Research of Gas-Superdisperced Water Compositions for New Installations of Volume Fire Extinguishing

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Abstract. There are presented data concerning new domestic and foreign installations of volume fire extinguishing by means of gas-superdispersed water compositions (GWC). The model of diffusion flame extinguishment with GWC is developed. There are carried out experimental studies of gas impact in GWC on the dispersion of droplets as well as on the effectiveness of fire extinguishing of solid materials and flammable liquids. The advantages and disadvantages of the GWC use are shown. It is revealed that the greatest effect of the use of GWC volumetric method is achieved at the extinguishing the smoldering materials.

1. Introduction
The new fire extinguishing substance - gas-superdispersed water composition (GWC) - is studied for the first time in Russia. Nowadays, both in our country and abroad there is carried out research with the purpose to integrate all advantages of fire extinguishing gas and dispersed water (DW) and at the same time to keep a volume method of fire extinguishing. The use of superdispersed water droplets allows to maintain the cooling effect of GWC for a long time due to slow sedimentation which increases the efficiency of fire extinguishing, mainly when extinguishing smoldering materials.

2. The analysis of technical means for GWC application
The analysis of the scientific and technical documentation [1-7] shows that realization of the volume fire extinguishing by means of DW is rather complicated and mostly impossible. Nowadays, fire extinguishing gases, aerosols or foam of high (rarely of medium) expansion are applied for volume fire extinguishing.

Gas-water compositions (GWC) are new fire extinguishing substances which consist of gas (nitrogen, argon, etc.) and superdispersed water droplets (in this work the droplet dispersion is 10 … 60 microns). Droplets of specified dispersion do not settle for a long time (till 10 minutes) and can accumulate to the volume of the protected relatively leak-proof compartment. At the same time, droplets together with fire extinguishing gas create the medium not sustaining combustion. As a result, the water amount necessary for fire extinguishing can make from 0,3 to 0,6 kg/m³ that is significantly less in comparison with the DW installations. Unlike fire extinguishing gases GWC have the cooling effect both on air indoors and on fire load.
GWC supply by means of automatic extinguishing installations (AEI) provides volume suppression of A and B class fires in accordance with GOST 27331. The volume method of fire suppression essentially distinguishes these installations from DW AEI which extinguish fires only on surface in accordance with SP 5.13130.2009 and GOST P 53288.

In figure 1 there is shown the calculated dependence of the change in specific heat amount absorbed at the evaporation of GWC droplets on the droplet diameter [8]. The graph demonstrates that droplets with diameter less than 90 microns absorb heat actively.

![Figure 1. The dependence of the specific heat amount (W/K m³), absorbed at the evaporation of droplets, on the diameter of droplets d in GWC.](image)

Abroad there is developed an automatic installation for volume gas-water fire extinguishing "Sinorix™ H₂O Gas" which supplies as nitrogen at the standard concentration to the protected compartment as DW with droplet dispersion of about 150 microns. The specified installation (Fig. 2) is certified in Russia.

![Figure 2. «Sinorix™ H₂O Gas».](image)

The pneumoacoustic sprays [9, 10] developed by JSC AKIN allow to receive GWC containing fire extinguishing gas and superdispersed water droplets (10 … 60 microns). The application of GWC of the given dispersion increases both the efficiency of fire extinguishing and the cooling effect in comparison with the analog ("Sinorix™ H₂O Gas"). It allows to reduce the amount of supplied water as well as damage from it. Sprays produced by JSC AKIN (Fig. 3) have resonators that provide generation of superdisperced water flow when disposed to compressed high-speed gas flow at a low
gas pressure. A typical distribution of the droplet diameter in the spray torch is shown in figure 4. When sprays operate, large drops are not formed.

![Figure 3. Pneumoacoustic sprayers by JSC AKIN.](image)

Measurement of droplet dispersion was carried out by means of Malvern Spraytec system. The Spraytec system is based on the method of laser diffraction. It means that scattered by spray drops radiation is registered at different angles using a highly sensitive silicon detector – a photodiode array.

![Figure 4. The typical volume distribution of drop sizes in DW.](image)

Depending on the chosen design of the sprayer it is possible to obtain the necessary spray diagram (Figure 5).

![Figure 5. Spray diagram for different sprayers.](image)
3. Model of diffusion flame extinguishment with GWC

FGBU VNIIPo EMERCOM of Russia and Joint-stock company "Acoustic Institute named after Academician N. N. Andreyev" (JSC AKIN) jointly research GWC to apply it by means of AEI [11-14]. There has been developed physical model of diffusion flame extinguishing with GWC which is based on the following mechanism [12]. Superdispersed water droplets are transported by gas and enter the flame reaction zone under the action of convective flows where droplet evaporation and heat removal from the flame occurs as well as dilution of the reaction zone by gas and water vapor. Water vapor forming inside the flame zone can be considered as "primary" steam influencing the flame.

As a source of the "secondary" steam can be considered zones of the burning substance torch, heated to a high temperature, as well as elements of the test chamber or protected compartment.

The calculated dependences that take into account the influence of "primary" and "secondary" steam on the effect of flaming combustion suppression are arranged. Evaporation of water droplets of diameter \( D_d \) significantly depends both on the heat exchange surface \( S_{hex} \) and the heat source power \( N \). Taking into account the flame height \( H_f \) there are determined the speed of air access to the reaction zone \( W \) as well as the mass airflow \( G_a \). As a result, for combustion in trays with diameter \( d \) there is defined the coefficient \( K \) which is the specific ratio of heat exchange surfaces for the selected power of the heat source and heat power \( N = 1,85 \text{ kW} \) (for a tray of diameter \( d = 50 \text{ mm} \)). The coefficient \( K \) can indirectly characterize the amount of water vapor formed and, consequently, the water involvement in suppression of the given seat of fire. The calculation results are shown in table 1.

| d, mm | N, kW | \( G_a, \text{kg} \cdot \text{s}^{-1} \) | \( W, \text{m} \cdot \text{s}^{-1} \) | \( D_h, \text{micron} \) | \( H_f, \text{m} \) | \( S_{hex}, \text{m}^2 \) | \( K \) |
|------|------|-----------------|-----------------|-----------------|-----------------|-----------------|------|
| 50   | 1,85 | 0,77 \cdot 10^{-3} | 0,027 | 26 | 0,295 | 0,138 | 1 |
| 100  | 7,4  | 2,1 \cdot 10^{-3} | - | 26 | 0,5 | 0,467 | 3,38 |
| 300  | 118,5 | 33,8 \cdot 10^{-3} | 0,086 | 46,4 | 0,68 | 1,92 | 13,9 |
| 500  | 290  | 106 \cdot 10^{-3} | 0,134 | 58 | 0,8 | 3,75 | 27,1 |
| 1000 | 1673,4 | 611 \cdot 10^{-3} | 0,193 | 70 | 1,6 | 15 | 108,7 |

Analysis of the calculation results shows that the change of the tray diameter \( d \) from 300 to 500 mm causes the coefficient \( K \) increase almost twice. It follows that the amount of water vapor may also differ twice which will reduce both the flow rate of nitrogen and water discharge in GWC. Calculations show that at fire suppression the share of superdisperced water can make 20...25 % of the total weight of GWC. During the number of fire tests there was noted that when increasing the tray diameter to 600 mm or more the rate of GWC discharge decreased.

4. Experimental study

In the course of the research there was investigated the influence of the type of fire extinguishing gas (nitrogen, argon and gas composition “Argonit”) on the dispersion of GWC drops as well as on the distribution over the fire chamber volume and the settling of gas-water mixture.

The results of a series of experiments showed that the replacement of nitrogen with argon or composition “Argonit” does not lead to a significant change in the dispersion of droplets in GWC. Figure 6 shows one of the measurement results concerning droplet size distributions in GWC: upper (a) - for argon and lower (b) - for nitrogen.
Uniformity of chamber filling with a misty layer of GWC "nitrogen-DW" is practically not broken in 2.5 minutes after ending the GWC supply. 10 minutes later there is a tiny (about 0.3 m) displacement of the misty layer "nitrogen-DW" in the upward direction (Fig. 7). As for GWC based on argon or "Argonit», the violation of misty layer uniformity occurs much faster.

There were also carried out fire tests which allowed to evaluate the influence of gases (nitrogen, argon, “Argonit”) in GWC on the effectiveness of fire extinguishing. Test results, given in [12], showed that GWC on the base of nitrogen provide suppression of standardized fires (SF) at lower volumes of gas and water. When carrying out each fire test there were recorded all signals from the thermocouples, pressure sensors, flow meters of nitrogen and water as well as from oxygen analyzer with an interval 1-second throughout the whole test by the measurement system and computer.

In order to determine the limit concentrations of nitrogen, at which the suppression effect of A and B class SF stops when supplying GWC, there were conducted more than 200 fire tests. As a SF there were used open burners and open stacks of laths according to GOST R 53288 as well as shielded burners according to GOST R 53280.3 and shielded stacks of laths (bars) in accordance with the method [15, 17]. The fire test method was in compliance with the above mentioned documents. During the tests there was changed the number of sprayers in the fire chamber as well as the design of sprayers while maintaining the dispersion of droplets in the spray torch.

Figure 6. The distribution of droplet sizes in the GWC at the gas pressure of 0.3 MPa on the sprayer (a - argon, b - nitrogen).
Figure 7. Displacement of GWC misty layer «nitrogen-DW» after ending the supply into the fire chamber.

At each series of tests there was changed the concentration of nitrogen supplied to the fire chamber by reducing the time of GWC supply with the sprayer at the constant pressure of components (nitrogen and water). After the FS had been extinguished, the following test was carried out, where the concentration of nitrogen supplied was reduced. A series of tests was stopped if during two or three tests the FS suppression was not reached. The obtained concentration was indicated as the minimum (limit) concentration. There were also carried out separate series of fire tests when only nitrogen (without water) was supplied with the sprayer.

The graph (Figure 8) shows the generalized dependence of the nitrogen concentration on its specific flow rate for several series of tests. The end of the inclined lines corresponds to the minimum nitrogen concentration at the each series of tests when the SF suppression was achieved.

The values of the minimum (boarding) nitrogen concentrations are shown in the graph by horizontal lines: blue (left) - for SF class B and red (right) - for SF class A.

For SF class B (shielded burners when they are placed on three levels throughout the height of the chamber and at free burning for 30 seconds) the minimum nitrogen concentration is:
- when applying nitrogen (without water) - 30.5 % vol.
- when applying GWC - 28 % vol.

For open burners and trays on the chamber floor the minimum nitrogen concentration in GWC is 24 % vol. at free combustion for 60 s (SF class B).

For SF class A (shielded stacks of laths when they are placed on three levels throughout the height of the chamber and at free burning for 360 s) the minimum concentration of nitrogen supplied to GWC is 33.0 % vol. and for open stacks of laths on the chamber floor at free burning time for 180 s - 13.1 %

5. Analysis of results

Fire tests showed that extinguishing shielded SF class A and class B is achieved at bigger volumes of nitrogen in GWC in contrast with open SF suppression. At the same time, the necessary volume of nitrogen in GWC for open SF class A (wooden laths) can be almost three times less than for shielded SF.

Earlier studies of VNIIPo showed [16] that gas expenditure to extinguish the smoldering materials significantly depend on the free burning time of the seat of fire. If this time is 2 or 3 minutes, the extinguishing is achieved at the standard gas concentration for n-heptane according to SP 5.13130. An increase in free burning time for more than 2 or 3 minutes without changing the gas expenditure causes the stochastic result of smoldering material extinguishing. At free burning for more than 6
minutes the suppression of smoldering fire was reached only when the oxygen content in the experimental fire chamber was up to 2.5 % vol. after long period of time.

Figure 8. The dependence of nitrogen concentration (Y, % vol.) on the specific flow rate of nitrogen (X, kg/m^3) in tests where SF suppression is achieved.

It is found that GWC eliminates both flaming combustion and smoldering fire of shielded SF class A at free burning time of 6 minutes and at the supplied nitrogen concentration of 33% vol., i.e. less than the normative nitrogen concentration for n-heptane according to SP 5.13130 (34.6 % vol.).

For SF class B (petrol) the difference between the minimum concentrations during fire tests is much less and the following:
- 16.6 % when comparing shielded and open SF at GWC extinguishing;
- 9 % for shielded SF at GWC or nitrogen extinguishing (without water).

In all cases it is necessary to take into account the cooling effect of superdisperced water in GWC both on the fire load and on the air quality in the protected area. It also contributes to better smoke deposition. After GWC supply the measured residual oxygen in the air of the fire chamber is not less than 13 % vol. that creates an environment suitable for breathing during the evacuation. GWC contains only natural, environmentally friendly ingredients.

Short-term stay of a person in the generated environment does not lead to wet clothes and moisture on the open body surface. After GWC supply excess water can be removed from the room by ventilation or by airing.

6. Conclusions
Thus, the greatest effect of GWC use is achieved at the extinguishment of smoldering materials. According to fire tests it is revealed that extinguishing flammable liquids with GWC can reduce the expenditure of nitrogen only by 9...16 %.

Studies have shown that the GWC keeps the characteristics of both gas and DW so it has a number of advantages that allow to use it in automatic volume fire extinguishing installations.

Installations on the basis of GWC will allow to provide the most effective protection of the following premises:
- a) where the damage as a result of extinguishing agent supply should be excluded, especially in the presence of smoldering materials (e.g. depositories of cultural values, volts of bank values, etc.);
- b) where fire is followed by a considerable heat release in the presence of a large amount of combustible liquids or cable production (e.g., cable structures, motor compartments of sea and river crafts, etc.).
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