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Application of water cumulative charge type water spout for extinguishing intense fires

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Abstract
The use of explosives to extinguish fires may appear antagonistic. However, with current theoretical knowledge of water as an extinguishant and knowledge of the theory and dynamics of explosives, their connection appears to be a synergistic system. In addition to theoretical information, this article describes a new method of special construction equipment of a water cumulative charge of the water spout type, which has the basic mission to extinguish an intense fire, such as a gas pipeline fire, etc., very quickly and safely. Furthermore, the article presents the course and results of experimental tests performed by its authors. The results are very promising. Cumulative water charges are particularly interesting in relation to their use by security forces, not only firefighters, but also the military and military security forces, which are more likely to encounter extreme situations where a rapid and radical solution is appropriate for stabilization of the situation.
Keywords: *Explosive;Water cumulative charge; Semtex 10-SE; heptan; fire;*

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Nomenclatures
p = Pressure [MPa]
k= thermal conductivity of the ambient gas [$W.m^{-1}.K^{-1}$]
d = drop diameter [μm],
α= heat transfer coefficient [$W.m^{-1}.K^{-2}$]
ν= kinematic viscosity [m^2s^{-1}]
η= dynamic viscosity [Pa·s]
c_p= specific heat capacity [$J·kg^{-1}·K$]
Nu = Nusselt number [1]
Re = Reynolds number [1]
Pr = Prandtlnumber[1]
V = Volume [m^{-3}]
n= Amount of substance in 1 kg of explosive [mol]
u = Flow speed [$km·s^{-1}$]
R = gas constant [$J·mol^{-1}·K^{-1}$]
T =Thermodynamic temperature [K]
M =weight of explosive [kg]

I. Introduction

Based on practical research related to the development of water charges for the disposal of booby-trapped explosive systems, the opportunity arose to use a directed water stream to design a pyrotechnic device to extinguish the flame of an intense fire source, such as damaged gas pipes, combustible tanks, flammable gas cylinders, ignited oil wells, etc., when a massive directional cumulative stream of water accompanied by a pressure wave will forcefully extinguish this intense source of flame.

For this reason, a design system called "water spout" was developed, the essence of which is the possibility of active extinguishing the focus of intense flame using the effect of cumulative charge. The advantage of this prototype is mainly in the cumulative charges are specially modified pyrotechnic explosives, which direct the explosive fumes into one place thanks to the cavity created in front of the high explosive charge. These charges are mainly designed for piercing or cutting durable and metallic materials. In this case, the cumulative cavity is filled with a soft metal insert, where the pressure and temperature of the explosion create a very narrow plasmatic beam, which has significant cutting and perforating effects. However, if we predetermine this type of charge for effective and fast extinguishing of a very intense flame, we must place a liquid medium - water instead of metal in the front part, in sufficient quantity so that the extinguishing effect is massive.For this reason, a design system called "water spout" was developed, the essence of which is the possibility of active extinguishing the focus of intense flame using the effect of cumulative charge. The advantage of this prototype is mainly in the cumulative charges are specially modified pyrotechnic explosives, which direct the explosive fumes into one place thanks to the cavity created in front of the high explosive charge.

With this step, we create a high-pressure water stream of narrow cross-section accompanied by a pressure wave during an explosion. The assumption is that the pressure wave which moves in front of the directed water stream blows away the intense flame, the created powerful water stream ensures heat removal from the fire epicenter and the accompanying water mist in this area prevents its re-ignition in the endangered area.
[1,2]

In its introductory part, this article deals with theoretical knowledge about the physical effect of water, then describes the design of the water spout device and then analyzes the results of experiments with this device for practical use.

II. Water and its extinguishing capabilities

Water is essential in fire protection. It is still the most widely used extinguishing agent for most common fires. Its main extinguishing effect is heat removal and it also has a certain inertization effect. The structure of the water molecule and the hydrogen bonds between the individual molecules result in extremely favorable physicochemical properties, such as good solubility of polar and ionic substances in water, high electrical permittivity, high value of specific heat capacity, heat of vaporization, etc.[3]

At fire temperatures, the ambient temperatures are many times higher than the boiling point of water. Under these conditions, a larger volume of water vapor is produced (than at 100 ° C) and it is also necessary to consider the specific heat capacity of water vapor when heating the steam from 100 ° C to ambient temperature. When breaking the water stream into smaller drops, water can also be used to extinguish fires for which it is not suitable in its compact form.Many applications used in fire protection are affected by other physicochemical properties of water - kinematic and dynamic viscosity, surface tension, density, thermal conductivity, specific heat capacity, enthalpy of vaporization, volume change during solid state transition (solidification), change volume during the transition to the gaseous state (evaporation), polar character (solubility, dilution), kinetic and potential energy.The physicochemical properties of water therefore affect its transport (both in repressive activities and in stable fire extinguishing systems), water fragmentation into different types of streams (different size fractions), penetration of stream (water droplets) into the environment, attenuation of thermal radiation and extinguishing. As a result, many drops fly through the burning space, do not evaporate and accumulate on the floor. These drops are inefficiently used to remove heat.[4]It is therefore clear from the previous text that water affects fire protection from many different points of view. And its extinguishing effectiveness depends on many physical factors, and the size of the water drop also plays a role here.

III. Water mist in relation to the extinguishing effect of the cumulative charge

The droplets with a diameter of 0.3 mm are small enough to evaporate easily in a hot layer of gas (smoke), but at the same time they have sufficient weight to reach the required distance. Droplets larger than 1 mm are likely to penetrate a certain distance through hot gases and flames without completely evaporating.[6]Water droplets with a diameter below 0.2 mm are not effective in extinguishing because they are unable to penetrate the flames. They are carried away by convection before they can achieve the desired cooling effect. Water droplets above 0.6 mm are generally too heavy and large to evaporate in the combustion zone. These drops can penetrate the burning gases onto the surface of walls, ceilings or hot surfaces. [7]

The range of droplet sizes in diameter from 0.1 mm to 1 mm is the most interesting in terms of extinguishing [5,7], according to the above information, a specific area of 0.3 - 0.5 mm is the most suitable for extinguishing.[6,7]

Since evaporation can only occur on the surface of the liquid, it is necessary to maximize the surface area per unit volume of fire water, see Figure 1 and Table 1, but in relation to the above.

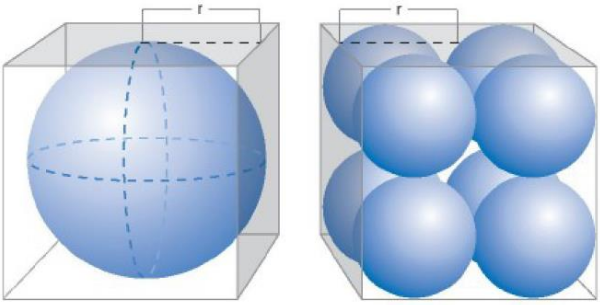

Figure 1Volume vs. surface area during water dispersion[8]

Table 1Droplet diameter [µm] and total surface area [m2] at volume 1 l

The diameter of dropletss [µm]	1000	100	10
The total number of droplets	$1{,}91.10^{6}$	$1{,}91.10^{9}$	$1{,}91.10^{12}$
Surface area [m^2]	6	60	600

Evaporation of droplets in a stream simultaneously involves mass and heat transfer processes, where the required heat is dissipated to the surface of the droplet by convection and conduction from the surrounding hot gases and water vapor is subsequently transported back to the gas stream by convection and diffusion. The evaporation rate of the droplet depends on its surface area, the characteristic heat transfer coefficient (α) and the relative velocity of the droplet to the surrounding environment.[5]
For spherical droplets in a stationary environment, the heat transfer coefficient can be defined as:

$$\alpha \approx \frac{k}{d}(W.m^{-2}.K^{-1}) \quad (1)$$

where k is the coefficient of thermal conductivity of the surrounding gas [$W.m^{-1}.K^{-1}$] and d is the droplet diameter [m].
However, in practical firefighting work, it cannot be assumed that the relative velocity between the droplets in water stream and the surrounding air is zero, so it is necessary to use more complex mathematical equations to describe heat transfer. Measurement of droplet evaporation in a "moving" air environment has been studied using a variety of sophisticated techniques [5]. The resulting data usually correlates using well-known dimensionless heat transfer / fluid flow coefficients.:

$$Nu = \frac{\alpha d}{k}(Nusselt\ number) \quad Re = \frac{vd}{\nu}\ (Reynolds\ number)\ (2)$$

$$Pr = \frac{c_p \eta}{k}\ (Prandtl\ number) \quad (3)$$

The parameters α, d, k have already been defined, ν, η, c_p are the kinematic viscosity, the dynamic viscosity and the specific heat capacity of the air at constant pressure.[5]

Drysdale[5] describes an experiment involving the evaporation of droplets in air at temperatures up to 220 ° C, for droplet sizes in the range of diameters 600 - 1000 µm and in the range $0 \leq Re \leq 200$:

$$Nu = 2 + 0{,}6 Pr^{1/3} Re^{1/2} \quad (4)$$

It was found that the above equation (4) correlates well with the experimental data and also met the theoretical requirement that Nu = 2 at Re = 0 (the case of zero relative velocity). The scope was given as 1 < Re < 70.103 a 0,6 < Pr < 400. [5]

Särdquist[10] also deals with the evaporation of water droplets under fire conditions. The author gives the derivation of equations concerning droplet lifetime and fall length for different droplet sizes. Criteria equations similar to the above are again given here for heat transfer. The Nusselt criterion for determining the heat transfer coefficient corresponds to Equation 6 and is further adjusted for droplets smaller than 0.1 mm in diameter (natural convection predominates) and droplets 0.1 - 1 mm (> 0.5 mm) in diameter (predominant forced convection).[10]

IV. Principle of operation of the "Water Spout" device

As mentioned in the introduction, due to the very promising possibility of extinguishing intense fires, a prototype called "water spout" was developed, the essence of which is the possibility of active extinguishing the focus of intense flame using the effect of water in synergy with the cumulative charge.

The advantage of this device lies in particular in the fact that cumulative charges are specially modified pyrotechnic explosive means which direct the explosive fumes into one place thanks to a cavity formed in the front part of the high explosive charge. In practice, these charges are mainly used for piercing or cutting solid or metal materials. The cumulative bulge is filled with a soft metal insert.Due to the pressure and temperature during the explosion, a very narrow metal beam is created - the so-called hammer, which has significant cutting and perforating effects (Figure 2). Detonation pressure is the highest pressure of the explosion products in the detonation wave if the laws of the ideal gas follow the equation of state [11]:

$$p \cdot V = n \cdot M \cdot R \cdot T; \qquad p = n \cdot M \cdot R \cdot T/V \qquad (5)$$

where:

p - pressure [MPa], V - volume [m^3], n - Amount of substance in 1 kg of explosive [mol], R - gas constant[$J \cdot mol^{-1} \cdot K^{-1}$], T - temperature [K], M - weight of explosive [kg].

However, if we predetermine this type of charge for effective and fast extinguishing of a very intense flame caused by a violent leakage of flammable gas or liquid, then we must place a liquid medium - water in the front part, in sufficient quantity so that the extinguishing effect is massive. With this step, we create a high-pressure water stream of narrow cross-section accompanied by a pressure wave during an explosionThe assumption is that the pressure wave, which moves in front of the directed water stream, so-called blows an intense flame, the created massive water stream ensures heat removal from the fire epicenter and the accompanying water nebula in this space prevents its re-ignition, see Figure 7, which show the individual time sequences of the performed experiment.In order to be able to use the explosive charge anywhere, even in a built-up area, the rear part of this charge must contain another mass of liquid of a certain volume in the so-called stuffing box.This water seal amplifies both the forward effect of the working stream and creates a massive water mist, which to some extent or completely compensates for the pressure wave propagating in all directions, including backwards. This will prevent possible damage to surrounding objects and buildings in the endangered area.[1]

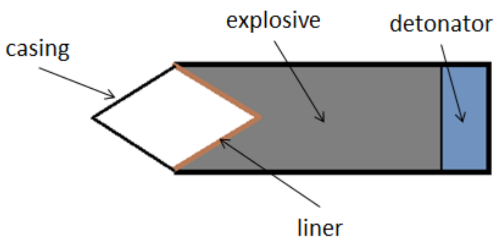

Figure 2Block diagram of the classical cumulative charge without water[2]

The following three factors in particular contribute to the extinguishing effect of the flame:

- shock wave that propagates in front of the water jet and blows out the flame,
- very fast-moving water jet, which removes the temperature from the incriminated place and completes the blowing of the flame,
- an accompanying water mist from both the main water stream and the sealing water body, which will then prevent it from re-igniting.

V. Construction of the prototype for experimental verification of the extinguishing effect

To experimentally verify the effect described above, a prototype water spout was designed using two plastic containers. A container with a volume of 70 liters was chosen as the container that was to simulate the function of the external so-called sealing canister.An internal so-called working canister with a volume of 8 liters was placed in this container by gluing. The same Semtex 10-SE explosive with detonator was then placed on this canister to meet the cumulative shape conditions. The entire contents of the outer container were then filled with water(Figure 3)

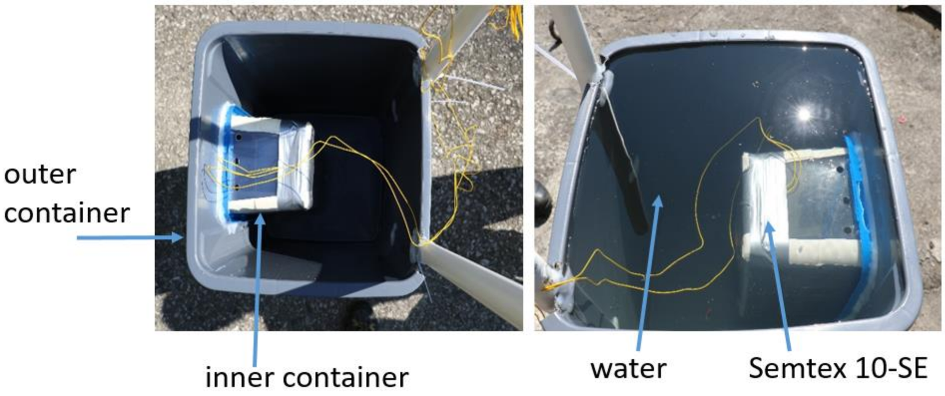

Figure 3Placing the explosive on the inner container and filling the entire system with water

Figure 4 shows location of the assembled prototype water spout in the test area in front of the PS-25 pyrotechnic device, which simulates a source of intense flame.

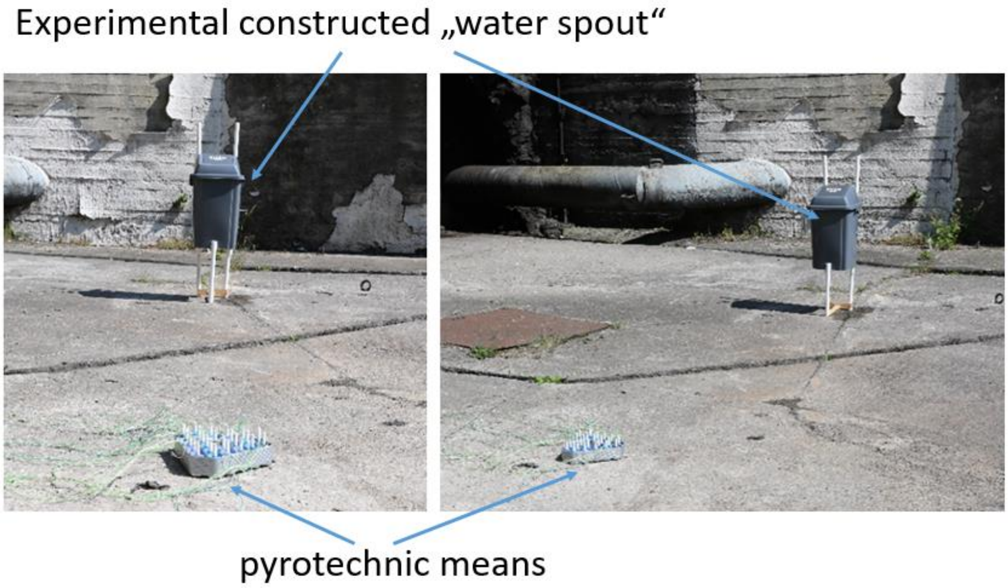

Figure 4Placing the assembled prototype water spout in the test area.

Two types of products with different effects were chosen to simulate an intense flame source in practical tests of the developed water spout:

- ground pyrotechnic light source PS-25
- Flammable Heptane

Ground pyrotechnic light source PS-25is a pyrotechnic light signaling means for day and night signaling, which is used, among other things, to imitate technical fires or to simulate the epicenter of a fire. Initiation is performed using a TZ-M lighter, or an electric pyrotechnic initiator EPIO, which are screwed into a hole in the middle of the special can.Highly flammable liquid and its vapors called HEPTAN is a volatile, clear, colorless liquid that evaporates even under normal conditions of temperature and pressure. Vapors may form explosive mixtures with air, are heavier than air and spread along ground.

Figure 5 shows a clear extinguishing reaction of the prototype water spout to the epicenter of the flame caused by initiation of 20 pieces of pyrotechnic product PS-25 during the explosion and formation of water spout jet. Using the approximation method of positional reading of the speed of water droplets from the captured video images of the high-speed camera during the performed tests, the actual speed of the created water stream was determined to be approximately 580 m / s.

Figure 5Practical test of the water spout in extinguishing a flame caused by the use of PS-25

The entire successful firefighting operation was performed within 1.15 seconds from initiation of the explosive to the extinguishing of the flame epicenter. The process was also recorded by a FLIR-T640 thermal camera, see Figure 6.

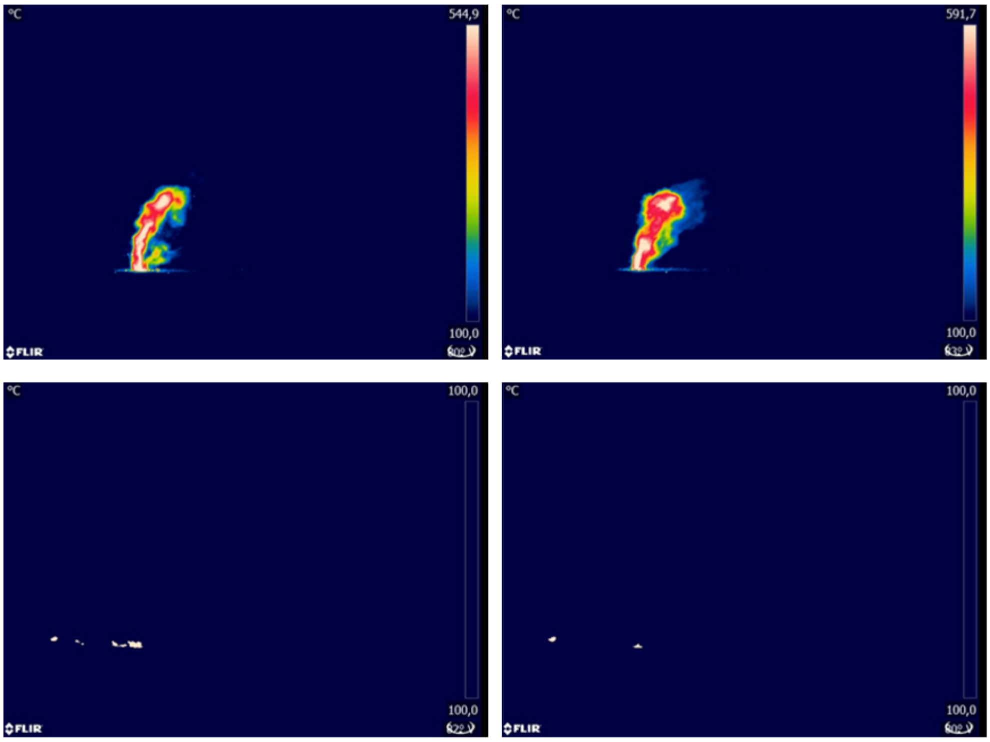

Figure 6Thermal imager views of the flame developed by the PS-25 just before (images at the top) and 1 second after the activation of the water spout (images below).

The individual time sequences of the prototype's activities in the realized practical experiments clearly document its very fast extinguishing reaction and thus its effectiveness. Selected time sequences of the experiment are shown in the following Figure 7. It can be seen from them that within one second the created simulated fire was completely extinguished.

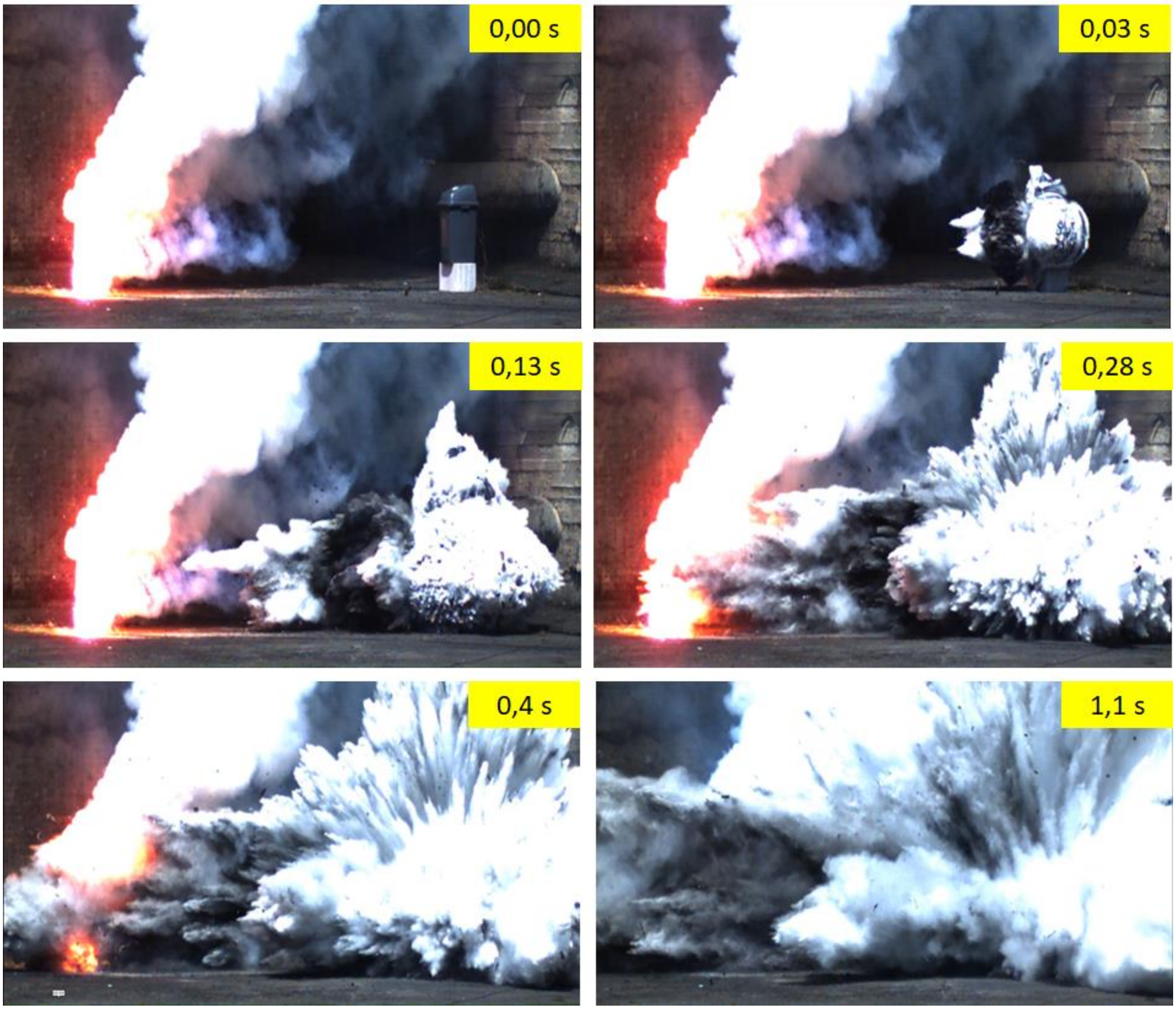

Figure 7Individual time sequences of the activity of the prototype water spout (the time experiment course is given in the upper right corner of the given sequence).

VI. Visualization design of the water spout prototype

The overall design of the cumulative water charge prototype is presented using the so-called spatial design visualization of individual components. Figure 8 then documents the area drawing of the individual functional parts in color. The individual basic components are:

- Inner container - (purple color) has a working purpose. Its water charge is directed to the massive cumulative working water stream when the explosive explodes. It should hold approximately 8 - 10 liters of extinguishing liquid. An explosive is placed in the back so as to create a compact unit of water cumulative charge for better handling. It slides into the front cavity of the outer container.
- Explosive - (red color) is formed as a charge into a cumulative shape, copying the back surface of the inner container. As already mentioned, it is a plastic explosive of the Semtex 10-SE type weighing about 750 grams. It must be fixed to the defined shape of the inner container so that it is not later deformed by sliding into the outer container, which acts as a rear seal.
- Outer container - (orange color) is a „stuffing“ box. It partly contributes to the acceleration of the directed water stream towards the front. The liquid placed in the rear space ensures the formation of a cloud of the water mist to compensate for ignition heat, shock and pressure waves. It should hold about 60 - 80 liters of water.On the inner side of the outer container there is a pressed space for placing the initiator - detonator, including about 50 grams of the loading charge, the so-called booster, Figure 9, which is a sufficient amount of so-called starting explosive for reliable initiation of the entire amount of main charge placed on the inner container. The channel, which is led to the upper surface, is used to locate the detonator supply line, see the red highlight in Figure 9.

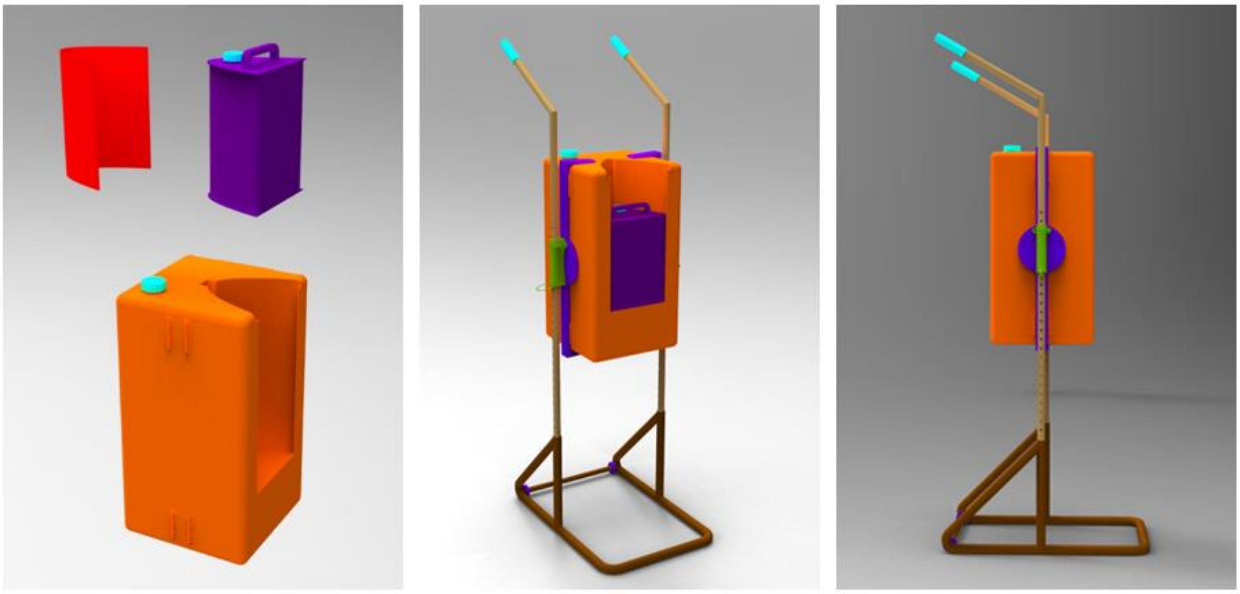

Figure 8Visualization of a prototype of a cumulative charge as a water spout.

The prototype unit is placed on a variable height-adjustable mobile stand (brown color), which ensures the correction of the height of the entire assembly, the directionality of rotation at its specific location and the possibility of moving from the assembly site to the fire epicenter, see Figure 10.

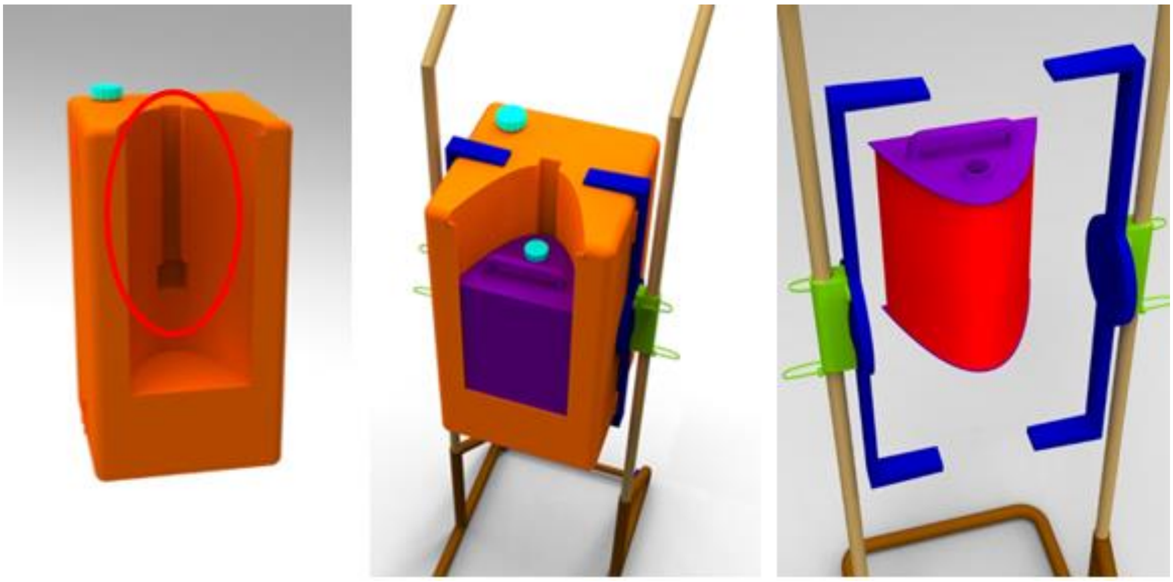

Figure 9Visualization of a prototype of a cumulative charge as a water spout

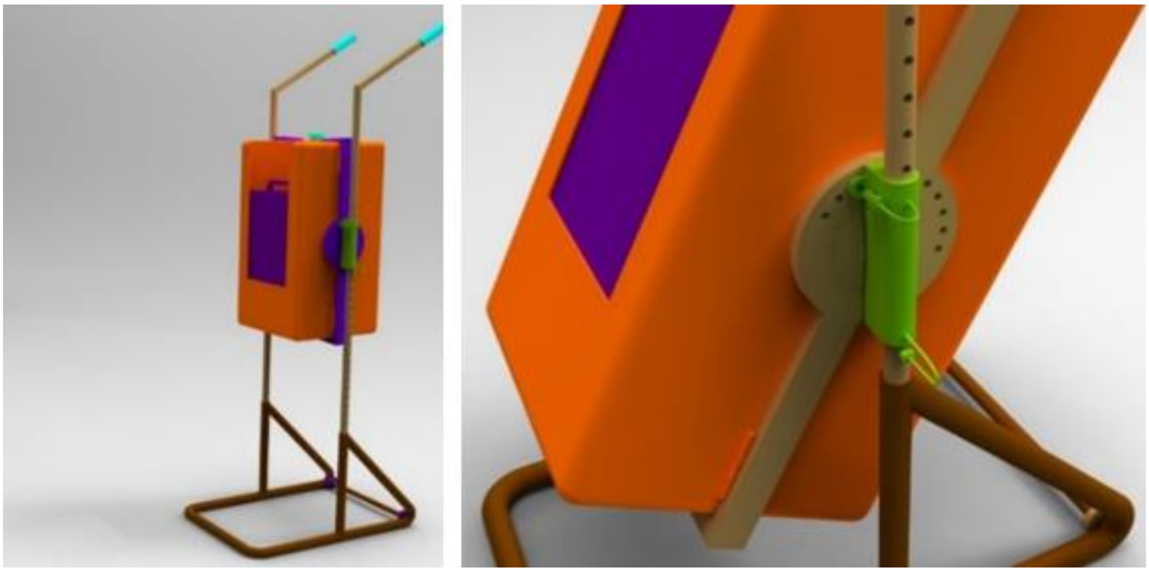

Figure 10Overall view of the assembled prototype of a water spout on a variable stand.

VII. Conclusion

The pyrotechnic mean described in this article ensures the extinguishing of the epicenter of an intense flame which is otherwise inextinguishable or very difficult to extinguish. Extinguishing is performed by impulse spraying of a water stream, which is created and directed by the cumulative effect of the explosive charge. The use of an explosive is particularly advantageous in this case because a shock and pressure wave moves in front of the water stream itself, which participates in blowing out the flame and the subsequent water stream removes heat from the fire and extinguishes the flame.Water mist that remains in space will then prevent the already extinguished flame from igniting again from the burning residues. As already mentioned in the text, its usability is high in many variants, eg in the explosion of a gas pipeline, burning of an oil well, in the liquidation of a radiant fire in the event of a tank, pressure cylinder or tank with combustibles, etc.The economic parameters cannot be quantified, as it is a question of protecting the lives and health of the intervening specialists in the unified intervention of the army and security forces on the otherwise unquenchable epicenter of the intense flame.

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References

[1]. Lichorobiec, S., Barcova, K. Verification of the Efficacy of the Special Water Shaped Charge Prototype.Defence Science Journal, Vol. 65, No. 5, September 2015, pp. 363- 366, DOI : 10.14429/dsj.65.8850.
[2]. Hütter, M., Lichorobiec, S.Ščurek, R. Application of Water Cumulative Charges as a Water Spouts for Intensive Flame Extinguishing. Defence Science Journal. 2018, vol. 68, Issue 3, p. 260-264. ISSN 0011-748X.
[3]. Wichterlova, J.Chemistry of dangerous inorganic substances. 1st edition Ostrava: Association of Fire and Safety Engineering, 2001, 63 s. ISBN 80-86111-92-X.
[4]. Jirák, Z., Vašina, B. Physiology and psychology of work. 2nd ed. Ostrava: University of Ostrava, Faculty of Medical Studies, 2009. ISBN 978-80-7368-610-9.
[5]. Drysdake, D., G. Grant a J. Brenton. Fire suppression by water sprays. Progress in Energy and Combustion Science. 2000, Volume 26, Issue 2, s. 52. DOI: 10.1016/S0360-1285(99)00012-X.
[6]. Hartin, E. Effective and Efficient Fire Streams: Part 2. In: [online]. [cit. 2014-09-24]. Available from: http://cfbt-us.com/wordpress/?p=1028
[7]. Grimwood, P. Euro firefighter. Lindley, Huddersfield, West Yorkshire: Jeremy Mills, 2008, xvii, 352 p. ISBN 19-066-0025-2.
[8]. Särdquist, S. Water and other extinguishing agents. Karlstad, Sweden: Swedish Rescue Services Agency, 2002. ISBN 91-725-3265-3.
[9]. Smutník, P. Determination of water flow efficiency as a function of pressure. Ostrava: VSB – TU Ostrava, Faculty of Safety Engineering, 2014, 61 pp. Diploma thesis.
[10]. Dojcar, O.; Horky, J. & Korinek, R. Blasting technology. Montanex, a. s., Ostrava, 1996, ISBN 80-85780-69-0.
[11]. Vávra P., Vágenknecht J. Theory of explosion effect, University of Pardubice, Faculty of Chemical Technology, 2004, ISBN 80-7194-494-7.

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Contribution in thecurrent study, he carriedoutexperimentswithWaterCumulativeCharges and provided data from these experimentswith his comments.

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Contribution in thecurrent study, he developedintroduction and other part ofthismanuscript and aditedallcontributionsof both authorstogether.