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Studying the Hypoxic Media Characteristics for the Protection of Facilities from Fires

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The first method involves the use of nitrogen-oxygen HM in fire extinguishing systems instead of nitrogen. The presence of oxygen in HM increases the volume of fire extinguishing gas. A calculation has been carried out that makes it possible to estimate how many times the amount of gas in the system increases as compared to the nitrogen charge on the back of the residual oxygen concentration in HM.

The second method ensures prevention of fire in the premises. The advantages of this method when applied in fire prevention systems (FPS) were noted.

The main characteristics of HM for FPS is the combustible materials ignition threshold (IT). Methods for determining IT were presented. The limited data on IT hinder the use of FPS.

The results of experimental studies were presented, which replenished the information about IT of a number of materials. Experiments proved that when the temperature in the protected premises drops, the IT of the combustible materials increases. This information provides an opportunity to significantly reduce the cost of FPS to protect industrial cold storage units and other facilities.

"WAGNER Group GmbH" has developed a program for calculating the FPS performance equipment depending on the facility air-tightness, wind load on the facility walls, wind ingress frequency and a number of other parameters.

The safety conditions to use the HM for people are shown.

The research findings can be used in designing FPS and fire extinguishing systems to protect facilities with the help of HM.

Keywords: hypoxic medium, nitrogen, oxygen, ignition threshold, fire extinguishing system, fire prevention system, fire test.

Abbreviations

AGFES – automatic gas fire extinguishing system;
HM – hypoxic medium;
MEC – minimum extinguishing concentration;
IT – ignition threshold;
FPS – fire prevention system.

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I. Introduction

The hypoxic medium (HM) is so named due to a low oxygen content as compared to the air atmosphere. HM is used in fire extinguishing relatively recently; its characteristics and application conditions have been studied only partially [1-4]. This paper addressed the characteristics and conditions of using the nitrogen-based HM, although argon or mixtures based on nitrogen and argon [5] can be used in HM instead of nitrogen.

The oxygen content in the premises, where fire protection is carried out is an important factor that determines the ignition of materials, fire propagation rate and heat generation rate. The decreased oxygen concentration can prevent and/or suppress a fire.

II. Characteristics of the HM to be Used in Fire Extinguishing Systems

The method of fire extinguishing by reducing oxygen concentration has been known for more then50 years. It is used in automatic gas fire extinguishing systems (AGFES), where, for instance, compressed fire extinguishing gas is applied. The method provides for fire detection by means of a fire alarm system (FAS) and subsequent gas supply from the AGFES cylinders through pipelines to the premises. In this case, gas dilutes the premises and reduces oxygen concentration up to the level that is necessary to extinguish a fire.

The findings of studies and experiments in the field of gas fire extinguishing by means of AGFES underly the numerous regulatory documents, for example, ISO 14520-1 [6], NFPA 2001 [7] and SP 485.1311500.2020 [8]. The main characteristics used to design AGFES is the design concentration of fire extinguishing gas, which is calculated as the product of the minimum extinguishing concentration (MEC) and a safety factor. ISO 14520-1 [6] and GOST R 53280.3 [9] establish the requirements for the "cup burner" method of fire testing, based on the results of which the MEC is determined. The method is based on extinguishing the heptane flame in a burner, which is located in a pipe and is surrounded by a gas mixture comprised of air and extinguishing gas. The methods established by ISO 14520-1 [6] and GOST R 53280.3 [9] differ insignificantly.

According to the requirements of ISO 14520-13 [10], nitrogen, which is intended for use in AGFES, must

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contain oxygen of no more than 0.1% by vol. Nitrogen with the specified characteristics is obtained at specialized plants, as a result of separating atmospheric air by cryogenic or other methods.

The disadvantage of using any extinguishing gas is the need to deliver it to the protected facility after the AGFES is triggered in order to restore its serviceability. This disadvantage is especially significant at the facilities, where fires occur relatively often, and at the facilities that are distant from supply depots.

To eliminate this disadvantage, AGFES use HM instead of compressed gas, for example, nitrogen. This allows using technical means that ensure obtaining HM from atmospheric air, directly at the protected facility.

Today, two technologies are used to separate oxygen part from air. Both technologies provide for preliminary air purification from dust, oil, dirt and water vapor. The purified air then enters the apparatus, where the first technology separates oxygen part when air passes through the membrane filters (Fig. 1). The second technology involves the use of an oxygen-trapping sorbent (Fig. 2) Only electric power is required to ensure operation of such devices, whereas the filters must be replaced periodically.

At the apparatus outlet, HM are obtained, the oxygen content in which depends on the volumetric capacity of the technical means. After decreasing the apparatus capacity, it is possible to obtain HM with an oxygen content of less than 1% by vol.

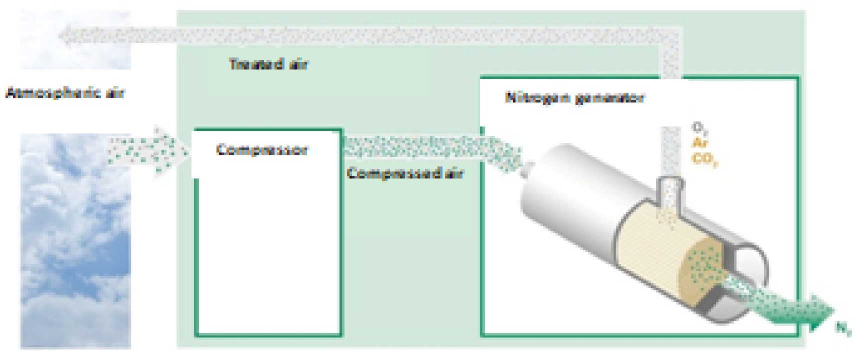

Figure 1: Diagram of technical means for obtaining HM based on the membrane technology

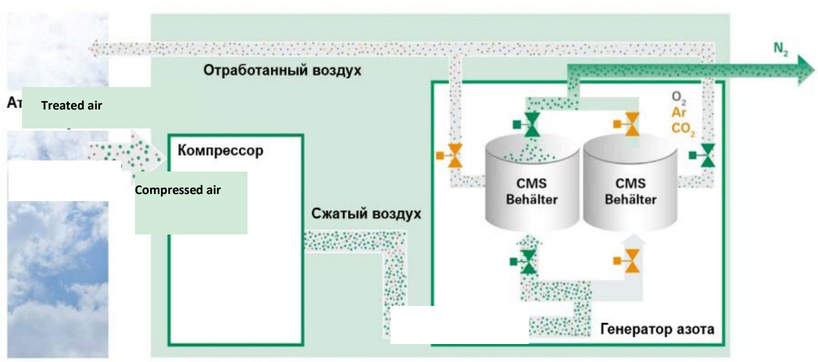

Figure 2: Diagram of technical means for obtaining HM based on the adsorption technology

To extinguish fires, the HM obtained via these technologies is accumulated in a receiver, the volume of which exceeds the volume of nitrogen cylinders in AGFES, because HM contains oxygen. No regulatory documents and calculated dependencies for such fire extinguishing systems are available in the Russian Federation.

The authors of this article have compiled a calculation program that determines the volume of HM to be supplied to the premises to reduce the oxygen concentration in relation to the source value (21% by vol.) up to 13% by vol. With this in mind, an assumption was made that the supply of an elementary volume of HM to the premises leads to an instant and uniform distribution of this HM volume in the atmosphere of the premises. The elementary volume of the resulting atmosphere subsequently leaks out of the premises, and the next elementary volume of HM is then supplied to the premises. Each calculation was carried out with a fixed residual oxygen content in the HM.

Based on the calculation results, a characteristic curve of the HM relative volume contained in AGFES versus the oxygen concentration in HM was plotted (Fig. 3). A relative (dimensionless) volume of HM in AGFES is determined as the ratio of HM volume to nitrogen volume according to ISO 14520-13 [10], which is required to reduce oxygen concentration in the premises from 21% by vol. to 13% by vol.

The calculation results demonstrate that the oxygen content in HM at a concentration of 1% by vol. increases the volume of HM by 6.5% as compared to nitrogen. An increased oxygen concentration in HM by over 2% to 3% by vol. leads to a significant increase in gas volume contained in AGFES, and, consequently, to either elevated gas pressure in the receiver, or to increased diameters of pipelines and fittings. The area of drain openings ensuring a decrease in the room pressure to the atmospheric one when supplying HM is increased as well. The calculation results allow estimating the increased volume of HM charge (amount) in AGFES as compared to the nitrogen charge.

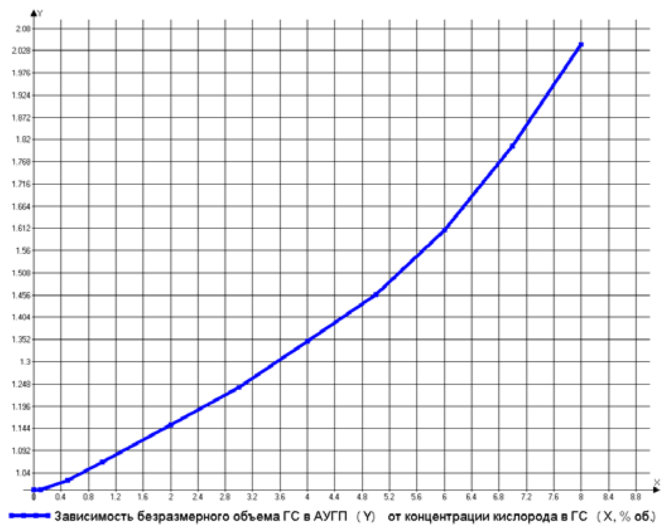

Figure 3: Dependence of the relative volume of HM in AGFES (Y) on the oxygen concentration in HM (X, vol. %)

X - residual oxygen concentration in HM, vol. %.
Y - HM relative volume.

AGFES containing HM traditionally protect process equipment, for example, furnaces for heating and preparing oil for further processing. The oxygen concentration in HM depends on the characteristics of the chosen apparatus and equipment. After supplying HM from receiver, some time is needed to recover the consumed gas, which can vary from several hours to a day. Therefore, if a continuous protection of the facility is needed, the main and standby receivers filled with HM are used.

III. Characteristics of HM to be Used in Fire Prevention Systems

It should be noted that any AGFES, including the one mentioned above that is based on HM, has another substantial drawback - it is triggered after the fire has already occurred and partially destroyed the facility property. The development of a fire leads to the development of hazardous fire factors (smoke, heat), and this allows detecting a fire. This is a time-consuming process. It is followed by a time delay in evacuating people from the premises and the supply of nitrogen or HM for one or two minutes, depending on the AGFES design standards. During the specified time, fire continues to develop and destroys property.

Thus, no damage can be avoided when using any AGFES. WAGNER Group GmbH, Germany, has developed a new method of using HM to eliminate this disadvantage.

The implementation of new method does not require waiting for a fire. The method provides for the supply of HM from air separation apparatus to protected premises and dilution of its atmosphere before a fire occurs. After reaching the required oxygen concentration in the premises, the supply of HM is stopped, and an artificial HM is created, where an ignition does not occur or it quickly goes out even if a combustible material is exposed to ignition source. Conditions are thereby created to prevent a fire. These types of systems are called "fire prevention systems" (FPS).

To date, more than 1000 FPS have been implemented and are being successfully operated, the maximum volume of one protected facility is 3,000,000 m^3.

When the leakage of HM from the premises exceeds the permissible value, gas detectors automatically turn on the supply of HM from apparatus and restore the initial conditions to prevent a fire. The process of supplying HM is performed repeatedly -

throughout the entire service life of the protected facility (Fig. 4).

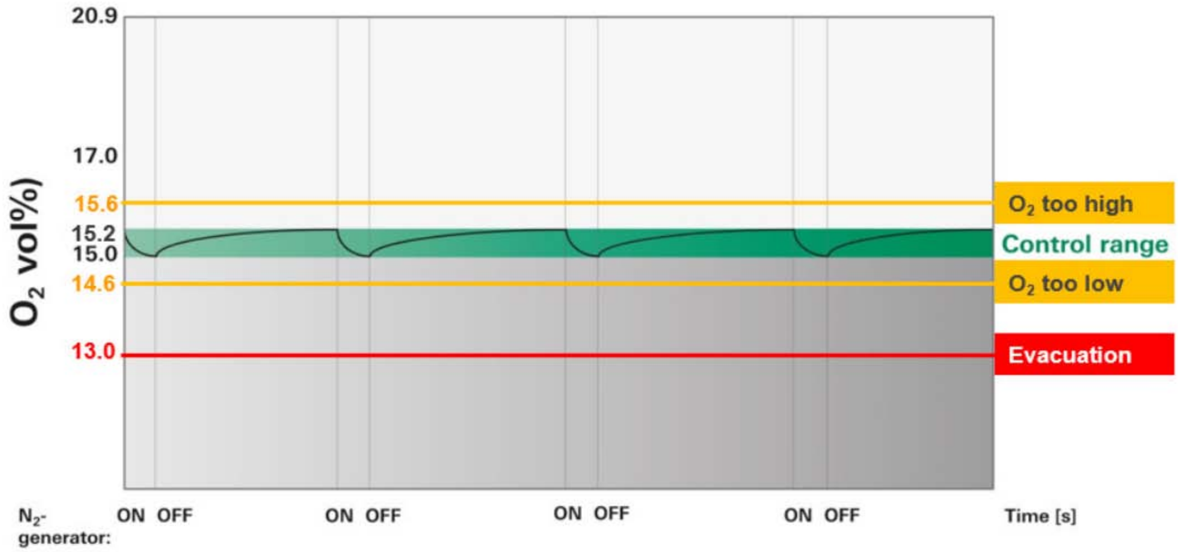

Figure 4: Example of dependence of oxygen concentration in a premises on time

For FPS, an important characteristics is the ignition threshold (IT) of various fire loaded materials in the premises.

According to ISO 20338 [11], for flammable liquids, IT is determined by the "cup burner" method, which is the same as the method for determining the MEC. The difference is that instead of MEC, IT is determined as the limiting oxygen value in the gas mixture flow that extinguishes the burner with a flammable liquid. The design oxygen concentration is calculated as a result of dividing IT by a factor of 1.1.

Experimental determination of IT of solids is carried out according to a separate method established by ISO 20338 [10]. It provides for the placement of a material test item in a fire chamber with a volume of 100 m^3 or 10 m^3, where HM is created at a given oxygen concentration. The sample is ignited with an acetylene burner for at least three minutes, and the burner is then turned off and the flame combustion time is recorded. If the sample combustion duration exceeds one minute, then the experiment is repeated at a reduced oxygen concentration. IT is taken to be equal to oxygen concentration in the chamber according to the results of at least three experiments, where flame combustion of a sample of solid material goes out for the time not exceeding one minute. In this case, the design oxygen concentration according to ISO 20338 [11] is calculated as IT reduced by 0.75% by vol.

IT and design oxygen concentration are the main characteristics for designing FPS. In foreign countries, the FPS is designed according to ISO 20338 [11], FprEN 16750 [12] or VdS 3527 [13], and in Russia - according to the company standard of Wagner-RU LLC, the latter was designed jointly with FGBU VNIIPO EMERCOM of Russia.

Standards [11-13] contain limited information about the IT of solids, which is not enough for designing FPS for multipurpose facilities. Therefore, Wagner-RU LLC, with the participation of FGBU VNIIPO EMERCOM of Russia, have conducted several series of fire tests to replenish the information about IT of various materials, taking into account the real conditions of their use.

The first series of experiments was carried out according to the method established by ISO 20338 [11], involving the materials that are often used at storage and other facilities as a fire load or as combustible construction, finishing or packaging materials. Some of the results of experiments to determine IT are shown in Tables 1 and 2.

Table 1: Ignition threshold of solid materials at a temperature of 20°C

Facility type (example)	Type of combustible material/ mixture of materials	Ignition threshold, O_2, vol. %
Data processing center (DPC)	Poly(methyl methacrylate)/polypropylene (PMMA/PP)	15.9
	ABS plastic	16.0
	Polypropylene (PP)	16.0
	Electronic and printed circuit boards from polyester/PVC	16.0
	PVC cable	16.9
Warehouses/record-keeping offices	Polyurethane foam (foam rubber) T20	14.0
	Polyurethane foam (foam rubber) T25\T30	14.5
	Corrugated fiberboard/cardboard	15.5
	Wrapping polyester film	15.9
	Pallet wood (pallet)	17.0
	Car tyres	18.0
	Ready-made fabric articles (clothes) in boxes on a wooden pallet in a wrapping film	15.5
	Products in cardboard packaging on a wooden pallet, wrapped in polyester film	15.5
	Wrapper rolls	15.9
	Plastic (PP) container	15.9
	Grain mixture in three-layer paper bags	17.5
	Tobacco	13.0
	Paper	15.0
	Cotton	16.0
	Linum	16.0
	Silk	16.0
	Rayon	16.0
	Natural wool	16.0
	Polyamide	16.0
	Copper-ammonia fiber	16.0
	65% polyester + 35% cotton	16.0

A separate series of experiments studied the effect of a reduced room temperature on IT. The experimental procedure complied with ISO 20338 [11], whereas the temperature of HM of minus 22°C was set in the chamber. The samples shown in Table 2 were used as combustible materials. The experimental results demonstrated that a decrease in the HM temperature causes an increased IT. For example, for corrugated fiberboard and cardboard at 20°C, the IT is 15.5% by vol., and at minus 22°C - 16.5% by vol. The obtained experimental results allow using FPS with industrial cold storage units and similar units at higher designoxygen concentrations, which significantly reduces the cost of equipment and electric power.

Table 2: Ignition threshold of solid materials at a temperature of minus 20°C

Facility type (example)	Type of combustible material/ mixture of materials	Ignition threshold, O_2, vol. %
Cold-storage warehouses (minus 22°C)	Single face corrugated fiberboard/cardboard	16.5
	Double face corrugated fiberboard	17.5
	Wrapping polyester film	16.5
	Plastic pallets	17.0
	Polypropylene boxes	17.5
	Packagings with frozen food in a double face corrugated cardboard	17.9

IT represents the main source parameter for choosing the FPS equipment. The performance of apparatus and equipment is an important characteristics, which is able to ensure the design oxygen concentrations over time, taking into account the facility operating conditions. The target performance depends on many factors: volume, height and tightness of the premises, number of walls open for wind ingress, average wind speed, temperatures inside and outside the premises, and a number of other factors.

The premises air-tightness is confirmed by measurements according to the method established by ISO 14520-1 [6] and GOST 31167 [14].

Taking into account these parameters, WAGNER Group GmbH has developed "Oxy-Calc" software product, which calculates the performance of devices and equipment contained in FPS. Calculation results are as follows:

- Equipment performance (m^3/h) at a given oxygen concentration in the HM at the outlet of the air separation apparatus, whereas the latter should be no more than 10% by vol. according to the requirements of ISO 20338 [11];
- Equipment power consumption (average and maximum values of kW/day).

Natural constraints for using the FPS are high requirements for the premises air tightness, the equipment power supply reliability, the lack of air exchange in the heating system, and the absence of permanent workplaces at the facility.

HM is suitable for people without self-contained breathing apparatus, at oxygen concentrations exceeding 13% by vol. The frequency and duration of staying of people in the HM determine the medical requirements, which differ depending on the regulatory safety provisions adopted in a particular country. General safety requirements are specified in ISO 20338 [11].

Safety requirements indicate that periodic staying of people in a hypoxic atmosphere should not be associated with heavy physical work - carrying loads, etc. It is also forbidden to carry out work wearing breathing filter equipment (gas masks, etc.).

IV. Conclusion

The nitrogen-oxygen HM have a number of advantages, and they can be used for fire protection of relatively sealed facilities. HM can be effectively used both in fire extinguishing systems and in fire prevention systems.

A calculation has been carried out, the results of which make it possible to evaluate the effect of the residual oxygen concentration in HM on the increased volume of the fire extinguishing gas in AGFES, when comparing HM with pure nitrogen.

The advantages of FPS as compared to AGFES were demonstrated. The results of experimental studies are presented, which replenish the source data for designing the FPS.

Experimental data on raising the ignition threshold of materials when room temperature is decreased allow reducing the cost of FPS to protect industrial cold storage units and similar facilities.

It was noted that HM at an oxygen concentration of above 13% by vol. is suitable for periodic staying of humans, in accordance with research results and current safety requirements [11-17].

The research results can be used in designing FPS and fire extinguishing systems to protect facilities using HM.

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