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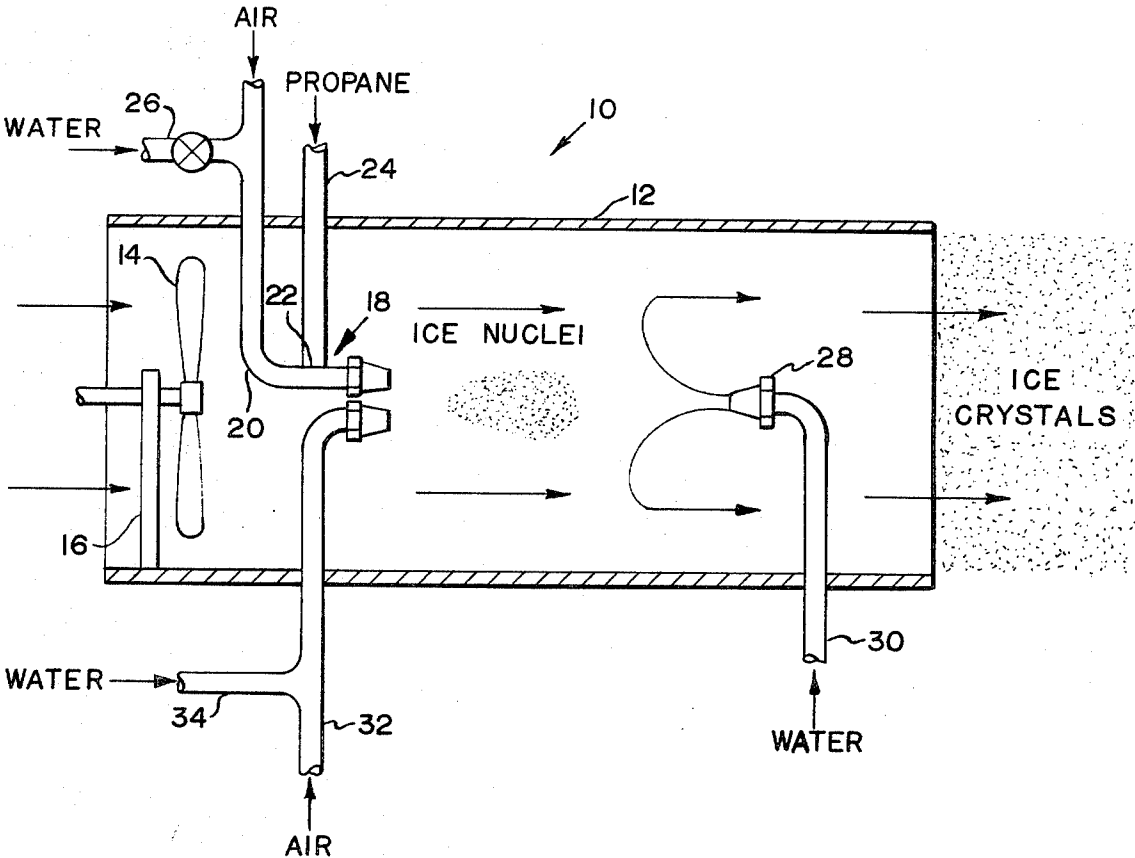
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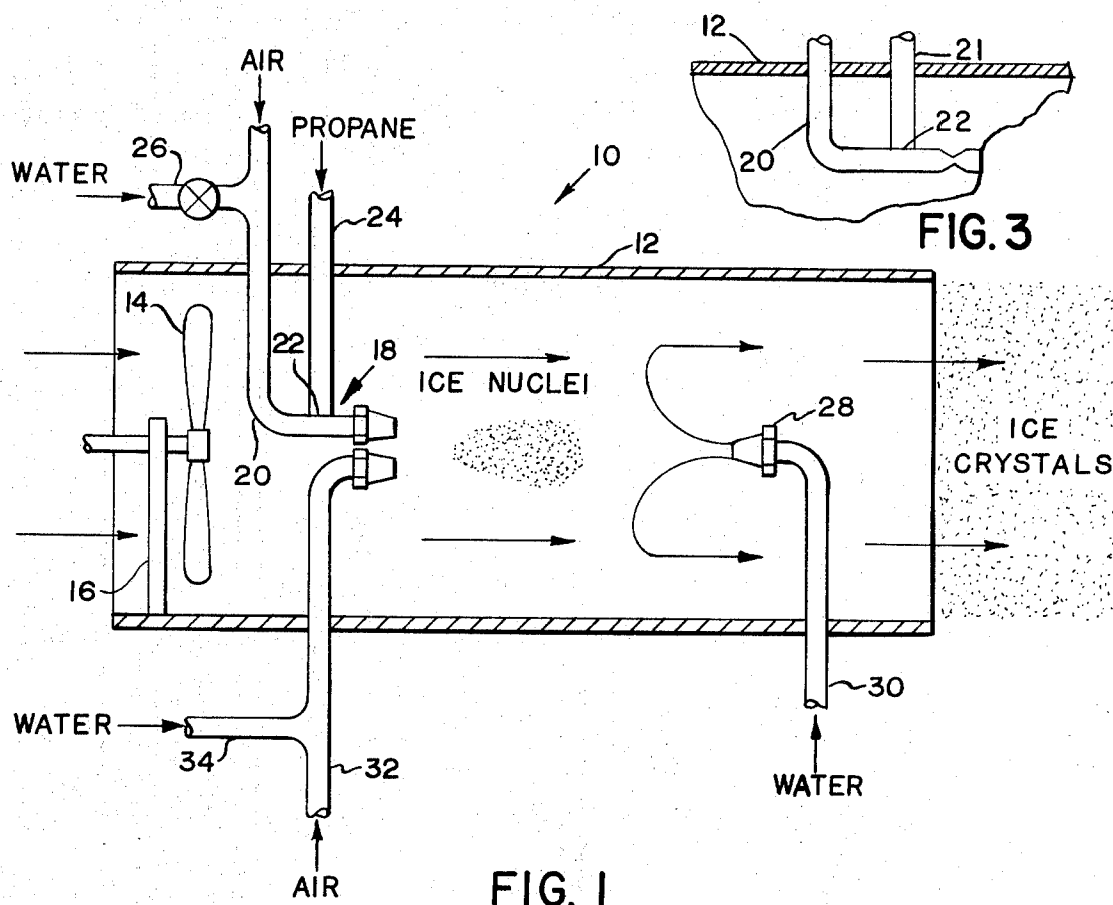
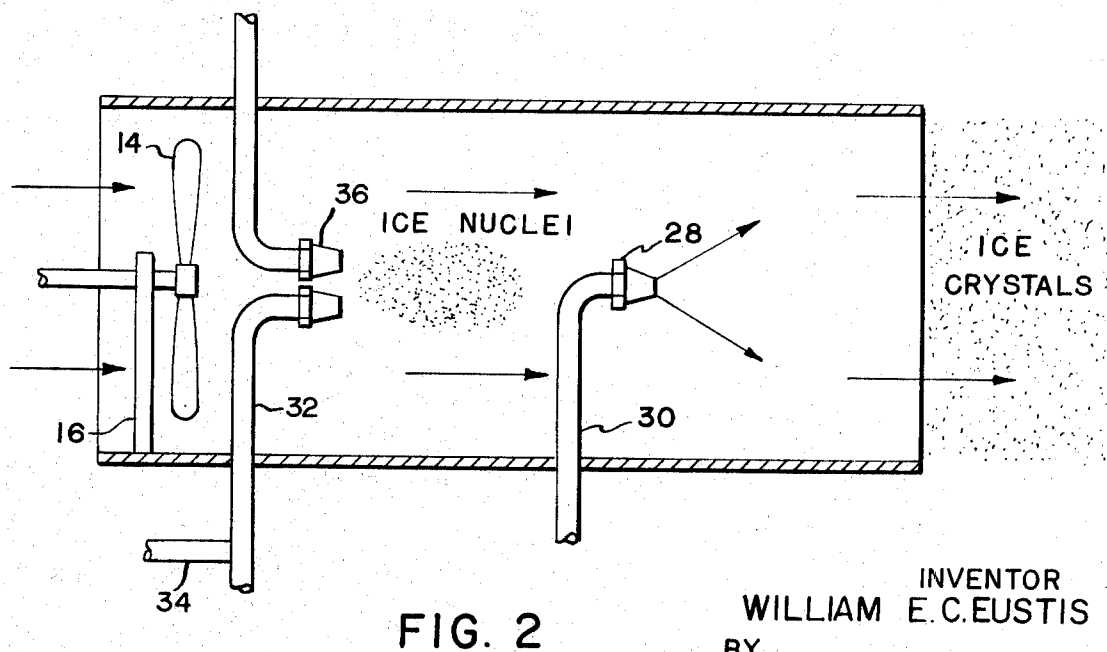
[54] ICE NUCLEI FORMATION
9 Claims, 3 Drawing Figs.

[52] U.S. Cl. 239/2
[51] Int. Cl. A01g 15/00
[50] Field of Search 239/2, 2
(S), 14; 62/121

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ABSTRACT: A method of making snow by controlling the size and life of ice nuclei generated in a snow-making machine. Ice nuclei are generated by homogeneous nucleation in a tunnellike housing through injection of propane or other refrigerant into a stream of moist air. The relative humidity about the ice nuclei stream is controlled relative to the temperature and humidity of the atmosphere to prevent or inhibit evaporation of the ice nuclei for such time as to ensure statistically effective mixing with adjacent liquid phase water droplets which are supercooled by the air mass. The ice nuclei formed infect the water droplets and they release their latent heat to the air to form snowlike particles.





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ICE NUCLEI FORMATION

BRIEF SUMMARY OF THE INVENTION

The purpose of a snow-making apparatus is to emit at least partially frozen particles which will gather on the ground as a more or less loose snowlike mass suitable for skiing. An essential property of any snow-making device is that it effects the initiation of the freezing process in a large proportion of the water particles generated, otherwise the spray produces an artificial ice storm.

In the state of the art today, the proper role of nucleation as the necessary initiation of freezing has not generally been recognized or clearly identified. The prior art in at least one instance discloses combining compressed air and pressurized water in a helically moving chamber and discharging the mixture through a nozzle. Upon discharge, the mixture forms ice crystals. (See U.S. Pat. No. 3,301,485). Also a mixture of water and crushed ice discharged through a nozzle into an ambient stream of air at less than 0° C. to precipitate snow crystals has been suggested. (See U.S. Pat. No. 2,968,164).

The primary drawbacks of the present methods and apparatus for snow making are that the nucleating portion of the snow-making process has been performed substantially simultaneously with the disintegration of the water stream into a water droplet spray without regard to controlling the sets of parameters such as humidity and temperature conditions which affect the formation of ice nuclei. This results in uneconomical and inefficient apparatus for making snow, with the attendant high cost.

To form frozen particles more is required than simply the cooling of the water to a temperature below 0° C. in the course of its emission and subsequent fall, for water when it is cooled below 0° C. does not start to freeze until a nucleus of the frozen phase appears. This nucleus may arise through collision between the cooling water particles and a bit of natural ice (isomorphic nucleation), or through the action of a foreign particle of some other substance, the crystalline, molecular or other structure of which somewhat resembles ice or otherwise effects the onset of the ice phase (heterogeneous nucleation), or through cooling of the liquid phase to such a low temperature that the ice nuclei appears spontaneously without the introduction of any foreign matter (homogeneous nucleation), which in water at atmospheric pressure occurs at about -40° C. Unless the onset of freezing is initiated in one of these three ways, the water particle below 0° C. remains in a supercooled state until it strikes the ground, where it freezes in the form of glaze or ice, generally too hard for skiing and too rough for skating.

In my invention, the production of ice nuclei is separated from the function of disintegrating the water stream and of cooling the resulting water droplets. It is accomplished by the cooling of moist air below the temperature of homogeneous nucleation either by adiabatic expansion of compressed air in an efficient nozzle, or by injection into cold moist air of liquid propane or other refrigerant, or both. Also, the operating conditions are so controlled as to permit ice nuclei to grow in size rather than evaporate so that they survive the time period e.g. 0.01—0.9 seconds or the few fractions of a second while they become mixed with the droplet spray. Generally the humidity about the ice-nuclei stream is supplemented and controlled to ensure that the ice nuclei do not evaporate or burn prior to seeding.

The nuclei cloud formed is then mixed with the supercooled water droplets where the ice nuclei infect the water droplets. The ice-infected droplets are then discharged into the atmosphere with which the ice-infected droplets exchange their latent heat during freezing of the droplets. The ice crystals then formed fall to the ground as more or less completely frozen snowlike particles.

Accordingly, in my invention, the individual steps required for controlling the growth and life of the ice nuclei are controlled separately to ensure economic and efficient results.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic and partially sectional view of my invention incorporated in a snow precipitator;

FIG. 2 is an alternative embodiment of my invention; and
FIG. 3 is another embodiment of my invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1, a snow precipitator is shown generally at 10 and includes a housing or tunnellike conduit 12 together with a propeller or fan 14 secured to the housing by a bracket 16, to move air through the housing and carry the ice crystals into the atmosphere. Disposed in the downstream or high pressure side of the propeller 14 is a nucleating zone 18 used to form the ice nuclei. The zone 18 comprises a feed conduit 20 for the introduction of a moist air stream and a diaphragm 22 to provide for the injection of propane, passing through a liquid to vapor phase change, or other refrigerant into the moist air stream. The conduit 20 passes through the housing and as shown is L-shaped. The diaphragm 22 is installed near the discharge end of the conduit 20 and further is connected to a conduit 24 which passes through the housing 12. In communication with the conduit 20 is a feed line 26 to bleed water into the air stream.

Located downstream of the propeller 14 or on the high pressure side and axially spaced apart from and generally axially aligned with the nucleating zone 18 is a second zone which includes a nozzle 28 which faces into the direction of the flow of air created by the propeller 14. The nozzle is connected to a water supply by conduit 30 which passes through the housing 12. Water flows through the conduit 30 and the nozzle 28 and is broken up into droplets of a size to suit the atmospheric conditions.

An air conduit 32 passes through the housing 12 and terminates in the vicinity of the nucleating zone. A water conduit 34 feeds into the air conduit 32. The air is discharged into the vicinity of the ice-nuclei stream to control the humidity about the stream.

In the operation of the snow precipitator, the propeller 14 is actuated by a motor or other means (not shown) to move ambient air at less than 0° C., and at atmospheric humidity through the housing. Compressed air at any humidity, including a high humidity, and at any convenient pressure, say 10 to 15 p.s.i. is introduced into conduit 20. Water at a rate determined by the relative humidity of the atmosphere but typically perhaps of from 0.1 quarts to 20 quarts/minute is bled into the compressed air through feed line 26. Liquid propane at a rate determined by the desired production rate of snow and typically from about 0.5 to 15 lbs./hour say for example 2 lbs./hour is discharged through the diaphragm 22, which has an orifice of about 0.010 inches, and into the saturated airstream. When discharged into the airstream, the propane goes through a phase change into gas and absorbs heat from the airstream. If desired, other expanding gases or refrigerants which have a high heat of vaporization and would lower the temperature of the air stream to below about -40° C. on expansion or in a phase change may be used. For example, other hydrocarbons like butane, ethane, methane, and other liquified gases such as liquid oxygen, halocarbons like freon, carbon dioxide, etc. may be used, as well as ammonia, and sulfur dioxide. The refrigerant may incur a phase change from a liquid to a gas or may simply be an expanding gas. Other typical refrigerants are set forth in the Handbook of Chemistry and Physics, 47th Edition, Section E, pages 17—25.

The expanding propane cools a portion of the saturated air below -40° C. and causes the formation of generally uniform ice nuclei by homogeneous nucleation within the air stream. The average particle size of the ice nuclei formed without addition of bleed water is generally between about 0.1 to 10 microns say for example less than one micron and with bleed water may be increased to between about 125 to 250 microns say about 150 microns. The nuclei are then discharged into the airstream. Water is introduced through the conduit 34 in combination with the air through conduit 32. The streams are

controlled to provide for a moist airstream to be introduced into the housing to ensure that the local relative humidity is sufficient to prevent reduction in nuclei size and in practice is probably 60 to 95 percent relative humidity.

Water enters the conduit 30 and flows through the nozzle at any temperature in excess of 0° C. and generally between 1° to 15° C. say about 4° C. at a rate of between 1—300 gallons/minute for example 15 gallons/minute and is forced through the nozzle 28 at any rate to produce the desired particle size between about 40 and 100 p.s.i. for example 80 p.s.i. This temperature is advantageous in that it prevents anchor ice from forming in the conduit 30 and in the nozzle. The nozzle breaks the water into droplets of suitable size say between 100 and 500 microns for example about 200 microns, and they are discharged countercurrent and directly into the flow of air and ice nuclei. The droplets are supercooled to below 0° C. by the ambient air flowing through the housing.

These supercooled droplets are then infected by collision with the ice nuclei previously formed. When a drop is infected with an ice nuclei, spicules of ice form very rapidly within it, releasing latent heat until the droplet becomes an ice water mixture at a temperature of about 0° C. remaining at this temperature until the freezing process is completed through the exchange of heat to the surrounding atmosphere. This exchange of heat with the surrounding atmosphere progressively continues both while the droplet is within the precipitator and after the ice crystals are discharged from the end of the housing into the atmosphere where the freezing process is continued until the droplet is all or largely all frozen and the particles fall to the ground as snow.

Normally and particularly with atmospheric conditions at low humidity the ice nuclei exchange latent heat with the surrounding atmosphere (ambient air) at a very rapid rate. These conditions tend to shorten the life of the ice nuclei and consequently the probability of achieving successful nucleation infections is diminished, since in an atmosphere of low humidity, the nuclei reevaporate very quickly. However, in my invention, the atmosphere about the ice nuclei is controlled from the time of the formation of the ice nuclei until they infect the water drops. This provides enough water content in the nuclei stream to preserve the nuclei until they infect the water drops. As described in the preferred embodiment the atmosphere is controlled by the introduction of the moist airstream through the conduit 32. Of course the humidity or moisture content about the ice-nuclei stream may be controlled in other ways. For example, a high enough moisture content may be provided in the nucleating zone itself through a high moisture content in the conduit 20. Also, the moisture content of the ambient air flowing through the housing may be controlled and the propane or other refrigerant injected directly into the airstream to form the ice nuclei.

Although the nucleating zone 18 has been shown to include an L-shaped conduit with the diaphragm located near the discharge end of the conduit carrying the moist air, it is possible for it to take other forms. For example, the moist air may flow through a venturi passage and the refrigerant injected prior to the constriction as shown in FIG. 3 at the constriction or just beyond the constriction. Also the nucleating zone may be of a nonunitary construction and the diaphragm disposed adjacent to the discharge end of the conduit 20.

When compressed air is allowed to expand adiabatically, the temperature of the air falls about 10° C. for each 8 percent decrease in pressure. Therefore, if the air is initially at a temperature near 0° C. expansion from a modest pressure of 20 lbs/inch is more than sufficient to bring the temperature below -40° C. If the atmospheric air initially has a relative humidity higher than about 50 percent, it will become saturated in the course of this expansion. In this situation, in the initial instant after the temperature falls below -40° C., very large numbers of very small ice nuclei, say for example, in the range of 40 to 60 angstroms form spontaneously. Those nuclei in this range generally reevaporate or burn off very quickly, but this can be inhibited by controlling the humidity of the airstream. It has

been found that by expanding compressed air which initially has a humidity of from 50 to 80 percent say, for example, 70 percent that this provides that the ice nuclei will survive even when the humidity of the ambient air is less than 50 percent.

Accordingly, in FIG. 2, in an alternative embodiment of the invention, the nucleating zone comprises a feed conduit 34 and a nozzle 36 in communication with the conduit 34. The nozzle 36 is adapted to release saturated compressed air through a nozzle to spontaneously form ice nuclei. Again, an efficient economic operation is provided wherein the formation and life of the ice nuclei is effectively controlled.

My invention has been described in reference to homogeneous nucleation when a refrigerant such as propane or carbon dioxide is injected into a stream of saturated air to lower the temperature to below about -40° C. to form the ice nuclei as shown in FIG. 1 or when compressed air is cooled by expansion as shown in FIG. 2. It is also within the scope of this invention that heterogeneous or isomorphous nucleation may be used to form the ice nuclei in the nucleating chamber, as for example by the introduction of silver iodide smoke or comminuted natural ice. Referring again to FIG. 1, the saturated airstream flows through the feed conduit 20 at a temperature of less than 0° C. A finely foreign nucleating agent such as a solid particle or product like a silver salt such as silver iodide is injected into this airstream such as through line 26. The silver iodide or other nucleating agent initiates the formation of ice crystals in a supercooled saturated airstream. Also, the airstream may be treated with foreign crystalline substances which may normally have a hemimorphic hexagonal crystalline structure similar to that of ice. For example, wurtzite has been found to be satisfactory. Also various natural minerals in a finely divided state may be similarly employed to initiate crystallization in the supercooled airstream; namely, zincite, nephelite, and lead iodide may also be used. If desired, ice nuclei per se may also be injected into the saturated stream. Also, certain resinous compounds, such as urea, have also been effective.

Although my invention has been described in reference to particular embodiments wherein the relative humidity about the ice-nuclei stream is controlled within certain limits, operating conditions at a particular time will determine the degree of relative humidity required about the ice-nuclei stream. Also depending upon the amount of snow to be generated, the flow rates of compressed air, propane, bleed water, ambient air, etc., will vary. Further, although the embodiments described showed a single nucleating zone and nozzle, there may be employed in a particular operation a plurality of chambers and nozzles within a housing and the orifice sizes may vary.

I claim:

1. A method for the making of snow which method comprises:

- providing in one zone water droplets having a temperature of less than 0° C.;
- forming ice nuclei in another separate zone;
- preserving the ice nuclei so formed by controlling the relative humidity of the atmosphere about the ice nuclei to inhibit the burning off of the ice nuclei prior to the infection of the water droplets; and
- infecting the water droplets with the ice nuclei whereby the latent heat is progressively removed from the ice infected droplets and the droplets become substantially all snowlike crystals.

2. The method of claim 1 wherein the ice nuclei are discharged from the separate zone in a nuclei stream and the nuclei are preserved by controlling the relative humidity between 70 and 95 percent within the nuclei stream.

3. The method of claim 1 which includes: forming the ice nuclei by injecting a refrigerant into a moist stream of cold air the refrigerant adapted to lower the temperature of the airstream to less than -40° C. and wherein the relative humidity of the airstream is controlled to provide sufficient humidity within the ice-nuclei stream formed to inhibit burning off of the ice nuclei.

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4. The method of claim 1 wherein the size of the ice nuclei formed are between 125 and 250 microns and the refrigerant is selected from the group consisting of propane, methane, freon, carbon dioxide and sulfur dioxide.

5. The method of claim 4 wherein the refrigerant is liquid propane which incurs a phase change from a liquid to a gaseous state.

6. The method of claim 1 wherein the ice nuclei are formed by the adiabatic expansion of compressed air and the ice nuclei are discharged from the one zone in a nuclei stream.

7. The method of claim 6 which includes controlling the moisture content of the compressed air to provide the proper humidity within the nuclei stream.

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8. The method of claim 1 which includes:

a. breaking water into droplets at a temperature of greater than 0° C.;

b. supercooling the droplets so formed to less than 0° C. by flowing a mass of ambient air about the droplets;

c. discharging the ice nuclei formed from the zone in a separate nuclei stream;

d. preserving the ice nuclei formed by controlling the relative humidity about the ice-nuclei stream; and

e. subsequently infecting the supercooled water droplets.

9. The method of claim 7 wherein the ice nuclei are formed by homogeneous nucleation.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,567,117 Dated March 2, 1971

Inventor(s) William E. C. Eustis

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 5, line 1, the reference numeral "1" should read -- 3 --; lines 1 and 2, cancel "the size of the ice nuclei formed are between 125 and 250 microns and". Column line 11, reference numeral "7" should read -- 8 --.

Signed and sealed this 17th day of August 1971.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

WILLIAM E. SCHUYLER,
Commissioner of Patent