Jr. of Industrial Pollution Control 32(2)(2016) pp 490-499
www.icontrolpollution.com
Research

OVERVIEW OF IMPULSE FIRE-EXTINGUISHING SYSTEM APPLICATIONS

V.D. ZAKHMATOV [1], M.V. SILNIKOV [2,3] AND M.V. CHERNYSHOV [2,3]*

[1] P.P. Shirshov Institute of Oceanology, Russian Academy of Sciences, Moscow, Russian Federation

[2] Peter the Great Saint Petersburg Polytechnic University, Saint Petersburg, Russian Federation

[3] Special Materials, Saint Petersburg, Russian Federation

(Received 6 July, 2016; accepted 22 August, 2016)

Key words: Rocket launches area, Fire and blast safety, Impulse firefighting systems

ABSTRACT

A new generation of automatic fire-extinguishing systems to beat out the flames at the spaceship launch area is proposed. The modernization consists of adding supplementary equipment to the existing automatic fire-extinguishing systems used at the launch pad via the addition of multi-barrel modules (MMs) that enable volley dispersion of the extinguishing media. The parallel executive system consisting of several MMs situated around the launch area at distances ranging from 50 m to 200 m can also be created. This modernization of the fire-extinguishing systems can quickly, effectively, and fully protect launch complex structures from high-powered rocket engine flame jets. This modernized approach can also provide effective light radiation and heat protection and can prolong the life duration of the expensive start facilities. The validity of the proposed project is confirmed by the results of the final successful tests of the modern MBMs ensemble situated around the goal in a semi-circular, which concentrated their volleys on the isolated local but powerful flame.

INTRODUCTION

The analysis of the fire protection practice of rocket launch areas during the last several dozen years have shown the low effectiveness of the high-power water supply systems (with a water supply rate from 330 l/s up to 500 l/s) designed to beat out the flames of the launch rocket engines, as quite convincingly demonstrated by the series of rocket launches in USA (Cape Canaveral). As we can judge, the executive systems provided real water propulsion slides, but could not protect the launch facilities satisfactorily (both in efficacy and in response time) (Comeau, 2004); this problem is common for rocket launch facilities in different countries, such as USA, Russia, China and Brazil, where the accidents with rocket explosions have occurred over the last several years. Up-to-date water monitors (water supply cannons) cannot provide enough water in a short enough duration due to their high complexity, the large time lag from the initial signal to water emission and their low reliability at the extreme operational regimes. The monitors require many seconds from the initial signal to the beginning of the maximum water supply regime (The Engineering Regulations of Fire Safety Requirements, 2008; Kuznetsov, *et al.*, 2004). As a result, the water emission to the rocket launch complex should begin during the minute before rocket start, which is unrealistic. In reality, water emission should begin only just after the rocket separation from the ground (Melkumov, *et al.*, 1978). As an alternative, the monitors can sprinkle the water to some other side before the rocket separation occurs and then turn towards the launch facilities only after separation has occurred. However, the strong water cannon cannot turn around more quickly than the tank turret (in practice, in 20 s to 30 s). The launch facilities undergo an intense heating from the flames during this period and their posterior cooling is not effective, even from a structural integrity point of view. The most intensive and destructive flame heat action corresponds to time lag in the range of 10 s to 30 s after the rocket separation.

The above-mentioned issues of the executive hydraulic systems, such as sprinklers, drenchers, and hydro-monitors, were known in the 1970s and into the 1980s (Garpinichenko, *et al.*, 1971;

***Corresponding author's email:** mvcher@mail.ru

Russian State Standard GOST 51115, 1997; Terebnev and Podgrushny, 2009). As a result, the Soviet ministries responsible for fuel and energy as well as the Ministry of Defense financed in the period of 1982-1991 (until the collapse of the USSR) research principally aimed to design new fire-extinguishing executive subsystems. These subsystems were both stationary impulse facilities directed to the fire source and mobile systems based on trailers and gun carriages. The impulse MM systems provided volley dispersions of the various fire-extinguishing media (different liquids, gels, powders, dust, or sand). The combined fire extinguishing approach easily controlled the type, scale and power of action; this approach provides the following important advantages: minimum extinguishing media expense, reduced damage to buildings and equipment, high distance and precision of the action on any of the areas, system compactness, the absence of pumps, pipelines, and tanks for extinguishing media, and promotion of safety for personnel.

The armored track-type fire service machines "Impulse-3M" (Fig. 1) with 50-barrel turret MMs based on T-62 Soviet tank chassis has operated successfully in Ukrainian (6 machines) and Russian (up to 10 machines) fire suppression units up to modern times. These machines are used primarily at nuclear power plants and in the chemical, oil and gas industry. Their application to ammunition storages and rocket launch areas is also recommended.

Fig. 1 Caterpillar fire machine "Impulse-3M" with a 50-barrel tower module; 20 kg - 25 kg of extinguishing agent is in the channel of each barrel; firefighting characteristics: distance – up to 110 m, area – up to 1000 m^2/s for the volley from 10 barrels, total area covered by 5 volleys - up to 3000 m^2 to 5000 m^2. The machine was designed and produced during the last years of the USSR by V.D. Zakhmatov's scientific group.

However, despite the numerous designers' letters and papers in special journals (Zakhmatov, 1994; Zakhmatov, *et al*., 1998), the development of impulse fire-extinguishing systems was never supported, both in Russia and in Ukraine. A new wave of interest in this research area arose in the last several years due to industrial accidents terrorist attacks and growth in the forest fire scale and the oil pollution quantity (Zakhmatov and Shkarabura, 2000; Zakhmatov, *et al*., 2008; Zakhmatov, 2012). A number of industrial projects are being realized now in China, the Czech Republic (Fig. 2), Estonia and Finland under Prof. V.D. Zakhmatov's scientific supervision. The financial support and work intensity are especially high in China, which has allowed us in the last two years to obtain the new results discussed in the final part of this paper.

Fig. 2 Czech caterpillar fire machine SPOT-55 equipped with a pair of water guns. The water expense is 2 × 40 l/s or 2 × 70 l/s, the distance is up to 50 m, a TV-camera is used for remote control of the water-guns, the water tank capacity is 12 tons of water and 1 ton of foam.

MATERIALS AND METHODS

The modern state of extinguishing media supply systems

The experience of the series of the industrial accidents during peace time has shown that the effectiveness of some up-to-date fire systems (even the best American and European models) is not satisfactory. The gun-carriage of fire barrels with 70 l/s to 330 l/s water (or low-expansion foam) supply rate and hydro-monitors with water supply rates of up to 400 l/s appear to be the most effective and vigorous to date. However, these gun-carriages of fire barrels are expensive, sophisticated and difficult to operate in everyday service, and require a long period between their installation and operation.

The tragic death of more than 20 firemen and destruction of 4 fire cars covered by burning oil splash at the oil storage fire in Vasilkov (Kiev region, Ukraine, 2015) demonstrated the necessity for extinguishing the fire from all dangerous objects from the maximum distances. Based on our experience, the eruptions of dozens of tons of burning oil and oil products to the distance up to 300 m to 500 m from the reservoir with the formation of large burning "lakes" are known to occur. The requirements to the fire-extinguishing systems in large-scale oil fires (quick, safe and precise extinguishing of the flame at the given limited area with its following cooling) are somewhat analogous to the requirements for the case of rocket launch.

The impulse fire-extinguishing systems combine the uniform flow rate by the continuous dense wave front beating the flame out and fire-directed water dispersion. Its effectiveness depends on such factors as:

- operability of its action on the fire flashpoint;

- sufficient concentration of the fire area irrigation by water or low-expansion foam, which also can be delivered at relatively large distances (the low-expansion foam distance is approximately 10% less than the water jet range (Zakhmatov, *et al.*, 1998)).

To improve these factors, most modern and powerful gun-carriage barrels are used to extinguish the fire on dangerous industrial objects (Zakhmatov and Shkarabura, 2000; Zakhmatov, 2012). The theory of high-velocity jet flows confirms (Pai, 1954; Omel'chenko, *et, al.*, 2003; Uskov and Chernyshov, 2006; Volkov, *et al.*, 2013) that such facilities provide us the maximum range of jet flow flight, which allows the firemen to be situated at a relatively safe distance from the front of the flame vortex. However, even the most modern specimens of gun-carriage barrels with a water supply rate equal to 70 l/s, 100 l/s and 150 l/s provide the maximum range distance of up to 110 m, which is evidently insufficient for personnel safety at extinguishing a flame.

Another unsolved problem is the control of high dynamic pressure jet irrigation square. When we increase the supply rate and range, we inevitably widen the irrigation square, even in windless conditions. Multiple expensive attempts of barrel modernization and surface strength factor enlargement based on fluid viscosity growth have not been able to obtain positive results to date. Even for windless conditions, at a liquid supply rate equal to 100 l/s to 150 l/s, the dispersion of liquid droplets is more than 100 m to 200 m, instead of the optimal distance equal to approximately 40 m to 60 m (Zakhmatov, *et al.*, 1999). Wind changes the irrigation area configuration crucially and shifts the liquid droplets up to 1 km. As a result, only a minor part of the dispersed water or low-expansion foam actually hits the fuel reservoir or the rocket launch burning facilities.

As a result of low fire-extinguishing system effectiveness, the firemen can work up to several hours in dangerous and harmful conditions (due to solids of the liquid rocket propellants, for example), under the threat of sudden fire front attack. Thus, the manufacturers of the fire equipment waste much of their efforts to enhance the range distance and to diminish the area of the distance irrigation. Solutions to these problems require providing the safe extinguishing of the burning reservoirs during the short period at the beginning of emissions of dangerous pollution, or contemporarily with the rocket separation, to provide the thermal protection of the launch facilities and to reuse such facilities for the future starts with minimal repairs.

Note that even the most powerful systems of launch facilities cooling are neither able to extinguish the large-scale fires nor to deactivate the emissions of the toxic rocket propellant. Extinguishing large-scale fires and deactivating emissions is crucially important because it typically occurs at the rocket collapse at its start, and also when the parts of rocket and its fuel reservoirs drop, explode and burn within a dozen or more seconds after the start at the space launching site territory.

The fire safety cars are traditionally applied to suppress such large-scale fires and deactivate the pollutants. These fire safety cars operate based on the release of hundreds of tons of water and the sedimentation of the poisonous clouds by the dispersed jets. The electronics of such systems is well-developed and unified in different countries. However, the mechanics of the executive devices of such systems, which consist of the pipelines, high-pressure tanks, large and heavy reservoirs and powerful pumps, is very complicated and slow.

To avoid these important problems in long-distance fire-extinguishing mechanics, we propose to equip the automatic quenching systems with inexpensive, easily and quickly installed executive systems consisting of MBMs using volley dispersion for the fire-extinguishing, heat-protecting, pollution-localizing media.

History of impulse fire-extinguishing system applications

Multi-barrel modules (MMs) were designed from the beginning of 1980s, initially based on the authors' initiative, and as a part of the Soviet state military and industrial programs afterwards. Those initial systems were MMs that dispersed water via shot or volley mounted two-axis gun carriages or sledge runners. These systems were produced in a large number and tested successfully in the field as well as at real fires in industry. The first 4-barrelled module (MM-4) was designed and tested under V.D. Zakhmatov's scientific guidance at the Moscow High Engineering and Technical School of the Soviet Interior Ministry in 1982. Since 1983, the 9-barrel module (MM-9) based on nine wagons began to be manufactured in Sverdlovsk (now – Yekaterinburg, Russia) at the Urals Staff of Mine-Rescue Works enterprise. MM-9 systems were widely used at the mines of the Soviet Non-Ferrous Metallurgy Ministry afterwards.

Subsequently, a new MM (MM-8) was demonstrated at the Soviet Civil Defense test field in Koncha-Zaspa (near Kiev) in September, 1984 at the All-Soviet Maneuvers of the Civil Defense. The burning stack of wood was successfully extinguished from the distance of 50 m over 2 s. This MM-8 module was designed under V.D. Zakhmatov's supervision in the repair shop of the Kiev Civil Defense regiment. The full volley of its 8 barrels dispersed 120 kg of fire-extinguishing powder and created the gas-particle vortex with an effective range of up to 60 m. As the vortex spreads, it widens its front from 1 m to 8 m in width and from 0.5 m to 3 m in height. The effective fire-extinguished area reached 350 square meters and was shaped as an oblong drop longitudinal cross-section.

At that time and up to now, the pneumatic one-barrel impulse dispersion system elaborated by Prof. I.M. Abduragimov and Dr. V.A. Makarov (Moscow High Engineering and Technical School of the Soviet Interior Ministry (Todes, *et al.*, 1975)) was the only rival of the mentioned MMs at the Soviet and post-Soviet territories. This system pulverizes up to 200 kg of the fire-extinguishing powder to the distance not more than 15 m to 20 m; thus, it can extinguish a fire of the low-pressure gas fountains from the distance up to 10 m. One-barreled systems are also inconvenient because their recoil is larger than the recoil of the multi-barrel systems of the same media supply rate and jet velocity (up to 20% to 35% in the above-mentioned case, for example).

Up to 40 MMs (MM-9 and MM-16) were manufactured at the pilot plants of the Soviet Academy of Sciences in May-July, 1986. These MMs were actively applied in the zone of the Chernobyl catastrophe (near Kiev, 1986, Fig. 3) to defend the transformer stations and to extinguish some parts of the 3rd and the 4th units of the Chernobyl nuclear power plant, which had suffered much of the blast and radiation damage. MM-8, MM-9 and MM-25 were successfully applied to quench the fire of 14 gas and oil wells at Neftyanye Kamni ("oil stones" at Caspian sea, now in Azerbaidzhan). These MMs were mounted at the wide deck of torpedo boat and, afterwards, at the high deck of Finnish floating crane. These MMs were arrayed and directed in such a manner that the vortices formed by the neighbor MMs were to meet at the 80 m to 100 m distance. This approach allowed us to reach the maximum effectiveness to beat out the turbulent integral fountain torch from a relatively safe distance. A volley of 40 barrels created a powerful vortex with a front width of up to 20 m and a front height of up to 5 m. After the flame was extinguished, oil workers landed on the oil platform deck to block the well without risk of the secondary fire. MMs acted simultaneously with the fire safety ships of the Caspian and Volga flotilla, but they sufficiently excelled the fire ship in terms of the range and scale of the fire-extinguishing vortex. At the same industrial accident, our MMs were effectively used to localize the oil pollution produced by the large-scale dispersion of the oil sorbates (granulated turf) onto the oil film.

(a) (b)

Fig. 3 a) single-barrel pneumatic impulse module mounted at sledges, industrially produced since 1987 for emergency gas-wells brigades; the system pulverizes 200 kg of extinguishing powder to 25 m and has an extinguishing range up to 15 m, total extinguishing area – up to 60 m^2 along trajectory. b) Module MM-9 mounted at gun-carriage; its volley pulverizes 180 kgs of the same powder up to 90 m with fire extinguishing range up to 60 m and a total extinguishing area of up to 550 m^2 along the trajectory. These 20 MM-9 modules have operated at Chernobyl area since June 1986 as fixed elements of an automatic remote-control fire system. Each module protected area equal to 300 m^2 to 800 m^2.

A high-power and long-distance 9-barrelled MM based on two-axis gun carriage diffuses up to 180 kg of fire-extinguishing media on the range up to 90 m by the area square up to 500 m^2 at its only volley from all its barrels. More powerful systems were designed later, for example, 25-barrelled MM which disperses 120 kg to 135 kg of useful media over the distance up to 60 m to 70 m with each of its volley from 8-9 active barrels; its fire-extinguishing area reaches 350 m^2 to 400 m^2 by a single volley, 1200 m^2 at volleys with long intervals between them, and up to 2500 m^2 when the intervals between volleys are equal to 3 s to 5 s. A 30-barrel recoilless MM with 152-mm barrel caliber (the barrels are optionally removable), which disperses 75 kg to 90 kg of the extinguishing media by each volley from 5 barrels to 6 barrels on 40 m to 45 m distance and quenches 150 m^2 to 200 m^2 area by each volley, was also designed and tested.

The Impulse-3 was in operation from the beginning of the 1990s. The alternative ex-USSR pilot models and projects failed at this time. Initially, this failure was caused by the incorrect choice of chassis. We can consider, for example, a 22-barrel powder spraying machine developed at the GAZ plant in Nizhny Novgorod using the experience of Impulse-3 development. The main disadvantage of this machine was that the lightweight design was used; as a result, the number of barrels was decreased to 22, and, the most significant, the salvo of only two guns was used. The last restriction practically eliminated the main MM advantages of long reach and comprehensive firefighting facilities. The second version of the multi-barrel module based on KRAZ track chassis failed because of the fault in the construction of the chassis. The frame of this module was not specially strengthened when the powerful wheeled gun was installed. The recoil thrust in the case of salvo of ten 200 mm caliber guns, spraying 250 kg of fire-extinguishing powder is comparable with the recoil of 152 mm to 155 mm caliber gunshot, when a supercharge is used.

Revival of the interest in the multi-barrel construction designed by Russian and Ukrainian authors has occurred in the last several years. New construction of the stationary MMs to be mounted on the two-axis gun carriage, which includes the hermetic containers for liquids and gels, was designed in 2013-2014. Hermetic containers for the working media are firm enough for their transportation, reload and charge; however, at the same time, they can be easily destroyed by the propelling wave of gunpowder gases into small and light pieces, which are not dangerous and fly out not further than to 10 m. The dispersing charges are manufactured in most convenient and safe for personnel modification. The metal cartridges with electric capsule bushing were manufactured in China industrially. The last stage of the field tests was conducted in 2014-2015 and revealed the high possibilities of the modified MM-9, MM-20 and MM-30 modules. These modules extinguished the strong standard fire source in 1 s from a distance of 100 m. The vortex of the working media spread to greater than 200 m, and the subjected area square was up to 1000 m^2 to 1200 m^2 for each volley of 200 kg of the useful media from 10 barrels.

The most completed multi-barreled system, MM-50, based on a T-62 Soviet tank chassis, is known as the fire safety car "Impulse-3M" (Fig. 4 and 5). MM-50 has been used in Ukraine (7 systems) and in Russia (12 systems) from 1992 to now. "Impulse-3M" can be used at the temperature range from -50^{0}C to +50^{0}C. This fact makes the system applicable in different weather conditions, from the cold Russian North, Siberia and far East cosmodromes ("Plesetsk", "Baykonur" and "Vostochny") to the tropical launch areas (Florida and French Guiana). One volley produced from 10 barrels disperses 250 kg of the fire-extinguishing powder up to 110 m. A series of 5 volleys covers the area up to 3000 m^2 without barrel recharge. We are not aware of analogous systems applicable for fire extinguishing in toxic, blast-dangerous, or radioactive surroundings, where the quickness and accuracy of volley and the armor protection for personnel are very important. A wide range of the ecologically pure natural materials (soil, sand, dirt, and dust) can be used as the working media. Due to above-mentioned advantages, this machine can be effectively applied to launch complex cooling, as well as for the suppression of any accidents at the launch area, including rocket destruction at the beginning of the trajectory or immediately at the start. "Impulse-3M" is armored; it has also light and heat radiation protection systems and can be used as a bulldozer to operate inside construction debris.

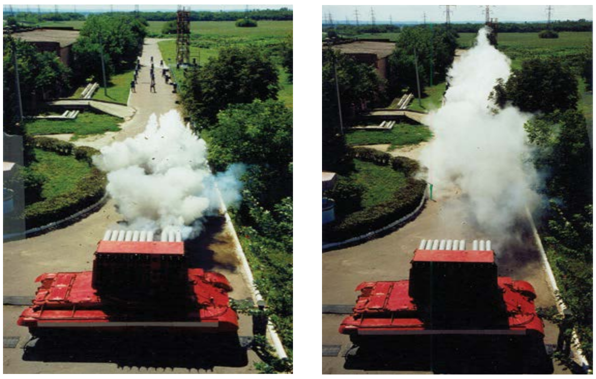

Fig. 4 a) Firefighting system MM-50: a 10-barrel volley spreads an extinguishing gas-powder hurricane to a distance of 60 m to 110 m to stop a "terrorist" (played by volunteers) attack, time is 0.18 s. after the initiation of the volley; b) the hurricane coverage area of 12 m long and 4 m to 12 m wide, the total area is over 1000 m^2, and the time is 1.8 s. after the initiation of the volley.

Fig. 5 Firefighting system MM-50 during hotbed extinguishing in an industrial area by artificial vortex through open gates, doors and windows.

"Impulse-3M" MMs are currently used at the chemical industry enterprises ("Azot" factory in Cherkassy, Ukraine), in radioactive areas (Chernobyl, Ukraine) and nuclear power plants (Balakovo, Russia), as well as in the oil and gas industry (specialized unit for the suppression of gas and oil fountains, Poltava, Ukraine; fuel enterprises "Gnezdinsky" (Chernigov region, Ukraine), in Syzran (Samara region, Russia), and in Bashkortostan, Russia), and also in the mining industry (Norilsk, Russia). It seems possible to apply the "Impulse-3M" MMs to rocket launch sites, but it would be more effective to modify its construction using special containers and dispersing charges of original design that are currently manufactured in China. The universal containers are appropriate for almost every working media, such as liquids, gels, powders, and other natural materials, which can be found at the place of accident and can be applicable for fire extinguishing, localization and deactivation of harmful pollutants. For example, microbiological remedies and live microorganisms can be used for biological destruction of oil and rocket propellant pollutions, their ecological screening, and soil re-cultivation.

Fig. 6 German IFEX module with paired barrels based on a "Leopard-1" tank chassis. Pneumatic impulse volley of 40 liters of water spray to the distance up to 40 m, capacity – 10 tons of water, high pressure compressor.

Table 1. Comparison of various impulse firefighting systems

Types of systems Technical parameters	Traditional hydraulic				Impulse pneumatic			Blank cartridge systems	
	GPM-54, Ukraine / Russia	**SPOT-55, Czech Republic**	**MTLB, Ukraine**	**T-119, China**	**5-bar. powder, Ukraine**	**IFEX – Leopard, Germany**	**5-barrel / fire water cannon / T-55, Russia**	**Vetluga, Russia**	**Impulse-3M**
Full weight, tons	43	42.5	40	18	38	45	43	25	36/21.6
Firefighting distance, m	15-20	50	15-20	35	35	45	40	50	80-120
Feed rate, liters per sec.	40	2 × 70	40	60	20	20	20	30	20-200
Area of firefighting, square meters	180-200	300-400	200-250	150	350	1500	1500	250-300	2000-3000
Weight of firefighting agent, tons	10.5+0.3 foam	11.8+0.5 foam	10	5	9	10	10	0.33	1.0-1.25
Firefighting agents	Water				Powder				Water, solutions, gels, powders, sand, dust, dirt
Cost, thousands of USD (authors' estimations)	110	390	145	120	350	1200	250	200	100/200
Aggregate characteristic	The use is limited because of the low efficiency							Low spray jet power	Safe range of the firefighting, high speed, maneuverable chassis

Other models of armored multi-barrel firefighting systems, including very sophisticated dispersers of compressed air, are produced by the following companies: IFEX, TSIS and Intervent. IFEX is the most well-known among these companies (see Fig. 6); IFEX produces the leading competitor to MMs. The comparison characteristics are given in Table 1.

RESULTS AND DISCUSSION

Special multi-barreled modules to be mounted around the rocket launch site

Special MM ("MM-laf") can be designed as a stationary module or a module based on a gun carriage or on a trailer. MM prototypes based on two-axis gun carriages were comprised of 7 barrels to 10 barrels or 25 barrels and applied to extinguishing fire in the Chernobyl area, coal and ore mines, a burning airplane at the runway, etc. The recoil of this MM does not exceed 1 m to 3 m at the volley from 9 barrels.

The "MM-laf" system does not require special maintenance, except for the initiation electric chain checks via small-amperage electric impulse. As a measure of supplementary safety control, 1 barrels or 2 barrels can be changed every year.

If the system is properly charged, and the containers with useful media and the pulverizing cartridges are assembled qualitatively, then "MM-laf" is reliable, even when this system stands 5 years without practice. Containers with fire-extinguishing media can, after all improvements, reach reliable workability after 15 years of storage. "MM-laf" also can be situated around the dangerous area very quickly, which is an important advantage of such systems in emergencies.

Very convincing ground tests of multiple means of protection of a fire-dangerous area by different MMs were conducted in China in December, 2014 (Fig. 7). Three improved MMs participated in the tests: MM-20 made the first volley from a distance of 100 m, MM-30 made the second volley from a distance of 120 m, and MM-9 made the third volley from a distance of 85 m. The model of the standard fire hotbed was extinguished by the very first volley; and the two other volleys demonstrated the reliable workability of the system and its multiple usages only. It was also demonstrated that the fire suppression with several MMs can be combined due to programmed dispersion of different working media from the various distances at different time intervals.

For any facility to be protected, the principles of flame spreading can be studied, depending on a number of factors (technologies and regimes of its applications, possibilities to switch off the power cables and fuel pipelines, the special features of the separate apparatus and venting, etc.). When the fire appearance and spreading is studied, it helps to determine the optimal fire-fighting tactics. Regarding MMs, the tactics involve setting the order of the volleys produced by groups of MMs and separate MMs and the time intervals between them. The effectiveness of a MM assembly depends on the ease of their work program change and correction, if the conditions at the protected area are changed during the fire development. MMs can change their positions, the order of the volleys, and the number of barrels participating in each volley; this flexibility makes the assembly function both powerful and very flexible.

Fig. 7 Field tests of the joint concentrated action of various improved MMs (MM-9, MM-20, and MM-30) in China (December, 2014).

Fire sensors and other transducers can be applied at the same system with the MM complex. It can help the system to cope with the arsons and quickly developing fires. As a result, this system has advantages not only in the possibilities to apply different liquids, gels, powders and other media but also in the possibility of the flexible control on the basic impulse dispersion parameters, such as the distance, scale, and shape of the moistened area. This type of control is achieved by the variation of the number of barrels, their mutual position in the same volley and in the different volleys, and the control of time micro-intervals between volleys.

Research and development works in Estonia, Czech Republic and other countries also lead to design of armored firefighting machines based on existing military tanks and armored cars chassis (see, for example, a project developed in the Czech Republic as a symbiosis of the "Given" tank and the MM-50 module shown in Fig. 8).

Special features of MM physics

To enable the use of a variety of working media, the dispersing system of MM is supplied with the universal containers filled by various liquids and mixtures. The ability of MM to perform complex (or combined) action can be characterized as its possibility to pulverize the working media of different states, densities, dispersibility, viscosity, as well as its rate of fire. The MM action scale is characterized by the size (width and height) of the dispersed tornado front and by the area or volume subjected to the tornado of the required concentration and velocity. This scale characterizes the ability of impulse tornado to extinguish the hotbed of fire spread on any area, to protect some objects from the heat flux, to localize the cloud of the active aerosols, and even to neutralize a group of criminals at the given area.

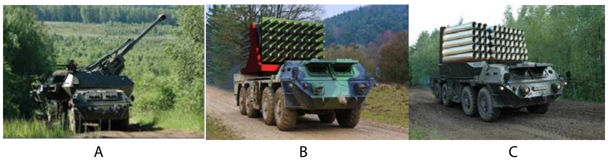

Fig. 8 a) Wheeled tank "Given" ("Susanna") on a Tatra chassis; b, c) images of a MM-Dana firefighting system with a 50-barrels module, which, after modernization, can be mounted on the same chassis.

The simultaneous volley from the multi-barreled system is the important advantage of the system only for gas–disperse media vortices. Tests confirm that these simultaneous vortices strengthen one another mutually at their confluence and interaction (Zakhmatov, 2015); their interaction allows for enhancement of the scales of the aggregate vortex action up to 1.5 s to 2.5 s times comparing with the arithmetic sum of the separate vortices action areas. It is possible to sufficiently increase the distance of the effective total tornado action (upto 4 s to 5 s) times compared with the shot from the alone barrel) as follows: up to 53 m when the sorbates are working media, up to 120 m at a volley dispersion from 10 barrels (20 kg of powder in each of them), and up to 60 m at a volley of water dispersion from 8 barrels (10 l of water in each). The uniformly moistened area increases correspondingly: up to 450 m^2 at the sorbate volley from 5 barrels; this area is 2 s to 3 s times more than the sum of the results of the separate actions of the same 5 barrels.

For comparison, the volley action of military missiles and shells usually enlarges its subjected area not more than 5 times compared with the arithmetic sum of the areas stricken by separate shots. The missile or shell flight distance does not enlarge at the volley.

Thus, we can surmise that the effectiveness of impulse MMs at its volley application can reach the effectiveness of the modern artillery while providing solutions to the other problems.

MMs create the gas-dust vortices with wide front surfaces or gas-droplet tornados. At interaction of these vortices with the flame and burning surface, the gas-dust vortices realize several mechanisms of fire extinguishing. Space scales, uniformity, high power and combined action are the basic advantages of the impulse fire extinguishing process, which can achieve rapid fire suppression at very small working media expense (less than 1 l/m^2). These low levels of working media expense cannot be reached by traditional methods: their typical numbers are 100 l/m^2 to 1000 l/m^2 when the specialized cars are used, 1 l to 10 l when the portative fire extinguishers are applied and 5 l/m^2 to 50 l/m^2 when automatic fire-extinguished systems (based on sprinklers, for example) are applied.

If the gas-powder vortex included special inhibitors, then the vortex impedes the burning of fuel because of its influence on fuel radicals. If the tornado consists of gas and water, then smoke removal by shock, flame suppression, cooling and destruction of the burning surface are the basic processes. Because the number of volleys and barrels can be large, and their vortices can be concentrated at the same area, the energy applied to fire suppression or to toxic pollution deactivation appears to be almost unlimited.

MM applications together with automatic fire suppression

For potential fire suppression, MMs can be situated, for example, in the protected buildings of a nuclear power plant or in enveloped areas of rocket launch site. As was demonstrated in the Dun-Hua field tests (winter 2014-2015), it is easy and inexpensive to double or triple the coverage of the protected area of the working media streams.

To diminish the probability of false alarm, the following methods can be used (Zakhmatov, 2012):

- enlarge the stability of heat and fire sensors due to their optimal structure, their duplication, and the introduction of the systems that differentiate the interference from real ignition;

- apply the sensors that use the logical circuits that can confirm the authenticity of the ignition message;

- centralize the stream of information on the area and the surrounding parameters.

A high MM performance can compensate for the time used on the analysis of the sensor system.

CONCLUSION

Eexecutives subsystems based on MMs proposed in this paper are novel, safe, and universal. The proposed MMs have some qualitative advantages over other subsystems serving the same goal in fire and rescue service:

- The consumption of the fire-extinguishing media is 10 to 100 times smaller. This feature allows the system to operate autonomously, using only the working media storages inside the MM barrels;

- The type, power and scale of the action can be easily regulated, changed and controlled;

- The type, power and scale of the action increase in proportion to the number of devices and the number of barrels in each device, without loss in reliability and effectiveness;

- The price of system manufacturing and service is very small (a large number of obsolete artillery barrels and tanks can change their applications to peaceful ones);

- The fire extinguishing process can be ecologically pure and can help in the civil population evacuation;

- High pressure volumes used in these systems are small in the size and time of existence (only parts of the second), with the firmness of the construction being 10 times higher than the stresses to which it is subjected;

- The system construction is very simple and rather safe in application; gas cylinders, compressors and pumps are not required;

- The useful media dispersion is reliable and stable over a wide range of temperatures (from -50°C to +50°C), winds, humidity, dust rates and other climate conditions;

- The secondary blasts of gas, steam, dust and air mixtures are prevented as a rule;

- The rocket fuel pollution onto the launch site area can be localized;

- The maximum distance from the flame enlarges up to 10 times; this fact enlarges the safety of firefighting activity and allows for the firemen to work from safe distances in practice;

- There are no restrictions on the state of the firefighting media; we can use fresh, or salty water, sand, dirt, dust and other liquids, gels and foams of various densities and viscosities. These media can be found on-site; this ability allows the long-duration operation of a MM complex, if required, without an exterior supply.

As a result, the fire-extinguishing systems based on MMs appears to be the best choice for ensuring the fire safety of rocket launch sites and also for prolongation of the operating period of launch facilities at their severe heating situations.

REFERENCES

Comeau, E. 2004. A Lot of Space to Cover. Fire Protection at the Kennedy Space Center. NFPA. 98 : 54-61.

Garpinichenko, A.M., Evtiushkin, N.M. and Kimstach, I.F. 1971. Firefighting Tactics. Part II. Literature on Construction Publishing House. Moscow.

Kuznetsov, N.P., Kurguzkin, M.G. and Nikolaev, V.A. 2004. Utilization of the Rockets with Liquid Fuel Engines (on Example of the 8K14 Rocket). Regular and Chaotic Dynamics, Moscow. Izhevsk.

Melkumov, T.M., Melik-Pashaev, N.I., Chistyakov, P.G. and Shiukov AG. 1976. Rocket Engines. Mashinostroenie. Moscow.

Omelchenko, A.V., Uskov, V.N. and Chernyshev, M.V. 2003. An Approximate Analytical Model of Flow in the First Barrel of an over expanded Jet. *Tech. Phys. Lett*. 29 : 243-245.

Russian State Standard GOST 51115. 1997. Fire Engineering. Combined Fire Barrels for Gun Carriages. *Tech. Req. Test. Methods*. Moscow.

Pai, S. 1954. Fluid Dynamics of Jets. D. van Nostrand Company, Inc., Toronto, New York, London.

Terebnev, V.V. and Podgrushny, A.V. 2009. Firefighting Tactics. Basics of the Fire Extinguishing. Moscow.

The Engineering Regulations of Fire Safety Requirements. The Federal Law of the Russian Federation No. 123-FZ, July 22, 2008.

Todes, O.M., Ionushas, K.K., Goltsiker, A.D. and Abduragimov, I.M. 1975. Investigation of the inhibition of the propagation of a flame in aerodisperse systems. *Combust. Explos. Shock. Waves*. 9 : 173-177.

Uskov, V.N. and Chernyshov, M.V. 2006. Differential characteristics of the flow field in a plane over expanded jet in the vicinity of the nozzle lip. *J. Appl. Mech. Tech. Phys*. 47 : 366-376.

Volkov, K.N., Emelyanov, V.N. and Zazimko, V.A. 2013. Turbulent jets – statistic models and Large Eddy Simulation. Fizmatlit. Moscow.

Zakhmatov, V.D. 1994. A pulsed gas-solid jet flow. *Combust. Explos. Shock. Waves*. 30 : 326-330.

Zakhmatov, V.D. 2012. Self-controlling impulse systems for firefighting and multi-aspect protection. *J. Fire. Blast. Saft*. 21 : 59-69.

Zakhmatov, V.D. 2012. System of multi-aspect termination of accidents at blast-dangerous and chemically dangerous industrial objects. *J. fire. Blast. Saft*. 21 : 43-59.

Zakhmatov, V.D. 2015. Fire-extinguishing powder and water distersion by shot or volley from multi-barrel modules. *J. Fire. Blast. Saft*. 24 : 57-66.

Zakhmatov, V.D., Tsikanovskij, V.L. and Kozhemyakin A.S. 1998. Jet throwing of fire-extinguishing powder from barrels. *Combust. Explos. Shock. Waves*. 34 : 106-110.

Zakhmatov, V.D., Kozhemyakin, A.S. and Tsikanovskij VL. 1999. Impulse multi-get gas-dispersed stream. *J. Fire. Blast. Saft*. 8 : 68-71.

Zakhmatov, V.D., Scherbak, M.V., Kovelev, S.O. and Gaydey VV. 2008. New technologies of oil spills localization at sea. *Oil. Gas. J*. 6 : 55-57.

Zakhmatov, V.D. and Shkarabura, N.G. 2000. The prospective methods of firefighting at nuclear power plants. *J. Fire. Blast. Saft*. 9 : 48-54.