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IMPROVEMENT OF TECHNICAL PARAMETERS OF FIRE VEHICLES AND EQUIPMENT

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Abstract. The improvement of the technical parameters of the fire vehicle implemented in a few groups is presented. Each parameter of these groups has a respective impact on the following features of the fire vehicle. The deficiencies of the main fire vehicles under operation, the improvement of the fire vehicles vacuum systems and extinguishing systems are presented.

Keywords: fire vehicles; vacuum systems; impulsive extinquishing technologies.

1. Introduction

Approximately 11-14,000 fires occur in Lithuania annually because of weather conditions. However, over the last eleven months in 2002 alone, 20152 fires broke out resulting in damages worth of 25,939611 Lt, although factual losses seem to amount to larger numbers as the damages related to the perturbations of production and other business activities have not been taken into account. This substantial increase of fires and the number of damages done therewith have been preconditioned both by inadequate human economic activities and sharp changes of the weather.

In addition, common tendencies and experiences of other countries testify to the fact that with the increase of human activities fire threats grow as well. Fires pollute the environment heavily and have a negative impact on human health. It is evident that the quicker the fires are put out, the less damage is done.

The goal of the fire and rescue services rests on rescuing human lives and property in the event of fires and other emergencies. Fire vehicles constitute technical means that enable fire services to ensure efficient performance of their functions. It is evident that technical specifications of the fire vehicles have a crucial impact on fire fighters' work efficiency. The immediacy of fire and rescue operations being rendered depends on the technical parameters of the fire and rescue equipment including the fire vehicles. The speed factor in emergencies plays the highest importance. Analyses of fire casualties indicate that 60 % to 70 % of people perish from the intoxication emitted by fire gases within the first stage of fire (up to 5-6 minutes from the beginning of the fire) [1]. Material damages due to fires have an immediate connection to the duration of the fire burning itself. According to research studies done in Great Britain, the reduction of the fire burning time by 1 minute can drop the number of fatalities in fires by 5,3 %. Therefore, technical specifications of the use of the fire vehicle in terms of the time factor have a crucial impact on putting out fires.

A case of fire fighting or elimination of an accident can be estimated by the time factors as follows:

$$T = T_d + T_v + T_p + T_{ges}, \quad (1)$$

here T – total response time, T_d – departure time of a fire vehicle from the fire station upon reception of an emergency call, T_v - driving time needed to reach the scene of an accident, T_p – preparation time for a fire vehicle and fire equipment to respond, T_{ges} – fire fighting time.

T_d depends on how quickly the fire vehicle is able to leave the garage, i.e. on the reliability and rapidity of its start-up and the brake system as well as on its convenience for the fire fighters to quickly get into it. *Tn,* driving time to the scene of an accident depends on the maximum driving speed that the fire vehicle can develop, on its dynamic specifications and mobility, off-highway driving properties and stability, as well as on its qualities of being informative and discernable to the people round about including distance to the accident as well as roadway and traffic conditions.

T_p time depends on what kind of equipment is installed in the fire vehicle and how fast such equipment and its aggregates can be prepared for and put into operation.

T_g time depends on technical specifications of the fire fighting equipment, availability of the extinguishing materials as well as approaches and intensity of supply of the fire extinguishing materials.

By assessing the constituent parts of the time factor in fire fighting and technical parameters of the fire vehicles, which influence fire extinguishing, three main groups can be distinguished, such as:

- Chassis.
- Fire body construction, body, and containers of the extinguishing materials.
- Special aggregates and equipment.

Each parameter of these groups has a respective impact on the following features of the fire vehicle: ability to arrive quickly and safely to the scene of an accident; capacity of carrying the necessary number of the fire fighters, equipment and the extinguishing materials; being able to efficiently supply extinguishing materials or ensure implementation of the required operations using specific aggregates. Consequently, the improvement of the technical parameters of the fire vehicle can be implemented in the following ways:

- By improving or changing the chassis base in the fire vehicle;
- By advancing or changing the fire vehicle body, equipment sections and containers designed for the extinguishing materials;
- By changing a pump, equipment, or any other specific aggregate, and by installing or using supplementary measures, which can improve fire extinguishing.

2. Deficiencies of the Main Fire Vehicles Under Operation

Manufacturers endeavor to select optimal technical parameters for the fire vehicles being made. However, due to the specific application of the fire vehicles the wear of their aggregates and other components tends to be very uneven.

While on duty the fire vehicles do not put on too many kilometers and their mileage is quite low in comparison with that of the transport vehicles, however, their operating mode is rather heavy and the operation time of such vehicles seem to come up to 11–30 years. During the entire duty period of the fire vehicle its worn-out aggregates and components need to be replaced more than once. Moreover, some its parameters tend to fail to meet the new requirements over the long period of operation.

Years ago the firefighters handled only fires. Nowadays they have to carry out various rescue operations that call for the need to make use of the supplementary equipment, which fails to be properly placed in the old-type vehicle bodies. New technologies require the change of the old components. It is not unusual that after long years of its operation manufacturers stop producing some of the aggregates or components to be replaced, therefore, it turns to be vital to search for the new alternative solutions. All this becomes crucial in view of ensuring further use of the old fire vehicles as in as much the acquisition of the new up-to-date equipment seems to be problematic due to the lack of financial resources.

Currently, the State Fire and Rescue Service runs 700 units of fire and rescue automobiles and special vehicles. Even 80 % of the main fire vehicles have been manufactured in the former Soviet Union, and they fail to be noted for their reliability and endurance. The deficiencies of such fire vehicles may be differentiated as follows: 70 % of the total vehicle deficiencies come to special aggregates and body constructions, out of which 24 % make up vacuum system and 18 % fire-pump breakdowns. The rest of 30 % of the deficiencies amount to the basic chassis, out of which 12 % come to transmission aggregates and 8 % to traffic security system failures respectively.

A matter of great concern is that all the fire vehicles mounted on GAZ or ZIL mark chassis have carburetor engines that consume A-80 gasoline, whereas in other countries the chassis of such fire vehicles are equipped only with more fuel-efficient diesel engines. It would be rational to implement economical-technical calculations concerning the costs of replacing carburetor engines with the diesel ones in such fire vehicles, which are envisaged to be operated for the next several years.

As we have mentioned before, the most acute issue to deal with lies in the centrifugal fire pumps filling vacuum systems as well as in the failures of the fire pumps them-selves including corrosion and rupture of both bodies and tanks. The replacement of these systems with the new ones or the improvement of the current ones would result in both significant upgrade of their technical specifications and extension of their operating time.

3. The Improvement of the Fire Vehicles Vacuum Systems

Before delivering extinguishing fluids, centrifugal fire pumps have to be filled up within the shortest possible time. Currently, the most common vacuum systems are used to ensure immediate fill-up of the pumps. The performance of the vacuum systems is based on sucking air out of the centrifugal pumps and the suction hoses attached to it. The air suction results in rarefaction (vacuum), whereas water being under atmospheric pressure fills up both suction hoses and centrifugal pumps.

Here are the following principal characteristic parameters of the vacuum systems:

- maximum vacuum pressure is gained;
- geometric suction height;
- time-span needed for sucking air both from the pump and connection hoses.

The maximum geometric suction height depends on the maximum vacuum pressure being formed. The sizes of the system gaps and seal couplings have an impact on the formation of the maximum vacuum pressure. Regrettably, all vacuum systems have the same deficiency, i.e. the geometric suction height cannot exceed 10 meters, and taking into consideration losses within the system the maximum suction height actually comes up only to 7 – 8 meters.

All fire vehicles produced in the former Soviet Union have been equipped with the same vacuum systems without any exceptions. These systems consume energy of the exhaust gases emitted from the engines to produce vacuum. An overall layout of such a vacuum system is presented in Fig 1.

These vacuum systems do not require transmission train and they are not provided with turning, scrolling and reversible motion parts, they are easily mountable as well. However, they have the following essential deficiencies:

- Corrosion of both the vacuum apparatus valves and its body metal surfaces being exposed to hot exhaust gases emitted from the engine;
- Big noise while in operation;
- Possible increased concentration of the exhaust gases within the working premises of the driver/operator;
- Formation of the uplift of the exhaust gases up to 0,2 Mpa;
- System failure to function autonomously;
- Lower vacuum pressure is formed in comparison with other vacuum systems in use (Table 1).

The basis of the vacuum system consists of the pump type being used. Upon analysis of the parameters and characteristics of the pumps used in the vacuum systems, it has been determined that it would be the most effective way to use membrane or piston suction pumps. The transmission train is required while operating these pumps. It is common practice in western countries to use the propeller-shaft of the pump gear or the shaft of the centrifugal pump itself in order to operate the suction pump. This means that the vacuum pump will function only in case the centrifugal pump keeps turning. However, oil-seals and seals of the centrifugal pumps equipped in GAZ and ZIL-type fire vehicles are not designed to operate without water for longer periods. Therefore, it is impossible to use the pump transmission for revving up suction pumps in the fire vehicles provided with PN 40UA and PN 40UV pumps. In this case one of the solutions rests an applying an electric engine of the direct current supplied from the vehicle batteries to rev up the membrane or piston suction pumps. It is quite simple to mount this suction pump on any area of the fire vehicle (Fig 2).

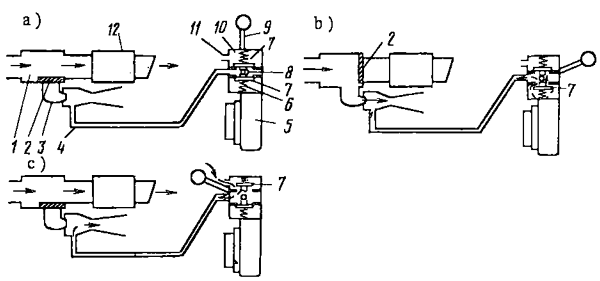

Fig 1. Vacuum systems using energy of engine exhaust gases. a)- Position in "off" mode, b) Water suction, c) Emptying of vacuum system, 1 – Body of vacuum apparatus, 2 – Valve, 3 – Injector, 4 – Coupling of centrifugal pump with injector's vacuum chamber, 5 – Centrifugal pump, 6 – Spring, 7 – Valve, 8 – Eccentric, 9 – Handle, 10 – Vacuum valve, 11 – Opening, 12 – Muffler for exhaust gases

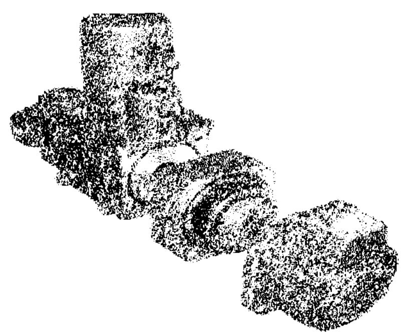

Fig 2. Piston suction pump driven by electromotor

Table 1. Comparable data and parameters of vacuum systems

Parameter	With gas injectors	With membranepumps	With piston pumps	With rotary vane pumps
Vacuum pressure gained, MPa	0,074	0,09	0,09	0,09
Maximum geometric suction height, m	7	8	8	8
Energy source	Engine exhaust gas	Gear of centrifugal pump	Gear of centrifugal pump	Electric engine of direct current
Operation	Manual	Manual or automatic	Manual or automatic	Manual
Negative impact on environment,vehicle aggregates or operator	Impact on vehicle engine andoperator	No impact	No impact	Impact onenvironment

Suction pumps to be produced in an experimental way with 0,00021m3 operating capacity and equipped with a 1,3 kW electric motor starter engine are shown in Fig 2. These piston pumps are meant both to improve the performance of the vacuum systems of the used fire vehicles and to save the recourses for it is not necessary to start up the engine in order to perform a pump leakage test.

4. Change of Body Constructions of AC 40(130)63B and AC 40(131)137-type Fire Vehicles

The body constructions of the fire vehicles of AC 40(130)63B and AC 40(131)137 types have been manufactured for several decades without any remarkable changes. Their main deficiencies are the following:

- Insufficiency of space to place supplementary rescue equipment;
- highly intensive corrosion of body and tank;
- covers of body sections do not shut securely and they become unsafe at work place when in an open position.

Every year more construction bodies of these types of the fire vehicles tend to become unusable due to deep metal corrosion, although their chassis could keep operating for a much longer time. Different possibilities have been considered to solve this problem. For example, it has been speculated to assemble one fire vehicle out of two, to replace the most worn-out parts of the body and to change the entire body with all of its components included. It is not always possible to rationally use all the aggregates and components by mounting one fire vehicle out of two. Replacing the most worn-out parts, we fail to eliminate any of the deficiencies mentioned above. Therefore, in view of improving the characteristics of the fire vehicles being used and prolonging their operational time, the priority has been given to the change of the entire body construction. These are the following requirements for the fire vehicle construction body:

- New body constructions and parts shall not reduce active and passive safety of the fire vehicles.
- Body constructions and parts shall not exceed such dimensions, total weight and axial load of the fire vehicle as designed by the manufacturer.
- Configuration of the compartments of the new body shall be fit for the necessary supplementary equipment to place.
- Body and tank shall be produced from rustproof materials or covered by a reliable anticorrosive coating.
- Blind-like aluminum made doors shall be used instead of compartment covers.

Such body constructions that met these and other additional requirements have been manufactured and mounted on the fire vehicles. An overall view of the fire vehicle equipped with a new body construction is depicted in Fig 3.

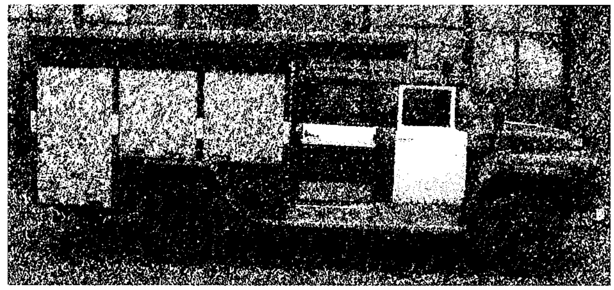

Fig 3. Overall view of the fire vehicle AC 40(130) 63B equipped with a new body construction

The body of the fire vehicle consists of a sub-frame; elastic suspension of the sub-frame (after getting rid of cramps); a frame of the body onto which aluminum plates are fixed by gluing; a tank and foamer container both produced of polypropylene; compartments equipped with blind-like aluminum doors; elements for the fixation of the equipment.

New body constructions of such types improve the following characteristics of the fire vehicles:

1. Enlargement of the body size by 0,6 m^3 allows to load more equipment.
2. Body, water tank and foam container are corrosion proof, because they are produced of rustproof materials.
3. Blind-like aluminum doors ensure safe seal of the equipment compartments, they have an aesthetic look and improve working conditions around the vehicle.
4. Elastic suspension of the body sub-frame allows avoiding undesirable tensions within the body constructions.

5. Improvement of Extinguishing Systems

Extinguishing systems comprise systems designed for the supply of the extinguishing materials (extinguishants) to fight fires. Water has been the most available and the most frequently used extinguishing material since times remembered. Water is distinguished for its distinctive physical and chemical qualities. For instance, it is noted for its heat absorption characteristics that the majority of the natural substances lack. For many years people have been trying to find better ways of delivering water to the scene of an accident and using it in the most effective way in fire fighting. It is not infrequent that damages resulting from inefficient application of water exceed those done by fire to the burned down property and other valuables. Water used in fire fighting tends to leak out and pollute the environment and severely deteriorate the ecological conditions in general. Although various up-to-date pumps, hoses, nozzles and sprayers are used to extinguish fires, water-based fire extinguishing technologies have not reached the top level of performance.

The core of the modern extinguishing systems of the fire vehicles is made from the fire pumps or other equipment designed to supply fire-extinguishing materials. The fire pump characteristics define the application of the equipment. Properly selected equipment enables to effectively make use of the properties of the fire pumps. As the time factor in fire fighting is essential, it is evident that the sooner the supply of the extinguishing materials is launched, the more efficient operation of fire fighting will evolve.

One of the ways to accelerate the beginning of fire fighting is to provide available systems of the fire vehicle with a fast response hose reel. The fast response hose reel allows the fire fighters to start the water supply as soon as the water pump is put into operation without wasting time for connecting hose lines. In addition, the fast response hoses are relatively light and much easier to handle. Research studies done in Great Britain have proven that the shortest fire fighting time has been gained by using the fast response hose reels [1]. However, as the fast response hose reels are of smaller diameters (19–38 mm), they are inclined to higher hydraulic losses. Furthermore, in order to ensure the required intensity of supplying the extinguishing materials, higher pressure is needed to operate fast response hose reels.

Therefore, combined (high/low pressure) pumps are used to operate fast response hose reels as they can reach the maximum pressure of 2–5 MPa. High-pressure nozzles are combined with the high-pressure 1–2 l/s capacity hoses. Then we wonder if it is possible to use the fast response hoses in the old fire vehicles whose fire pumps are capable of reaching the pressure of 1MPa only. The answer is affirmative; it can be done. The only condition is that it is vital to select hoses and nozzles of appropriate parameters. More than several times we have noticed that the incorrect selection of the equipment with inappropriate specifications has failed to bring the results expected. With a view of applying fast response hoses in old fire vehicles, it is essential to have a quality nozzle-sprayer of about 2 l/s capacity capable of operating efficiently under low pressures (0,3–0,4 MPa) [2]. For the determination of the fire hose parameters, the following formula can be used [3]:

$$FL = CQ^2L, \quad (2)$$

here: FL – hydraulic losses within the hose, kPa; C – hose hydraulic resistance coefficient; Q – capacity in hundreds l/min; L – length of hoses in hundreds m (mostly up to 60 m).

Completed calculations indicate that the diameter of the fast response hose should be not less than 25 mm. The mounting of such a hose on the fire vehicle is depicted in Fig 4.

Extinguishing possibilities of the fire vehicle can be improved significantly by using the fire pumps with better characteristics. However, it is the rotating engine that defines the use of the fire pump. It is not uncommon that even the manufacturers sometimes fail to properly tune up the conformity parameters of the engine and the fire pump, such as their outputs, rotary moments, and the number of revs. Therefore, the same fire vehicles equipped with different pumps can have different supplying features of the extinguishing materials. After replacing exiting fire pumps of type PN40 in old fire vehicles with the new fire pumps that meet up-to-date parameters, the possibility to use the advanced extinguishing system becomes real. Modern fire pumps are very expensive (price per item comes up to 20–50,000 Litas). Thus, their thorough technical and economical analysis and studies should be done before making the selection and using them.

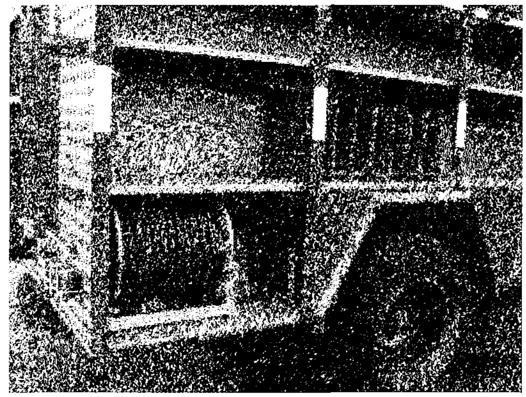

Fig 4. Mounting of the fast response hose on the fire vehicle with the new body construction

Even using modern centrifugal pumps, it is not possible to prevent water spillage on the scene of a fire accident. In fact, this leaking water is not involved in fire extinction but is being contaminated and wasted. This is due to the fact that part of this water fails to absorb the entire possible heat and tends to evaporate. This is also explained by the high tension of the water surface, which does not allow it to penetrate into the burning substances. It is evident that the more we will atomize the water, the more of the surface area we will be able to obtain from the same volume of water, which will directly contact with the fire heat and thus water properties will be used more efficiently. For instance, if water were poured as if from the bucket, its features would be used only at 5–10 % efficiency. Thus, the increase of the surface area of the extinguishing water augments the efficiency of the water consumption as well. The simple way to increase the extinguishing water surface area is to atomize water into fine drops. The smaller the drops are developed, the better use of the water properties can be implemented and less water is consumed in fire fighting. The following ways are designed in order to better atomize the water that is being supplied for fire fighting:

1. To use special nozzles-sprayers that can atomize water into small drops much better.
2. To increase the pressure of the water supplied, which is being atomized much better while flowing through the nozzle.
3. To reduce tension forces of the water surface.

In the first case using modern nozzles it is possible to obtain 0,3mm drop sizes within the water jet under the pressure of 0,4-0,7 MPa. It is quite complicated to further atomize the water into smaller drops without increasing pressures. Therefore, instead of the single-stage centrifugal pumps, multi-stage are used in the fire vehicles. The pressure of the supplied water is increased from 1MPa to 4MPa. In particular cases volumetric (membrane and piston) pumps are used and the pressure is increased up to 6-20MPa. Under higher pressure the water is atomized better and thus less water is needed. However, under higher pressures (up to 20 MPa) it is impossible to supply bigger quantities of water, as the forces of the nozzles reaction increase and the fire fighters would fail to cope with such forces [4–5]. Furthermore, the small quantity of water, which is well-atomized and under the high pressure, turns into a fog. The water droplets constituting this fog are too small and lack sufficient kinetic energy, thus they may be easily blown away from the focus of the fire by the fire gases.

In the third case different chemicals that reduce the water surface tension forces are used. Such chemicals are called foams or moisteners. Such water with less surface tension forces not only can be atomized better, but also it can penetrate better into the burning surfaces. However, quality foams are quite expensive, and they are basically used for producing the foams meant to extinguish substances that are lighter than water. Recently the newly discovered CAFS systems have been used more broadly. The CAFS is the Compressed Air and Foam Extinguishing System. The principle of the system is based on water and foam mixture, which aerated with compressed air, produces high quality and stable foam, which is being delivered through hoses and nozzles to fire fighting. A special foam of type "A" is used to form the mixture and only 0,1–1 % water concentration is required, whereas the ordinary concentration for the foam comes to 3-6 %. The water – foam mixture is mixed with air in proportion 1:7. Therefore, hoses filled up with the foam are light, as they contain more air than liquids. The main scheme of the CAFS system is submitted in Fig 5.

While using the CAFS system, the extinguishing efficiency increases by 3–5 times compared with extinguishing with plain water [6–7]. The efficiency is reached due to the fact that water is being sustained within stable foams and does not leak out of the fire place (e.g., while using a solid water jet, up to 90 % of water leaks out from the fire place without any extinguishing effect. In order to ensure the functioning of the system, an air compressor, a foam dosage device, a water pump and devices for pressure regulation are required. The systems can be either an autonomic one provided with an individual motor, a compressor and other devices, or it can be the pump powered by the fire vehicle and transmission. As the CAFS systems use water very economically, there is no reason to load the fire vehicles with the large containers of the extinguishing materials. Upon mounting the CAFS systems onto the existing fire vehicles, it would be possible to reduce the volume of the water tanks and to increase the number of the equipment that is taken out and is necessary for various rescue operations. The new fire vehicles equipped with the CAFS systems could be smaller and of higher mobility. However, in order to define both the efficiency of the systems and the optimal parameters

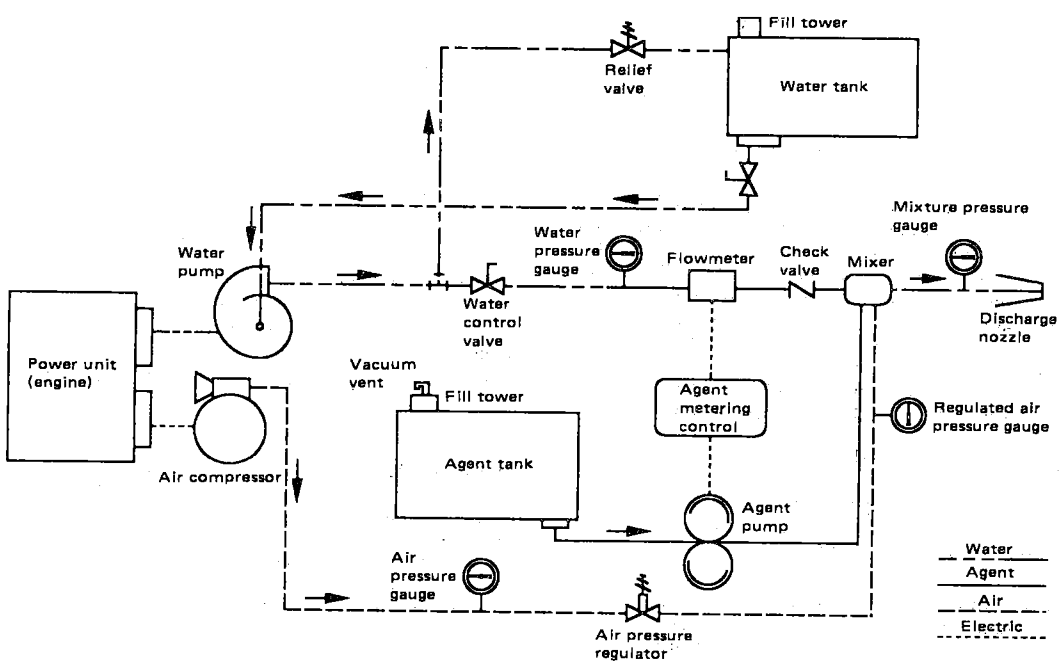

Fig 5. The main scheme of CAFS system

within appropriate fire vehicles, further analyses and practical tests are required, as the extinguishing costs may get higher when the system is being used improperly.

Having analyzed the facts mentioned above, with a view to improve the technologies of supply of the extinguishing materials, the search for the unconventional ways have become important. Today the water is chiefly supplied for extinguishing via volumetric and centrifugal pumps by using its hydraulic liquid characteristics. The pressure energy of the pressurized and out-flowing water through the opening (i.e. fire nozzle) is transformed into jet kinetic energy. If we use the energy of the compressed air or other gases to eject water through the nozzle (instead of the compressed water energy) the jet speed could be much faster. The water droplet speed within the jet sprayed out in an ordinary way reaches tens m/s, while using the compressed air energy the water droplet speed can reach hundreds m/s. Furthermore, because of such speed, water spray is atomized into fine droplets due to the air resistance (even up to 2 microns in diameter). Consequently, the extinguishing water covered area enlarges as well as the water efficiency. In Table 2 and Fig 6 you can see droplet sizes, their number as well as the covered area obtained when water volume is one 1 litre [8–9].

When water is supplied in fine droplets, it is possible to reach the use of all of its properties as close as 100%. In addition, the factor of the possible damage of the property and other valuables by water flooding is eliminated completely: facilities that are not within the extinguishing area remain safe from being flooded. The majority of fires could be addressed while using smaller and higher mobility fire vehicles, as large water tanks would not be necessary. Currently, the fire services of some countries have been introducing impulsive extinguishing technologies based on the use of the compressed air energy for ejecting extinguishing water. The general principle of its functioning is shown in Fig 7.

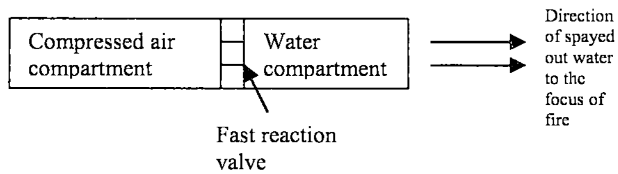

Fig 7. Principle scheme of the impulsive nozzle

Impulsive nozzles function in the following order:

- Compressed air compartment is filled up from the air container;

- Water compartment is filled up from the water tank;

- When the fast reaction valve is opened, compressed air and water compartments get merged;

- Water being under air pressure is ejected within a very short time (from several to several tens of mili-seconds) to the focus of fire;

- Further on the process is repeated from the beginning.

Studies on the impulsive extinguishing technologies have not been completed yet and need to be further updated and tested. However, even now they allow us to use the properties of the extinguishing water more efficiently and to reduce the response time.

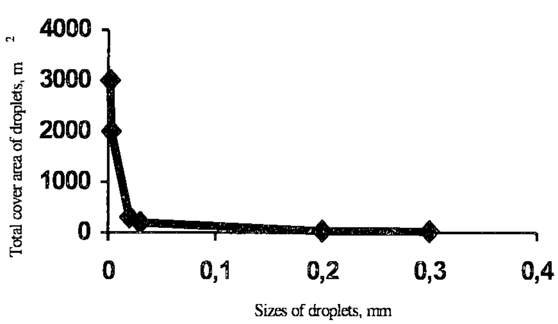

Fig 6. Dependence of the total covered area of 1litre water volume droplets on their diameter size

Table 2. Diameters of water droplets, their number and the total surface area obtained from 1 litre water volume

Droplet diameters, mm	Droplet number	Total surface, m^2
0,3	$7{,}1\times10^{7}$	20
0,2	$2{,}4\times10^{8}$	30
0,03	$7{,}1\times10^{10}$	200
0,02	$2{,}4\times10^{11}$	300
0,003	$7{,}1\times10^{13}$	2000
0,002	$2{,}4\times10^{14}$	3000

6. Conclusions

1. The improvement of the technical parameters of the fire vehicle can be implemented in the following ways:

- By improving or changing the chassis base in the fire vehicle;
- By advancing or changing the fire vehicle body, equipment sections and containers designed for the extinguishing materials;
- By changing a pump, equipment, or any other specific aggregate, and by installing or using supplementary measures, which can improve fire extinguishing.

2. The replacement of centrifugal fire pumps filling vacuum systems with the new ones or the improvement of the current ones would result in both the significant upgrade of their technical specifications and the extension of their operating time.

3. Piston pumps with 0,00021 m^3 operating capacity and equipped with a 1,3 kW electric motor starter engine are meant both to improve the performance of the vacuum systems of the used fire vehicles and the save recourses.

4. The impulsive extinguishing technologies have

not been completed yet and need to be further updated and tested. They allow us to use the properties of the extinguishing water more efficiently and to reduce the response time.

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