Встановлено, що гасіння пожеж гелеутворюючими складами є перспективним напрямом підвищення ефективності гасіння, особливо в багатоповерхових будівлях і спорудах різного функціонального призначення, оскільки дозволяє запобігти побічним збиткам від заливання нижніх поверхів.

Для оперативного гасіння пожеж в житлових і промислових спорудах запропоновано нова установка пожежогасіння гелеутворюючими складами. У ній за рахунок використання колінчастого подовженого ствола зі спеціальним змішувачем та розпилювачем досягається раціональне використання вогнегасної здатності гелеутворюючих складів. Ця нова установка дозволяє здійснювати гасіння гелеутворюючими складами з відстані 3–5 м до осередку пожежі, забезпечуючи безпеку пожежного-рятівника.

Сконструйовано, виготовлено і апробовано натурний зразок оригінального двохколінчастого ствола-розпилювача ранцевої установки. При проведенні експериментальних досліджень доведено, що його використання завдяки компактності в складеному стані і простоті розгортання в робоче положення, забезпечує зручність транспортування і оперативність задіяння в швидко змінних умовах пожежі, особливо в будинках підвищеної поверховості.

З подаванням гелеутворюючих складів у дрібнорозпиленому вигляді, досягається зниження їх витрати для гасіння вогнища, у порівняні з раніше запропонованими технічними рішеннями, у 1,5 рази.

Для визначення ефективного значення дисперсності і інтенсивності розпилення гелеутворюючих складів в математичних моделях витрати на гасіння модельного вогнища та часу його гасіння використані поліноми другого ступеня. Невідомі коефіцієнти визначені стандартним методом найменших квадратів. В результаті були визначені раціональні значення діаметра крапель (1 мм) і інтенсивності подачі (0,6 л/с) гелеутворюючих складів, що забезпечило технічний оптимум їх використання. Таким чином було встановлено, що параметри гасіння модельного вогнища 1А дрібнорозпиленими гелеутворюючими складами відповідають сумарному витраті в 2,5 кг, що в 3,5 рази менше в порівнянні з водою

Ключові слова: гелеутворюючі склади, подовжений ствол, установка гасіння, дрібнорозпилений струмінь, модельне вогнище

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IMPROVEMENT OF THE INSTALLATION WITH AN EXTENDED BARREL OF CRANKED TYPE USED FOR FIRE EXTINGUISHING BY GEL-FORMING COMPOSITIONS

K. Ostapov
PhD*
E-mail: ostapovk_90@ukr.net
I. Kirichenko
Doctor of Physical and Mathematical Sciences, Professor
Department of Physical and Mathematical Sciences**
Y. Senchykhin
PhD, Professor*
V. Syrovyi
PhD, Associate Professor*
D. Vorontsova
PhD
Department of Geometric Modeling and Computer Graphics
National Technical University «Kharkiv polytechnic institute»
Kyrpychova str., 2, Kharkiv, Ukraine, 61002
A. Belikov
Doctor of Technical Sciences***
A. Karasev
PhD***
H. Klymenko
PhD***
E. Rybalka
PhD***
*Department of Fire Tactics and Rescue Operations**
**National University of Civil Defence of Ukraine
Chernyshevska str., 94, Kharkiv, Ukraine, 61023
***Department of Safety of Vital Functions
Prydniprovska State Academy
of Civil Engineering and Architecture
Chernyshevsky str., 24a, Dnipro, Ukraine, 49600

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1. Introduction

Since the early 1990s, 82 % of fires in the world have been extinguished with the use of water [1]. Liquid water-based fire-fighting means have found the most common application owing to availability and convenience of transportation to the place of a fire. In addition, water contributes to wide possibilities of using various technical means and tactical techniques to ensure safe work of personnel of fire brigades [2].

However, it should be emphasized that despite all the advantages of water, it has a major drawback, which is related to its huge consumption when flowing down inclined surfaces and leading to needless flooding of sites located below, which eventually decreases its fire-extinguishing effectiveness [3].

The use of water and its solutions for fire-fighting by its distant supply to the fire site by compact or sprayed jets makes it possible to overcome the respective distances and contributes to extinguishing fires in hardly accessible areas [4]. However, about 90 % of its volume are usually wasted, not taking part in the process of extinguishing and leading to side damage from flooding the lower floors [5]. Moreover, wasted water requires an additional number of fire-fighting staff, and, most importantly, additional time that is inappropriately wasted during firefighting in multi-storey buildings [6].

The use of gel-forming compositions (GFC) enables significant reduction of the losses of fire-extinguishing substance (FES) (including water), direct and consequential damages of its use [7]. When using FES on the surface of the fire-extinguishing site, the protective firefighting gel layer is formed, which is quite solidly self-fixed at the inclined and vertical surfaces, and this, compared with using water alone, reduces losses of FES [8].

Another advantage of GFC is a high fire-retardant action, caused by the cooling influence of water contained in gel. Moreover, after the evaporation of all water from a gel layer, a porous layer of dried xerogel is formed, which prevents repeated ignition.

The relevance of this work is predetermined by the need for further development of technical means to deliver gel-forming compounds to a fire site to enhance the effectiveness of their use when extinguishing fires at buildings and facilities.

2. Literature review and problem statement

Application of GFC offers a possibility to extinguish fire by using basic mechanisms that stop burning, specifically: insulation of a combustible substance in the combustion area, as well as cooling down the zone and a combustible substance [9]. Paper [10] determined the positive properties, related to the efficiency of suppression of fires with GFC, which significantly affect fire extinguishing. One of the main indicators of the effectiveness of fire-fighting with gel-forming compounds is their indicator of fire-extinguishing capacity. Indeed, when extinguishing solid combustible materials, this indicator of GFC, based on the ratio of the weight of fire-extinguishing substance that falls on one installation of the area of the simulated site of a fire, is considerably lower than when using water [11]. Although here we must add that the significant influence of the diameter of sprayed drops of GFC and their feeding intensity on fire-extinguishing capacity of gel-forming compounds was not taken into account.

In research [12], a portable installation for fire-extinguishing by gel-forming compounds was designed for the use of GFC. Solutions of the components of gel-forming compounds in these installations are arranged in two capacities. The pressure in the capacities of the installation is created using the cylinder with compressed air. Permanent value of the pressure in the capacities is ensured by the reduction gear of direct action, which makes it possible to adjust pressure within (0.4÷0.58) MPa. Manual barrel-mixer regulates the mass supply of the extinguishing substance within (0.18÷0.22) kg/s. The spray angle is regulated within 4÷90° by replacing deflectors in the barrel-sprayer. Air and aqueous solutions are supplied by means of the system of flexible hoses with the internal diameter of 8 mm. Fire extinguishing capacity of the FEC during fire-extinguishing the simulated fire 1A (total area of 6 m^2) with the use of portable installation of extinguishing by gel-forming compounds, makes up 1 kg/m^2, which is by 0.5 kg/m^2 better than the indicator of extinguishing by water. One of the drawbacks of the proposed installation is the use the barrel-mixer, which made it possible to carry out the supply of GFC only by a compact jet, which leads to their excessive consumption and does not make it possible to use them as efficiently as possible.

In paper [12], an autonomous installation for fire-extinguishing by gel-forming extinguishing compositions (APFGFC) was designed to confirm the theoretical calculations and test results with respect to the application of GFC to extinguish fires in apartments. Supply of GFC components in it occurs through separate sprayers, which makes it possible, if necessary, to use alternately one sprayer. Total simultaneous mass submission of both sprayers was found to be within 0.11÷0.13 kg/s. The fire extinguishing capacity of GFC during extinguishing the simulated fire 1A by APFGFC is 0.75 kg/m^2, which is 2 times better than the indicator for extinguishing with water. However, this installation requires spraying GFC by two separate devices, which prevents one operator from supplying GFC for extinguishing quite accurately – the main drawback of this technical device.

In paper [13], the autonomous installation for extinguishing with gel-forming compounds APGFC–II was designed to study the influence of modes of GFC supply on the results of fire extinguishing. The frame from the mask produced by company "Drager" (Germany) was used as its frame. Two plastic containers of 8 l each and a cylinder with compressed air of the volume of 6.8 l were attached to the frame. To ensure constant pressure in containers with the components of GFC (0.3 MPa), a reducer of direct action was used. The components of GFC and air were fed through a system of flexible hoses with an inner diameter of (5÷8) mm. The installation had the regulated flow of GFC components within (5÷12) kg/min. To ensure rapid opening and closing of taps at feeding liquids and gases, the pistol-type devices, which provided the possibility of both separate and joint supply of the components of GFC, were used. In the installation APFGFC-II, compressed air was supplied to the sprayers under pressure of 0.3 MPa, thus ensuring a pneumatic spraying. To do this, the pneumatic spray nozzles CO-71 (FIZTECH, Russia), which made it possible to vary the angle of the sprayed jet flame within 4÷90°. Thus, installation APFGFC-II supplied water in the dispersed state. Fire extinguishing capability of GFC during extinguishing the simulated fire 1A made up 0.5 kg/m^2, which is 3 times better than the indicator of extinguishing with water. However, this setting had essential drawbacks: the distance of GFC supply is 1 meter that is dangerous for a fire-fighter and use of GFC component – compressed air – for the formation of the sprayed jet.

In paper [14], the autonomous installation for extinguishing with gel-forming compounds APEGFC–M was designed to implement the use of GFC in practice. The installation contains the supporting frame, on which two containers by 50 liters each for GFC components and two cylinders with compressed air, connected via the reducing gear of direct action, were mounted. Moreover, the components of GFC, contained in the containers under the pressure of compressed air, owing to the system of joint flexible hoses, are located both in the barrel-sprayers that have one tap each to turn them on and off, which is associated with the separate or joint supply of GFC components to a fire-extinguishing site.

This installation is equipped by the system of direction of the barrels-sprayers to a fire-extinguishing site with verification by the angles of inclination to the horizon, angles of deviation, height and basic width of the symmetrical location and fixation of the barrels-sprayers. The installation meets the requirements regarding its safe location within the fire site, but makes it possible to feed GFC components only by compact and flat-radial jets, which reduces the fire-extinguishing capacity of GFC. During extinguishing with the installation APEGFC–M of the simulated fire 1A, it is 0.6 kg/m^2, which is only 2 times better than extinguishe ing a similar fire site with water. The dimensions, weight, involvement of several fire-fighters (minimum 3 people) and special equipment for the transportation to the place of fire extinguishing are the shortcomings of this installation.

Summing up the above, we can conclude that there are means of firefighting by gel-forming compounds. Under known conditions they ensure fire extinguishing by finely dispersed jets from short distances that are not dangerous for a fire-fighter and by flat-radial jets from longer distances. But they are not always used effectively enough, which is due to the excessive cost of GFC components [15]. Therefore, the scientific and technical problem involves the substantiated development of non-sizeable technical means of fire-extinguishing by finely-dispersed gel-forming jets from the distances that are safe for a firefighter. Naturally, this problem can be solved only by designing new installations for firefighting by gel-forming compounds, taking into consideration the requirements for labor safety and rational use of GFC components.

3. The aim and objectives of the study

The aim of this study is to improve the installation for extinguishing by gel-forming compositions with the extended barrel that makes it possible to suppress fire from the distance that is safe for a firefighter under condition of ensuring the optimal dispersion and intensity of the jet of gel-forming compositions.

To accomplish the aim, the following tasks have been set:

– to substantiate the basic ways of creation of a physical model (sample) of the portable installation for extinguishing by finely-dispersed jets of gel-forming compositions with rational values of dispersion of their drops at different feeding intensities, which ensures safety of effective fire extinguishing;

– to conduct a study of the parameters of the installation for extinguishing by gel-forming composition with the extended barrel of the cranked type.

4. The principle of operation of the installation for extinguishing fire by gel-forming compositions with an extended barrel

To supply a finely dispersed GFC jet from the distance that is safe for a firefighter, the new structure of the installation for fire-extinguishing by gel-forming compositions with the extended barrel of the cranked type was designed. Its structure is shown in Fig. 1. It is based on the task of decreasing the consumption of GFC with the simultaneous ensuring a safe distance from a firefighter to the center of the fire (for portable fire extinguishing equipment, it is minimum 3 m). The set task is solved by using in the new installation the extended barrel that contains pipes for the main line of parallel supply of the liquid GFC component and the joining nozzle-mixer with a sprayer mounted on their outlet ends. In this case, in order to extend the barrel, it is made in the form of a 2–3-cranked structure. Its outlet ends are joined by the nozzle-mixer with a sprayer, where the flows of the liquid components of GFC join and their drops, split by the sprayer, are fed to the fire site.

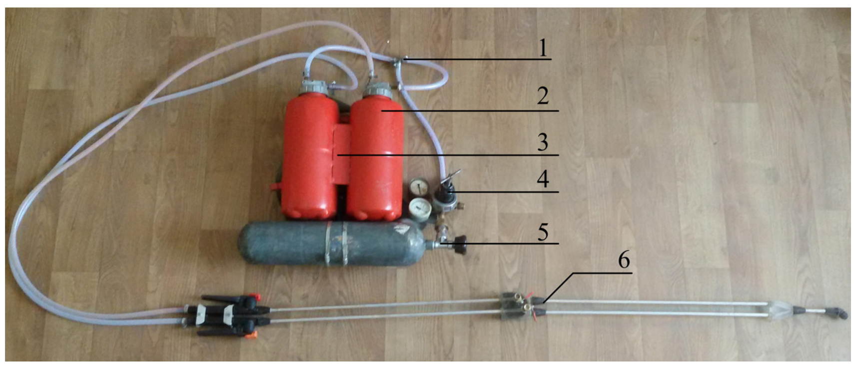


Fig. 1. Installation with the extended barrel of cranked type for extinguishing by gel-forming compositions: 1 — system of joining flexible hoses; 2 — capacities with solutions of GFS; 3 — frame of the installation; 4 — reducer with pressure indicators (manometers); 5 — cylinder with compressed air; 6 — extended cranked barrel

The main element of the new installation for extinguishing by gel-forming composition is the extended cranked barrel-mixer with a sprayer (Fig. 2), which makes it possible to change dispersion of GFC jet. It contains:

– pipes of the main lines of feeding GFC components (1, 2);

– a special nozzle-mixer with the sprayer (3) at its outlet ends, which makes it possible to vary dispersion of GFC spraying within 0.5–5 mm. In this case, in order to extend the barrel, it was made in the form of two pipe main lines as a 2–3-cranked structure (4–6) with a length of the crank of 1 m.

The principle of operation of the installation is as follows.

Constant value of pressure 4 MPa is ensured in the capacities with GFC components due to the cylinder with compressed air and the reducing gear. As a result, when the barrel handle is pressed, two independent jets of GFC components are fed in parallel along the pipes (1, 2) of the cranked barrel. Subsequently, they are mixed in a special nozzle-mixer and supplied for extinguishing through the sprayer (3) of the finely dispersed jet of GFC.

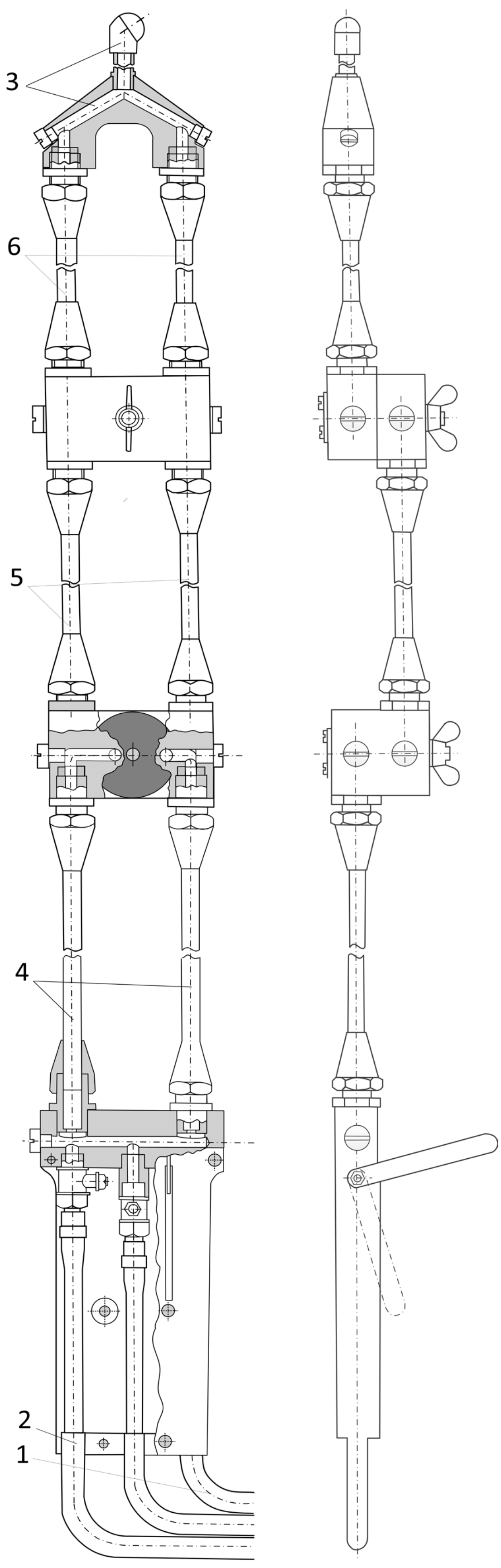


Fig. 2. Extended cranked barrel of the installation for extinguishing by gel-forming compositions: *a* — front projection; *b* — profile projection

Application of the extinguishing installation with the extended barrel of the cranked type makes it possible to supply finely dispersed GFC jet from the distance of 3–5 m, thereby implementing the safe operation of a rescuer. The use of the sprayer in the design makes it possible to change the size of GFC drops and this greatly simplifies carrying out experiments to determine the optimal value of GFC dispersion. The fact that it is compact in the folded state and easy to deploy to the operating position ensures the convenience of transportation and efficient application under rapidly changing conditions of a fire.

5. Procedure for studying the parameters of the installation with an extended barrel for extinguishing by gel-forming compositions

The optimum value of dispersion and intensity of GFC spraying was determined in comparative tests on extinguishing simulated fires 1A, which were characterized by the extinguishing capacity.

In the course of the previous experiments the size of drops was estimated visually, by exploring though a microscope the sample of the hydrophobic material (Teflon) with spraying the fire-extinguishing substance on its surface (Fig. 3). To facilitate observations, the solutions were colored with a dye.

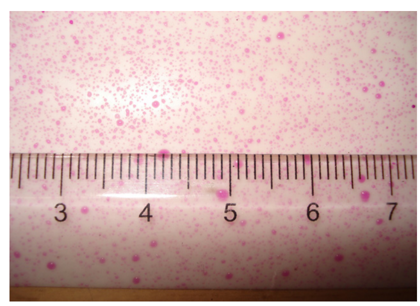


Fig. 3. Photographs of the fire-extinguishing substance drops, obtained from hydraulic spraying on the hydrophobic surface

Preparation of the installation for operation involves filling the containers with aqueous solutions of GFC components through the upper pouring necks and air pumping into the high-pressure cylinder to achieve a pressure of 20 MPa.

Testing was carried out on the simulated fires 1A, which involved a stack of 72 wooden bars laid in 12 layers by 6 layers in each with the cross-section in the shape of a square with the side of 40 mm. To make simulated fires, we used a workpiece of ordinary pine wood with humidity within (10÷14) %. The stack was placed on a metal stand from steel corners of dimensions of 500×40×4 mm, at the distance from the floor surface of 400 mm. For ignition, the metal deco for fuel of the dimensions of 400×400×100 mm was placed under the stack. The deco was set horizontally, covered with a water layer of the thickness of 20 mm and then 1 liter of gasoline A-80 was poured into it. The tests were conducted at the velocity of wind around the simulated fire of (1÷2) m/s, at the air temperature of 19 °C, the temperature of water, fuel and water solutions of the components of the gel-forming composition of 18 °C.

To conduct the trials, aqueous solutions of gel-forming components, which by the weight content of dry substances corresponded to the optimized composition, were prepared in two separate measuring capacities.

The prepared solutions were poured into the installation for extinguishing by gel-forming compositions. Then the simulated fire was started. After 480±5 s of free combustion, the gel-forming composition was fed from the windward side. To ensure the safety of a fire-fighter, extinguishing of the simulated fire was performed from the distance of 3–5 m by a continuous jet (Fig. 3). Intensity of spraying gel-forming compositions was regulated by changing the pressure in the installation.

The duration of fire suppression that was equal to the time interval from the beginning of feeding the solution to the end of combustion was recorded. The result was considered positive if extinguishing lasted up to 40 s and the flame did not appear 600 s after completion of extinguishing. The weight of the extinguishing substance, consumed for fire suppression, was determined by weighing the installation before the beginning the extinguishing and after it.

Fig. 4. Extinguishing the simulation fire 1A by the installation with the extended barrel of the cranked type for extinguishing by gel-forming compositions

Results of extinguishing the simulated fire of class 1A are shown in Table 1.

Table 1

Results of testing the extinguishing simulated fire 1A by the installation for extinguishing by gel-forming compositions with the extended barrel of cranked type

No. of experiment	Diameter of drops of GFC d, mm	Intensity of GFC I supply, kg/s	Weight of GFC consumed for extinguishing the simulated fire m, kg	Duration of extinguishing simulated fire t, s
1	1	0.3	3	25
2	2	0.3	3.5	30
3	3	0.3	3.5	35
4	4	0.3	4	40
5	1	0.4	3	20
6	2	0.4	3.5	25
7	3	0.4	3.5	30
8	4	0.4	4	35
9	1	0.5	2.8	15
10	2	0.5	3.3	20
11	3	0.5	3.1	25
12	4	0.5	3.8	33
13	1	0.6	2.5	20
14	2	0.6	3.1	23
15	3	0.6	3.3	24
16	4	0.6	3	30

6. Results of studying the parameters of the installation with an extended barrel for extinguishing by gel-forming compositions

Mathematical models of the consumption of the weight of GFC for extinguishing the simulated fire are shown in the form of a polynomial of the second degree, unknown coefficients of which were determined using the least squares methods. The following functional dependences were obtained:

– weight of GFC, [kg]:

$$y = 1.485 + 0.66575 \cdot x_1 + 5.3875 \cdot x_2 - -0.04375 \cdot x_1^2 - 0.41 \cdot x_1 \cdot x_2 - 6.875 \cdot x_2^2;$$

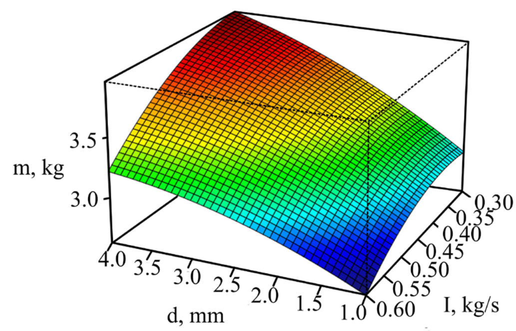
– extinguishing time, [s]:

$$y = 53.025 + 5.035 \cdot x_1 - 152 \cdot x_2 + +0.375 \cdot x_1^2 - 4.8 \cdot x_1 \cdot x_2 + 150 \cdot x_2^2.$$

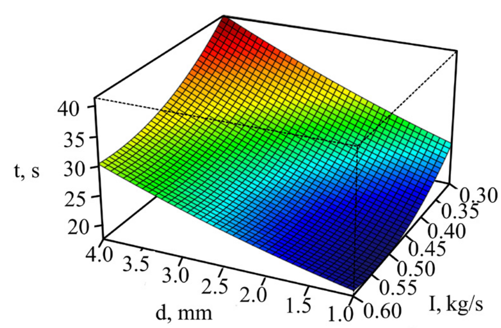
In the following dependences, which are shown in Fig. 5, parameter x_1 is the diameter of GFC drops, mm; x_2 is the intensity of GFC supply, kg/s.

The use of the performed calculations in system *R* enabled assessing all coefficients of the regression according to Student criterion at the significance level α=0.01 and the number of degrees of freedom N_0=10. Confidence interval was ±0.125 kg for the deviation of the weight of GFC and ±0.93 s for the time of extinguishing the simulated fire.

The obtained models were verified for adequacy by Fisher criterion (*F*-criterion) at the significance level α=0.01. Calculation value of *F*-criterion was 16.55 and 77.86 for two models, respectively, which is significantly higher than the tabular value F_*=5.67 for significance level α=0.01 and degrees of freedom κ1=4, κ2=11. Therefore, all constructed models are adequate with guarantee of 99.0 %.



a



b

Fig. 5. Diagrams of functional dependences: *a* – consumption of GFC weight for extinguishing the simulated fire; *b* – consumption of time for extinguishing the simulated fire

The use of both these models, and tabular data of testing extinguishing of simulated fire 1A makes it possible to determine the rational values of dimensions of drops is 1 mm and intensity of GFC spraying is 0.6 kg/s.

7. Discussion of results from applying the installation with an extended barrel for extinguishing by gel-forming compounds

As it is known, the basic mechanisms of combustion termination are: cooling the zone of combustion or of burning substances, dilution of substances involved in combustion, insulation of combustible substances from the combustion zone, inhibition of chemical reaction of oxidation. Gel-forming compositions in various degrees have all the mechanisms of combustion termination. Since water is the basis of such compositions, they have a high cooling action. Water vapor that is formed during GFC evaporation ensures a dilution effect. The layer of the xerogel formed after evaporation of water from the gel layer has the insulating effect. It is possible to introduce the inhibitors of burning to the gel-forming composition, which makes it possible to increase the fire-extinguishing effect of such compositions. Thus, the organization of extinguishing fires with the use of gel-forming compounds is considered a rather promising direction, especially in multi-storey buildings and buildings for different functional purposes.

Existing means of fire extinguishing by gel-forming compounds ensure extinguishing by finely dispersed jets from the distance that is dangerous for a fire-fighter or by compact and by flat-radial jets from the distance that is safe for a fire-fighter, however, with excessive consumption of GFC component [15]. Given the above, the use of the existing means is not safe and is not sufficiently effective.

The solution of these problems is ensured by the use of the installation of extinguishing by gel-forming composition with the extended barrel of the cranked type. Its design makes it possible to extinguish a fire by GFC from the distance of 3–5 m, which is safe for a fire-fighter. The fact that it is compact in the folded state and easy to deploy to operating position ensures convenience of transportation and operation efficiency.

One of the most important indicators of the effectiveness of gel-forming compositions is their indicator of fire-extinguishing capacity, however, during previously conducted studies, the influence of the diameter of droplets and the intensity of GFC dispersion was not considered. That is why to determine the optimal value of dispersion and intensity of GFC spraying, we conducted comparative trials of extinguishing simulated fires A1, which characterized the efficiency of fire suppression in different modes of operation. Based on the results of comparative tests, we obtained the rational values of the dimensions of drops of 1 mm and intensity of GFC spraying of 0.6 kg/s, which allowed extinguishing the simulated fire 1A with the consumption of gel-forming compositions of 2.5 kg. Thus, the application of the designed installation makes it possible to decrease the losses of gel-forming substances by 1.5 times in comparison with the existing means of extinguishing by GFC and by 3.5 times in comparison with extinguishing by water. The obtained results of the study give grounds to consider that conducting subsequent work in this direction is relevant.

The difficulty with reliability of the cranked design of the extended barrel can occur during its practical application. Indeed, during the experimental trials of the operating sample of the new extinguishing installation, it was found that to ensure the convenience of variation of the barrel extension in practice, it is advisable to make a 3- or 5-cranked barrel. It is also advisable not to use in mass production the structures from aluminum and polymeric materials that are deformed during the lengthy influence of high temperatures. These problems are not difficult to solve by applying modern refractory materials. In addition, the cranked way of the barrel extension can be replaced with the telescopic, which is more convenient.

8. Conclusions

1. The installation for extinguishing by gel-forming compositions with the extended barrel of the cranked type for extinguishing fires in high-rise buildings was proposed. The operation principle of the installation with the extended barrel for extinguishing by gel-forming compositions was explored and presented. The design of the improved installation makes it possible to extinguish fires by GFC from the distance of 3–5 meters that is safe for a firefighter and vary the spray dispersion of GFC from the compact jet to drops of the dimension of 0.5 mm. The fact that the designed installation structure is compact in the folded state and easy to deploy to the operating position ensures the convenience of transportation by one firefighter and operation efficiency under rapidly changing conditions of a fire. Thus, the designed structure of the installation determines its effective use in practice.

2. The experimental studies concerning establishment of the operation parameters of the installation with the extended barrel of the cranked type for extinguishing by gel-forming compositions were conducted. The basic parameters that make it possible to implement effective extinguishing by GFC, rational values of the drops diameter of 1 mm and spraying intensity of 0.6 kg/s were determined. It was found that such parameters of spraying gel-forming compositions make it possible to obtain their fire-extinguishing capability of 0.42 kg/m^2. Thus, the application of the designed installation makes it possible to reduce the losses of gel-forming composition by 1.5 times in comparison with the existing means of extinguishing by GFC and by 3.5 times in comparison with extinguishing by water.

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