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HAIL SUPPRESSION BY APPLICATION OF EXTERNAL ELECTRIC FIELD

Singh N

Department of Physics, Rajasthan college of Engineering for Women,
Bhankrota, JAIPUR-302 026 (India)

ABSTRACT

The lightning is often followed in the cloud by a rapidly increasing intensifying echo and then by a gush of rain or hail at the ground. The increase in radar reflectivity in small volumes of the cloud following lightning suggested that the electric discharge is influencing the size of particles in the cloud. The analysis indicated that within 30 seconds after a lightning discharge, the mass of some droplets increased as much as 100-fold as the result of an electrostatic precipitation effect. Later observations disclosed that the rain gush phenomenon can also occur in regions of the cloud that are colder than 0^0C and that here gush can be of hail or rain. During a lightning discharge maximum electric field (~10 e.s.u.) is produced near the channel. It has been shown that action of a constant and uniform electric field accelerated the condensation of water vapor by a factor depending upon the intensity 0f electric field. It was shown that a droplet acquires a particular size under very low supersaturation under an electric field, which would otherwise, require very high supersaturation. We have shown that in the resultant effect on a droplet due to an external electric field and the field induced due to the central dipole, the rate of nucleation in water vapor condensation and ice glaciations is about 100 times more near break-down for dry air, as compared to that in absence of electric field. The calculations show that at a given relaxation time and temperature, the equivalent supersaturation decreases with increase in electric field. Effective role of external electric field in nucleation has been applied to explore the hail suppression phenomenon. It has been found that an application of a small external electric field is equivalent to a large supersaturation ratio. Large size ice crystals (hails) are split into smaller particles, so that damage caused by hails is reduced. At the same time, this happens at an early stage.

KEY WORDS: Rain gush, nucleation rate, polarizability, hail suppression, lightning discharge, ice nuclei.

***Corresponding Author**
Dr. Narayan Singh
Department of Physics, Rajasthan college of Engineering for Women,
Bhankrota, JAIPUR-302 026 (India)
Email: dr.narayan001@gmail.com

1. INTRODUCTION

Hail is primarily a phenomenon of temperate climate. It is rare in polar region because the air is seldom unstable enough to generate strong vertical wind velocities. The surface of earth is too cold. Hail is also rare in the Tropics because the freezing level in the atmosphere is too high. A warm cloud cannot produce ice. Hailstones grow in the updrafts of convective clouds (Fig.1.).

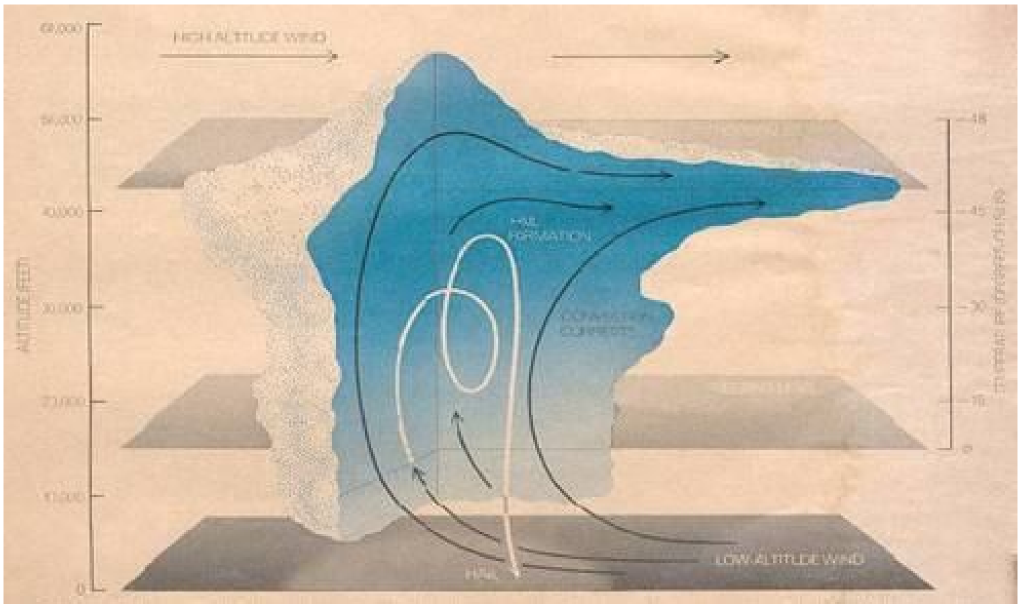

Fig.1 - Growth of hailstones in the up drafts of convective clouds

The hailstones differ in appearance. The layering of hailstones carries a good deal of information about the hailstones. Layering also gives the history of
the shape of the stone and whether or not it is tumbled or wobbled at its fall[1].

HAIL SUPPRESSION

Suppressing hailstones appears to be a possibility because hail grows from supercooled water, which is unstable and can be made to freeze by adding tiny particles of appropriate substances. The hail suppression in a recent past has not been considered very much. A lot of damage to society had occurred in the form of damage to human lives, buildings, vegetables etc.

A summary of Technology Assessment of Hail Suppression[2] concluded that widespread operational hail suppression would not result in any serious adverse environmental impacts, but that the possibility of adverse effect should not be discontinued. The major areas of concern are the effects of silver and altered precipitation on the environment. Hence, the following studies were recommended:

1. The effect of altered precipitation on ecosystems
2. Basic studies on plant and microorganism adaptation to seeding agents
3. The potential for combination of seeding agent silver with other metals, pesticides, power plant emission products, and other pollution sources.
4. Tracer studies of nucleants in seeded storm cells to locate their deposition in the environment.
5. Monitoring of silver levels and dynamics in the soil-plant-aquatic environment before and after cloud seeding activities over the long term.

But, Smith and Musil[3]reported from the observation of the interior characteristics of Swiss hailstorms made with the T-28 armored research aircraft as part of Grossversuch IV, that the most significant observation is that no supercooled raindrops were found in this station, where the observations were made between the -10^{0}C and -15^{0}C levels. The nearly spherical graupel particles found could have developed from raindrops that freeze at a lower altitude. If so, however, the drop freezing process must have proceeded very quickly in this unseeded storm. The indications are that the hail in the storm developed through the accretion of cloud liquid water rather than that of supercooled raindrops.

The largest cloud seeding system in the world is that of the People's Republic of China, which believes that it increases the amount of rain over several increasingly arid regions, including its capital city, Beijing, by firing silver iodide rockets into the sky where rain is desired. There is even political strife caused by neighboring regions which accuse each other of "stealing rain" using cloud seeding. About 24 countries currently practice weather modification operationally. Russian military pilots seeded clouds over Belarus after the Chernobyl disaster to remove radioactive particles from clouds heading towards Moscow.

In India, cloud seeding operations were conducted during the year 2003 and 2004 U.S. based Weather Modification Inc, in state of Maharashtra. In 2008, there were plans for 12 districts of Andhra Pradesh.

To our knowledge, no attempt has been made for hail suppression instead of cloud seeding by AgI. The cloud seeding is very expensive. It has been theoretically explained that application of external electric field would cause the rapid formation of large number of small sized ice particles or super cooled water droplets (rain gush).

Normally there exists an electric field in the clouds. During a lightning discharge the maximum electric field (~10e.s.u.) is produced near the channel. The electric field so generated may affect the rate of condensation of water vapor.

Varshneya[4,5] and Pruppacher[6]found that when charged ions and aerosols come in contact with the neutral drops, the nucleation process is enhanced. Evans[7]and Connolly et al[8]. experimentally demonstrated the effect of an electric field on the production of ice crystals in cloud chambers and argued that the accelerated charged water molecules move to the crystal tips, thereby increasing the nucleation rate.

Ehre et al[9]. demonstrated that water freezes differently on positively and negatively charged surface.

The lightning is often followed in the cloud by a rapidly intensifying echo and then by a gush of rain or hail at the ground. The increase in radar reflectivity in small volume of cloud following the lightning suggested that the electric discharge is influencing the size of particles in the cloud[10]. The analysis indicated that within 30 seconds after a lightning discharge, the mass of some droplets increased as much as 100 fold as the result of an electrostatic precipitation effect. Later observations disclosed that the rain gush phenomenon can also occur in regions of the cloud that are colder than 0^0C and that here gush can be of hail as well as of rain. Explanation to the rain gush has been provided by Levin and Ziv[11].

Singh et al[12].have shown that in the resultant effect on a droplet due to an external electric field and the field induced due to the central dipole, the rate of nucleation in water vapour condensation and ice glaciations is about 100 times more near break-down for dry air, as compared to that in absence of electric field. The calculations show that at a given relaxation time and temperature, the equivalent supersaturation ratio decreased with increase in electric field[13,14].

The polarizability is an important parameter in electric field induced nucleation phenomenon neglecting the vibrational motion, the polarizability is about $5x10^{-23}$ cm^3 at 273K. Introducing the vibrational motion, the increase in polarizability results in the increase in Gibb's free energy and hence the increase in nucleation rate and equilibrium concentration but decrease in relaxation time.

Wei et al[15]. carried out experiments to clarify the effects of an electrostatic field on ice formation. The results indicated that the electrostatic field was capable of inducing nucleation of water supercooled at a relatively high temperature and raising the temperature of supercooling by up to 1.6^0C. The analysis indicated that dipole polarization of water molecules by the electrostatic field is the primary factor in this phenomenon. Under an electrostatic field, water molecules have a tendency to align with the electrostatic field. Water molecules with dipole moments along the direction of electrostatic field are the most stable, and have the more value for the Boltzmann distribution function[16].

Murino[17]studied the effect of an electric field on the condensation of water vapour and concluded that under similar temperature conditions a bigger size of drop can be produced in a given time than the one obtained in the absence of an electric field.

Mandal and Kumar[18]experimentally investigated effect of electrical discharge and high electric fields on ice nucleation. But, in no case was ice nucleation observed in presence of high electric fields with discharge.

The growth of electric field in thundercloud electrification[19] and the role of ions[20]have been discussed. Kishore et al[21].discussed the effect of external electric on the nucleation of ice particles. Also, they have established[22] the equivalence between supersaturation ratio and external electric field.

Effective role of external electric field in nucleation has been applied to explore the hail suppression phenomenon[22,23] It has been found that an application of a small external electric is equivalent to large supersaturation ratio. Large size ice crystals (hails) are split into smaller particles, so that damage caused by hails is reduced. At the same time, this happens at an early stage. Similar equivalence has been shown between external electric field and temperature[24].

To our knowledge no attempt has been made for hail suppression instead of cloud seeding. The cloud seeding is very expensive. We have theoretically explained that application of external electric field would cause the rapid formation of large number of small sized ice crystals or super cooled water droplets (gush). It has also been found that supersaturation required for ice or water nucleus formation, would be very much large in absence of electric field, which is equivalent to smaller value of electric field.

2. THEORETICAL CONSIDERATION

Water is strongly polarizable medium. A perturbation by an external electric field induces an electric dipole moment on the embryo of water as well as on the surrounding water vapor molecules. The moment induced on the embryo is

$$M = E\, r_w^3 \qquad \text{………………(1)}$$

with $r_{w,}$ the radius of water embryo and E, the inducing external electric field.

The moment induced on a water vapor molecule is

$$M_1 = \alpha E$$

with α, the polarizability.

The ele. field generated at any point to the embryo dipole is

$$\vec{M} = \left[\left| 3\left(\vec{M}.\vec{X}\right)\vec{X} - X^2\vec{M} \right| / X^5 \right] --(2)$$

With X, radius vector joining centre of an embryo and water vapor molecules.

The induced moment on a vapor molecule can be written as

$$M_1^{'} = \alpha\left(\vec{E} + \vec{E}_1\right) -----------(3)$$

The potential energy of vapor molecule is

$$U = -\vec{E}.M_1^{'}$$

The average attractive potential energy is

$$\vec{U} = -\frac{\alpha}{2}\left[\left(\frac{E^2 r_w^3}{X^6}\right) + E^2 r_w^6 / X^6\right] -----------(4)$$

The change in potential energy of a molecule in a transition through distance λ is

$$d\vec{U} = -\left(9\alpha\lambda E^2\right) / 2r_w -------------(5)$$

where λ, mean free path.

The corresponding gain in kinetic energy is

$$K.E. = \frac{1}{2} m_w v^2$$

m_W, mass of water vapour molecule and v, its velocity.

The increase in mass (dm_W) of embryo in time (dt) is

$$\frac{dm_w}{dt} = \rho s_n v$$

With surface area of water embryo of radius r_w and ρ, the density of the water vapour molecules.

$$\frac{dm_w}{dt} = \rho s_n \left(9\alpha\lambda E^2 / m_w r_w\right)^{1/2}$$

The increase in radius with respect to time,

$$\frac{dr_w}{dt} = \left(\frac{\rho}{\rho_w}\right)\left(9\alpha\lambda E^2 / m_w r_w\right)^{1/2}$$

Integrating within limits r_w=0 to r^*_w (critical radius nucleus) and t = 0 to t = τ_N (relaxation time),

$$r_w^* = \left[3\rho\left(9\alpha\lambda E^2 / m_w\right)^{1/2} \tau_N / 2\rho_w\right]^{2/3}$$

The rate of nucleation in absence of electric field

$J_0 = fn_1 / \tau_o$

τ_o, the relaxation time, n_1, the number concentration of monomers.

where $n_1 = N\rho_w / M_w$

N, Avagadro's number, M_w, molecular weight of water.

In presence of electric field,

$$J_N = \frac{fn_1}{\tau_N}$$

The combined nucleation rate

$$J_{ON} = J_o + J_N = \frac{fn_1}{\tau_N}$$

sThe factor of enhancement in nucleation rate

$$R_E = \frac{J_{ON}}{J_O}$$

$$R_E = 1 + \frac{\tau_o}{\tau_N} = 1 + f(E)$$

Similarly, in heterogeneous case, factor of enhancement

$$R_E^' = 1 + f^'(E)$$

The factor of enhancement $R^'_{E/o}$, due to electric field in heterogeneous nucleation compared with the homogeneous case in absence of electric field is

$$R_{E/O}^' = J_{ON}^' / J_o$$

$$R_{E/O}^' = \left(\frac{\tau_o}{\tau_N^'}\right)\left[1 + f^'(E)\right]$$

3. RESULTS AND DISCUSSIONS:

The variation of the factor of enhancement in the nucleation rate as a function of the electric field has been shown in Fig.2. This factor in the electric field induced heterogeneous nucleation has been compared with that in the electric field free homogeneous case. The factor varies directly with the externally applied electric field. In this figure the enhancement has been plotted only up to electric fields of 10 e.s.u. which corresponds to approximately breakdown electric field of moist air. Such high electric fields are observed within thunderclouds.

Typical values of the factor of enhancement in the nucleation rate of water nuclei as the function of temperatures supersaturation ratio at 250K, 260K and 273K in an electric field of 10 e.s.u. (cut off value) are shown in table 1.

Table 1: Typical values of the factor of enhancement in the nucleation rate of water nuclei as the function of temperatures supersaturation ratio.

$S_{V.W.}$	R_E	$R_E^{'}$	$R'_{E/O}$
T = 250 K			
1.005	8.17	171.63	9.73×10^4
1.05	23.41	171.17	9.87×10^3
T = 260 K			
1.005	8.45	175.02	9.54×10^4
1.05	24.31	174.51	9.67×10^3
T = 273 K			
1.005	8.83	179.28	9.31×10^4
1.05	25.47	178.78	9.44×10^3

Thus, the factor of enhancement varies directly with the externally applied electric field. Hence, number of smaller ice particles is increased and large hail formation is reduced. Also with increase in temperature, the factor decreases. But at a given temperature, with increase in supersaturation ratio, the factor decreases. (Fig. 2).

For the homogeneous nucleation in the presence of an electric field of 5 e.s.u., our present modification provides a decrease of 43.98 % in relaxation time compared to the values estimated following Murino[17] and 98.8 % compared to the value in the absence of an electric field. The nucleation is achieved more quickly, and hence there is a marked enhancement in nucleation rate in the presence of an electric field. In the absence of an electric field for a given radius the relaxation time varies directly as the square root of temperature. For $r_w^* = 5A^o$ we have $\tau_o = 5.55 \times 10^{-4}$ s at $T=250^o$. But in the presence of an electric field the relaxation time varies as the -3/2 exponent of temperature. The results have been compared with the values obtained by Murino's expression[17].Thus the consideration of dipole term decreases the relaxation time.

The relaxation time, in the absence of an electric field, varies directly with the radius of the nucleus, But, in the presence of an electric field, it varies as $r_w^{3/2}$.

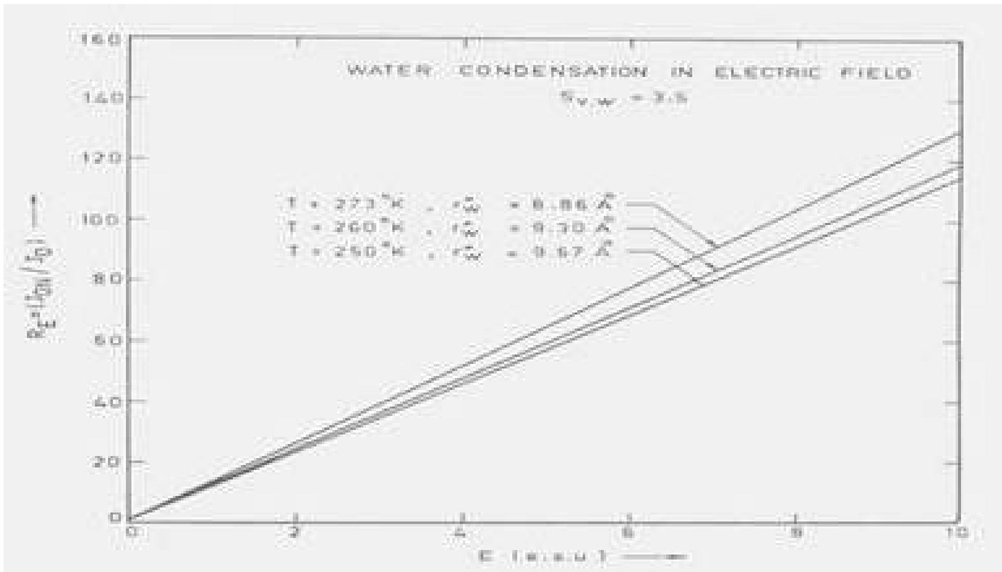

Fig.2- The variation of the factor of enhancement in the nucleation rate of water nuclei with electric field(E) at a given supersaturation for different temperatures

At a given temperature the relaxation time in absence of an electric field varies inversely with $l_nS_{v,W}$ but in the presence of an electric field, the relaxation time varies as $(l_nS_{v,W})^{-3/2}$.

Thus, due to the presence of an electric field the relaxation time is reduced by 3/2 power of $l_nS_{v,W}$. It has been found that for a critical nucleus at a given temperature the requires supersaturation is much less than in the absence of an electric field, For example, at 270K, $\tau_o = 11.54x10^{-4}$s the supersaturation required in absence of an electric field in 3.07. In the presence of electric field of 5 e.s.u., we get in the homogeneous nucleation, $(S_{v,W})_M = 1.12$ and $(S_{v,W})_N = 1.08$.

The relaxation time for the formation of a critical nucleus in the absence of an electric field is determined by the temperature and supersaturation (or critical radius). In the presence of an electric field, the relation time inversely with the electric field. In this case, before the attainment of the critical radius and even after that, the growth of the drops in the present case is factor compared to that obtained by the expression of Murino[17]. Typical values of relaxation times for homogeneous and heterogeneous processes with and without electric field under different conditions of temperature and supersaturation have been presented in table 2.

Table-2. Typical values of critical radii at 273K and E = 5 e.s.u. as the function of $S_{v.w}$. (A) Homogeneous nucleation process and (B) Heterogeneous nucleation process

A-Homogeneous nucleation process

$S_{V.M.}$	$r_w^*(A^o)$	τ_o (μs)	τ_M (μs)	τ_N(μs)	τ_{ON} (μs)
1.005	2225.00	258300	116614.5	66008.2	52580.00
1.01	1115.00	129500	41368.5	23416.1	19840.00
1.05	227.50	26400	3812.67	2158.12	1995.00

B-Heterogeneous nucleation process

$S_{V.M.}$	$r_w^{'*}(A^o)$	$\tau_o^{'}(\mu s)$	$\tau_M^{'}(\mu s)$	$\tau_N^{'}(\mu s)$	$\tau_{ON}^{'}(\mu s)$
1.005	4.286	497.5	9.859	5.580	5.519
1.01	4.289	497.8	9.869	5.580	5.524
1.05	4.311	500.4	9.945	5.629	5.566

CONCLUSION:

high electric field produces lightning discharge creating ionization of medium and a large number of ions are formed, Most of these ions get attached with ice embryo and require less energy of formation of critical nuclei of less radius. Therefore, the number of critical nuclei is enormously increased. Hence, for a given amount of water a large number of ice particles of smaller size are formed immediately after lightning.

From the above study, it is concluded that the nucleation of ice particles in electric field is very much effective. A small external electric field is equivalent to very large value of $S_{v.w}$ which otherwise, never exists in the clouds. Also in electric field induced nucleations in critical nuclei of smaller sizes is formed containing smaller number of water molecules and require less energy for formation. Hence equilibrium concentration of critical ice nuclei is enhanced as compared to the electric field free case of nucleation. Also from the equivalence of $S_{v.w.}$ with E, it is evident that electric field is more efficient than $S_{v.i.}$. This explains the rain gush after lightning.

Therefore, the number of critical nuclei is enormously increased. Hence for a given amount of water a large number ice particles of smaller size are formed immediately after lightning, suppressing the formation of larger hails.

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