THE AERODYNAMIC STAND FOR RESEARCH OF ICE-FORMING CHARACTERISTICS OF REAGENTS

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Abstract

The installation developed for operative research of efficiency of ice-forming pyrotechnical compositions used for suppression of hailfall is presented. In the work, we describe the variant based on a small aerodynamic stand which makes it possible to control efficiency of ice-formation of full-size generators in the on-line mode and to study nucleation activity of new reagents in dynamic conditions. Elements of the developed technology for research of the pyrotechnic compositions used in practice of active influences of hail-suppression services are described. Experimental data for one of the pyrotechnic compositions based on silver iodide (AgI) are presented.

1. Introduction

Ice-forming reagents are effective means of artificial crystallization of supercooled clouds and fog, which determines their extensive use in practice of active influences (AIs) in many countries, including the Republic of Moldova (RM). The ice-forming aerosol based on applied reagents is dispersed into cloudy atmosphere by means of special generators (rockets, pyrocartridges, ground-based and airborne devices); their application is determined by technologies and tasks of AIs [1].

The present-day ice-forming pyrotechnical compositions based on silver iodide (AgI), which are used in antihail rockets for impacts on hail-hazardous clouds in the RM, yield more than 10^{13} g^{-1} of active ice-formation particles at a temperature of the cloud (simulated) environment of -10°C. In the RM, large-scale works on protection of agricultural crops from hail damage are carried out on a regular basis (in 2009 the area of territories under protection will be 1.4 mln ha); thousands of antihail rockets are utilized for these purposes every year. All this has resulted in a necessity to organize a special laboratory for the study of properties and for the control of quality of applied ice-forming pyrotechnic compositions. Data on such their characteristics as ice-formation threshold and active nuclei yield in the temperature range 6 -12°C are the most important predictors of the AI techniques confirmed by respective theoretical evidences [2]. Another reason of the laboratory foundation was a necessity to attest quality of Alazan -6 antihail rockets that are assembled in the RM. In addition, the practical operation of antihail rockets is associated with their occurrence in high-humidity conditions and exposure to solar radiation, which can also have an adverse effect on properties of applied reagents; this can negatively affect estimations of results of AIs and the technology applied in the RM.

Results of the studies concerned with the problems of development of AI technologies show that efficiency of impact facilities depends on many factors: content of ice-forming substance in the composition (e.g., AgI, PbI_2, CuS, and organic substances), applied pyrotechnics, design parameters of aerosol generators, etc. [3]. Moreover, the efficiency of pyrotechnic generators depends on observance of technological conditions of their fabrication as well as on period and conditions of storage. Herein, a tendency of efficiency decreasing, sometimes by orders of magnitude, can be observed [4].

Therefore, it is necessary to pay particular attention to the problems of testing of reagents and compliance of their quality with requirements of the AI technology. It is obvious that, for experimental measurements of ice-forming activity of reagents and their properties, as well as impact facilities, the problems of testing procedure and reproducibility of results within reasonable errors play the most crucial role.

The aerodynamic stand allows testing any type of pyrotechnical generators of ice-forming aerosols, which are used at present in both operations on protection of agricultural crops from hail damage and in operations (experiments) on modification of precipitation.

It should be noted that, despite the considerable number of countries implementing projects on AIs, laboratories of this level are infrequent in Europe (Russia, Bulgaria).

2. The technique for the determination of efficiency of ice-forming aerosol generators

The necessity to test the activity of reagents in dynamic conditions is based on the numerical model of thermocondensation aerosol formation, which was developed in the late seventies of the past century; it allowed revealing basic process parameters that determine size of formed particles. On the basis of these conclusions, it was proved that, in experimental techniques for determination of ice-formation efficiency, precisely full-size generators in aerodynamic conditions approximated at the most to real AIs must be applied. In order to create these conditions, techniques based on the use of aerodynamic stands with different characteristics and different sizes were developed. The technique developed in the NPO Taifun (Russia) is widely known; it allowed studying characteristics of ice-forming efficiency of full-size aerosol generators at the air-flow velocities up to 100 m/s [5, 6]. The data obtained by virtue of this stand differed significantly from those obtained for micromodel samples of the generators in static conditions of their operation (not involving airflow). The greatest differences were observed in the supercooling temperature range above 10°C [7]. The high energy consumption of the installation and the structural complexity restrict its mass production and application for affordable testing of reagents.

Small aerodynamic installations are known to be applied in these studies; they allow generating velocities of airflow of micromodel generators up to 300 m/s [8]. However, pointed comments with respect to the modeling scale and errors attributed to it have not resulted in the development of the given direction.

An original factor of capabilities of the stand designed in the RM is the availability of a horizontal aerodynamic tube (HAT), in which conditions of the formation of ice-forming aerosol particles are simulated for operation of such its full-size generators as antihail rockets. For example, the length of an Alazan -6 rocket is 1400 mm; the caliber is 82 mm. Other similar generators applied for AI purposes in Europe (rockets Loza (Bulgaria) and AIPHa-G (Romania)) do not exceed the mentioned characteristics of the Alazan -6 rocket.

The method for the determination of efficiency of ice-forming aerosol generators consists in the measurement of number of ice crystals formed upon introduction of a specified amount of aerosol into a supercooled water fog; the aerosol is generated in the course of operation of the generator under testing in a high-velocity air flow. The model fog is generated in a cloud chamber, being cooled to a specified experiment temperature, by means of a jet of hot water vapor or by mechanical dispersion of water.

Number of active ice-formation nuclei appeared in the model medium (water vapor, droplets) is estimated by number of ice crystals precipitated per unit area of the cloud-chamber floor, where special devices are installed for their counting. In the capacity of these devices, glass plates are used; they are covered with a polymerizing film; after solidification, it preserves imprints (replicas) of precipitated ice crystals. Microthermostats are also applied; they preserve ice crystals in the course of the time required for their counting by means of an optical microscope.

The range of measured values of active particle yield depends on technique of registration of ice crystals, air-flow rate in the aerodynamic tube, and weight of the ice-forming substance in the process of operation of its generator. For the HAT, the value range is from 10^8 to 10^{18} g^{-1}. As the upper limit, we can consider the theoretical yield of active particles for the most active ice-forming substance - silver iodide. At a measurement temperature of -15°C it amounts to 10^{19} g^{-1}.

3. The aerodynamic stand for the testing of ice-forming aerosols

The aerodynamic stand comprises the following complex of basic equipment:

1. Horizontal aerodynamic tube with an Eiffel chamber. The diameter of the HAT d = 330 mm; the length L = 9 m. In the Eiffel chamber (d = 500 mm, L = 3 m), a device for taking samples of ice-forming aerosol from the air flow is placed. The general arrangement of the aerodynamic tube in two project views is shown in Figs. 1 and 2. In the front part of the aerodynamic tube, before the Eiffel chamber, an access panel is arranged for the installation of full-size generators of ice-forming aerosols and large fragments of samples of pyrotechnical compositions with reagent. The flow velocity (m/s) in the HAT is determined by the method of measurement of gas dynamic pressure (P_d) by a Pitot s tube :

$P_d = P_t - P_{st}$, where P_t is the total gas pressure, Pa; P_{st} is the static gas pressure. Then, the gas velocity is calculated by the formula

$$v = \sqrt{\frac{2P_d}{\rho}}$$

where ρ is the gas density under operation conditions, kg/m^3.

Fig. 1. A fragment of the HAT.

Fig. 2. A fragment of the HAT with a system for sampling and dilution of aerosol.

The dynamic gas pressure is calculated by the formula: $P_d = \rho \times b \times K_t$, where p is the micromanometer scale reading, Pa; b is the coefficient depending on pitch angle of the micromanometer measuring tube; K_t is the pressure tube coefficient determined under its metrological certification. For the pressure tube applied in the design of the HAT, K_t is 0.3÷0.55.

2. The system of sampling and dilution of aerosol. The system of sampling and dilution allows representative taking samples of the aerosol generated by a generator in air flow of the HAT. The intake is placed in the Eiffel chamber; it allows continuous sampling of a part of the air flow with the aerosol under study from the HAT. With a view to prevent losses of aerosol particles, the flow velocity in the intake main is settled not less than 5 m/s. A branch flow can be diluted with pure air, which has passed through a filter, in a ratio from 1 to 100. For the measurements, aerosol is taken from a branch flow and introduced into a cloud mixing chamber. In case of necessity, the taken sample is diluted in special stills with V = 125 and 1000 l.

3. The cloud mixing chamber. The determination of ice-forming activity of reagents (their aerosols) is carried out in a mixing chamber with a working volume of 1200 l. The mixing chamber is prepared on the basis of an ILKA KTLK 1250 climate chamber. The general arrangement of the mixing chamber and its working volume, where a supercooled cloud environment (model water fog) is created, are shown in Fig. 3.

Fig. 3. Cloud chamber.

In the upper part of the cloud chamber, a lighting unit is installed; it forms a beam of light for visual observation of the process of formation of fog, variation in its density, and appearance of ice crystals.

On the working table inside the chamber, on its floor, thermostats are placed; ice crystals formed in cold fog on particles of aerosol under testing are precipitated on mirror surface of the thermostats.

The accuracy of temperature measurement in the chamber working volume is ±0.1°C.

For the experiment (measurement) temperature, we take the temperature settled in the chamber working volume after the formation of fog in it, before the aerosol sample introduction.

The lifetime of vapor fog in the chamber at the initial water content 1÷2 g/m^3 is 2÷3 min.

Fog in the cloud chamber is generated by the condensation of a hot water vapor being introduced into a cooled volume.

The activation of samples of ice-forming aerosol is carried out in the chamber at specified temperature levels up to T = -20°C.

For the determination of the yield of active particles of ice formation according to this technique, it is necessary to take into account a number of factors, ignoring of which can significantly distort obtained results:

- availability of significant temperature gradients in the chamber working volume;
- inhomogeneity of water content of supercooled fog;
- run-to-run reproducibility of fog parameters;
- local supersaturation of water vapor upon introduction of aerosol in the chamber;
- coagulation of aerosol particles in the process of obtaining and introduction into the chamber, their precipitation on chamber walls, injector, and feeding hoses.

The error due to the influence of temperature gradients in the chamber working volume at the experiment temperature -10°C (in the center of the chamber) for such highly active reagents as silver iodide is on the order of 1.5%. The error increases when measurements are carried out at higher temperatures. Here, the particle yield increases rapidly with decreasing temperature and, at a temperature of -5°C, it can lead to total overstatement of measurement results by +25%.

The experimental studies described in [9] afford grounds to consider that the errors due to the influence of fog water content in the range 0.4÷3 g/m^3 stay within the spread of experimental data.

The estimation of accidental errors of measurements has shown that the error of a separate measurement is ±15% in the temperature range -10   20°C and ±30% at the fog temperature -5°C.

4. The device for registration and counting of ice crystals. The determination of concentration of formed ice crystals according to the developed technique consists in the objective registration of ice particles (crystals) formed with participation of reagent aerosol; it involves the counting of their number in the microthermostats installed on the chamber floor (Fig. 4). The quantity of the microthermostats is determined by tasks of concrete experiment.

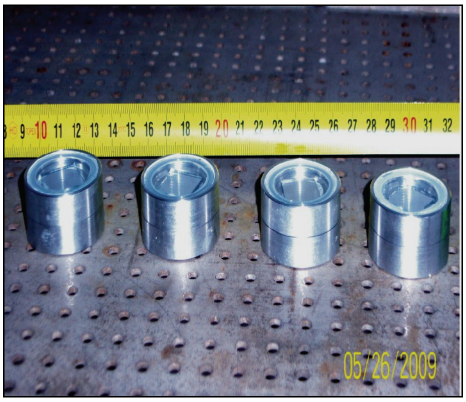

Fig. 4. Microthermostats.

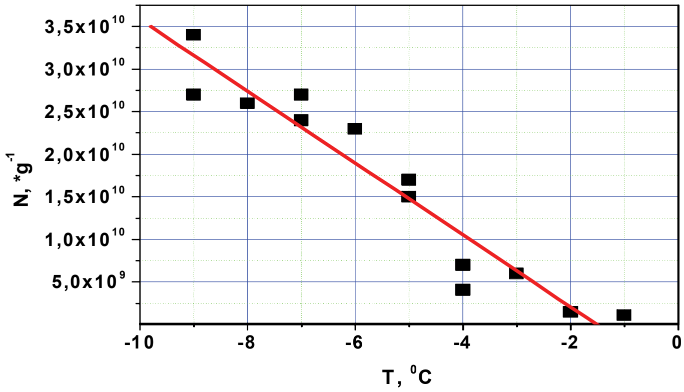

Fig. 5. Temperature dependence of the yield of active particles of a pyrotechnic composition of antihail rockets.

The duration of one measurement (experiment) on the aerodynamic stand with respect to the measurement of the yield of active particles of ice formation at a set temperature is 30÷40 min.

On the basis of the designed aerodynamic stand and developed procedure of testing of ice-forming pyrotechnic compositions, there were carried out experiments on the determination of practical yield of active particles of a pyrotechnic composition for one of the series of antihail rockets, which were used for active influences on hail-forming processes by the *Special Service on Active Influences on Hydrometeorological Processes of the Republic of Moldova* in 2003 (Fig. 5). The analysis shows that obtained results are in a good agreement with the results obtained for this composition in other laboratories of the kind.

4. Conclusions

An installation has been designed, the nodal element of which is an aerodynamic tube, in which, in laboratory conditions, it is possible to simulate the generation of an ice-forming aerosol on approximation to the flight of an antihail rocket in the instant of seeding of a hail-hazardous cloud.

The tests carried out for various pyrotechnic compositions applied in practice of AIs on hail processes in the RM by the Special Service on Active Influences on Hydrometeorological Processes of the Republic of Moldova have shown that the designed installation and the developed procedure of testing make it possible to study, with satisfactory accuracy, the yield of ice-forming nuclei of currently available pyrotechnic compositions and their generators.

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