Для покращення параметрів імпульсних установок пожежогасіння щодо далекобійності та масо-габаритних показників запропоновано заміну пневматичного метального заряду на газодетонаційний заряд. Заряд сформовано на основі суміші пропану-бутану технічного з киснем, а детонаційне згорання суміші забезпечено шляхом застосування електророзрядної системи ініціювання детонації.

Експериментально підтверджено, що застосування газодетонаційного метального заряду замість пневматичного заряду в імпульсних установках пожежогасіння дозволяє покращити їх параметри. Зростання далекобійності водяним струменем, яке досягнуте в розробленій установці, зменшує вплив теплового випромінювання на рятувальника, чим забезпечується доцільність застосування таких установок для гасіння масштабних пожеж. Зниження тиску газу у балонах установки за рахунок переходу з енергії стиснення на енергію хімічного згорання забезпечує зменшення маси устаткування та збільшення кількості пострілів вогнегасною речовиною за однаковими розмірами аналогічних установок з пневматичним зарядом. Зокрема, в експериментальній установці з газодетонаційним зарядом ефективна далекобійність водяного струменю, в залежності від початкового тиску заряду в межах 0,1÷0,3 МПа, склала в діапазоні від 8 до 19 метрів для маси вогнегасної речовини 1 кг та в діапазоні від 5 до 14 метрів для маси вогнегасної речовини 2 кг.

Визначені параметри електророзрядної системи, за яких забезпечується ініціювання детонації з мінімальними витратами електричної енергії. Зокрема, у разі застосування спеціальної свічки запалювання двома синхронізованими іскровими розрядами, при повній енергії розряду 15 Дж з застосуванням конденсатору ємністю 1,75 мкФ та індуктивності розрядного кола 400 нГн, детонація виникає у трубі діаметром 73 мм в умовах проведених досліджень на відстані не більше, ніж 180 мм.

Отримані результати можуть бути використані під час проектування установок з газодетонаційним зарядом

Ключові слова: імпульсна установка пожежогасіння, вогнегасна речовина, газодетонаційний заряд, далекобійність, дисперсність розпилення

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EXPERIMENTAL INVESTIGATION OF THE FIRE-EXTINGUISHING SYSTEM WITH A GAS-DETONATION CHARGE FOR FLUID ACCELERATION

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1. Introduction

Annually, approximately 25 thousand fires break out in Ukraine in the natural ecosystem (forestry, open areas) [1]. This leads to huge material losses and casualties. The consequences of fires increasingly often force one to consider the improvement of fire-fighting technologies.

As practice shows [2, 3], successful struggle with natural fires can be ensured only through technical means and ways of extinguishing. Efficiency of applying the fire-suppression means is associated with fire-extinguishing effectiveness. By definition, the fire-extinguishing efficiency is an inverse magnitude of the least concentration of extinguishing fluid, with which combustion cessation is achieved [4]. It is known

[5], that the specified minimum concentration of extinguishing fluid is determined by its quantitative and qualitative composition, which is created in the region of a fire. Due to creation of the optimum ratio of quantitative and qualitative indicators of a fire-extinguishing fluid, its minimum consumption for fire-extinguishing is achieved. Particularly, an increase in dispersion of water droplets in a water jet that is fed to the fire center provides for an increase in the surface area of heat exchange between water and hot medium [6, 7]. As a result, a decrease in the minimum concentration of a fire-extinguishing agent that leads to the extinguishing of a fire, with a corresponding decrease in water consumption of extinguishing, is achieved. Thus, the important characteristics of the means of water fire-extinguishing include productivity of feeding a fire-extinguishing agent, which is a quantitative indicator, and dispersion of a water jet that refers to a quality indicator.

In recent years, the pulsed means of firefighting have been intensively developed. These means provide pulsed creation of a finely dispersed water jet, which is carried out periodically. Pulsed feeding of large portions of a fire-extinguishing agent to the fire center provides an "instant" increase in concentration of a fire-extinguishing agent, with the help of which a fire is extinguished. Periodic feed of an extinguishing agent creates sustainable conditions for fire suppression. That is why the important characteristics of pulsed fire-extinguishing means are mass of a fire-extinguishing agent that is fed by pulse, feeding periodicity and dispersion of water droplets in a jet. An increase in instant productivity of water feed with a decrease in average productivity occurs in by pulse. As a result, the pulsed ways of fire-extinguishing ensure the most efficient water consumption for fire-extinguishing.

Pulsed firefighting means are applied under conditions of intense influence of thermal radiation from the fire flame on a firefighter. This limits the minimum long-range, at which this fire-extinguishing means is used. At an increase in fire intensity, there occurs the need for an increase in long-range of a water jet and a rise in the time of maintaining sustainable conditions for stopping a fire. As a result, for suppression of fires of different intensity, there is need for regulation of effective fire extinguishing distance, mass of a fire-extinguishing agent, which is fed by pulse, and the number of shots with a fire-extinguishing agent. A vast number of pulsed fire-extinguishing means are mobile. That is why an important characteristic of such means is the weight of equipment. A decrease in the weight of equipment makes it possible to increase the payload (the mass of an extinguishing agent).

Thus, the relevance of carrying out the studies, aimed at improving the pulsed fire-extinguishing systems is associated with the need to enhance fire extinguishing distance, to reduce the weight of equipment, to increase the number of shots with a fire-extinguishing agent and to ensure regulation of characteristics of the plant.

2. Literature review and problem statement

Characteristics of pulsed fire-extinguishing systems are largely determined by the type of the propellant charge.

In papers [8, 9], it was proposed to use a gunpowder charge as propellant in fire-extinguishing plants. Due to the use of a gunpowder charge, high jet velocities are achieved. Particularly, at the plant, which was developed in the paper [8], this velocity amounted up to 300–600 m/s at the weight of a fire-extinguishing agent of 0.6 kg and effective long-range of 5–15 m. At such velocities, the break of the flame that occurs during gas fountain combustion is achieved. A gunpowder charge has advantages as for specific power, which determines its widespread use in the military sphere. Due to high specific power of the charge, a decrease in weight and overall dimensions of the plant is provided [10]. However, as regards the pulsed fire-extinguishing plants, there are some difficulties in recharging such plants, impossibility of combustion of a typical gunpowder charge in case of contact with water. Conditions of storage and use of charges get more complicated, the cost of a shot of a fire-extinguishing agent increases due to the need to use specially manufactured gunpowder cartridges. The problem of plant recharging was partially eliminated by creating multi-barrel pulsed fire-extinguishing plants. In particular, the firefighting machines "Impulse-3M" of the joint production of the Russian Federation and Ukraine, "SPOT-55", produced in the Czech Republic, "Leopard-1", produced in Germany, were designed [11]. In general, the above listed problems of using powder charges as propellant in the pulsed fire-extinguishing plants have not been solved yet.

In papers [12, 13], the characteristics of pulsed fire-extinguishing plants, which applied compressed air (pneumatic) charge as propellant, were studied. Using this type of a charge, the problem of quick recharging of plants with the help of pneumatic valve systems was solved. This ensured an increase in the number of shots from a single barrel during fire-extinguishing. The specified number of shots is limited by the volume of compressed air of a charge, which is stored in high-pressure cylinders, which are separately placed outside the barrel for throwing. By creating the working air pressure in the barrel channel of more than 2.5 MPa, the necessary long-range and dispersion of a water jet were achieved. Particularly, IFEX plants provide for dispersion of water droplets in the range of 2–200 μm. It is known [5] that a fire is extinguished most effectively by a water jet, where the dimensions of drops are 100–200 μm. Depending on the varieties of IFEX plants, determined by their capacity, a range from 0.5 m to 30 m was achieved. Thus, the application of a pneumatic charge in pulsed fire-extinguishing plants makes it possible to use a fire-extinguishing agent effectively.

In addition, a decrease in overall dimensions of the plants with a pneumatic charge on condition of providing the required number of shots was achieved by increasing the pressure, at which gas is kept in containers, up to 25 MPa. At an increase in gas pressure, the weight of the cylinder increases, which is for steel cylinders 1.2–1.5 kg per 1 liter of compressed gas. As a result, taking into consideration other elements of equipment, the weight of portable pulsed fire-extinguishing plants exceeds the weight of a fire-extinguishing agent by 2...2.5 times. For mobile plants, which are placed on vehicles, with water consumption of 1,000 l, this ratio decreased to 1.5 times [12, 14]. Replacement of material of an air cylinder from steel with other materials of lower density makes the plant very costly.

In the case of application of a pneumatic charge, problems with an increase in long-range occur. This is due to technical limitations of high-speed control of valves at high pressure and high flow rate of gas. There is also a limitation of maximum velocity of pneumatic charge throwing, which cannot exceed the sound velocity of a propellant charge in gas [15, 16].

It is possible to solve these problems due to the use of a gas-detonation charge in pulsed fire-extinguishing plants [17]. This propellant charge is a fuel-oxygen or a fuel-air mixture, which detonates during throwing a fire-extinguishing agent. Due to the detonation of a charge, there is an explosive increase in pressure by 15–20 times and in gas temperature – by 10 times. This makes it possible to create a propellant gas charge at a low initial pressure and temperature, and to throw a fire-extinguishing agent at high pressure and temperature of gas. A decrease in the initial pressure of a propellant charge reduces the mass flow rate of gas for throwing. As a result, an increase in the weight of cylinders for storage of a propellant charge is ensured by reducing both the volume of gas and working gas pressure in cylinders. And an increase in temperature of gas that provides throwing makes it possible to increase the long-range.

It is known [18] that depending on the parameters of the ignition system, there occurs either slow deflagration combustion of such a charge or explosive detonation combustion. Under conditions of deflagration combustion, effectiveness of conversion of chemical energy into kinetic energy is rather low. As a result, at deflagration combustion, initial velocity of a water jet is low.

Based on the above, the parameters of the system of electric discharge ignition, at which initiation of detonation in gas-detonation charge occurs, remain undetermined. It is also required to determine the long-range and dispersion of a water jet that is achieved in the pulsed fire-fighting plant with the gas detonation charge.

3. The aim and objectives of the study

The purpose of this work is experimental research into parameters of the pulsed fire-extinguishing system with the gas-detonation charge, at which an increase in long-range is achieved under condition of ensuring optimal dispersion of a water jet.

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

– to conduct experimental measurements of parameters of the system of electric discharge ignition, at which we achieve detonation combustion of fuel in the fire-extinguishing plant with the gas-detonation charge based on the mixture of technical propane-butane with oxygen;

– to conduct experimental measurements of long-range and dispersion of a water jet in the experimental fire-fighting plant with the gas-detonation charge.

4. Materials and methods to study a fire-extinguishing system with a gas-detonation charge

Description of the system. The structure of the experimental fire-extinguishing plant with the gas-detonation charge of fluid acceleration is shown in Fig. 1, which was improved by the prototype of the plant [19, 20] by developing a new system of detonation initiation and adjusting it to the task of water jet throwing. The barrel of a plant consisted of two sections: accelerating 1 and charging 3, which were separated by a discontinuous membrane 2. Water was poured into the accelerating section. The gas-detonation propellant charge was formed in the charging section by filling it with a mixture of technical propane-butane (referred to below as LPG) with oxygen in the stoichiometric ratio. Volumetric ratio of combustible gas (mixture of technical propane-butane) to oxygen was measured during filling of the charging section at partial pressure of these gases with the help of manovacuum gauge 4. Initiation of gas-detonation propellant charge in charging section 3 was performed by spark-discharge system 5.

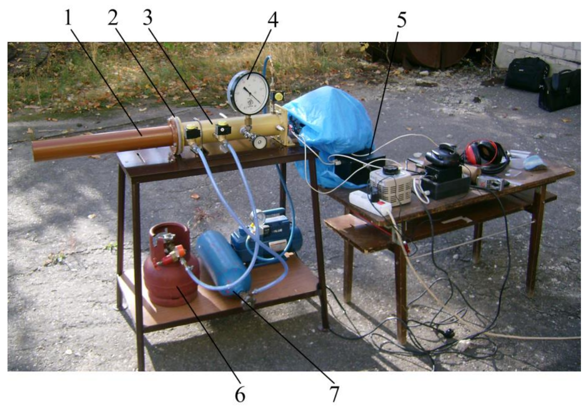


Fig. 1. Experimental fire-extinguishing plant with a gas-detonation charge for fluid acceleration: 1 — accelerating section; 2 — discontinuous membrane; 3 — charging section; 4 — manovacuum gauge; 5 — spark-discharge system; 6 — capacity with the mixture of technical propane-butane; 7 — a container of oxygen

The fire-extinguishing plant with the gas-detonation charge had the following parameters (Table 1).

Table 1

Characteristics of the experimental plant with gas-detonation charge

Parameters	Measurement units	Characteristic
Type of charge	–	gas-detonation charge
Inner diameter of barrel	mm	73
Volume of fluid (water) in barrel	l	1–2
Volume of combustible gas charge	l	1,7
Initial pressure of charge	MPa	0.1–0.3
Length of charging section	m	0.38
Length of acceleration section	m	0,6

To obtain high-voltage electrical pulse, which initiates the charge detonation, the capacitor assembly from 2 sequentially connected capacitors of type E-53 by 3.3 μF and a special spark by two synchronized spark discharges was used. The capacitors were connected by parallel buses. The distance between the axes of spark gaps was 5±0.1 mm, the length of discharge intervals amounted to 1.5±0.1 mm.

Measurement tools and technique. Measurement of electric capacitance was carried out using the RLC meter with parameters E7-22, which has the measurement error of ±(0.7 %+0.3 μF).at the measurement boundary of 2000 μF. Voltage of capacitors charging was measured with the multimeter Sanwa CD771, produced in Japan, which has a relative error of voltage measuring of ±0.8 %+2 LSD.

Pulsed electric current during discharge of capacitors' battery was measured using the current sensor of the compensation type, made by company Honeywell CSNN191, produced in the USA. The error in current measuring with the help of the sensor was ±2.5 %. The sensor was connected by the circuit of the double-polar voltage source. The current output was converted into the signal by voltage using an external resistor. Voltage was taken on the precision resistor, which has a deviation in designation value of no more than 0.1 %.

For calculation of stoichiometric coefficients, the composition of the mixture of technical propane-butane was studied. The research was carried out with the help of the gas chromatograph HP 5890 Series II, made in the USA, which was equipped with the capillary chromatographic column HP-Al/S and flame-ionization detector [21]. The composition of the LPG, used in the research, was: ethane C_2H_6 – 7.8 % (vol.), propane C_3H_8 – 70.9 % (vol.), propylene C_3H_6 – 2.7 % (vol.), isobutene C_4H_{10} – 9.4 % (vol.), n-butane C_4H_{10} – 9.2 % (vol.). The error of determining the composition was 0.1 % (vol.). It was determined that by stoichiometric composition, volume fraction of fuel is 16.05 %. Oxygen was obtained with the help of the oxygen station AirSep D, which provides volume fraction of oxygen of not less than 95 %.

Control of formation of stoichiometric mixture was executed by measuring pressure with manovacuum gauge MVP4-Y2 of precision class of 1.5 (1.0), produced in Ukraine. Reliability of sealing of the charging camera was checked by controlling the absence of pressure changes on the vacuum gauge after switching off the vacuum pump for 1 minute. To clear the charging section of the plant barrel from the air before filling it with a mixture, we used the single-phase vacuum pump TW-2A of the company Value, produced in China, which has performance of 115 l/min. and ensures vacuuming up to gas pressure not higher than 10 Pa. Under condition of conducted research, the charge temperature was 25 °C. The initial pressure of the charge was equal to atmospheric.

To measure dynamic pressure in the charging section of the plant barrel, we used pressure piezo sensors based on ceramics ZPT-19 with thickness of the measuring element that was equal to 10^{-3}. Sound velocity in this type of ceramics reaches 2.500 m/s. Hence, the resolution of this sensor was $4 \cdot 10^{-7}$ s. In the sensor, the piezo element is attached to the rod from the material, which has sound wave propagation rate that is equal to piezoceramic ZPT-19. The length of the agreement rod is equal to 0.15 meters. Hence, we will obtain the reflected signal from the end of the rod will return no earlier than $8 \cdot 10^{-5}$ s. This time enables registering without distortion a pressure jump in the wave front, the duration of which is a few microseconds. Three sensors were placed along the charging section at the distance between the sensors of 114 mm. In this case, the distance from the end of the barrel to sensor 1 (No. 1) was equal to 180 mm. The rate of the pressure wave propagation was determined by the difference of time of sensors operation. The signals were measured from the sensors by the digital oscilloscope TEKTRONIX 2024B, produced in the USA with synchronization by front of the input signal that arrived from the system of detonation initiation (signal No. 4 on measuring oscillograms).

Video registration of average velocity of fluid throwing was carried out using a high-speed camera Evercam 1000-4-M 9 with shooting frequency of 100 frames per second, produced in the Russian Federation.

Sequence of the course of research. Experimental research of the experimental fire-extinguishing plant with the gas-detonation charge of fluid acceleration was carried by the scheme, which is shown in Fig. 2.

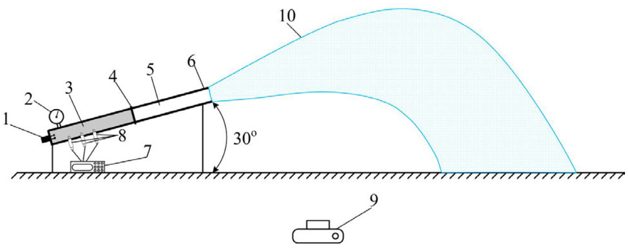


Fig. 2. Scheme of conducting the experimental studies of the research fire-extinguishing plant with gas-detonation charge: 1 – spark discharge system; 2 – manovacuum gauge; 3 – charging section; 4 – discontinuous membrane; 5 – accelerating section with fluid; 6 – barrel of the plant; 7 – oscilloscope; 8 – pressure piezo sensors; 9 – high-speed camera; 10 – fluid jet

Research was carried out in the following sequence. Barrel 6 was placed on the ground surface at increase angle value of 30°. The detonation propellant charge was formed in charge section 3. Water was poured into acceleration section 5. Detonation initiation was provided with spark charge system 1 with the capacitive energy storage. The rate of detonation front propagation was determined by readings of three pressure piezo sensors 8, mounted sequentially along the length of the barrel at equal distances from one another and attached to oscilloscope 7. The presence or absence of detonation in the fuel mixture was determined by the results of measurements of piezo sensors. Minimum energy of the initiation systems, which provides a reliable detonation initiation, was studied [22]. A change in the discharge energy was provided due to a change in voltage of charging of capacitors.

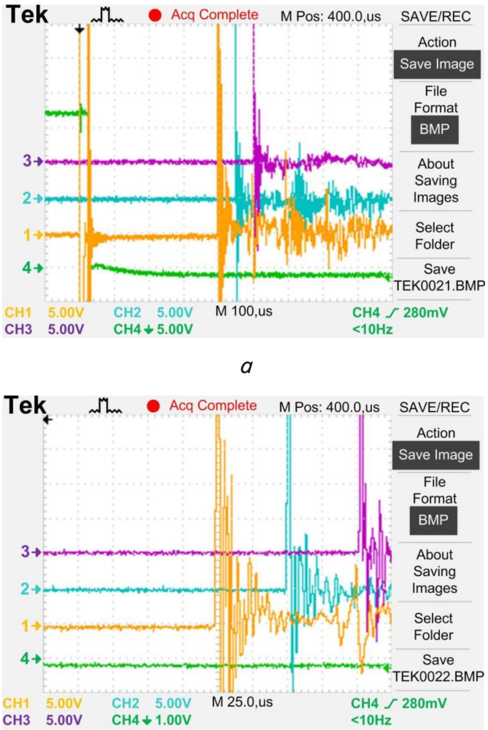
Video registration of a shot of water jet of fluid 10 was carried out using a high-speed camera 9. The long-range of a shoot was measured by fall-out of droplets on the horizontal surface of the experimental ground. The maximum distance, at which the fluid was thrown, was determined with the use of the measuring tape.

To measure the water drops dimensions, an experiment with the water jet drops trapping on the hydrophobic surface was conducted. The water jet drops fell on a wax-coated glass surface that has a maximum water-repellent property to the dispersed water medium. The samples of glass with water drops were placed in the field of the microscope of brand Sigeta MB-111, produced in China (in place of a microscopic slide) and the study for establishment of water drops dimensions was conducted.

5. Results of studying the fire-extinguishing plant with a gas-detonation charge

The operation modes of the electro-discharge system, under which detonation initiation occurs, were identified. Specifically, oscillograms of the signals from the pressure piezo sensors in the presence of detonation initiation are shown in Fig. 3. It follows from the presented results that a shock wave, which is manifested in a jump-like change of signals, comes to the sensors. The difference in time of sensors operation was near 50 µs. At the distance between the sensors of

114 mm, we have the velocity of the shock wave propagation of about 2,300 m/s, which corresponds to the detonation wave velocity in the mixture of LP-gas with oxygen [23].



a

b

Fig. 3. Signals from the sensors (curves 1, 2, 3) and voltage capacitor (curve 4) that were obtained during detonation initiation: *a* — by the time of signal deployment of 100 μs/div; *b* — by the time of signal deployment of 25 μs/div

It is seen from curve 4 (green color curve) that voltage of charging the capacitor assembly from measurement of the voltage divisor was equal to U=4.2 kV. By the readings of the multimeter, voltage of charging was 4.20±0.05 kV. This corresponded to the discharge energy of 15.4±0.1 J.

According to the results of approximation of the measured voltage and current curves (Fig. 4), obtained in a short circuit mode, it was found that inductance of discharge curciut is L_C=400±10 nH and active resistance is 80±5 mOhm. The period of oscillatory dumping discharge was T_{RLC}=5,2 μs.

Thus, the total time of energy input in spark discharge was about 30 μs, while the time of first-quarter period of discharge, which is an important parameter for initiation [24], was about 1 μs.

During the shots with the fire-extinguishing agent from the plant barrel, the total and effective range of a water jet flight were measured. Total distance was determined by the long-range of the flight of water jet drops and effective distance was determined by the maximum radius of the water jet disclosure at a shot.

According to research results, the long-range of a water jet, depending on the initial pressure of the gas combustible charge within 0.1÷0.3 MPa was measured. The experiment was repeated three times under the same conditions of research in order to obtain reliable results. The obtained results of the studies were processed by the least squares method and are shown in Table 2 and in Fig. 5.

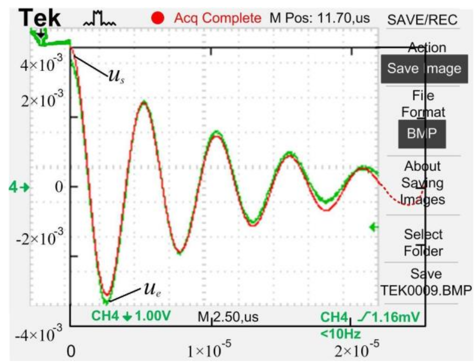


Fig. 4. Results of approximation of the experimental curve u in a discharge curciut, with index u_s — estimation and u_e — experimental

Under conditions of conducted studies, average dispersion of water droplets was 100–200 μm [25]. It is known that the dispersion depends on velocity of a shot of fire-extinguishing agent. High-speed photo recoding showed that averaged initial velocity of a shot in the experimental fire-extinguishing plant was 20–30 m/s.

Table 2

Long-range of a water jet (effective/total) in m, depending on the initial gas pressure and the mass of the thrown fire-extinguishing agent

Initial gas pressure in charge section of a barrel, MPa	Weight of fire-extinguishing agent (water), kg							
	1				2			
	Effective long- range, м		General long-range, м		Long-range effectiveness, m		General long-range, m	
0.1	8.3	$8.25±0.846_{0.9}$	14.3	$14.3±0.67_{0.9}$	4.9	$5.23±0.876_{0.9}$	10.1	$10.53±1.09_{0.9}$
	7.7		13.9		5.8		11.2	
	8.7		14.7		5.3		10.7	
0.2	14.1	$14.15±0.68_{0.9}$	19.8	$19.83±0.756_{0.9}$	11.1	$10.83±0.774_{0.9}$	16.4	$16.03±1.064_{0.9}$
	14.6		20.3		10.3		15.3	
	13.8		19.4		10.8		16.0	
0.3	17.8	$18.33±1.312_{0.9}$	25.1	$25.83±1.767_{0.9}$	14.7	$14.35±0.846_{0.9}$	21.1	$20.83±0.774_{0.9}$
	18.6		26.3		14.1		20.8	
	19.1		26.8		13.9		20.3	

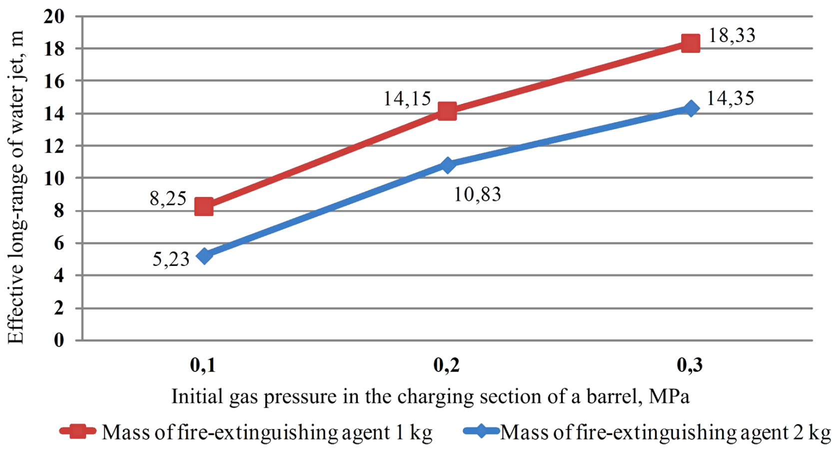


Fig. 5. Chart of effective long-range of a water jet depending on initial gas pressure and weight of the propellant fire-extinguishing agent

The obtained results make it possible to establish technical requirements for the system of charge formation to ensure a regulated long-range of a water jet shot.

6. Discussion of results of studying the fire-extinguishing plant with a gas-detonation charge

To assess the feasibility of practical application of the pulsed fire-extinguishing plant with the gas-detonation charge (DG), its characteristics were compared with the known analogues. In particular, it was compared with the widespread plants of pulsed firefighting "IFEX 3000", manufactured by Germany [12] and "Vitiaz UIP-1", produced in Belarus [26], which use the pneumatic charge. Parameters of these plants are given in Table 3.

Table 3

Tactic and technical characteristics of fire-extinguishing plants

Parameters	IFEX 3000	Vitiaz UIP-1	Plant with GD charge
1. Volume, l:			
– capacity for water	12	10	20
– air cylinder	2	6	–
– capacity for mixture of technical propane-butane	–	–	0.2
– oxygen capacity	–	–	1
2. Range of throwing fire-extinguishing agent, m:			
– effective	10	10	>19/>14
– total	16	20	>26/>21
3. Pressure, MPa:			
– inside the capacity for water	0.6	0.8	0.5
– in the barrel of the plant	2.5	2.6	0.1–0.3*
4. Water amount at one shot, l.	0.8	1.0	1.0 or 2.0
5. Duration, s:			
– of preparation before operation	40	25	30
– barrel recharging not more than	3	5	3

*Note: * – as a result of detonation, pressure increases by 15 times*

Based on these parameters, we see that in the plant with the gas-detonation charge, in comparison with similar plants with the air charge, an increase in long-range is achieved, a decrease in volumetric consumption of propellant charge is ensured and the volume of the available fire-extinguishing agent increases.

In the course of fire-extinguishing, the personnel of fire-rescue units should take into account a safe distance from the location of a rescuer to the fire hearth in order to reduce the influence of thermal radiation from the fire [27, 28]. We perform a calculation to determine a safe distance from the fire center to the operation place of a rescuer, using the procedure [29]. It is known that critical density of the radiation heat flow amounts to 4.2 kW/m^2 [29]. The timber storage with the dimensions of 8×10 m on the plan will be taken as a fire. Let us write down the parameters for timber, such as combustion temperature of 1,100 °C and ignition temperature of 300 °C. In the calculation, the safety coefficient will be accepted as 1 [29], which takes into consideration the more stringent conditions at thermal radiation, as the reduced degree of blackness of human skin will be accepted as 0.95 [29], which consists of degrees of blackness of surfaces of the fire flame and of a rescuer in the special clothing and gear, and the coefficient of radiation will be 5.67 W/(m^2·K^4) [29, 30]. It was calculated with these data that a safe distance from the operation place of a rescuer to the place of a fire will be not less than 27 m. If personnel of fire-rescue units are closer than 27 m, they will be under critical influence of thermal radiation from a fire and will get injuries. This example shows the importance of increasing the long-range of portable plants of pulsed firefighting.

Due to the fact that the plant with the gas-detonation charge surpasses all known plants by indicators of throwing long-range, it is advisable to introduce the additional function of the shot long-range control. In this case, the shot long-range will depend on the intensity of a fire. A shot from a shorter distance increases the firing accuracy, which increases the fire-extinguishing efficiency.

For example, based on the tabular data (Table 2), it is recommended to a rescuer with the similar plant to use shots with a fire-extinguishing agent at pressure of 0.1 MPa and the mass of a fire-extinguishing agent of 1 kg to extinguish a fire of weak intensity, but covering a large area. In the case of extinguishing a fire of strong intensity, it is recommended to transfer to the mass of fire-extinguishing agent of 2 kg with an increase in pressure in propellant charge up to 0.3 MPa.

A decrease in the initial pressure (before detonation) in the barrel by one order of magnitude in the fire-extinguishing plant with the gas-detonation charge leads to a more complete use of the working gases from cylinders, a decrease in the weight of tanks due to reduced thickness of the walls. High specific heat of fuel combustion with reduced weight of equipment for pulsed fire-extinguishing creates an opportunity to increase the number of shots with a fire-extinguishing agent in the fire-extinguishing plant with the gas-detonation charge by 2 times.

A mode of fuel combustion affects the long-range of a shot. Such dependence is explained by the fact that in the mode of deflagration combustion of a propellant charge, due to a slow increase in gas pressure in the barrel of the fire-extinguishing plant, the combustion zone volume increases during acceleration of a fire-extinguishing agent. That is why under the deflagration mode of combustion, the maximum pressure in combustion products decreases and, accordingly, so does energy efficiency of the shot. In the experimental plant, electric discharge system provides the detonation combustion mode of a propellant charge. Due to ultra-sound velocity of propagation of the detonation wave, such combustion occurs at sustainable volume of the combustion zone. That is why in this mode, pressure in combustion products takes maximum values, which provides an increase in the long-range of a shot.

It is not advisable to use discontinuous membranes in pulsed fire-extinguishing plants with the gas-detonation charge. That is why there is a problem of creation of excess pressure in the charging section of the plant. This problem can be solved by pulsed filling of the charging section with the gas-detonation charge at high pressure under conditions of counteraction of water inertia forces.

To obtain the function of dependence of the long-range on the initial pressure and the mass of the charge, the matrix of initial conditions and research results needs expansion, which is planned to do in subsequent studies.

7. Conclusions

1. We experimentally determined parameters for the electric discharge system for the experimental pulsed fire-extinguishing plant with the gas-detonation charge, at which detonation initiation is achieved at the minimally total consumption of the charge energy. In the case of using a special spark plug by two synchronized spark discharges at total energy discharge of 15 J with application of the capacitor of 1.75 μF and inductance of discharge curciut of 400 nH, detonation occurs in the tube of the diameter of 73 mm under conditions of the conducted research at the distance of not more than 180 mm. The obtained data make it possible to design a power efficient ignition system with minimal weight and dimensional parameters for the fire-extinguishing plant with the gas-detonation charge. The maximum long-range is provided due to detonation combustion of the charge.

2. The effective long-range of a water jet depending on the initial pressure of the gas combustible charge within 0.1÷0.3 MPa, which was in the range of 8 to 19 meters for the mass of an extinguishing agent of 1 kg, and in the range of 5 to 14 meters for the mass of the extinguishing agent of 2 kg. In this case, dispersion of water drops was 100–200 μm. The date obtained would make it possible to design the fire-extinguishing plant with controlled long range.

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