APPARATUS FOR GENERATING ICE NUCLEI SMOKE PARTICLES FOR WEATHER MODIFICATION

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4 Claims, 3 Drawing Figures

ABSTRACT

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.
FIG. 3

LOG NO. OF SMOKE PARTICLES PER UNIT VOLUME

MACH NUMBER

- ROUND NOZZLE
- FLAT NOZZLE
APPARATUS FOR GENERATING ICE NUCLEI
SMOKE PARTICLES FOR WEATHER
MODIFICATION

This application is a division of application Ser. No. 285,995 filed Sept. 5, 1972, now U.S. Pat. No. 3,835,059.

BACKGROUND OF THE INVENTION

A number of different methods are practiced in seeding clouds and fogs. One conventional method of seed-
ing 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 com-
15 pound 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 collis-
5 on of water droplets present in a cloud or fog with
ice-nuclei compound particles introduced therein. Ice nu-
20 cleation takes place in a cloud as the ice-nuclei com-
pound 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 evapo-
rat
15 ring 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
5 an ice-nuclei compound of relatively high vapor pres-
20 sure in a hot gas (such as the hot exhaust gas of an air-
craft engine) and quenching the vapor with the outside
air.

These seeding methods of the prior art generally in-
15 volve 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
20 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
25 handling of inflammable, toxic, or corrosive solutions.
Perhaps the greatest disadvantage to these methods is
that upon quenching each yields low net supersatura-
20 tion of the ice-nuclei compound vapor. The reason
for this low saturation is twofold. First, in order to
reach the supersaturation necessary for particle nuclea-
tion, quenching of the ice-nuclei compound vapor is
achieved by mixing with outside air; however, this si-
10 multaneously dilutes the vapor and reduces the super-
saturation. Secondly, because of the relatively slow
cooling process of the prior art, the nucleated particles
25 (which are likely to be in the liquid state at least at the
beginning) abstract the vapor and either reduce the su-
30 persaturation 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-
40 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 material, having a suitable vapor
pressure, to form an organic vapor laden mixture. This
50 method suffers from the disadvantages noted above in
producing a high number of smoke particles; namely,
the simultaneous reduction of supersaturation from di-
luting 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 nucle-
ation for smoke particle formation are directly related
to the true supersaturation or undercooling of the sys-
tem. Therefore, creating an effective undercooling or
65 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 elimina-
tion 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 super-
30 heated 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
25 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 nu-
clease with the water in a cloud, under proper tempera-
ture conditions, and result in the formation of ice crys-
tals.

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
35 supersonic nozzle, resulting in the formation of ice-
nuclei smoke particles suitable for weather modifica-
tion.

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 undercool-
ing 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 supersat-
40 uration level, at least at the stage of particle nucleation.
Furthermore, the rapid cooling rate of our invention
reduces the vapor abstraction effect of particles al-
ready formed, allowing more particles to nucleate.
Cloud seeders may find our invention useful in combi-
nation with cloud seeding agents which do not produce
detrimental effect upon the environment. This advan-
tage is particularly important when one considers the
possible detrimental influence to the ecology of silver
from the current weather modification agent, silver io-
dide.

DESCRIPTION OF THE PREFERRED
EMBODIMENTS

A way of determining the effectiveness of ice-nuclei
smoke particle 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 10^5 for typical operating conditions, while that for jet mixing is of the order of 10 under the same conditions. The nominal level of supersaturation 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.

<table>
<thead>
<tr>
<th>Ice-Nuclei Compound</th>
<th>Steam temperature</th>
</tr>
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<tbody>
<tr>
<td>Metaldehyde</td>
<td>120°C - 160°C</td>
</tr>
<tr>
<td>Phloroglucinol</td>
<td>150°C - 210°C</td>
</tr>
<tr>
<td>1-5 dihydroxynaphthalene</td>
<td>170°C - 265°C</td>
</tr>
</tbody>
</table>

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 elimination 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 psi. Steam formed in the generator was introduced through a ¼ inch I.D. copper tubing via a superheating coil into an evaporator (shat-
3,899,129

ter 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 psi. 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 yielded 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 volume) 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 μm, while that for metaldehyde was approximately 0.2 μm. 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 × 10^6 particles cm^-3. The highest concentration in undiluted expanded state observed was 1.5 × 10^9 particles 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 10^4 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. In an apparatus for generating ice-nuclei smoke particles comprising:
   means for generating superheated steam,
   an enclosed containing means holding therein an ice nuclei compound,
   a multi-opening fluid discharge means maintained within said containing means where multi-openings of said discharge means are disposed to direct fluid discharged therefrom at the surface of said compound,
   a conduit means connected to an outlet of said generating means and to an inlet of said discharge means whereby said conduit means carries therein said superheated steam from said generator to said discharge means wherefrom steam discharged at said compound surface evaporates compound into said steam,
   a converging-diverging nozzle means,
   a further conduit means having connections to an outlet of said containing means and to an inlet of said nozzle means and constituting a passage for steam laden with vapors of said compound leaving said containing means and entering said nozzle, wherein said vapor laden steam is quenched substantially by adiabatic and isentropic expansion at supersonic velocities.

2. In the apparatus of claim 1 wherein said further conduit comprises a coil disposed for heating by a heat source whereby said vapor laden steam in passing therethrough is further heated.

3. In the apparatus of claim 1 wherein said nozzle means discharges said vapor laden steam at a speed greater than Mach 1.

4. In the apparatus of claim 1 wherein said nozzle means has a speed of from about Mach 2.0 to about Mach 2.5 and a capacity of about 2 liters per second.

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