.03	4.20	4.31	4.03	
6	The value of flow, l/s	3.67	4.03	4.36	5	3.00
	Resistance, m·s²/l²	0.53	0.58	0.67	0.69	

Thus, the head loss in the main hose line add up to the head loss in the main fire hoses and hose branching, and the head loss in the working hose lines – from the loss of head in the working fire hoses, the fire barrel and the difference in elevation of the location of the pump and the fire barrel. With this in mind, we write formula (1) in the form:

$$H_{p.} = n \cdot S_{m.h.} \cdot Q^2 + S_{br.} \cdot Q^2 + n \cdot S_{w.h.} \cdot Q^2 + S_{barr.} \cdot Q^2 + Z\ , \quad (7)$$

where n is the number of sleeves; $S_{m.h.}$ is resistance of one main hose, m s²/l²; $S_{br.}$ is resistance of hose branching, m s²/l²; $S_{w.h.}$ is resistance of one working hose, m s²/l²; Z is the difference between the elevation marks of the pump and the fire barrel, m.

3. Results and Discussion

The research results presented in this section were obtained for the first time and were not covered in the works of other authors.

The pump-hose system with one barrel is sequential (Fig. 2, a) and formula (7) is applicable for its calculation. It is important for the operator working on the pump to know what head is needed on the pump to ensure the required flow rate on the fire barrel. From the formula (7) it is seen that the head is influenced by the resistance (diameter) and the number of hoses, as well as the difference between the elevation marks of the pump and the fire barrel.

Let us consider the case when the height difference is constant and equal to zero. At the same time, we change the number of hoses in the main line from 1 to 12 and in the working line from 1 to 3, as well as the head on the pump from 10 to 100 meters. Calculations are carried out for the 3rd position of the dispenser (Fig. 1, position 7) of one fire barrel SPRUK 50/0.7 "Viking", since in practice when extinguishing a fire this position allows creating the most optimal flow rate of extinguishing agent. As a result, we obtain the dependence of the flow rate of the extinguishing agent on the head at the pump for a different number of hoses (Fig. 4).

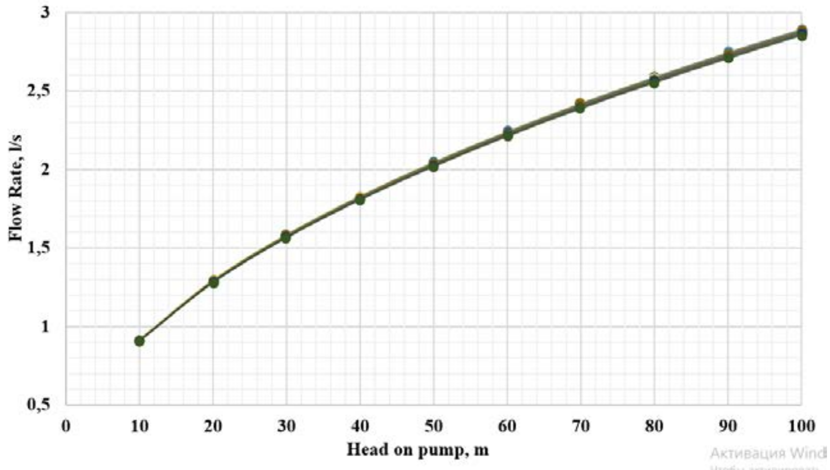


Figure 4. Dependence of the flow rate of extinguishing agent on the head at the pump when changing the number of hoses.

From the obtained dependencies it is seen that the flow rate of a fire barrel operating in a system consisting of a 1st trunk and 1st working hose is on average by 1.5 % higher than the flow rate of a barrel operating in a system of 12 trunks and 3 workers hoses. Such a difference is not noticeable during practical work, therefore it can be concluded that a change in the number of hoses has a slight effect on the flow rate of the extinguishing agent and may not be taken into account in further calculations.

Let us consider the effect of the difference in elevation of the pump and the fire barrel on the flow rate of the extinguishing agent. To do this, the dependence for various head on the pump is constructed (Fig. 5). The method “from pump to pump” is used to supply extinguishing agent to a considerable height: one tank truck is installed on a water source, a main line is laid to the pump of the second truck, installed at the entrance to the building, then a fire extinguishing substance is supplied to extinguish the fire. With this method, the total head is the sum of the head on the pumps of tank trucks, therefore, in the nomogram shown on Fig. 4, the head range varies from 10 to 200 meters. Calculations are also carried out for the 3rd position of the dispenser of the fire barrel SPRUK 50/0.7 "Viking" according to the formula (7).

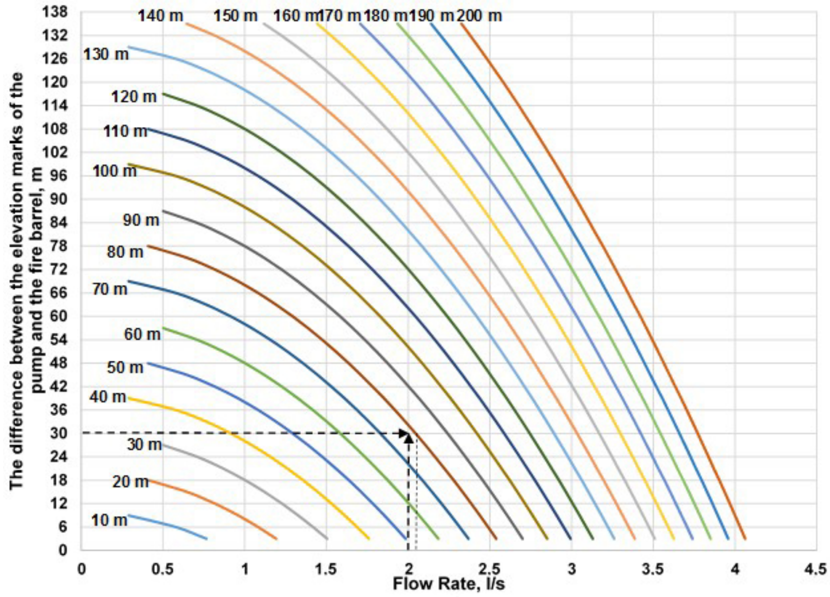


Figure 5. Dependence of the flow of extinguishing agent on the difference in elevation of the pump and the fire barrel for various heads on the pump.

Let us analyze the procedure for using the nomogram shown in Fig. 5. Suppose that we need to determine what head is required to be created at the pump of fire truck for the uninterrupted supply of extinguishing agent with a flow rate of 2 l/s to the 10th floor of an apartment building. Since the standard height of the floor is 3 m, the barrel must be fed to a height of 30 m. On the abscissa axis, we fix the required flow rate, and on the ordinate axis, the required height difference between the pump and the fire barrel. Then, from the point with these coordinates, we put the segment on the right to the intersection with the nearest chart. The head described by this graph is 80 m and it must be created on the pump. At the same time, we note that the actual consumption will be slightly higher than required, which is correct in the calculations of fire extinguishing tactics.

Let us consider the most common case is a mixed pump-hose system (Fig. 3c), consisting of one main and three working lines, branching and three barrels SPRUK 50/0.7 "Viking". The head losses in such a pump-hose system consist of the sum of the head losses in the main and one of the working hose lines. Moreover, the head losses in parallel working hose lines are equal to each other. Based on the expression (7) and taking into account that the head at the entrance to all working lines are equal, we can write the system of equations:

$$\begin{cases} H_{w.} = H_{p.} - \left(n \cdot S_{m.h.} + S_{br.}\right)\left(Q_1 + Q_2 + Q_3\right)^2, \\ H_{w.} = \left(n \cdot S_{w.h.1} + S_{barr.1}\right) \cdot Q_1^2 + Z_1, \\ H_{w.} = \left(n \cdot S_{w.h.2} + S_{barr.2}\right) \cdot Q_2^2 + Z_2, \\ H_{w.} = \left(n \cdot S_{w.h.3} + S_{barr.3}\right) \cdot Q_3^2 + Z_3, \end{cases} \tag{8}$$

where $S_{w.h.1}$, $S_{w.h.2}$, $S_{w.h.3}$ is resistance of one working hose of the first, second and third hose line, respectively, m·s^2/l^2; Z_1, Z_2, Z_3 is the difference between the elevation marks of the pump and the first, second and third fire barrel, respectively, m. In this system of equations, the unknowns are $H_{w.}$, Q_1, Q_2, Q_3.

Obviously, a change in the parameters of one of the working hose lines entails a change in the flow rate of fire barrels in the other two. The parameters considered in this case include: resistance of the working hose line, position of the dispenser of the fire barrel, and also the difference in the heights of the location of the pump and the fire barrel. Thus, the problem is reduced to solving the system of equations (8) to determine the relationship between the flow rates of fire barrels. As a result of calculations by expressing unknowns Q_1, Q_2, Q_3 in terms of $H_{w.}$ from the system (8), we obtain the equation

$$C_1 H_{w.}^4 + C_2 H_{w.}^3 + C_3 H_{w.}^2 + C_4 H_{w.} + C_1 = 0, \tag{9}$$

where

$$C_1 = B_1^2 + 64 A A_1 A_2 A_3,$$

$$C_2 = 2B_1 B_2 - 64AA_1A_2A_3(H_{н.} + Z_1 + Z_2 + Z_3),$$

$$C_3 = B_2^2 + 2B_1 B_3 + 64AA_1A_2A_3(Z_1H_{н.} + Z_2H_{н.} + Z_3H_{н.} + Z_1Z_2 + Z_2Z_3 + Z_1Z_3),$$

$$C_4 = 2B_2B_3 - 64AA_1A_2A_3(Z_1Z_2H_{н.} + Z_2Z_3H_{н.} + Z_3Z_4H_{н.} + Z_1Z_2Z_3),$$

$$C_5 = B_3^2 + 64AA_1A_2A_3Z_1Z_2Z_3H_{н.}$$

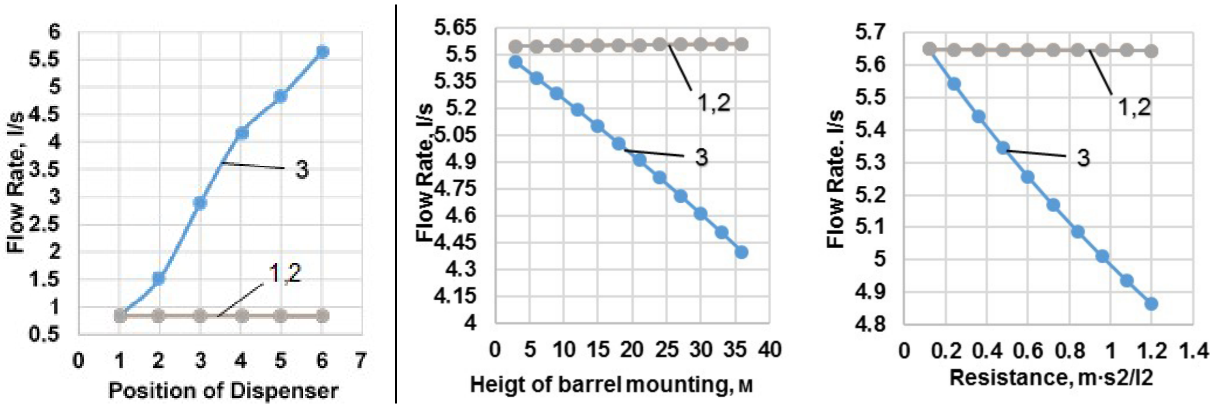
$$B_1 = (A_1 - A - A_2 - A_3)^2 - 4(A_2A_3 - AA_1),$$

$$B_2 = 2(A_1 - A - A_2 - A_3)(AH_{н.} - A_1Z_1 - A_2Z_2 - A_3Z_3) + 4(A_2A_3(Z_2 + Z_3) - AA_1(H_{н.} + Z_1)),$$

$$B_3 = (AH_{н.} - A_1Z_1 - A_2Z_2 - A_3Z_3)^2 - 4(A_2A_3Z_2Z_3 - AA_1H_{н.}Z_1)$$

$$A = \frac{1}{nS_{m.h.} + S_{br.}},\ A_1 = \frac{1}{nS_{w.h.1} + S_{barr.1}},\ A_2 = \frac{1}{nS_{w.h.2} + S_{barr.2}},\ A_3 = \frac{1}{nS_{w.h.3} + S_{barr.3}}.$$

Let us determine the dependence of the flow rate on the resistance of the working hose line, the position of the dispenser of the fire barrel, as well as the difference in the heights of the location of the pump and the fire barrel when changing them on one of the three working barrels in the system. Equation (9) was solved numerically in Microsoft Excel. The results obtained for the head at the pump of 100 m are presented in Fig. 6.



a b

Figure 6. Dependence of the flow of three barrels when changing in one of them: a is the position of the dispenser; b is the location of height relative to the fire tank pump; c is the resistance of the working line 1 is the dependence for the first barrel; 2 is the dependence for the second barrel; 3 is the dependence for the third barrel.

From the graphs presented, it can be seen that the flow rates of two trunks are the same and change by no more than 1.5 % when changing these parameters on the third barrel. At the same time, analyzing Fig. 6a, we can conclude that when the position of the dispenser of the fire barrel changes, the flow rate increases by more than 5 times, which is due to an increase in the barrel cross live section of the barrel and, as a result, a significant decrease in local resistance. From Graph 3 in Fig. 6b, it follows that when the height difference between the barrel and the fire tank pump increases by more than 10 times, the barrel flow rate decreases by 20 %, which can affect firefighting, especially if the water is delivered to a considerable height. At the same time, the flow rate on the first and second trunks are almost the same. Fig. 6c shows that with a 10-fold increase in the total resistance of the working line of one of the trunks, the flow rate decreases by more than 15 %. Therefore, when fighting fires, the number of hoses in the working line is minimal and, as a rule, no more than three.

4. Conclusions

1. A formula has been obtained for calculating the head at the fire truck pump, taking into account the influence of the characteristics of all elements of the pump-hose system when using fire barrels with a variable flow rate.

2. The hydraulic calculation of the pump-hose system with one fire barrel with a variable flow rate has been done. It has been established that an increase in the number of hoses to 12 in the main and up to 3 in the working line leads to a decrease in barrel consumption by 1.5 %, which does not affect the firefighting process. Also the graphs have been compiled of the dependencies of the flow rate of the barrel

on the height of its location for various heads on the fire truck pump. The nomogram compiled from these graphs is applicable in practice to determine the actual flow rate on the barrel when feeding it to a considerable height.

3. The influence of a fire barrel with a variable flow rate on a pump-hose system with several barrels was studied. Based on the calculations, it can be concluded that a significant effect on the flow rate is exerted by a change in the position of the dispenser, the height of the barrel and the number of hoses in the working line (total line resistance). It was also established that the flow rate of the other two system barrels varies slightly (up to 1.5 %), which in practice can be ignored.

The listed results of the work are aimed at increasing the efficiency of the use of pump-hose systems by fire departments for extinguishing in multi-storey buildings.

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