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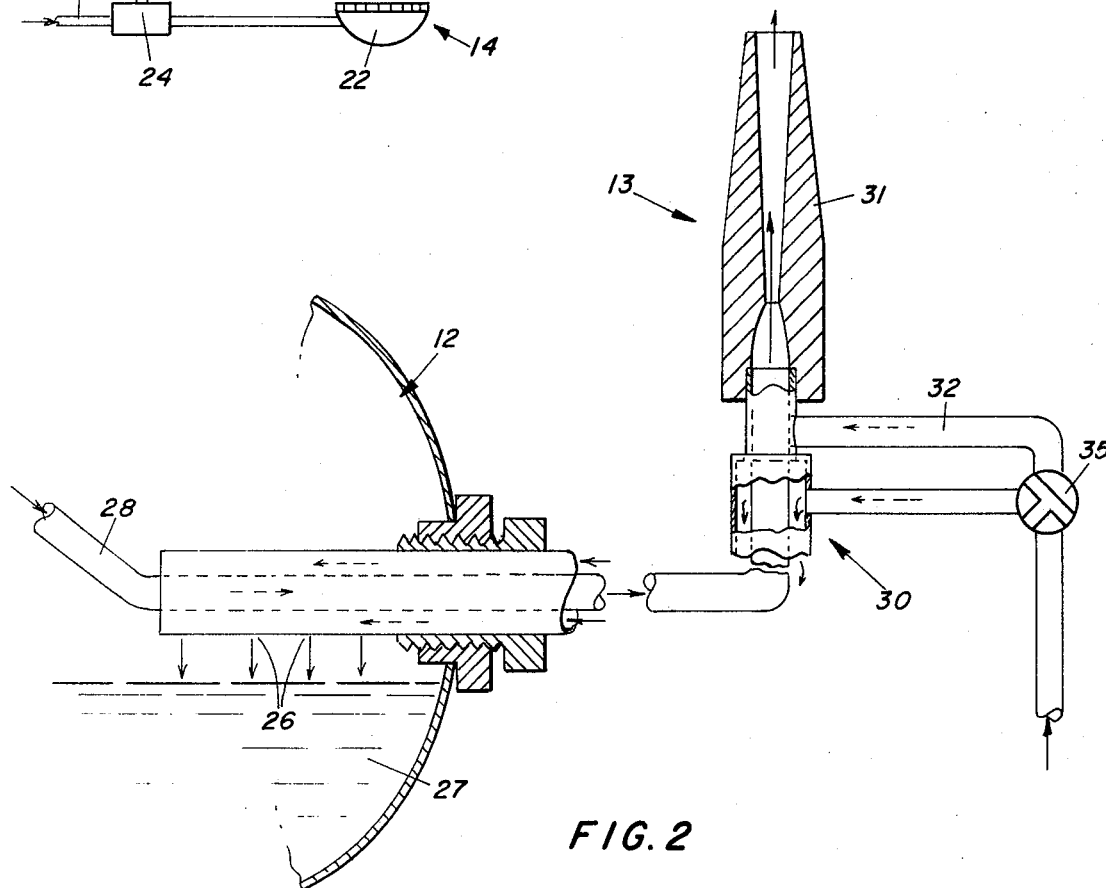
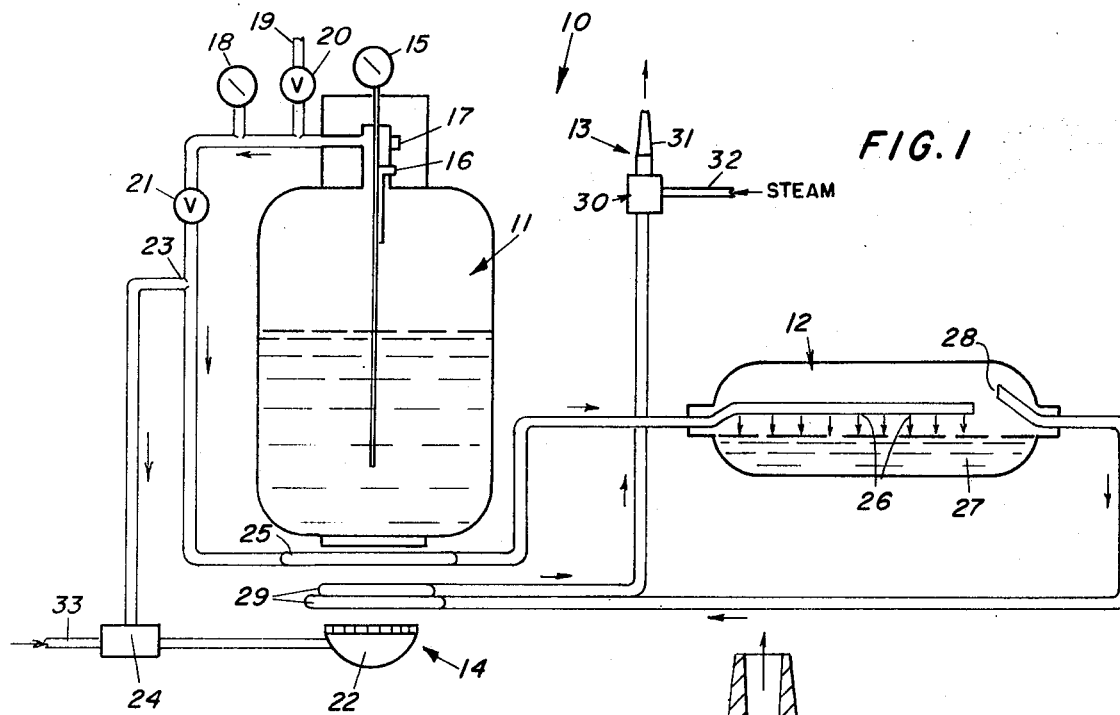
NORHIKO FUKUTA ET AL

3,835,059

METHOD OF GENERATING ICE NUCLEI SMOKE PARTICLES FOR  
WEATHER MODIFICATION AND APPARATUS THEREFOR

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2 Sheets-Sheet 1



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METHOD OF GENERATING ICE NUCLEI SMOKE PARTICLES FOR

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2 Sheets-Sheet 2

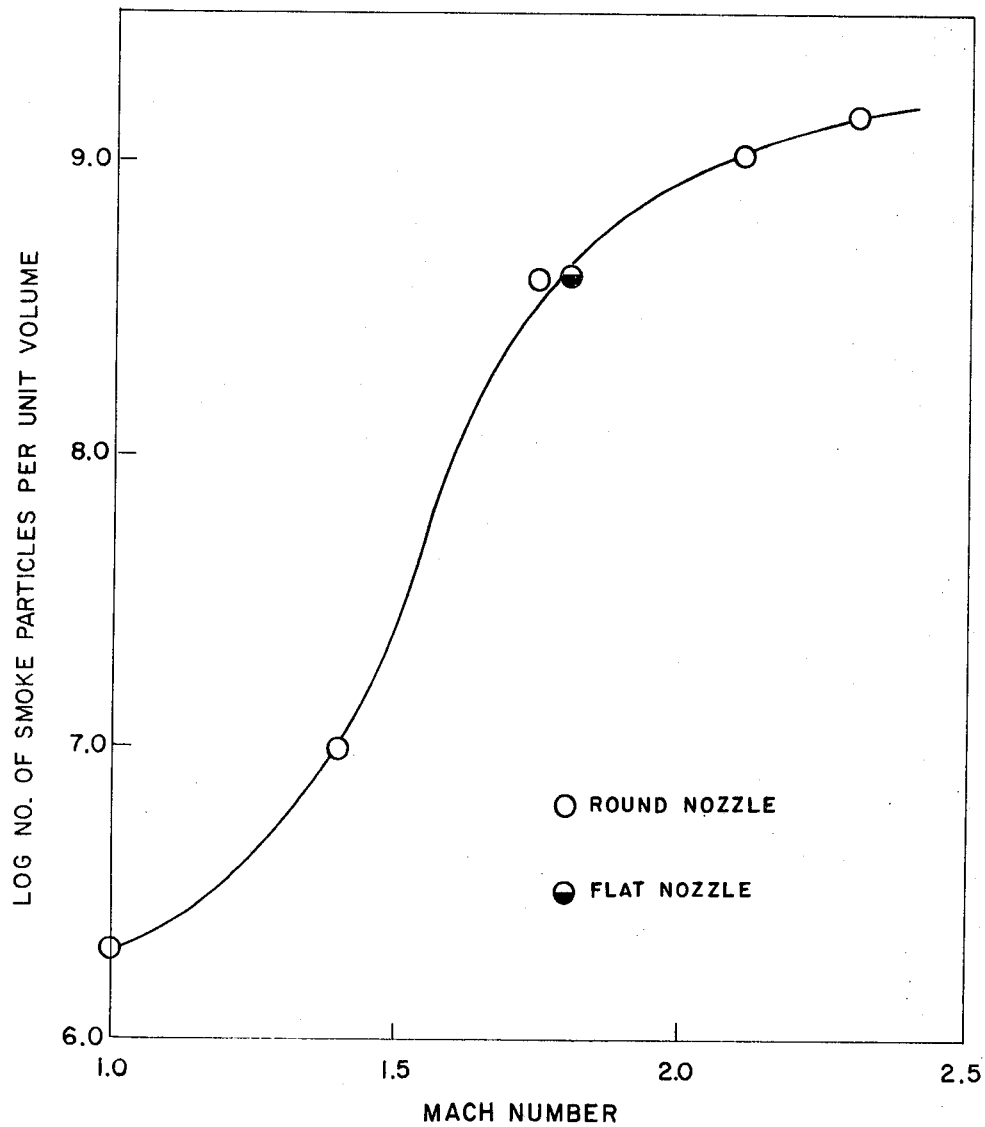


FIG. 3

1

3,835,059

## METHOD OF GENERATING ICE NUCLEI SMOKE PARTICLES FOR WEATHER MODIFICATION AND APPARATUS THEREFOR

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6 Claims

### ABSTRACT OF THE DISCLOSURE

Ice-nuclei smoke particles are produced through contact of an organic ice-nuclei compound with superheated steam under pressure followed by internal adiabatic and isentropic expansion using a supersonic nozzle.

### BACKGROUND OF THE INVENTION

A number of different methods are practiced in seeding clouds and fogs. One conventional method of seeding involves dispersing a fine smoke, spray or dust of a solid substrate (ice-nuclei compound) into a cloud. Currently silver iodide is the most widely employed ice-nuclei compound. In practice an ice-nuclei compound is evaporated in the flame of a sprayed organic solution and subsequently is condensed by contact with cooler outside air. Ice nucleation occurs by the collision of water droplets present in a cloud or fog with ice-nuclei compound particles introduced therein. Ice nucleation takes place in a cloud as the ice-nuclei compound particles apparently cause the water molecules within a cloud or fog to assume an ice lattice structure. This process requires the temperature of the cloud to be below the freezing point of water (0° C.).

Another widely practiced seeding method is evaporating an ice-nuclei compound in a pyrotechnical reaction and then quenching the resulting vapor with cooler outside air.

Another seeding method involves spraying a silver iodide liquid ammonia solution into the atmosphere.

A fourth method of the prior art involves evaporating an ice-nuclei compound of relatively high vapor pressure in a hot gas (such as the hot exhaust gas of an aircraft engine) and quenching the vapor with the outside air.

These seeding methods of the prior art generally involve the use of jet or subsonic mixing of the ice-nuclei compound vapor with cooler outside air. Jet mixing methods involve expelling ice-nuclei compounds (in vapor form) through an orifice directly into the outside air without prior cooling or quenching at velocities below Mach 1.

In each of the above methods a number of problems arise. The first method necessitates the burning of a combustible, while the second and third require the handling of inflammable, toxic, or corrosive solutions. Perhaps the greatest disadvantage to these methods is that upon quenching each yields low net supersaturation of the ice-nuclei compound vapor. The reason for this low saturation is twofold. First, in order to reach the supersaturation necessary for particle nucleation, quenching of the ice-nuclei compound vapor is achieved by mixing with outside air; however, this simultaneously dilutes the vapor and reduces the supersaturation. Secondly, because of the relatively slow cooling process of the prior art, the nucleated particles (which are likely to be in the liquid state at least at the beginning) abstract the vapor and either reduce the supersaturation or prevent the level from rising. A known disadvantage to using organic ice-nuclei compounds for weather modification is the relatively low number of active nuclei produced per unit weight of organic material, compared with that of silver iodide.

A known method for the production of organic ice-

2

nuclei smoke particles is a vapor mixing technique. This method involves bringing a hot gas in contact with an organic material, having a suitable vapor pressure, to form an organic vapor laden mixture. This method suffers from the disadvantages noted above in producing a high number of smoke particles; namely the simultaneous reduction of supersaturation from diluting the vapor with cooler air occurs as well as the abstraction of vapor by the growing smoke particles.

It can be shown theoretically that the rates of nucleation for smoke particle formation are directly related to the true supersaturation or undercooling of the system. Therefore, creating an effective undercooling or means for quenching is essential to generate a sizeable number of ice-nuclei smoke particles. The creation of an effective means of quenching as well as the elimination of the disadvantages of the prior art noted above are accomplished by the process and apparatus of our invention.

### SUMMARY OF THE INVENTION

Our method for generating ice-nuclei smoke particles employs a vapor mixing technique whereby a superheated inert carrier gas is contacted, under pressure, with a suitable ice-nuclei compound to form a vapor laden gas (i.e. mixture of inert carrier gas and ice-nuclei compound vapor). The vapor laden gas is then quenched internally by nearly adiabatic and isentropic expansion. The vapor laden gas after quenching may be dispersed into a cloud or fog in the form of ice-nuclei smoke particles. These ice-nuclei smoke particles nucleate with the water in a cloud, under proper temperature conditions, and result in the formation of ice crystals.

Practically, the process involves the production of superheated steam which is introduced into a chamber containing a suitable ice-nuclei compound to form a vapor laden steam of the compound vapor and steam. The vapor laden steam is then quenched by means of a supersonic nozzle, resulting in the formation of ice-nuclei smoke particles suitable for weather modification.

The supersonic nozzle is employed to overcome the disadvantages of quenching with external cold air. A supersonic nozzle is known to perform nearly adiabatic and isentropic expansion. The quenching or undercooling is only a function of the Mach number or speed of the nozzle at constant temperature.

Our invention provides for the internal cooling of vapor laden gas (i.e. prior to contact with outside cold air). As a result, our process sharply raises the supersaturation level, at least at the stage of particle nucleation. Furthermore, the rapid cooling rate of our invention reduces the vapor abstraction effect of particles already formed, allowing more particles to nucleate. Cloud seeders may find our invention useful in combination with cloud seeding agents which do not produce a detrimental effect upon the environment. This advantage is particularly important when one considers the possible detrimental influence to the ecology of silver from the current weather modification agent, silver iodide.

### DESCRIPTION OF THE PREFERRED EMBODIMENTS

A way of determining the effectiveness of ice-nuclei smoke particles formation is to determine the saturation ratio of the particles in air. The saturation ratio is a ratio of the true vapor pressure to the saturated vapor pressure. In the case of nominal saturation ratios such values are strictly theoretical calculations, whereas actual saturation ratios are based on observed vapor pressures.

The nominal saturation ratio created in supersonic flow is of the order of 10<sup>6</sup> for typical operating conditions, while that for jet mixing is of the order of 10 under the same conditions. The nominal level of super-

saturation cannot be reached in the supersonic nozzle because of the vapor abstraction by the particles formed. However, tests clearly show that the supersonic condensation method increases the smoke particle concentration by a factor of  $10^3$  compared with that in the jet mixing method.

A supersonic nozzle consists of converging and diverging sections. The nozzle may be flat or round. Its dimensions are simply determined by the speed or Mach number of the nozzle (i.e. the velocity at which a gas passes through the nozzle) and the nozzle flow capacity. Nozzle speeds greater than Mach 1 have proven effective for increasing particle concentration and saturation ratios. A wide range of nozzle capacities may be employed as the value is not critical. The capacity should be sufficient to generate the desired number of particles within a particular time. Capacities as low as one liter/second are effective, yet greater capacities are useful. For practical cloud seeding operations, the nozzle should be designed to give a speed of Mach 2.0 to 2.5.

A chemically inert carrier gas is needed to generate ice-nuclei compound vapor. Ice-nuclei compounds, such as organics, tend to decompose when strongly heated during evaporation into the carrier gas. Steam, heated well above the saturation temperature, is a suitable carrier gas. Furthermore the high heat content, nontoxic nature, safety and availability of steam make it particularly advantageous.

The ice-nuclei compound must be capable of forming an ice lattice structure upon nucleation. A number of materials, both inorganic as well as organic are suitable, but the organic are preferred in our invention. Phloroglucinol, 1-5 dihydroxynaphthalene, and metaldehyde are well known as organic ice-nuclei compounds. While the steam pressure of the generator system is determined by the supersonic nozzle employed, the steam temperature depends upon the ice-nuclei compound used. The temperature of the evaporator chamber must not exceed the thermal decomposition temperature of the ice-nuclei compound. The ice-nuclei compound is generally in powder form, and cannot be gaseous or liquid at ambient conditions. The following table lists some suitable ice-nuclei compounds and the temperature range under which they may be evaporated.

Ice-Nuclei Compound:	Steam temperature, ° C.
Metaldehyde	120-160
Phloroglucinol	150-219
1-5 dihydroxynaphthalene	170-265

After the vapor laden steam is formed, it is then either superheated or passed through a heat exchanger and introduced into the supersonic nozzle and subsequently expelled into a fog or cloud.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic of the ice-nuclei smoke particle generator assemblage.

FIG. 2 is a schematic of the nozzle adapter.

FIG. 3 is a graphic comparison of smoke particle concentration with varying nozzle speed.

The generator assemblage 10 consists of four major units: a steam generator 11, an evaporator 12 for ice-nuclei compounds such as organics, a supersonic nozzle system 13, and a heat source 14. The steam generator 11 and heat source 14 serve to produce the superheated steam necessary for the process.

Water is introduced into the steam generator through an inlet 19, which may be opened and closed as needed by a suitable valve 20. The water is added to the desired level, as indicated by a water level gauge 15, and then heated by the desired heat source to produce steam. The pressure is monitored by a suitable gauge 18. A bleeder valve 16 may be provided to eliminate unused steam, and a safety valve 17 is provided to allow for the elimina-

tion of steam when the system reaches undesired pressures.

A heat source, such as electric coils, or a solid flame burner 22, is provided below the generator. Propane, natural gas, or city gas are suitable fuels.

Steam produced in the generator 11 rises under pressure upward through the main steam line to a junction 23 where a portion flows from the main line to the gas flow control 24 (a pressure sensitive valve, which adjusts the gas flow 33 to the burner 22) while the remaining steam is introduced via a superheating coil 25 into the evaporator 12, which contains the ice nuclei compound 27, through small nozzles 26 directed onto the surface of the compound. The vapor laden steam which forms then passes back into the line 28 and is further heated either by superheating coils 29 or alternatively by a heat exchanger 30, in order to prevent the deposition of compound and water vapor in the nozzle system 13. The vapor laden steam then is discharged via a nozzle 31.

FIG. 2 specifically illustrates passage of the vapor laden steam after leaving the evaporator and passing through an adapter (heat exchanger) 30 which also allows the preheating and cleaning of the nozzle by simply passing a hot steam source 32 outside as controlled by a three-way valve 35. The vapor laden steam passes through the line, after being superheated, to the converging diverging supersonic nozzle 31.

The temperature of evaporator is controlled so as not to exceed the thermal decomposition of the ice-nuclei compound.

The flow within the system of hot and dry steam as well as the vapor laden steam is clearly indicated by the arrows in FIGS. 1 and 2.

The following examples are provided to more fully illustrate the invention but are not to be construed as limiting the scope thereof.

#### Example 1

16 liters of deionized water were added to a steam generator as illustrated in FIG. 1. A liquid propane gas cylinder having a capacity of 5 gallons provided the solid flame heat. The safety valve was designed to have a cracking pressure of 150 p.s.i. Steam formed in the generator was introduced through a 1/4" I.D. copper tubing via a superheating coil into an evaporator (shatter proof and having a 1 gal. capacity) containing 2 kg. of metaldehyde. The temperature of the evaporator was maintained at 140° C. A supersonic nozzle having a capacity of 2 liters/sec. and a speed of Mach No. 2.1 was employed. The steam pressure was maintained at 107.4 p.s.i. The ice-nuclei smoke particles generated were found acceptable for seeding a cloud having a temperature of -2° C. or below. Injection of the metaldehyde smoke particles produced in clouds of higher temperature yield no immediate effect. However, upon subsequent cooling nucleation occurs.

#### Example 2

In the same manner as Example 1, 2 kg. of 1-5 dihydroxynaphthalene was tested. The evaporator temperature was maintained at 200° C. and a suitable smoke resulted.

#### Example 3

Ice-nuclei smoke particles produced in the manner of Examples 1 and 2 were immediately diluted by introduction into one end of a dilution tunnel. The tunnel consisted of a steel tube 62 cm. in diameter, 330 cm. long, and a variable speed electric fan placed in the middle of the tube creating a wind tunnel effect. The smoke was transferred to an ultramicroscope cell by means of a syringe which collected the resulting diluted air at the opposite end of the tunnel to determine the particle concentration. The concentration (number per unit column) was readily deduced from the magnification

and dilution factors by taking a succession of 30 snap counts and averaging. The average radius of 1-5 dihydroxynaphthalene smoke particles was less than  $0.1\text{ }\mu\text{m.}$ , while that for metaldehyde was approximately  $0.2\text{ }\mu\text{m.}$  FIG. 3 graphically illustrates the results of determining the concentration of 1-5 dihydroxynaphthalene smokes at varying nozzle Mach numbers. At Mach 1, the concentration in undiluted expanded state was  $2.1 \times 10^9$  particles  $\text{cm.}^{-3}$ . The highest concentration in undiluted expanded state observed was  $1.5 \times 10^9$  particles  $\text{cm.}^{-3}$  at Mach 2.3. No difference in concentration was observed in using flat and round nozzles having the same Mach number.

Thus it is clear that the supersonic condensation method increases the smoke particle concentration by a factor of  $10^3$  at the most, over that of the sonic mixing process.

The invention in its broader aspects is not limited to the specific details shown and described, but departures may be made from such details within the scope of the accompanying claims without departing from the principles of the invention.

We claim:

1. A method of generating ice nuclei smoke particles comprising:

(a) generating a vapor laden mixture of an inert carrier gas consisting of steam and an ice-nuclei compound capable of forming an ice lattice structure upon nucleation, by superheating said inert carrier gas and contacting said superheated gas, under pressure, with an ice-nuclei compound at a temperature not exceeding the thermal decomposition temperature of the compound;

(b) quenching said mixture substantially by adiabatic and isentropic expansion at supersonic velocities.

2. The method of claim 1, wherein said ice-nuclei compound is organic.

3. The method of claim 2, wherein said organic compound is selected from the group consisting of metaldehyde, phloroglucinol, and 1-5 dihydroxynaphthalene.

4. The method of claim 1, wherein quenching is carried out at a velocity greater than Mach 1.0.

5. The method of claim 4, wherein the velocity is in the range of from about Mach 2.0 to about Mach 2.5.

6. A method of generating ice nuclei smoke particles comprising:

(a) contacting, under pressure, superheated steam with an ice-nuclei compound selected from the group consisting of metaldehyde, phloroglucinol, and 1-5 dihydroxynaphthalene, at a temperature not exceeding the thermal decomposition temperature of said compound in order to form a mixture of superheated steam and compound vapor;

(b) quenching said mixture by adiabatic and isentropic expansion using a supersonic nozzle.

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