An Airborne Generator of Metaldehyde Smoke

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(Manuscript received 17 February 1967, in revised form 14 June 1967)

ABSTRACT

A high-output airborne metaldehyde smoke generator was designed for cloud seeding purposes and tested on the ground and in cumulus clouds.

The condensation method was employed for smoke production. Hot exhaust gas from the aircraft engine was diluted with air and used as the carrier gas for metaldehyde powder to evaporate and recondense. An output of 10^{12} nuclei sec^{-1} was estimated, effective at −5C.

1. Introduction

Metaldehyde, $(CH_3CHO)_4$, a cyclic tetramer of acetaldehyde, is one of the common organic compounds. The excellent ice-nucleating ability of metaldehyde was found by the present author (1963). The ice nucleation takes place as high as −1C and the material possesses some suitable characteristics for cloud seeding application. Since then, a series of systematic studies has been carried out from general basic problems towards application, including building and testing of a small smoke generator (Fukuta, 1965; Fukuta *et al.*, 1966). With the test generator, a high efficiency was achieved at the warmer regions of subzero temperatures. Considering a peak of ice crystal growth rate recently reported in this warm region around −4C by Hallett (1965) and Todd (1964), the possibility of modifying modestly supercooled clouds with such effective nuclei as metaldehyde appears attractive.

Prior to this work, there were some cloud seeding experiments with other organic ice nuclei. Phloroglucinol powder, the solution and the suspension, were seeded from an airplane in wintertime layer clouds (Braham, 1963) and some relatively weak effects were observed. Knollenberg (1966) reported on cloud seeding with urea powder. Each crystal of this material cools itself when partially dissolved in water, presumably helping ice nucleation; however, smoke particles prepared by condensation of the vapor were reported to be ineffective (Langer *et al.*, 1963).

For practical cloud seeding, a large number of ice nuclei are required, as pointed out elsewhere (Fukuta, 1966), and only the condensation method fulfills this requirement. The condensation method allows material in the vapor phase to be quenched to form fine particles.

In-cloud seeding minimizes two disadvantages of metaldehyde—coagulation and evaporation of the smoke particles. Thus, it is able to provide a higher yield of ice nuclei at warmer temperatures than silver iodide when a jet-mixing-type of condensation method is employed for smoke generation.

For these reasons, an airborne metaldehyde generator was built and tested in clouds.

2. Airborne metaldehyde smoke generator

For effective production of smoke, metaldehyde must evaporate into the carrier gas as quickly as possible, and as soon as it has evaporated, it must be quenched by turbulent mixing with cold air. Keeping the vapor at high temperature will result in its thermal decomposition, or depolymerization, into paraldehyde or acetaldehyde. The longer the duration of high temperature, or the higher the temperature, the more it decomposes. Decomposition will be complete if the vapor catches fire or passes through flame.

Since the exhaust gas of an automobile engine does not appreciably harm the activity of metaldehyde smoke (Fukuta *et al.*, 1966), exhaust gas from the aircraft engine, diluted with cold air, was used as the carrier gas for metaldehyde vapor.

In order to reduce the total weight of the smoke generator, metaldehyde powder mixed with 7% Cab-O-Sil[1] to fluidify it is fed directly into the hot carrier gas. Although the metaldehyde crystal itself has a density of 1.27 gm cm^{-3}, that of the powder is only about 0.15 gm cm^{-3} when mixed with the Cab-O-Sil. The cost of metaldehyde is \$2.00 kg^{-1} in 55-kg drums.[2] Thus, it is about one-fortieth the cost of regular 2% AgI-KI-acetone solution containing the same weight of silver iodide.

In seeding from airplanes, the aircraft costs and associated operational expenses may far exceed the cost of the seeding material. Nevertheless, the "cost

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[1] Obtained from Cabot Corporation, 125 High St., Boston, Mass. 02110 (equivalent to Aerosil, i.e., very fine particles of silica).

[2] Commercial Solvent Co., 260 Madison Ave., New York, N. Y. 10016.

efficiency," the nuclei output per cost of seeding operation, is an important quantity for consideration in the engineering of seeding methods. The "cost efficiency" of metaldehyde is quite high in comparison to AgI, at least for the relatively warm activation temperatures.

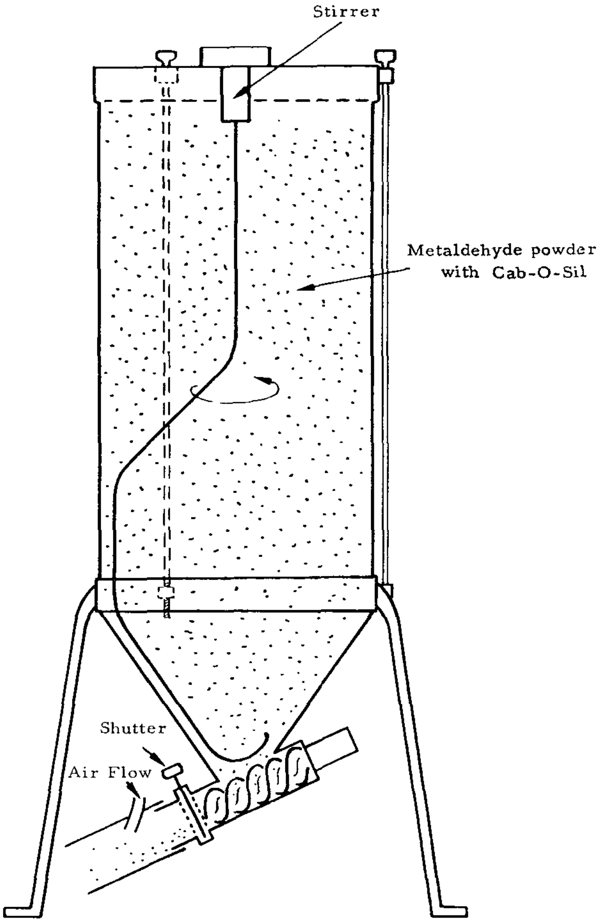

Fig. 1. Metaldehyde powder disseminator.

The metaldehyde disseminator consists of a hopper (Fig. 1) with a stirring device to keep the powder loose, and a feed screw at the bottom. The hopper holds about 10 kg of the powder, the output of which can be changed from zero to 0.5 kg min^{-1} by adjusting the shutter and screw speed. The disseminator is housed in the fuselage of the airplane. The powder issuing from the disseminator is conducted to the smoke generator shown in Fig. 2. Air entering through a control butterfly valve is warmed by heat exchange and made turbulent by a series of vanes before it reaches the powder conveyed from the disseminator. The powder is then dispersed and mixed with the exhaust air. Since the exhaust gas still sustains a considerable static pressure at the end of the tube, the latter was specifically designed so as to prevent blow-back. The observed temperature drops from 700C at T_4 to 250–300C at T_5, indicating a rapid mixing between exhaust gas and metaldehyde-carrying air. Evaporation of the powder takes place within a fraction of a second. In the following fractions of a second it forms into fine crystalline particles, due to turbulent mixing with cold outside air. Although we previously had observed a fair amount of decomposition of metaldehyde vapor at temperatures above 200C within a period of several seconds, it still seemed to be tolerable at temperatures between 250 and 300C for such a short period of time as mentioned above. A ground test of the generator mounted on the airplane showed production of a large volume of bluish smoke, indicating an average particle size far below 1 μ. This method may be used to produce smoke of other organic nuclei.

The Cessna C-180 engine has a cylinder volume of 7.9 liters and produces about 2×10^4 liters min^{-1} of 780C exhaust gas at its cruising speed of 200 km hr^{-1}. A rough laboratory test showed that $1.8\times10^{-2}\sim18\times10^{-2}$ gm metaldehyde could evaporate in a liter of air within a fraction of a second at about 200C. Therefore, the possible maximum output of metaldehyde is 0.15–1.5 kg min^{-1} at a carrier gas temperature of 200C.

An output of about 0.5 kg metaldehyde min^{-1} at a carrier gas temperature T_5 of 250–300C was obtained and used for cloud seeding tests. The power of the nuclei generator, the number of ice nuclei per unit time, was estimated to be roughly 10^{12} sec^{-1} at −5C (cf., Fukuta *et al.*, 1966).

Photographs of the smoke generator and the powder disseminator are shown in Fig. 3.

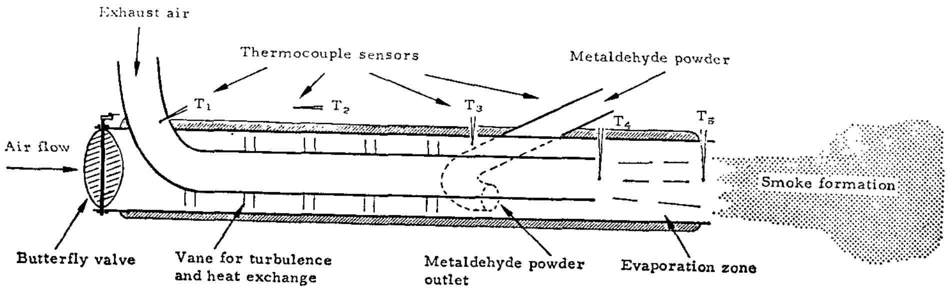

Fig. 2. Airborne metaldehyde smoke generator constructed of 1.6-mm mild steel and consisting of an outer pipe 15 cm in diameter and 3 m long, and an exhaust tube 7.5 cm in diameter.

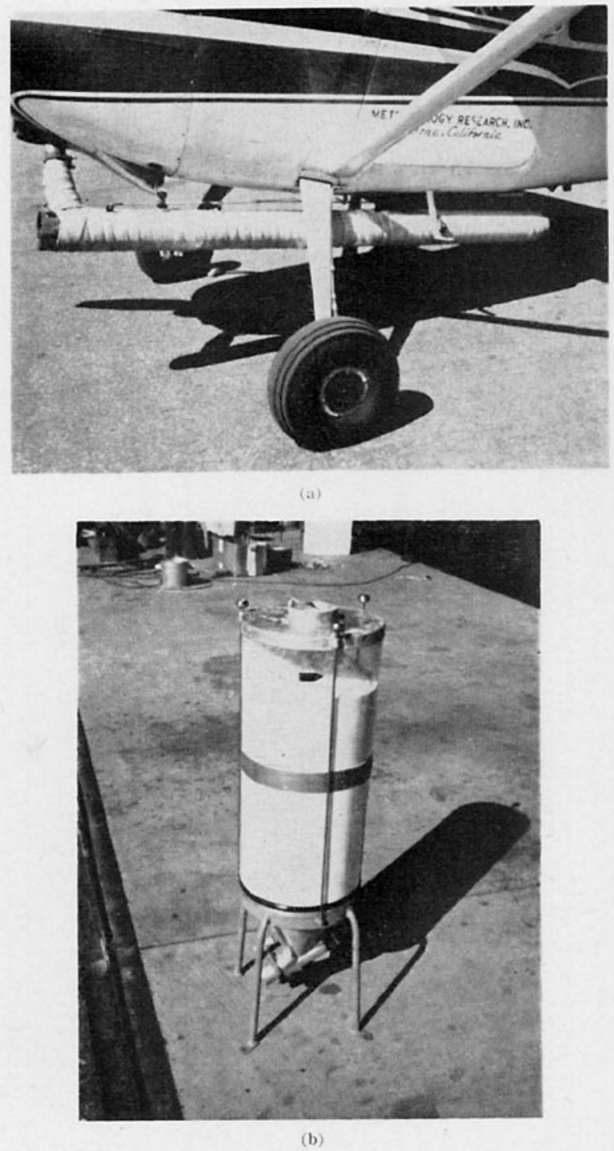

FIG. 3. Airborne metaldehyde smoke generator attached to Cessna C-180, a., and the metaldehyde powder disseminator, b.

3. Tests of the smoke generator in cumulus clouds

In order to test the smoke generator, seedings were carried out on four days on single cumulus clouds in Flagstaff in early August 1966. Position of the seeding airplane was plotted by 3-cm tracking radar and the condition of the seeded clouds were examined by 10-cm PPI display of the Nike-Ajax radar and recorded on time-lapse 16-mm film. A time-lapse sky camera, a Polaroid Land camera, and a raingage network were also used to record the cloud and rain. Data from Winslow and Navajo Ordnance Depot soundings were used for the analysis. Seedings were performed below the clouds on two days. Seeding on the first day failed, but an echo appeared on the scope 10 min after the start of the seeding on the second day, developed up to 4×1.5 km^2, and lasted 45 min. In-cloud seedings were operated on two days at subfreezing levels. Several minutes after the seeding on the first day, the cloud started building up and an echo appeared 13 min after the start of seeding, developed up to 10×12 km^2 size and lasted more than 1 hr (see Fig. 4). Seeding operators observed a large number of ice crystals and some soft graupel at the end of the penetration seeding. The in-cloud seeding on the second day failed to produce any echo. Although a considerable amount of the analyses were done on those data [for further details, see Fukuta (1967)], and the results appeared to be consistent with the expectations for the type of clouds in the experiments, the limitations of the data preclude any definitive conclusions being drawn about the seeding effectiveness. Such conclusions must await more advanced field investigations, now planned for 1967.

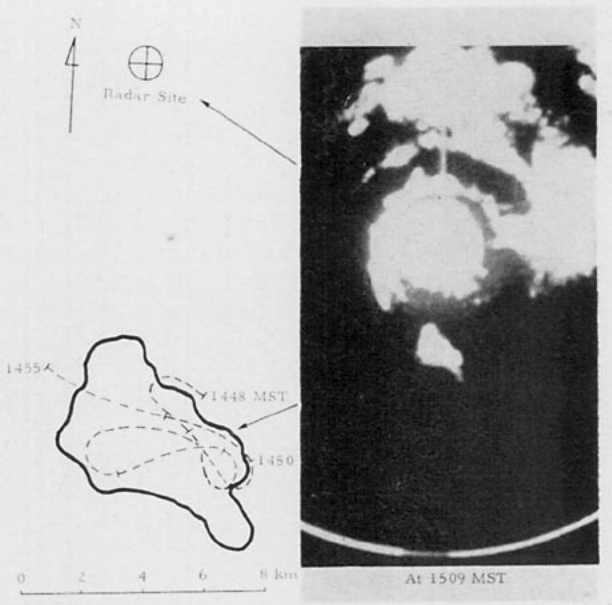

FIG. 4. The shape and position of radar echo and those of effective part of metaldehyde plume estimated independently (11 August 1966, Flagstaff).

4. Some remarks on the nature of metaldehyde smoke and the ice nucleation mechanism in clouds

The metaldehyde smoke particles thus produced have a limited lifetime because of evaporation. The time t for the complete evaporation of a particle of initial radius r is conveniently given by the Langmuir formula (Green and Lane, 1964),

$$t=\frac{r^2\rho}{2DmC},$$

where ρ is the particle density, D the diffusion coefficient of the evaporating molecules, m the mass of a molecule, and C the saturation concentration of the vapor in molecules cm^{-3}. The lifetime of a 1-μ particle at 0C was previously estimated to be about 1 hr (Fukuta *et al.*, 1966). Accordingly, at 0C, the lifetime of a 0.1-μ particle, which may be about the minimum possible size, is expected to be slightly less than 1 min. The lifetimes of most of the smoke particles at 0C is accordingly expected to fall in between 1 min to 1 hr.

Although the time lag for ice nucleation on metaldehyde particles has not been examined closely, it is generally longer at warmer temperatures and shorter at colder temperatures. Airborne seeding releases the particles near or directly into the cloud. The lifetime of most of the submicron particles produced by the generator described above can be expected to be much longer than the nucleation time lags at temperatures around −5C. This is especially true since the metaldehyde particles may induce polarization in the supercooled water droplets, causing them to attract each other. Since an electric field is known to help ice nucleation in water at air-water-solid intersection (Pruppacher, 1963), ice nucleation by metaldehyde at the time of contact with supercooled water droplets is likely with the help of good parametric matches to ice crystal surfaces, soft crystal lattices, and its own electric field. These factors may cut down the apparent time lag of the process. Thus, the nucleation can be efficient and can begin with droplets which already are at a fair size and thus have a head start for total crystal growth.

The evaporation of metaldehyde, which can be considered a disadvantage for some operational seeding, actually may prove to be advantageous for certain situations. The nuclei would be gone an hour or so after release and so could not cause a possibly unwanted direct nucleation effect in a far downwind location.[3] Nevertheless, as with AgI, the lifetime is long enough to permit seeding from below cloud base, which facilitates the diffusion of the material continuously into the most important portions of convective clouds. The evaporation effect may even prove helpful in the seeding of individual convective cells, where the decrease in particles vs. time minimizes the extra glaciation high in the cloud which can otherwise inhibit the growth of hydrometeors initiated earlier and lower down. Another way to consider this latter effect is to note 1) that a good feature of metaldehyde smoke is the relatively flat curve of effectiveness vs. temperature (for 10^{14} sec^{-1} at −20C, laboratory calibrations indicate 10^{12} sec^{-1} at −5C), and 2) the evaporation decay makes the curve time dependent and alters it in the direction of greater flatness when a rising parcel is considered. In summary, there are some advantages to a seeding material with a definite lifetime. The lifetime can be controlled by the particle size emitted by the generator, and can be adjusted somewhat to obtain the optimum seeding effects.

Acknowledgments. The author thanks Dr. Paul B. MacCready, Jr., for his helpful discussion and Messrs. LeRoy Blum and Wallace L. Wilson for their cooperation in building the airborne metaldehyde smoke generator and in the cloud seeding.

This work was supported by the Bureau of Reclamation as part of Project Skywater under Contract No. 14-06-D-5589.

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[3] A peak of ice nuclei four times larger than the background was detected at a place more than 250 mi distant in a downwind direction from the silver iodide generators (the plume traveled during hours of darkness) according to a paper by R. F. Reinking and L. O. Grant, "Long distance detection of artificial ice nuclei: Case studies from a long term climatology of ice nuclei in the Colorado Rockies," presented at the Amer. Meteor. Soc., Conference on Physical Processes in the Lower Atmosphere, 20–22 March, 1967, Ann Arbor, Mich.