A New Approach to the Testing of Ice-Forming Aerosols in Cloud Environments

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***Abstract* — The elaborated method allows tracking the dynamics of the process in climate chamber under impact of the ice-forming reagent. Simultaneous registration of cloud transmittance and recording of the ice forming process gives us an integral picture of AgI reagent effect on testing cloud. In this study we find a positive correlation between testing cloud transmission and ice particle formation. We showed that count of ice particles and determination of its density and size is possible directly in climate chamber as well as dynamics of particles deposition.**

***Key Words* — AgI–based ice-nucleating reagent, cloud-chamber, imaging methods.**

I. INTRODUCTION

In order to obtain accurate information about the efficiency of the pyrotechnic compositions used for active impacts on atmospheric processes, it is necessary to carry out a direct simulation of the process with respect to all the main parameters that determine the conditions for the formation of ice-forming particles, their dispersion and structural properties, and thermodynamic conditions of their application [1]. The conditions of motion of a real rocket generator in the air during the seeding of hail-hazardous cloud can be successfully simulated under laboratory conditions. This approach is most appropriately met by a technique based on the use of a ***horizontal aerodynamic tube***, which provides reliable information on the dispersion and ice-forming characteristics of the aerosols generated during its motion in the atmosphere.

Quantitative examinations of ice-forming reagents are based on measurements of the dimensions and number density of aerosol particles. An extensive review of different methods of the aerosol parameter measurements was written by Huimin Liu [2]. The characterization of small aerosol particles in situ by ***optical methods*** is a persistent objective in applied purposes for climate modeling under laboratory conditions. Since the optical methods are not intrusive and do not create any disturbance to the aerosol pattern, they may be compatible with most of existing climate modeling chambers. In imaging optical methods, such as photography, high-speed videography, and holography, aerosol droplets are visualized at the time when they pass through the measurement zone.

The data handling in imaging methods is slow, but it is possible to solve this problem by an ***automated analysis*** of images. The main problems of ***imaging methods*** are the limitation of the number of samples in the recording volume and droplet number density. In addition, the working distance is also limited, and the sample volume is a function of droplet diameter; that is, high-quality optics and windows are required. The charged coupled device (CCD) detectors are widely used to record the droplet pattern digitally followed by data processing, which is obligatory needed for the analysis of obtained results.

Optical methods suitable to study reagent action can be divided into point diagnostics versus imaging techniques and, further, into methods utilizing external illumination versus passive methods [3]. The methods do not use additional light sources to detect the particles. The recent development of CCD cameras of reasonable cost and yet sufficient sensitivity and time resolution make these instruments very attractive for on-line monitoring purposes, especially in aerosol based applications where simple-to-use and rugged instruments are favorable. The possibility to obtain a visual overview of the aerosol in combination with quantitative evaluation of spray particle parameters underlines the attractiveness of imaging methods in comparison to measurement techniques, which provide essentially only point information. The strength of imaging lies in its capability to submit an overall indication of anomalies in the spray pattern, which could be misinterpreted or not understood at all by point diagnostics. The integrated information from an extended region of the aerosol action gives a more reliable indication of the trend of operational parameters than a measurement from one point only. For these reasons, and due to their relative technical simplicity and ease of use, the CCD imaging methods seem to have significant potential for process optimization and for continuous process monitoring during experiment.

II. EXPERIMENT

The optical methods most fully correspond to the purposes of ice-forming reagent characterization in a climate chamber under conditions that are maximally approximated to real ones. The development of a custom-built optical measurement system is a preferable decision, which allows us to combine our climate chamber with the required aerosol characterization method.

A. Design of techniques for testing aerosols.

The optical methods are employed for the operative measurement of aerosol parameters directly in the cloud chamber. The optic system is adjusted according to specific parameters of aerosol forming reagents. The existing imprint method was used for the calibration of the optical method.

B. Data acquisition, processing and analyzing.

Experimental data acquisition and processing was organized on the base of a personal computer (PC). The specialized automation software was developed and modified during stage implementation to experimental data analysis. The main focus of data analysis was on the determination of dynamics of the physical processes in cloud chamber under impact of reagent. Also we pay attention on the determination of the number of nucleation centers and their size distribution. The examination of this phenomenon is very important not only for practical purposes for the hail prevention service, but also for a better understanding of the processes of hail formation on the whole.

The experimental complex of laboratory equipment was created for the assessment of ice crystals productivity per gram pyrotechnic mixture. The investigation of dynamics of cloud dissipation under ice forming reagent impact was performed on home-built nephelometer system [4]. The dynamics of atmosphere conditions were determined by registration of optical transmittance of a monochromic laser beam (green 532 nm) through the allocated volume of the testing chamber. The aerodynamic stand makes it possible to test any type of full-size pyrotechnical generators of ice-forming aerosols that are currently used both in procedures on the protection of agricultural crops from hail damage and in procedures (experimental) intended on the modification of precipitation.

The measurement system was supplemented by damp-proof camera equipped by microscope lens. The window of microscope was situated on the bottom of climate chamber on the same level as glass patterns used in imprint method. Registration of images after the seeding of model cloud process was taken directly during deposition process in cloud-chamber.

Thus, we are able to record transmittance of tested cloud simultaneously with imaging of deposition process of generated ice-particles. The system time was used for synchronization of recorded data.

Our microscopic imaging system was calibrated with standard micro scale 10 µm. We estimate errors of measurement due to small field of view of micro lens and a small number of registered particles as close to 100%.

We estimated also life time of cloud in our climate chamber before experiment with ice-forming reagent. The fog dissipation process was registered without action of ice-forming reagent and shown on Fig. 3 (c) and Fig. 4 (3, 3'). We have determined time frame for experiment with reagent in climate chamber from cloud life time.

The test experiment on our stand was performed with well-known AgI-based reagent used in anti-hail rocket "LOZA". The efficiency and yield of pyrotechnic compositions was determined in the temperature interval corresponding to cold layers of clouds (-6 to -20ºC). The dimensions and number of generated particles were determined under the method of imprints and were compared with data obtained directly from cloud camera.

III. RESULTS

Figures 1 and 2 show impact of low and high concentration of ice-forming reagent on testing cold cloud simulated in climate chamber at temperature -11ºC. The fog generator forms cloud which is stable during 6 min and slowly dissipate during next 15 min. The ice-forming aerosol was produced in full-size rocket aerosol generator and was

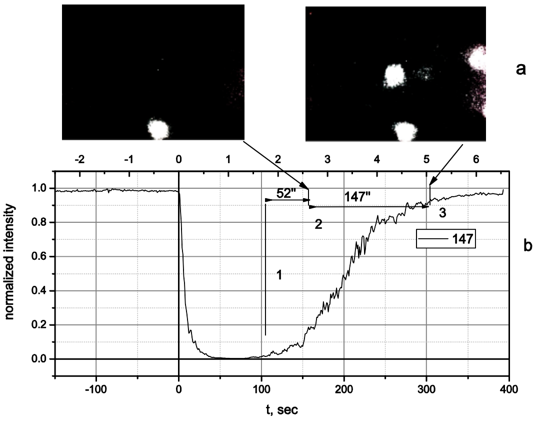

Fig.1. Microphotograph of first ice-particles and final picture of ice-particles deposition under impact of reagent (a). Time diagram (b) of transmission of test cloud under impact of reagent. Marks denote time of: 1 - introduction of reagent, 2 - first ice particle deposition, 3 - end of deposition. Low reagent concentration.

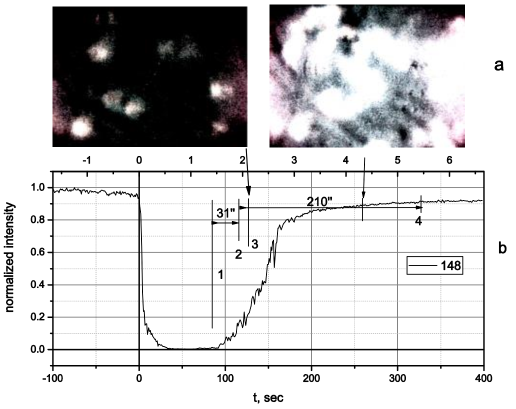

Fig.2. Microphotograph of first ice-particles and final picture of ice-particles deposition under impact of reagent (a). Time diagram (b) of transmission of test cloud under impact of reagent. Marks denote time of: 1 - introduction of reagent, 2 - first ice particle deposition, 3 – intermediate state, 4-end of deposition. High reagent concentration.

introduced in climate chamber after homogenization of testing cloud ((1) on Fig.1 and 2).

Under cloudy conditions, it is more energy-efficient to first form super cooled droplets and as a secondary product ice crystals form of the heterogeneous freezing of those super cooled droplets. The nucleus form of ice crystals was developed as well as its forms of growth considering the interaction with the three neighbors of the ice crystal.

From our time diagrams we can define next stages: (1) Fast cloud (fog) generation about 10 sec and its homogenization during 30 sec; (2) Ice nucleation on AgI particles and their deposition accompanied by increasing of transmittance of cloud.

Microscopic camera captures first particle 30-50 seconds after introduction of ice-forming reagent in climate chamber ((2) on Fig.1 and 2). The deposition of ice particles lasts 2.5-3.5 min. We exploited the high-contrast imaging mode for easier counting of ice particles. The number of ice particles per unit of area of microscope can be directly compared with patterns prepared for imprint method and used for calculation of the efficiency of tested reagent. The high contrast mode allows us to estimate particles dimension as 50-70 μm. But measurement of definite size and calculation of size distribution remains inaccessible.

On Fig. 3 we present the deposition of ice particles as scatter graph. The colored squares correspond to events of deposition fixed by camera and their positions on graph correspond to number of events. Thus we can estimate deposition time relatively to transmittance of cloud. The main number of particles landed before significant changes in transparency of cloud for impact of 16-fold diluted aerosol (low reagent concentration). When in case high aerosol concentration we observe that atmosphere in chamber becomes transparent before deposition process. The difference we can explain on the assumption of rates of the processes. The ice forming is "slow" process consisting from nucleation, growth of embryos and following deposition. The transmittance reacts "immediately" on changes in atmosphere of climate camera. The aerosol of high concentration forms ice particles that accompanied by increasing of transparency and after that ice particles achieve windows of microscope. In case of low aerosol concentration the number of nuclei is not enough to clear atmosphere, i.e. fog density was too high for small nucleus number of diluted aerosol.

Thus, in case of impact of aerosol with high concentration the time diagram of atmosphere transmittance reliably reflects ice nucleation process. From the time shift between transmittance and deposition (1) on Fig. 3(a) we can define deposition time of ice particles with mean dimension about 50 μm.

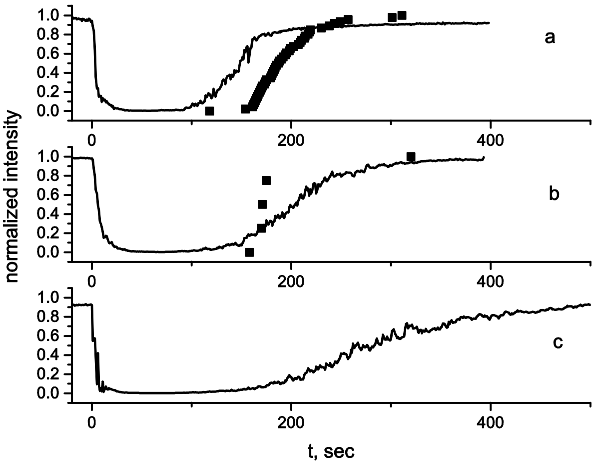

Fig.3. Time dependence of cloud transmittance (a) under impact of high reagent concentration, (b) 16-fold reagent, (c) dissipation of cloud in chamber without impact of reagent. Deposition of ice-particles is marked by squares.

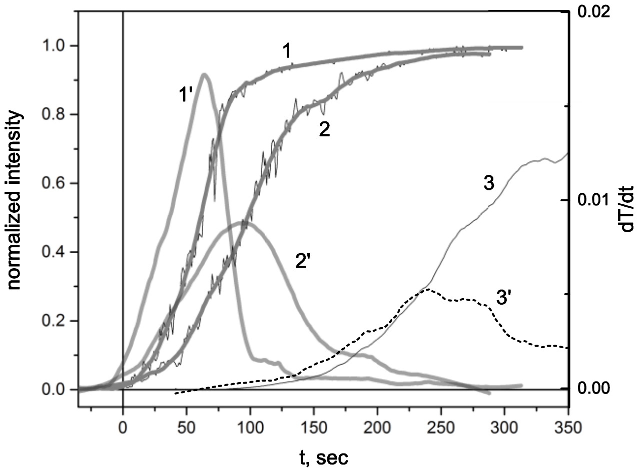

Fig.4. Time diagrams of transmittance of testing cloud during impact of high (1) and low (2) reagent concentration. Curves 1' and 2' are derivatives of corresponding processes. Curves 3 and 3' are transmittance and its derivative for free dissipation of cloud.

We compared impact of ice-forming aerosols with different concentration on transmittance of tested atmosphere on Fig.4. The moment of aerosol introducing was chose as zero. The mechanism of interaction of diluted aerosol with cloud is more complicating (curves 2 and 2'). The influence of cloud life time intervenes on tail transmittance characteristics only (curves 3 and 3'). We can allocate three segments with different slope on curve 2. First one is related to ice particle deposition as on curve 1. Two residual parts are related probably with interplay between interaction of cloud with reagent and diffusion process in chamber.

CONCLUSION

We demonstrate the efficiency of method for investigation of testing cloud under impact of ice nucleation reagent. Automation of measurement system allows us recording and processing laser beam transmission and imaging of ice particles formation.

The elaborated method allows tracking the dynamics of the process in climate chamber and fast calculation of cloud parameters and ice-forming process. Simultaneous registration of cloud transmission and ice forming process gives us more integrate picture of ice-forming reagent impact on testing cloud. In this study we find a positive correlation between testing cloud transmission and ice particle formation. We showed that count of ice particles and determination of its density and size is possible directly in climate chamber as well as dynamics of particles deposition.

The some shortcomings were detected during implementation of elaborated technique. First problem is related to processing of micro photos of deposited particles. Home-build camera equipped by micro lens has low resolution and small field of view, whereas the used camera is fast enough for imaging ice-forming process. We can determine reliably only number of particles and time of registration. Our system allows us determine mean size of particles but measurements of definite size and calculation of size distribution remains inaccessible.

The second problem is stability of cloud and uncertainty initial cloud parameters. The cloud density and it stability does not influence directly on determination of ice-forming reagent efficiency. It should be taken into account for determination of parameters of laser beam propagation through a testing cloud.

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