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IMPROVING THE INSTALLATION OF FIRE GASING WITH GELELATING COMPOUNDS

It is established that the organization of fire extinguishing with the use of gel-forming compounds is a promising direction to increase the efficiency of extinguishing, especially in multi-storey buildings and structures of various functional purposes. Given the shortcomings of existing technical solutions for the use of gel-forming compounds for effective fire extinguishing, the need to develop new structures (spray barrels) is justified. The proposed solutions should ensure, above all, the safety of the fire rescuer. New designs of spray barrels must have a distance of supply of gelling compounds to make work of the operator safe, as well as meet the general technical requirements for fire extinguishers. An autonomous installation of extinguishing with gelling compounds for remote fire extinguishing by plane-radial jets of components of gelling compounds has been developed. It is proposed to fix the spray barrels with a special device to guide them to the object that has to be extinguished with verification of the angles to the horizon, angles of deviation relative to the plane of aiming, the height and width of the symmetrical placement. In this manner, it allows more efficient feeding at a distance of up to 10 meters of the two components of the gelling compounds and prevents premature or delayed mixing. Full-scale samples of RS-10 spray barrels were designed and manufactured to supply flat-radial jets of gel-forming compounds at a distance of up to 10 m. The method of optimal planning of experiments was used to calculate rational values of geometric parameters of the initial cross-section of the RS-10 spray barrel. The problem of 4-factor (second-order) optimal planning of the experiment of the process of plane-radial jet supply by means of RS-10 spray barrels is formulated and carried out. The main design parameters of the spray barrel (cutout of the rigid plate sector and its thickness) are determined, which correspond to the area of rational geometric parameters. The obtained results can be used in the design of extinguishing systems with gelling compounds.

Keywords: gelling compounds, spray barrel, extinguishing system, plane-radial jet, remote fire extinguishing, exit section

1. Introduction

Since the early 1990s, about 82% of fires in the world have been extinguished using water [1]. Liquid water-based fire extinguishers have found the most widespread use due to the availability and ease of transportation to the scene of the fire. They allow the use of various technical means and tactics that ensure the safe work of firefighters [2].

However, it should be emphasized that despite all the advantages of water, it has a significant disadvantage, which is its large losses when draining from sloping surfaces and useless flooding of objects below, which ultimately reduces its fire-fighting efficiency [3].

The use of water and its solutions for extinguishing fires by remotely feeding them into the fire with compact or spray jets allows to overcome relatively long distances and helps to extinguish fires in hard to reach places [4]. However, about 90% of water is usually wasted without directly participating in the extinguishing process [5]. Moreover, wasted water requires an additional number of personnel of fire and rescue units, and most importantly - additional time, which is unacceptably wasted in firefighting.

Significantly reduce the loss of extinguishing agent (EA) (including water), as well as direct and indirect damage, allows the use of gelling compounds (GC), the use of which can significantly reduce the total damage by tens of times [6]. When using GC on the surface of the fire extinguishing object creates a fire-retardant layer of gel, which is quite strong self-fixing on inclined and vertical surfaces, which, compared with the use of only one water, significantly reduces the loss of EA [7]. Another advantage of GC is the high fire-retardant effect due to the cooling effect of the water contained in the gel. Moreover, after evaporation of all water from the gel layer, a porous layer of dried xerogel is formed, which prevents re-ignition.

The urgency of the work is caused by the need for further development of technical means for the delivery of gelling compounds to the fire to increase the efficiency of their use in extinguishing fires in buildings and structures.

2. Analysis of recent research and publications

The use of GC makes it possible to extinguish fires by using the main mechanisms of cessation of combustion, namely: insulation of combustible substance in the combustion zone, as well as cooling of this zone and the surface of the combustible substance [7]. In [8] it was determined that the efficiency of extinguishing fires with gel-forming compounds is significantly influenced by the peculiarities of GC supply. In [9] it was determined that the effectiveness of gelling compounds is assessed by the time and consumption of fire extinguishing agent to extinguish the fire. In this way, the best efficiency is achieved by separately and simultaneously feeding the components to the fire extinguishing facilities and mixing them on the surface of the combustible substance. Therefore, recently a lot of attention in the creation of new promising models of equipment for extinguishing fires with gelling compounds is paid to installations capable of separate and simultaneous supply of GC components.

In [10], a portable gelling unit with gelling compounds was developed for the use of GC. The solutions of the components of the gelling compounds in this installation are placed in two containers. The pressure in the tanks of the device is created by means of a cylinder with compressed air. Ensuring a constant value of pressure in the tanks is carried out by a direct-acting reducer, which makes it possible to regulate the pressure within (0.4 ÷ 0.58) MPa. The manual mixer barrel allows to regulate mass supply of fire extinguishing substance within (0,18 ÷ 0,22) kg / s. The spray angle is adjusted within 4 ÷ 90 degrees by replacing the deflectors in the spray barrel. Air and aqueous solutions are supplied by a system of flexible hoses with an inner diameter of 8 mm. The main disadvantage of the proposed installation is the use of the mixer barrel, which as a result of mixing the two components of the gelling compounds in the cavity of the barrel often fails due to blockage of the outlet.

In [11], autonomous extinguishing systems with gel-forming compounds “AUTGOS” and “AUTGOS-P” were developed and manufactured to study the influence of GC supply regimes on fire extinguishing results. The existing frame from the insulating gas mask of Drager (Germany) was used as the frames of both units. Two 8-liter plastic containers and a compressed air cylinder were attached to the frame. A 2-liter cylinder was used for the AUTGOS installation, and a 6.8-liter cylinder was used for the AUTGOS-P installation. In order to ensure a constant pressure in the tanks with GC components equal to 0.3 MPa, a direct-acting reducer was used. In the installation "AUTGOS - P" compressed air was also supplied in the spray at a pressure of 0.3 MPa. The components of GC and air were supplied by means of a system of flexible hoses with an inner diameter (5 ÷ 8) mm. Both units have an adjustable consumption of GC components within (5 ÷ 12) kg / min. To ensure rapid opening and closing of the taps when supplying liquids and gases, pistol-type devices were used, which provided the possibility of both separate and joint supply of GC components. The difference between the two units is that the “AUTGOS” unit provides hydraulic sawing of fire extinguishing agent, and “AUTGOS - P” - pneumatic sawing. For this purpose in the last installation nozzles of the pneumatic sprayer CO - 71 which allowed to vary an angle of a torch of the sprayed stream within 4 ÷ 90 degrees. The main disadvantage of these technical means: the inability to carry out firefighting from a safe distance for the fire rescuer. These fire extinguishing agents with gel-forming compounds and methods of their supply actually allowed to extinguish from a distance of not more than 1 meter. In these cases, from the point of view of safety of personnel and requirements of state standard on length of a stream of EA, it is impossible to use effectively and widely GC in practice.

In this manner, the unsolved part of the problem is the substantiation, development and establishment of rational parameters of technical means of supply of gel-forming compounds, which will allow extinguishing from a safe distance of 6 or more meters for the rescuer. In solving which it is necessary to take into account the general technical requirements for fire extinguishers and safety of the rescuer when extinguishing with gelling compounds.

3. The purpose and objectives of the study

The aim of the work is to study the installation of fire extinguishing with gelling compounds when feeding them from a safe distance.

To achieve this goal the following tasks were solved:

– to develop the physical configuration of the fire extinguishing system, which will ensure the supply of gelling compounds from a safe distance and to develop a new design of spray barrels for use them while extinguishing fires with the use of gelling compounds;

– to investigate the rational relations of the parameters of remote binary supply of gel-forming compounds during fire extinguishing, taking into account their remote delivery to fires.

4. Development of the physical configuration of the fire extinguishing system with gelling compounds

To implement remote binary supply of GC for a safe and appropriate distance, developed an autonomous extinguishing system with gel-forming compounds AUTGOS – M, the design of which is shown in Fig. 1 [12].

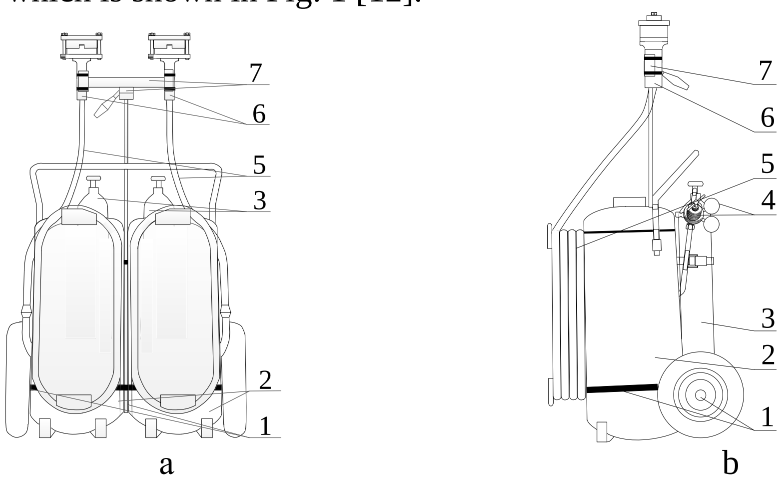


Fig. 1. Installation AUTGOS – M: a – frontal projection; b – profile projection

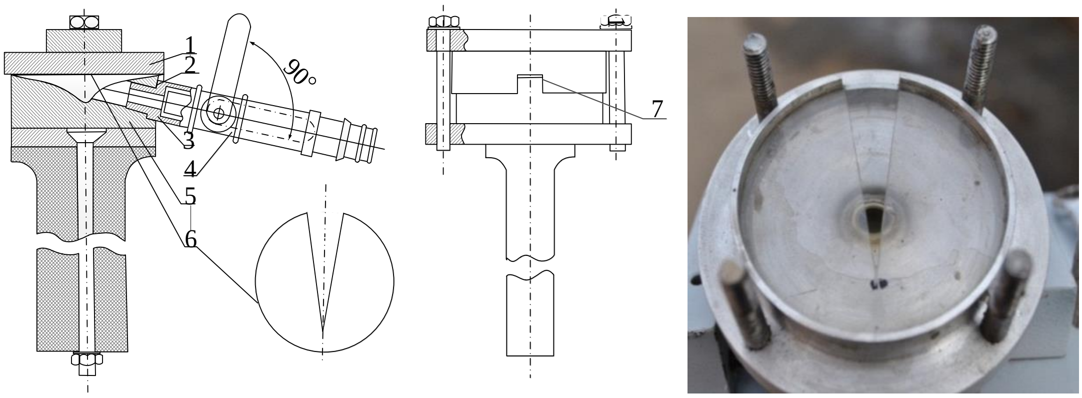
This installation contains a supporting frame (frame) 1, where two tanks 2 with increased capacity of the components of the GC solution and two cylinders with compressed air 3, which have indicators of visual control of pressure in the tanks 4 and are connected by a direct action reducer. Moreover, the components of the GC contained in the containers under the pressure of compressed air, due to the system of connecting flexible hoses 5 are in the spray nozzles 6, which have one tap for closing and opening, which is associated with separate or joint supply of components GC on the object of fire extinguishing. The proposed design differs in that it additionally implements a system of guidance of spray barrels 7 on the object of fire extinguishing with verification by angles of inclination to the horizon, angles of deflection, height and base width of symmetrical placement and fixation of spray barrels mounted on the supporting frame (on the frame) [13].

Accessories to the installation AUTGOS-M: 1 - installation trolley frame; 2 - tanks with aqueous solutions of GC components; 3 - cylinders with compressed air; 4 - reducer with pressure indicators (manometers); 5 - system of connecting flexible hoses; 6 – two spray barrels; 7 - device for aiming barrels

From the known installations the new installation differs in the increased stock of components of EA, and due to the new offered trunks-sprays SR - 10 [14], possibility to remotely (to 10 m) and aim to give on extinguishing of GC within 1 ÷ 2 minutes. Moreover, the supply of EA/GC can occur as one or both barrels together so that the components of GC already on the approaches to the fire begin to form a gel.

In fig. 2 shows a prefabricated diagram and photo of the spray barrel SR-10 with an open lid, which can be used when working at a distance of up to 10 m components of the GC compact and flat-radial jets. Its design features of production and the basic principle of work with it are also shown.

The barrel of the pistol type SR-10 contains a hollow body 5 with some internal sampling of material, which on the one hand has an inlet cylindrical hole 2. To the inlet through the adapter 3 threaded connection connected ball valve 4, which regulates the supply of aqueous solution EA/GC. On the opposite side there is an initial profile-regulated section, which is formed due to the replaceable covers 1 with "P" - a similar cut in them 7, thus realizing the supply of aqueous solutions by plane-radial jets into the atmosphere. The size of the outlet width is regulated by changing the lids 1 with a "P" - shaped cutout with different section widths, and the height - the thickness of the rigid plates 6 placed between the housing 5 and the lid 1.



a b

Fig. 2. Barrel-spray SR – 10: a – prefabricated circuit; b – barrel with open lid

As for the supply of the two components of the GC, they are through the outlets of both barrels SR - 10, sprayed from the rectangular sections between the housing and the lid, and then mixed and form a gel.

The general view of AUTGOS - M and its work is shown in fig. 3

a b

Fig. 3. Autonomous installation of extinguishing by gelling compounds AUTGOS-M: a – general type of installation; b – installation during work

The use of an autonomous extinguishing system with gelling compounds AUTGOS – M allows to increase the efficiency of extinguishing fires with gelling compounds [14].

5. Investigation of rational relations of parameters of remote binary supply of gelling compounds

Research on the work of fire and rescue units is known to be associated with a systematic approach. Its main principle is the desire to take into account as many parameters and characteristics that affect the reliability of the results. Nevertheless, some of them are neglected as insignificant for the studied process, others are set as initial conditions. For example, the working pressure (water pressure) in a particular case can be considered a constant value. Design parameters such as the height X_1 of the barrel slit and the cutout of the sector X_2, and the range and width (X_3 and X_4) of the EA/GC spray can change and significantly affect the extremes of the desired optimums.

Considering the process of supplying GC to the fire as an action of STS, such problems are formalized by the methods of experimental planning theory to obtain the best results [10] and find the best ones. Mathematically, this is formulated as follows:

$$y_j = f(x_1, x_2, ..., x_i), \quad i = 1,2,...,k;\ j = 1,2,...,l, \tag{1}$$

where y_j – the required variable, which depends on the parameters of the studied process; $x_1, x_2, \ldots, x_i$ – parameters that change during the experiments.

In particular, in the SR-10 spray barrels (Fig. 3), which were fed to the hearth of the model fire GC from distances up to 10 meters, it was possible to vary their design parameters.

The main criteria for obtaining the desired variant of the geometry of the barrel is to achieve the greatest possible range and width of the jet. Therefore, the construction of the plan of the experiment of EA/GC supply for fire extinguishing was carried out on the basis of data of personnel decoding of video recordings of EA movement (Fig. 3). The angle of the barrels corresponded to the recommended α=30° to achieve the maximum range L_{max}.

According to the theory of optimal planning of the experiment, we present the dependence of the time of movement of the drops in (supply range) of water depending on four variables x_i, i=1,…,4, polynomial quadratic model

$$y = b_0 + \sum_{i=1}^{4} b_i x_i + \sum_{i=1, i \neq j}^{4} b_{ij} x_i x_j + \sum_{i=1}^{4} b_{ij} x_i^2, \tag{2}$$

where b_0, b_i – is the value of the corresponding regression coefficients at zero (x_0 = 1), linear, quadratic variable parameters x_i; b_{ij} – regression coefficients indicating the influence of variables x_i i x_j on y.

Let's express this function y in normalized (dimensionless) values, ie in the form of:

$$\begin{aligned} y = {} & b_0 + b_1(x_1-1{,}5)/2 + b_2(x_2-30)/20 + b_3(x_3-7{,}35)/3{,}35 + \\ & + b_4(x_4-1{,}225)/0{,}525 + b_{11}(x_1-1{,}5)^2 + b_{12}(x_1-1{,}5)((x_2-30)/20) + \\ & + b_{13}(x_1-1{,}5)((x_3-7{,}35)/3{,}35) + b_{14}(x_1-1{,}5)(x_4-1{,}225)/0{,}525 + \\ & + b_{22}((x_2-30)/20)^2 + b_{23}((x_2-30)/20)((x_3-7{,}35)/3{,}35) + \\ & + b_{24}((x_2-30)/20)(x_4-1{,}225)/0{,}525 + b_{33}((x_3-7{,}35)/3{,}35)^2 + \\ & + b_{34}((x_3-7{,}35)/3{,}35)((x_4-1{,}225)/0{,}525) + b_{44}((x_4-1{,}225)/0{,}525)^2. \end{aligned} \quad (3)$$

Then, having made the corresponding calculations we will write down this function in real measured values X_1, X_2, X_3, i X_4. Here X_1 (cutout thickness, mm) and X_2 (sector cutout, deg) of the initial section nozzle of a barrel-spray (fig. 2); X_3 (range) and X_4 (width) of the GC supply front, m.

The coefficients of the regression equation in expression (2) are found using the least squares method:

$$\begin{aligned} & b_0 = 0{,}85;\ b_1 = 0{,}09;\ b_2 = 0{,}02;\ b_3 = 0{,}2;\ b_4 = 0{,}38;\ b_{11} = 0{,}108; \\ & b_{12} = -0{,}05;\ b_{13} = -0{,}44;\ b_{14} = 0{,}35;\ b_{22} = -0{,}02;\ b_{23} = -0{,}03; \\ & b_{24} = -0{,}04;\ b_{33} = 0{,}21;\ b_{34} = -0{,}19;\ b_{44} = 0{,}14. \end{aligned} \quad (4)$$

In this manner, after the transition from normalized values to real, we obtain (5):

$$\begin{aligned} y = {} & 0{,}56 - 0{,}009X_1 + 0{,}02X_2 + 0{,}13X_3 - 1{,}27X_4 + 0{,}109X_1^2 \\ & - 0{,}003X_1X_2 - 0{,}13X_1X_3 + 0{,}67X_1X_4 - 0{,}0008X_2^2 - \\ & - 0{,}0004X_2X_3 - 0{,}004X_2X_4 + 0{,}02X_3^2 - 0{,}11X_3X_4 + 0{,}52X_4^2. \end{aligned} \quad (5)$$

Investigating this expression to the extreme we find approximate values of optimal variables $x_i^{opt}, j = 1,\ldots,4$,

$$X_1^{opt} = 1{,}76 \text{ ìì};\quad X_2^{opt} = 23{,}77\ ^\circ;\quad X_3^{opt} = 9{,}41 \text{ ì};\quad X_4^{opt} = 1{,}71 \text{ ì}.$$

Where do we find $y^{\text{îðt}} = 1{,}158\text{c}$.

Consider the maximum supply efficiency of extinguishing agent at $X_1^{opt} = 1{,}76 \text{ ìì};\quad X_2^{opt} = 23{,}77 \text{ ãðàä}$.

Their graphical dependence is shown in Fig. 4.

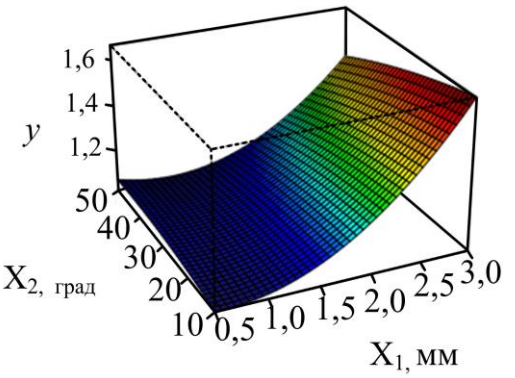


Fig. 4. Function graph *y_1* at the intersection of planes: $X_1^{opt} = 1{,}76 \text{ ìì};\quad X_2^{opt} = 23{,}77\ ^\circ;$

A similar graphical dependence of the maximum supply efficiency of the extinguishing agent at $X_3^{opt} = 9{,}41$ m; $X_4^{opt} = 1{,}71$ m shown in fig. 5.

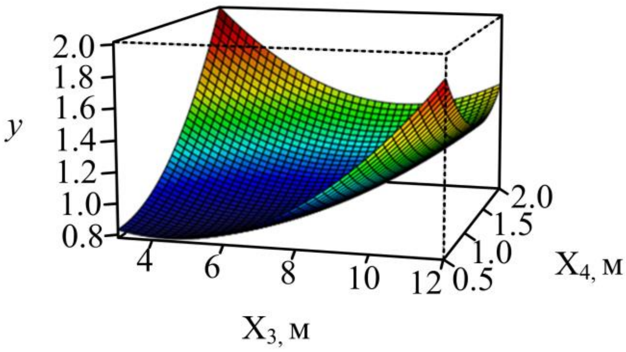


Рис. 5. Function graph *y₁* at the intersection of planes: $X_3^{opt} = 9{,}41$ ì ; $X_4^{opt} = 1{,}71$ ì .

It will be recalled that the main criteria for measuring the variable geometry of the spray barrel in our studies are the feed range and the width of the plane-radial jet. Because these parameters affect the effectiveness of extinguishing the fire and the protection of neighboring objects from the fire from its thermal radiation.

The graphs show that the optimal geometry of the original section corresponds to the dimensions: height 1.76 mm; sector cutout 23.77 °. In this case, the maximum efficiency of the extinguishing agent to the fire-fighting object corresponds to the range of the plane-radial jet L_{max} = 9.41 m with a front coverage width of 1.71 m.

In this manner, the experiments carried out on the basis of the theory of optimal planning and their results confirmed the efficiency of the device for the formation of plane-radial jets of extinguishing agents in conditions close to real.

6. Discussion of the results of the study of the fire extinguishing system with the gelling compounds

Based on the analysis of domestic and foreign publications, as well as patents on the subject, it is determined that the use of existing fire extinguishers when using GC solutions is not always effective, and therefore not appropriate. The experience of previous research in the field of fire extinguishing with gelling compounds indicates a lack of appropriate equipment and tactical and technical support, which significantly hinders their widespread use in practice. However, the organization of fire extinguishing with the use of gelling compounds is considered a very promising area, especially in multi-storey buildings and structures of various functional purposes.

Given the shortcomings of existing technical solutions for the use of gel-forming compounds in firefighting, the need has been identified and new solutions have been developed in the design of spray barrels that meet a certain list of necessary requirements.

The supply distance of the GC must be safe for the operator and meet the general technical requirements and test methods of fire extinguishers, according to state standards. These requirements state that the minimum length of the jet of extinguishing agent in fire extinguishers designed to extinguish model hearths of class "A" must be at least 6 meters.

The forms of both sprayed jets must provide the highest possible percentage of the use of GC components to extinguish the fire from a given distance (more than 6 meters). It is shown that plane-radial jets could solve this problem, covering “at the same time” a larger fire front than with the help of compact jets. This, when applying the GC at a distance of up to 10 meters, does not allow premature or delayed to create a gel on the fire, realizing it at this distance more effectively.

The placement, orientation and movement of both barrels in space when aiming at the object of firefighting, should ensure maximum efficiency of the GC. The minimum feed distance of 6 meters and the smallest possible dependence on biomechanical movements of barrels of different qualifications should be taken into account. In the developed autonomous extinguishing installation with gel-forming compounds AUTGOS-M it is offered to carry out fixing of trunks-sprays by means of the special device. It allows firefighters to guide the barrels on the object of fire with verification of the angles of inclination to the horizon, the angles of deviation relative to the plane of aiming, the height and base width of the symmetrical placement. In this manner, the supply of two components of the GC, at a distance of up to 10 meters, can be implemented more efficiently. At the same time their premature or late mixing is not allowed.

During practical implementation, there may be difficulties with the reliability of the device for fixing the spray barrels. Indeed, during the experimental tests of the current model of an autonomous fire extinguishing system, it was found that in practice it is advisable not to use in serial designs of aluminum and polymeric materials, which are deformed under prolonged exposure to high temperatures. But these issues are not difficult to solve by using modern refractory materials.

The technical characteristics of the AUTGOS-M installation, namely: pressure, size, volume of tanks for extinguishing agent, are as close as possible to the existing fire-fighting equipment in order to unify its use and meet the requirements of state standards.

To calculate the rational values of the geometric parameters of the initial cross section of the spray barrel RS-10 used the method of optimal planning of experiments. Graphical interpretations of the obtained solutions are presented in Fig. 4, 5, indicate that the estimate of the area of rational geometric parameters of the nozzle corresponds to the found dimensions of the slotted hole of the structure of the spray barrel RS-10.

In this manner, to ensure efficient supply of plane-radial jets of gel-forming compounds, the main design parameters of the spray barrel are determined. Rational values of the geometric parameters of the output section correspond to the cutout of the sector of the rigid plate $\varphi_0 = 23.77°$ at a thickness of 1.76 mm. The proposed spray barrel is intended to be used for the supply of plane-radial jets of gelling compounds at a distance of up to 10 m. The results of the study give grounds to consider promising further work in this direction.

7. Conclusions

1. A new autonomous extinguishing system with gel-forming compounds for remote fire extinguishing by plane-radial jets of components of gel-forming compounds has been created. In the developed autonomous extinguishing system with gelling compounds, it is proposed to fix the spray barrels with the help of a special device. It allows you to guide the barrels on the object of fire with verification of the angles of inclination to the horizon, the angles of deviation relative to the plane of aiming, the height and base width of the symmetrical placement. In this manner, the supply of the two components of the gelling compounds at a distance of up to 10 meters can be implemented more efficiently. At the same time their premature or late mixing is not allowed.

2. Full-scale samples of RS-10 spray barrels were designed and manufactured for the supply of plane-radial jets of gel-forming compounds at a distance of up to 10 m. The optimal geometry of the initial section, which corresponds to the dimensions: height 1.76 mm; sector cutout 23.77°. In this case, the maximum efficiency of the extinguishing agent to the fire-fighting object corresponds to the range of the plane-radial jet L_{max} = 9.41 m with a front coverage width of 1.71 m

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УДОСКОНАЛЕННЯ УСТАНОВКИ ГАСІННЯ ПОЖЕЖ ГЕЛЕУТВОРЮЮЧИМИ СПОЛУКАМИ

Встановлено, що організація гасіння пожеж із застосуванням гелеутворюючих сполук є перспективним напрямом підвищення ефективності гасіння, особливо в багатоповерхових будівлях і спорудах різного функціонального призначення. Враховуючи недоліки існуючих технічних рішень, щодо використання гелеутворюючих сполук для ефективного гасіння пожеж, обґрунтована необхідність розробки нових конструкцій (стволів-розпилювачів). Запропоновані рішення мають забезпечувати перед усім, безпеку пожежного рятівника. Нові конструкції стволів-розпилювачів повинні мати дистанцію подачі гелеутворюючих сполук безпечну для оператора-ствольщика, а також відповідати загальним технічним вимогам до засобів пожежогасіння. Розроблено автономну установку гасіння гелеутворюючими сполуками для дистанційного пожежогасіння плоско-радіальними струменями компонент гелеутворюючих сполук. Запропоновано виконувати фіксацію стволів-розпилювачів за допомогою спеціального пристосування для наведення їх на об'єкт пожежогасіння з верифікацією за кутами до горизонту, кутами відхилення відносно площини прицілювання, висоті і ширині симетричного розміщення. Таким чином це дозволяє більш ефективно подавати на відстань до 10 метрів дві компоненти гелеутворюючих сполук і не допускає передчасного або запізненого їх змішування. Сконструйовані і виготовлені натурні зразки стволів-розпилювачів РС-10 для подачі плоско-радіальних струменів гелеутворюючих сполук на відстань до 10 м. Для розрахунку раціональних значень геометричних параметрів вихідного перетину ствола-розпилювача РС-10 використано методику оптимального планування експериментів. Сформульовано і здійснено постановку задачі 4-х факторного (другого порядку) оптимального планування експерименту процесу подачі плоскорадіальних струменів за допомогою стволів-розпилювачів РС-10. Визначені основні конструктивні параметри ствола-розпилювача (виріз сектору жорсткої пластини та її товщина), які відповідають області раціональних геометричних параметрів. Отримані результати можуть бути використані під час проектування установок гасіння гелеутворюючими сполуками.

Ключові слова: гелеутворюючі сполуки, ствол-розпилювач, установка гасіння, плоско-радіальний струмінь, дистанційне пожежогасіння, вихідний перетин

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