FIRE SUPPRESSION BY WATER MIST GENERATED BY SOLID PROPELLANT PROPULSION

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ABSTRACT

The behavior of fire suppression by water mist spray has been studied by exploiting the experimental setup which employs the solid propellant gas generator for water mist production. The burning products of solid fuel form a supersonic flow injected through the nozzle into the diffuser chamber having another input for the water component ejected from the storage. High values of temperature and pressure at stagnation point impart the substantial kinetic energy to the flow, which provides the atomization of water droplets into mist spray. The valuable property of achieved fire extinguishing mixture relates to the presence of inert burning products and vapor phase, which enlarge the volume of fire extinguishing jet allowing it to operate as a flooding agent along with the effect of heat consumption due to water evaporation. Proposed technique has been tested on the suppression of standard gasoline pool fire.

KEYWORDS: Fire suppression, Water mist, Gas generator

INTRODUCTION

Since the phase-out of halons has been approved, the fire fighting community is in a permanent search (e.g.[1]) for the worthy replacement of this efficient extinguishing agent acting by the perfect kinetic scheme of combustion reaction inhibition. Unlike the using of halon's chemical extinguishing capability, possible substituting technologies considered here are based on the physical effects. There are, as distinguished for the water mist[2] for instance, following primary mechanisms: gaseous and surface cooling due to evaporation, oxygen displacement by vapor phase in the flame zone and blocking radiant heat transfer to the unburnt fuel's surface. In fact, the effects of the same nature accompany the using of other types of extinguishing substances, which could be divided into the following categories[1]: inert gases, solid aerosol systems and water mist. Each of them has their own merits and disadvantages (see recent vigorous discussion in the IAFSS mailing list at the end of 2006) and there is no such a recognized superior fire suppressant as halon was. Surely, above mentioned classification is rather optional and does not isolate items from each other. Thus, solid aerosol particles are to be delivered by some inert gas, water mist may be treated as a liquid aerosol mixture or other mutual combinations could take place depending on the specific technique.

In order to provide energy source for the production of sufficient amount of extinguishing mixture and its delivery to the fire site, considered "physical-type" facilities require substantial weight and space allowances, which are much greater than "chemical" (halon-based) ones need. This becomes the crucial factor of actual arrangement, which could be settled down by two ways described below.

First, the compressed gas systems are the most widely spread facility, which serves as a storage of inert gas[3] applied directly to fire as an extinguishing agent as well as a power source to push the water (or any other suppressing component, e.g. foam) through the nozzle to produce extinguishing mixture[4-7]. Thus, high-pressure compressor equipment (installed inward or remotely used) is necessary to inflate working body into facility.

Another approach to a problem is the use of solid propellant gas generator, which generally has a potential increase of efficiency by converting the chemical energy of the fuel. Again, variable combinations of techniques are available[1]. By customary application of gas generators[8-10], extinguishing agent is produced directly by the propellant's burning products only, which are the pure exhaust gases or solid aerosol mixture, depending on the propellant composition. Hybrid scheme[11-16] uses the high-pressure burning products as an energy source to release the suppressing component (primary or additional), which could be of gas or liquid consistence, from the storage. One more application[17] of jet engine to fire suppression consists in just an accelerating delivery of extinguishing mixture prepared somehow separately.

This study presents the approach to application of solid propellant propulsion for production of water mist. Distinctive feature of such a technique (if comparing with commonly used hybrid gas generators) is that the gas generator is utilized here not only as a auxiliary power source to drive self-maintained extinguishing agent, but acting as a straight origin, which directly generates the water mist spray.

DESCRIPTION OF THE METHOD AND SETUP

The primary concept of the proposed approach[18] to the production of fire extinguishing mixture consists in using the kinetic energy of supersonic flow generated by the burning products of solid propellant gas generator[19]. Nitrocellulose/nitroglycerine double-based propellant, optionally including ballistic modifiers, has been used to achieve higher energetic efficiency of the output of fuel's chemical potential. General arrangement of a setup is shown in Fig. 1, where main components are indicated, which are gas generator *1* and diffuser chamber *2*. The burning of the solid propellant charge is initiated by the squib *4* and, as stable regime of combustion under approximately uniform pressure level has been reached, exhaust gases are injected into the diffuser chamber through the nozzle *3*. The nozzle is located eccentrically and inclined for some angle relatively to the symmetry axis of generator. It results in the formation of straight and slanting compression shocks inside the diffuser providing intensive mixing of exhaust gas with water component and atomization of water droplets into the mist spray. For the example of construction shown in Fig. 1, three gas generators are mounted in the case *5*. Such an arrangement gives some flexibility in the operating of suppression process by designating the order and launch time point of specific generator. Thus, cycling discharge of extinguishing mixture (shown[20] to be an effective suppression tactics) could be easily performed. Water component is contained in the outer storage under atmospheric or slightly excessive (up to 2 bars) pressure and is ejected into the diffuser chamber through the inner flow area *6* of the case. The appearance of assembled facility is shown in Fig. 2.

CALCULATIONS OF GAS GENERATOR PARAMETERS

In order to achieve a carefully arranged fire suppression facility based on the use of solid propellant propulsion, basic requirements to the gas generator's lay-out should be met. The value of the pressure in the combustion chamber is the principal parameter, which defines the ballistic performance of gas generator itself as well as the overall characteristics of fire extinguishing mixture such a flow rate at the outlet *7* (Fig. 1) and water droplet's size distribution. As for the design of gas generator, combustion chamber pressure must have such level that following conditions to be provided:

- stable regime of solid propellant's combustion;
- designated flow rate of exhaust gas injected through the nozzle;
- reasonably balanced weight and space behavior of facility;
- general safety regulations.

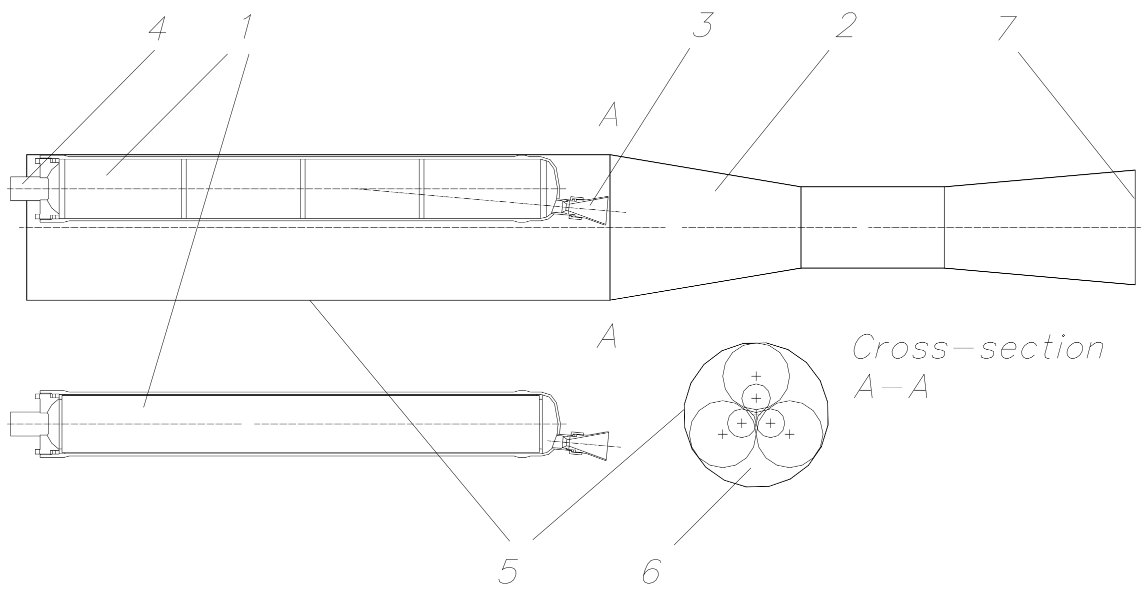


FIGURE 1. Schematic drawing of the setup. *1* – gas generator, *2* – diffuser chamber, *3* – nozzle, *4* – squib, *5* – case, *6* – water flow area, *7* – outlet

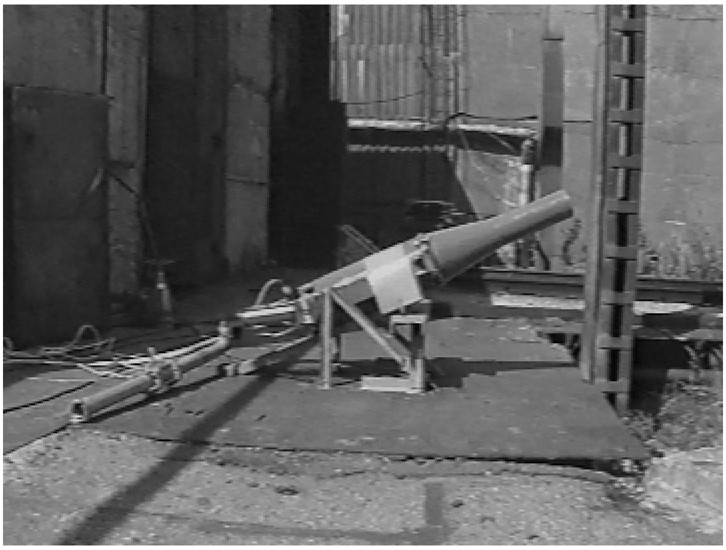


FIGURE 2. Appearance of the assembled fire suppression facility

The minimal pressure level ensuring stable combustion of considered nitrocellulose/nitroglycerine double-based propellant stands around 3 MPa (30 bars). So, such a device could be ranked as a high pressure system (according to NFPA classification[4]) with operating pressure level of 3.5...5.0 MPa (35...50 bars) assigned for this type of propellant. Use of substantially higher pressure value, despite having potentially greater energetic efficiency, results in the weighting of framework due to necessary thickening of gas generator's case walls and may infringe safety requirements.

Geometry of the burning surface of solid propellant charge considered here are shown in Fig. 3. The burning process is presumed to occur on the inside channel and both ends for case *a* and on the right-side end for case *b*. Such an ordinary configuration, which avoids (at least at the present research stage) advanced ballistic developments, is intended to achieve an easily arranged and simply manufactured facility. An important demand for the gas generator's design is maintenance of the nearly uniform pressure level during the operation time. The pressure in combustion chamber is a certain function of propellant's burning surface area, which is defined as follows:

$$S(e) = \frac{\pi}{2}\left[D^2 - (d+2e)^2\right] + \pi(d+2e)(L-2e) \quad [1]$$

$$S(e) = \frac{\pi D^2}{4} \quad [2]$$

where Eqs. [1] and [2] stand for cylindrical channel (Fig. 3a) and butt-end (Fig. 3b) respectively; S is burning surface area, e is linear increment of charge depletion, D, d and L are outer and inner diameters and length of charge respectively.

The series of calculations for different ratio of charge's sizes is shown in Fig. 4. It is to be noted that cylindrical channel geometry hardly provides the desired uniform burning surface area (and pressure level consequently) distribution in time unless larger inner diameter is used, which shortens the burning time and results in poor packing factor. In turn, butt-end configuration decreases substantially the burning area level (for the same assigned size), while giving the one's obvious uniformity.

The overall ballistic performance of the gas generator is defined by the general relationship[21]:

$$\bar{S}\rho u_0 p^{\nu} = \frac{pF}{\beta} \quad [3]$$

where $\bar{S} = 1/e_{\max} \int_0^{e_{\max}} S(e)de$ is averaged burning surface area, ρ is propellant's density, u_0 is normalized burning rate, p is combustion chamber pressure, ν is pressure coefficient, β is efflux factor and F is nozzle throat. For the ideal performance of jet propulsion the efflux factor could be obtained through the stagnation parameters as $\beta = A(k)\sqrt{RT}$ (here $A(k)$ is function of specific heats ratio, R is specific gas constant and T is stagnation temperature). However, due to considerable dissipative momentum and heat losses, an efflux factor β^* is to be rather empirically determined coefficient, which is obtained by means of the series of experiments involving the processing of measurable parameters such as pressure, propellant burning rate and geometric sizes for the similarly arranged gas generators according to relationship [3].

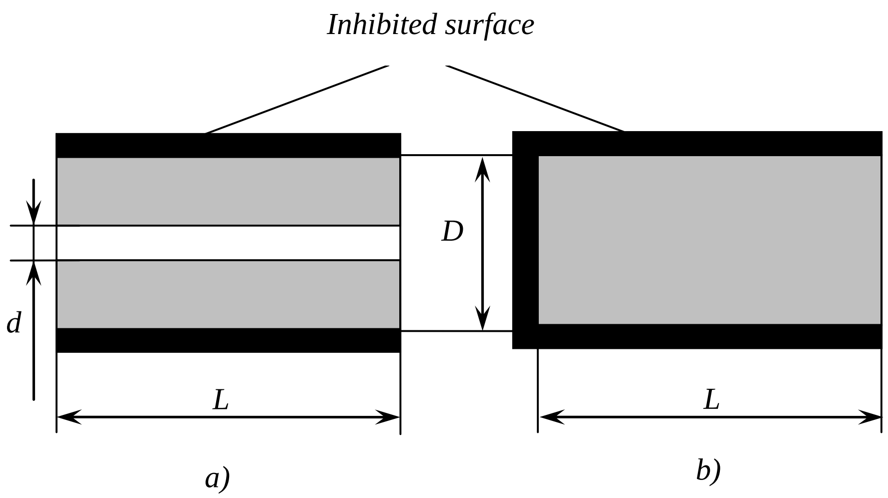


FIGURE 3. The geometric configuration of the burning surface of solid propellant charge
a) – cylindrical channel, *b)* – butt-end

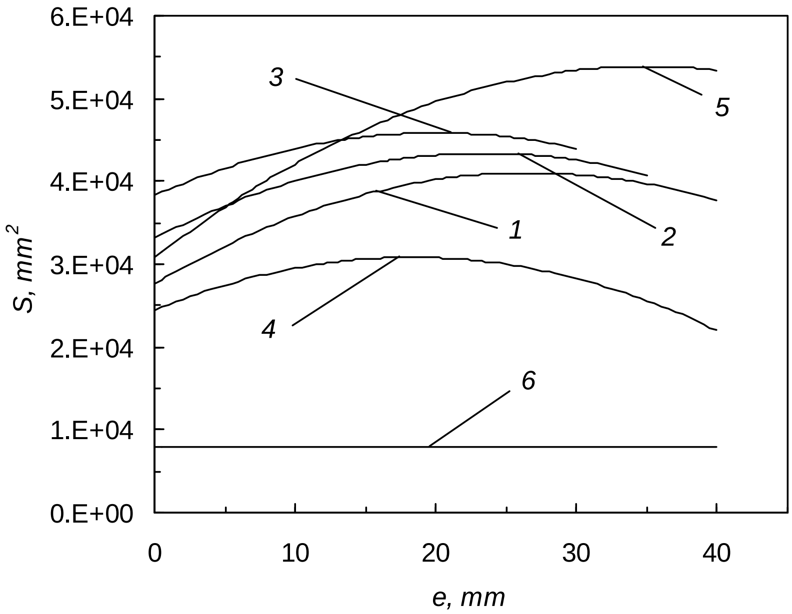


FIGURE 4. The dependence of burning surface area on linear increment of charge depletion $D = 100$ mm. Cylindrical channel: *1* – $d = 20$ mm, $L = 200$ mm; *2* – $d = 30$ mm, $L = 200$ mm; *3* – $d = 40$ mm, $L = 200$ mm; *4* – $d = 20$ mm, $L = 150$ mm; *5* – $d = 20$ mm, $L = 250$ mm; *6* – butt-end

The pressure in the combustion chamber is defined as follows:

$$p = \left(\frac{\bar{S} \rho u_0}{F} \beta^* \right)^{1/(1-\nu)} \qquad [4]$$

The actual arrangement of gas generator is specified by the crucial inputs: operating time t_w and flow rate $\dot{m} = \bar{S} \rho u$, which correspondingly define the necessary values of propellant's charge mass $m = \dot{m} / t_w$ and operating pressure from the Eq. [4].

EXAMPLE OF USE

Series of experiments have been carried out to outline basic characteristics of designed facility. The parametric study showed the direct effect of gas flow's temperature and pressure on the dispersion degree of water droplets. Fig. 5 presents the typical size distribution of water droplets traced on the oiliness film surface located on the about 1 m distance from the setup's outlet (Fig. 1). Since the water evaporation occurs already in the diffuser chamber due to the high temperature of input gas flow, the droplet size is gradually decreases to the lower limit value that could ever exist (and measured by the unsophisticated visual observation) in the physical conditions surrounding the fire behavior. Actually, the full range of water droplet size could be achieved if needed by specific fire suppression scenario. An additional valuable property of produced fire extinguishing mixture consists in the presence of vapor phase, which enlarges the volume of fire extinguishing jet allowing it to operate as a flooding agent at the very beginning of fire suppression process, much before the water droplets evaporation by the flame itself.

Resulting effect of the using of proposed technology is shown in Fig. 6. Here, some portable modification of the facility (having the following primary characteristics: equipped mass – 12 kg (including 9 kg of water), operating time – 30 seconds, extinguishing mixture jet's range – 8 m, registered water droplets size – 20...150 μm) is applied to suppress the certificated test fire source TP-5 approved by regulation[22]. Actually, this is a pool fire occurring in square tray of the 0.33×0.33 m surface area and 50 mm depth loaded by 0.65 kg of gasoline.

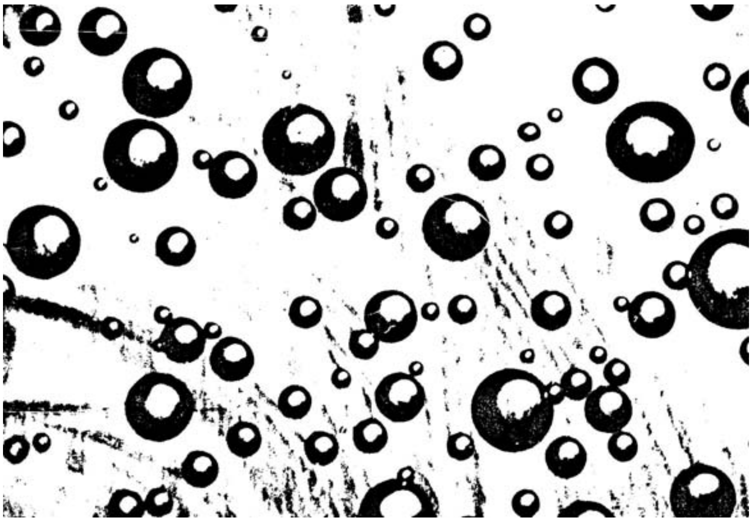


FIGURE 5. The image of water droplets size distribution. Largest droplet's diameter is approximately 100μm

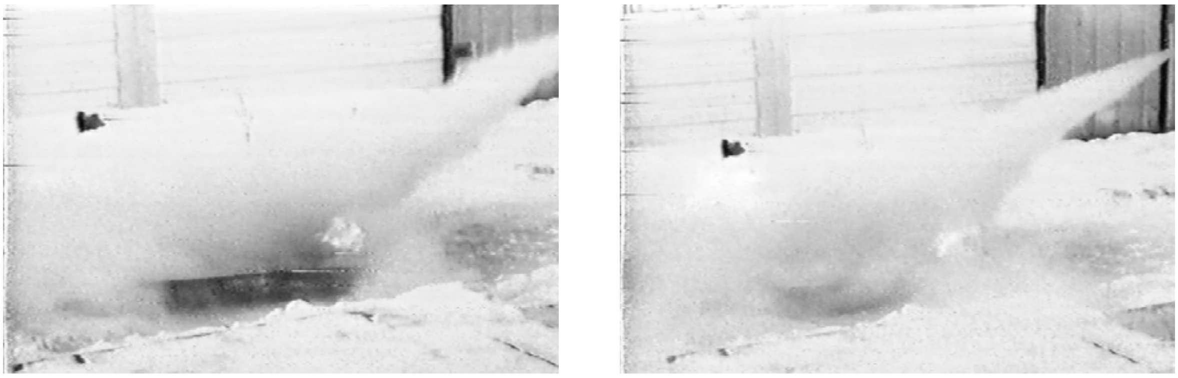
t = 2 *s*

t = 4 *s*

t = 7 *s*

t = 9 *s*

FIGURE 6. The demonstration of the practical application



t = 13 *s* *t* = 14 *s*

FIGURE 6(Cont'd). The demonstration of the practical application

CONCLUDING REMARKS

Proposed approach to water mist production by the using of solid propellant propulsion has shown noticeable fire suppression capability through the series of testing application to the various types of fire sources. One of the most remarkable advantages in the findings is that almost entire spectrum of the water droplets size distribution could be achieved if needed. On the contrary, the nozzle technique (e.g.[4-7,23,24]) restricts the droplets size range to narrow band restricting efficient application to the limited classes of fire, which should be designated in advance.

However, apparent demerits exist and should be clearly realized. Firstly, nitrocellulose/nitroglycerine double-based propellant has a very high stagnation temperature in the combustion chamber, so do the exhaust gases. Therefore, some cooling means are desired. Then, burning products of such type of propellant definitely could not be regarded as a clean agent, even if taking into account small propellant-to-water mass ratio (evaluated as 1/50 through the investigations carried out herein). So, this technology could hardly be applied in occupied area, especially in closed space.

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REFERENCES

1. Kim, A., "Overview of Recent Progress in Fire Suppression Technology", Proceedings of 2nd Symposium of the National Research Institute of Fire and Disaster, pp. 1-13, 2002. (also: National Research Council of Canada, Institute of Research in Construction, Report No. NRCC-45690).
2. Mawhinney, J.R., Dlugogorski, B.Z. and Kim, A.K, "A Closer Look at the Fire Extinguishing Properties of Water Mist", Fire Safety Science: Proceedings of the Fourth International Symposium, pp. 47-60, 1994.
3. Underwriters Laboratories, Standard for Inert Gas Clean Agent Extinguishing System Units, UL 2127, 1999 Edition.
4. NFPA 750, Standard on Water Mist Fire Protection Systems, National Fire Protection Association, 2000 Edition.
5. Yao, B. and Chow, W.K., "A Review of Water Mist Fire Suppression Systems", Journal of Applied Fire Science, 10:3, 277-294, 2000-2001.

6. Mesli, B., Quilgars, A., Chauveau, C. and Gokalp, I., "Extinction Limits of Opposed Jet Turbulent Premixed Methane Air Flames with Water Mist", Fire Safety Science: Proceedings of the Sixth International Symposium, pp. 445-456, 1999.
7. Adiga, K.C., Hatcher, R.F., Jr., Forssell, E.W., Scheffey, J.L., DiNenno, P.J., Back, G.G., Farley, J.P. and Williams, F.W., "Electronic Space Fire Protection: False Deck Mockup Fire Testing of Nanomist Systems", Proceedings of Halon Options Technical Working Conference, 2005.
8. Gruzdev, A.G., Osipkov, V.N., Orionov, Y.E., Rostorguev, A.N. and Sheitelman, G.Y., "Use of Solid Propellant Gas-Generating Compositions in the Means of Fire Extinguishing, Safety and Emergency Rescue", High Energy Materials. Demilitarization and Civil Application (HEMs-2004): Proceedings of the International Workshop, pp. 51-54, 2004.
9. Berezovsky, J. and Joukov, S., "PyroGen Fire Suppression Grenades", Proceedings of Halon Options Technical Working Conference, p. 480, 1999.
10. Wierenga, P.H. and Holland, G.F., "Developments in and Implementation of Gas Generators for Fire Suppression", Proceedings of Halon Options Technical Working Conference, Albuquerque, NM, p.453, 1999.
11. Bennett, J.M., "Compact Affordable Inert Gas Fire Extinguishing System", United States Patent No. 6016874, January 25, 2000.
12. Grzyll, L.R., "Solid-Solid Hybrid Gas Generator Compositions for Fire Suppression", United States Patent No. 6045637, April 4, 2000.
13. Fallis, S., Reed, R., Lu, Y.-C., Wierenga, P.H. and Holland, G.F., "Advanced Propellant/Additive Development for Fire Suppressing Gas Generators", Proceedings of Halon Options Technical Working Conference, p. 361, 2000.
14. Mitchell, R., "Crew Compartment Live Fire Test Results with Hybrid Fire Extinguishers", Proceedings of Halon Options Technical Working Conference, p. 469, 1999.
15. Grzyll, L.R. and Meyer, J.A., "Development of a Solid-Solid Hybrid Gas Generator Fire Suppression System", Proceedings of Halon Options Technical Working Conference, 2005.
16. Lu, Y.-C.(F.) and Wierenga, P., "Further Advances in the Development of Hybrid Fire Extinguisher Technology", Proceedings of Halon Options Technical Working Conference, p.371, 2000.
17. Poulsen, T.E., "High Velocity Fire Extinguishing Nozzle", United States Patent No. 5046564, September 10, 1991.
18. Leschev, A.Y, Lipanov, A.M., Makarenko, A.D. and Timofeev, O.A., "Method of Production of Combined Fire Extinguishing Jet", Russian Federation Patent No. 2058168, April 20, 1996.
19. Leschev, A.Y, Lipanov, A.M., Makarenko, A.D. and Timofeev, O.A., "Gas Generating Facility", Russian Federation Patent No. 2050869, December 27, 1995.
20. Kim, A.K., Liu, Z. and Su, J.Z., "Water Mist Fire Suppression using Cycling Discharges", Proceedings of Interflam'99, Edinburgh, UK, pp. 1349, 1999.
21. Lipanov, A.M. and Aliev, A.V., The Design of Solid Propellant Jet Propulsion, Mashinostroenie, Moscow, 1995. (In Russian)
22. Russian Federation Standard No. R-50898-96, Supplement E, 1997.
23. Ndubizu, C., Ananth, R. and Williams, F.W., "Water Mist Suppression of PMMA Boundary Layer Combustion - A Comparison of NanoMist and Spray Nozzle Performance", Naval Research Laboratory Memorandum report NRL/MR/6180-04, 2004.
24. Ndubizu, C.C., Ananth, R and Tatem, P.A., "The Effect of Droplet Size and Injection Orientation on Water Mist Suppression of Low and High Boiling Point Liquid Pool Fires", Combustion Science and Technology, 157, 63-86, 2000.