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THE LOBE STRUCTURE IN ICE ACCRETED ON AN ALUMINIUM CONDUCTOR IN THE PRESENCE OF A DC ELECTRIC FIELD

by

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ABSTRACT

Supercooled droplets of 38 μm mean volume diameter are accreted on a smooth aluminium cylinder of 3.15 cm in diameter in order to study the effect of an electrostatic field upon ice formation on a power-line conductor. The results obtained show that ice grown in the presence of an applied negative field of 15 kV cm^{-1} exhibits a cusped-lobe structure characterized by surfacial outward knobs, convex rings of fine air bubbles and radial lines of large air bubbles; in the same conditions, a positive electric field of 15 kV cm^{-1} does not produce such lobe features. On the other hand, accretion tests performed in the absence of an electric field with a 38 μm droplet spectrum show that the well-developed cusped-lobe structure appears in ice at low ambient temperature and air velocity. In the present experimental conditions, the formation of cusped lobes observed in the presence of a negative electric field could be explained by a decrease in the temperature of the deposit due to a reduction of impact velocity of the charged droplets and/or an increase in the local heat-transfer coefficient at the surface of the ice accretion. Corona wind from ice points, always in the opposite direction to the impinging droplets, may also reduce their impact velocities. In addition, corona wind and roughness of the surface may contribute to a better evacuation of the latent heat and thus decrease the deposit temperature. The difference between the effects of a negative DC field and those of a DC positive field of the same strength comes from a stronger ionization intensity and/or a stronger deformation of water drops in the negative electric field.

INTRODUCTION

The influence of an electric field upon ice nucleation (also called electrofreezing) has been studied by many authors: Magono and Sekiya (1955), Pruppacher (1963, 1973), Roulleau (1969), Abbas and Latham (1969), Gabarashvili and Kartsivadze (1968), Roulleau and others (1971), Smith and others (1971), Evans (1973), Doolittle and Vali (1975). According to these studies, ice nucleation by an electric field can occur in natural clouds only when an intense DC electric field and ice or hydrophobic substance are present. All these conditions exist at the surface of the conductors of high-voltage transmission lines exposed to an icing cloud. In order to study the effect of an electrostatic field at the surface of a DC power-line conductor upon the formation of glaze and rime, a research program has been undertaken at the Université du Québec à Chicoutimi. In a previous paper (Phan and Laforte 1981) the authors showed that some properties of ice, particularly density and adhesive strength, decrease with increasing strengths of a DC electric field and these reductions are more important under a negative field. It was also shown in this paper that the influence of the electric field decreases with the conductivity of water and the size of the supercooled droplets. For example, the decrease in the density of ice obtained from distilled water droplets of 15 μm in a negative field of 20 kV cm^{-1} is 37% compared to the field free value, the corresponding percentage of decrease in density being only 2% for tap-water droplets of the same size.

The effect of the electric field upon the accretion intensity (defined as the product of the collection efficiency of water droplets, the liquid water content and the air velocity) has been reported recently by the authors (Phan and others in press). It was shown that, at low or medium intensities of accretion (1 to 2 g m^{-2} s^{-1}), "ice trees" are formed and the mass of ice accreted on an aluminium conductor decreases with increasing intensity of the applied electric field. For a negative electric field equal to or above 15 kV cm^{-1}, the mass of ice accreted becomes negligible. Besides, the effect of the electric field upon the density and the visual aspect of the ice (ice treeing) decreases with increasing intensity of accretion. Alternating electric field has practically no effect on the density of ice when the rate of accretion is equal to 15 g m^{-2} s^{-1}. The relationship between corona discharge and ice treeing was also investigated in the above-mentioned report. For an intensity of accretion of 2 g m^{-2} s^{-1}, if the ambient temperature is kept at -5°C, corona activity, namely the amplitude of the current pulses, is very important but the visual aspect of ice presents few or no ice trees. On the other hand, at an ambient temperature of -10°C, there are few or no corona pulses but the visual aspect of ice presents numerous ice trees with very small branches. This means that there is probably no evident relationship between the corona discharge and the formation of the ice trees. Although the effect of a DC electric field, especially a negative electric field, upon the ice formed on the conductors of power lines has been studied by the authors, its mechanism is not fully understood. The objective of the present work is to investigate the influence of an electric field upon the ice formed at a high intensity of accretion. As mentioned previously, at a high intensity of accretion, the effect of the electric field upon the visual aspect of the ice is negligible, with very little or no ice treeing, but lobe structures with large air bubbles appear in the ice accretion. Briefly, this work aims at studying the effect of a DC electric field on the porosity of glaze and rime formed on an aluminium conductor.

EXPERIMENTAL PROCEDURE

Experiments were conducted in a cold chamber with dimensions of 4.80 x 2.80 x 2.56 m where a minimum temperature of -35 ± 0.5°C can be maintained. Figure 1 shows the main elements of the apparatus. A smooth straight aluminium conductor with a diameter of 3.15 cm was placed on the axis of a mesh cage with a diameter of 1 m. In order to obtain uniform ice accretions, the conductor was rotated at 1 rpm, but in some experiments a stationary conductor was also used. Supercooled droplets were blown perpendicular to the cylinder through an opening in the cylindrical mesh cage (Fig.1) and the wind direction

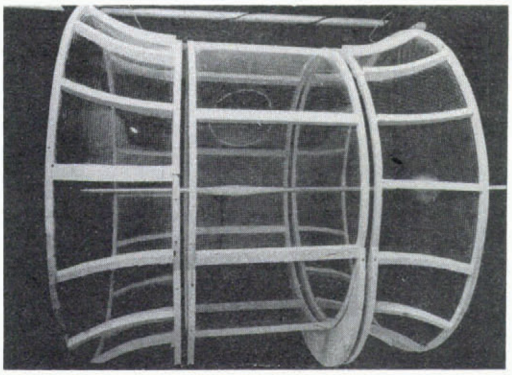


Fig.1. Cylindrical mesh cage used for the ice accretion test.

was about 45° with respect to the vertical plane containing the conductor. In some experiments, ice samples were grown in a horizontal wind tunnel with a working section of 23 x 23 cm placed in the cold room. The conductor was placed horizontally in the central part of the working section. This arrangement has been described in detail in a previous report (Phan and Laforte 1981). The sprays are fed with tap water of conductivity varying from 45 to 68 μmho cm^{-1}. High voltage is supplied to the conductor from a Messwandlerbau power supply of 200 kV, (AC/DC) 10 kVA. The median volume diameter of the droplet spectrum, which was measured in the absence of an electric field using the silver colloid film method (Godard 1960), is 38 μm. The liquid water content of the air was measured by the single-cylinder method (Rush and Wardlaw 1957). In most of the experiments performed in the presence of an electric field, the liquid water content, the ambient temperature, and the velocity of the air were kept constant at 0.8 g m^{-3}, -10°C and 8 m s^{-1}, respectively. With experiments performed in the absence of an electric field, the deposit temperature of ice near the aluminium cylinder was recorded by a thermoresistor fixed at the conductor surface. The accuracy of the temperature was within 0.2°C. Nevertheless, during the accretion test, a fluctuation up to a maximum of ±1°C could not be avoided completely so that errors of this magnitude must be considered in the values given in the text. Due to the relatively high voltage used, the deposit temperature could not be measured during the experiments performed in the presence of an electric field.

For each experiment, a high voltage was applied to the conductor, followed by water spraying. The corona current produced was then recorded. At the end of the accretion test, which lasted for about 90 min, an ice sample of 3 cm length was cut from the central part of the ice accretion. Ice pieces taken from this central part were used to prepare the thin sections with a sledge-type microtome and the porosity of ice was studied by examining the photographs of the thin sections of ice obtained through ordinary transmitted light.

RESULTS

Air bubbles in ice accreted in the presence of an electric field

Figure 2 shows thin sections of ice accretions grown in the mesh cage under the same atmospheric conditions. In fact, the ambient temperature T_a, the air velocity V, the liquid water content W and the mean volume diameter were kept constant at -10°C, 8 m s^{-1}, 0.8 g m^{-3} and 38 μm, respectively. In this figure, it can be seen that ice accreted under a DC positive field of 15 kV cm^{-1} on the surface of the conductor (Fig.2(c)) is very similar to that grown in the absence of a field (Fig.2(a)). These photos show the fine bubble layering that traces the growth morphology of the ice deposits on a rotating cylinder. The density of ice is about 0.87 g cm^{-3} for the three samples shown in Figure 2. It can be seen that under a negative applied field of 15 kV cm^{-1} (Fig. 2(b)) thin sections of ice present outward convex rings of fine air bubbles with large distinct radial air bubbles. These features are typical of the well-developed cusped-lobe structure which has been observed in natural and artificial ice accretions grown in dry conditions. The corona current was also measured by a DC micro-ammeter and the results obtained give a current of 2 μA for the ice sample grown under a positive field of 15 kV cm^{-1} while the corresponding current under a negative applied field of the same strength is 12 μA.

The effect of a negative electric field on the lobe structure and large radial air bubbles is again clearly illustrated in Figure 3. The tests corresponding to this figure were conducted in the wind tunnel and the liquid water content was 2.2 g m^{-3}, with the other atmospheric parameters the same as those used in Figure 2. Due to the rather large value of liquid water content, the deposit temperature of the ice accretion (Fig.3(a)) approaches the melting point of ice, in other words the growth regime is wet. It may be observed with ice accreted in the wet growth regime under an electric field of -15 kV cm^{-1} and -20 kV cm^{-1} (Fig.3(b) and (c)) that the fine air-bubble layers are more convex and developed than those shown in Figure 2(b), which corresponds to a dry growth regime. In addition, the surface protuberances or outward knobs in Figures 3(b) and (c) are distinctively separated with radially elongated air bubbles located between the lobes. The density of the ice accretions shown in Figures 3(b) and (c) decreases considerably with the applied field. It varies from 0.90 in the absence of a field (Fig.3(a)) to 0.50 and 0.45 at -15 and -20 kV cm^{-1} (Fig.3(b) and (c)), respectively.

Lobe structure in ice grown in the absence of an electric field

From the air-bubble features observed in an ice accretion grown under an electric field, it is obvious that the electrostatic field modifies the growth condition during the accretion process to promote the development of the cusped-lobe structure.

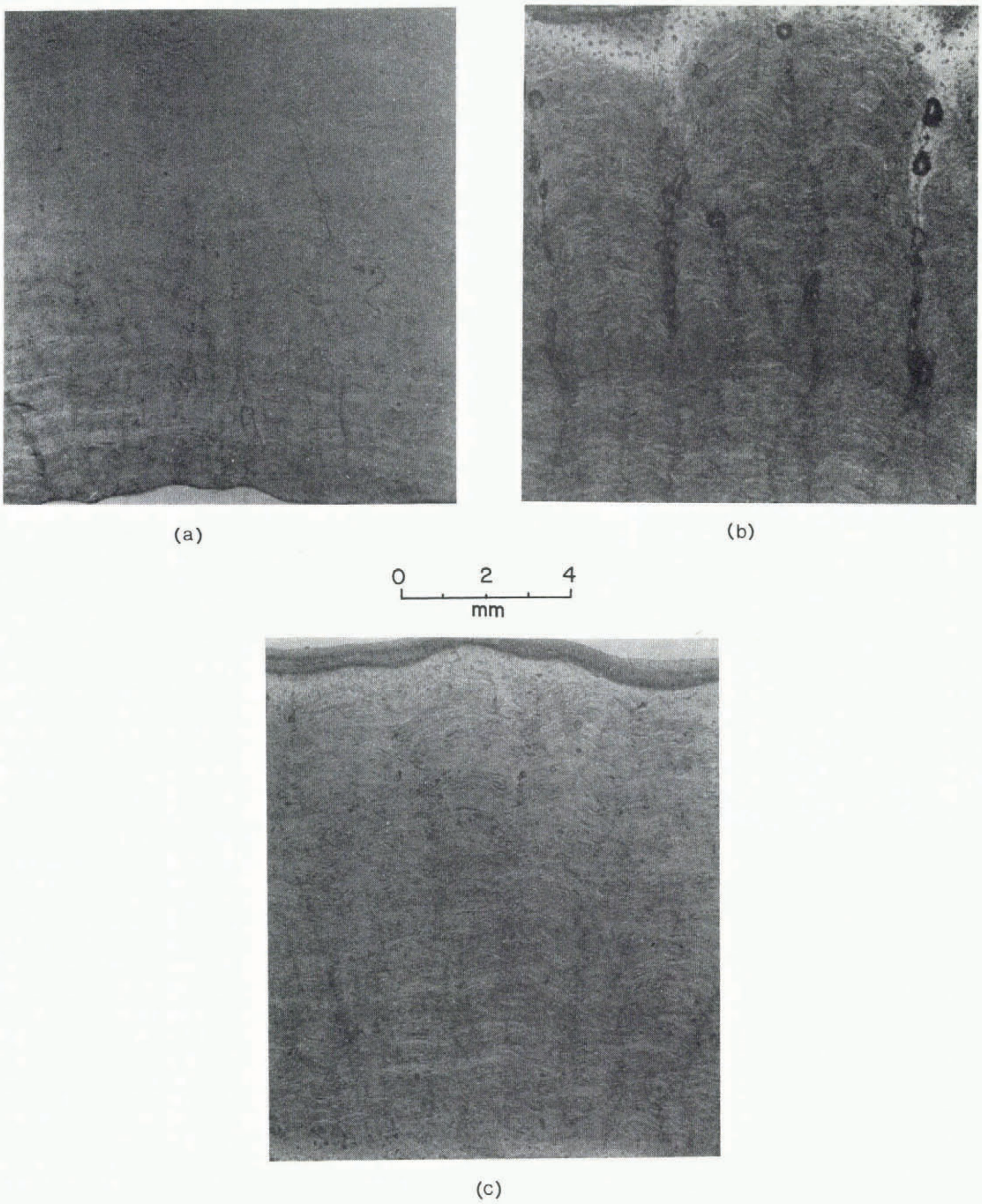
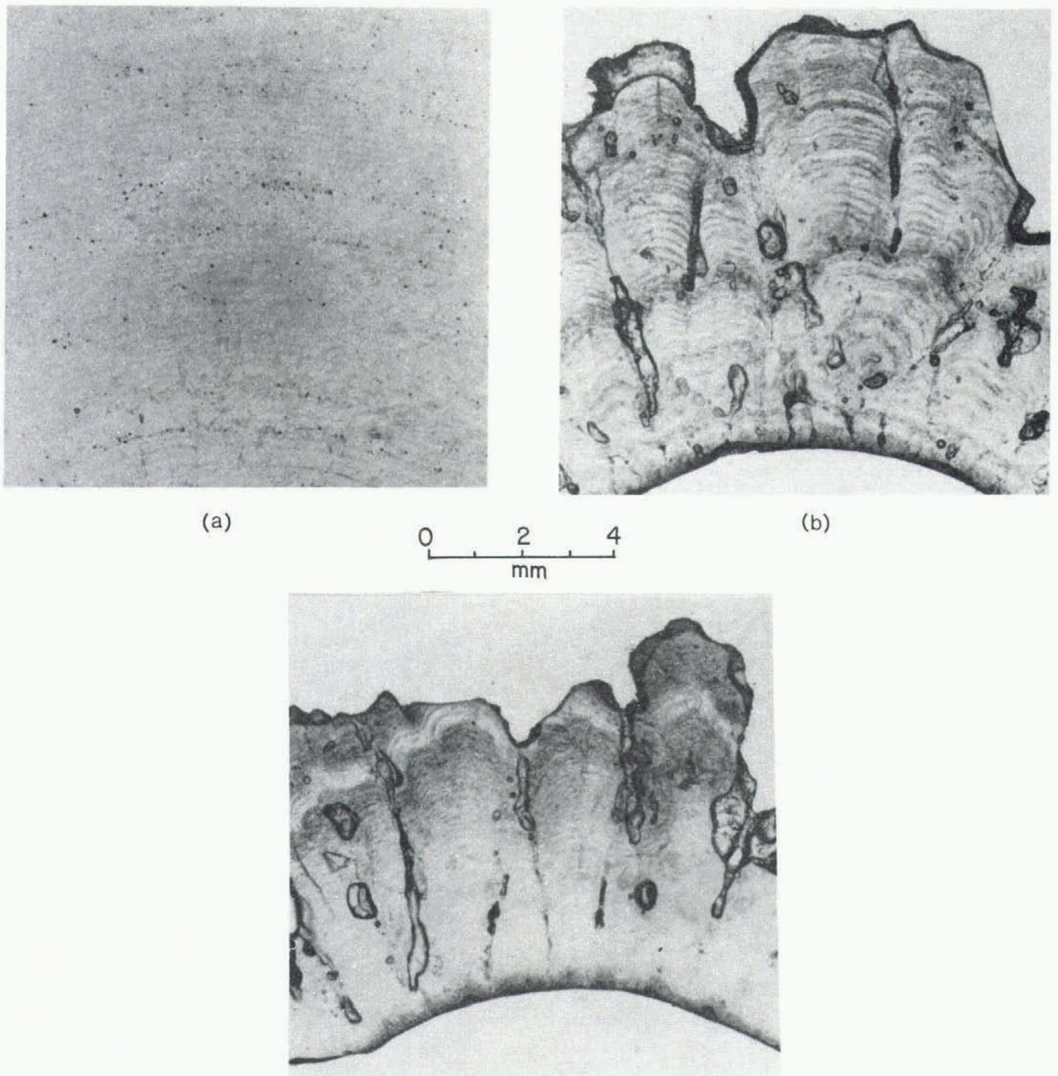


Fig.2. Effect of electric field on bubble features of ice accretions grown in the same atmospheric conditions on a rotating conductor.
(T_a = -10°C, V = 8 m s^{-1}, W = 0.8 g m^{-3})

(a) 0 kV cm^{-1} (b) -15 kV cm^{-1} (c) +15 kV cm^{-1}



(c)

Fig.3. Lobe structure of ice grown in wind tunnel under negative electric field of different intensities.
(T_a = -10°C, V = 8 m s^{-1}, W = 2.2 g m^{-3})

(a) 0 kV cm^{-1} (b) -15 kV cm^{-1} (c) -20 kV cm^{-1}

For this reason, it appears important to investigate in the absence of a field the atmospheric conditions which may produce ice with a lobe structure similar to that observed in Figures 2 and 3.

Figure 4 shows the thin sections of ice obtained with droplets of 38 μm mean volume diameter and liquid water content of about 0.6 g m^{-3}. This series of experiments was conducted in the wind tunnel where the ambient temperature and the air speed were varied from -2 to -15°C and 4 to 20 m s^{-1}, respectively. In Figure 4, it is shown that the cusped-lobe structure with clear convex rings of fine and radially elongated air bubbles developed especially at low ambient temperatures or at low air speeds. Indeed, if the ambient temperature was kept constant at -10°C (Fig.4(a) and (b)) the cusped-lobe structure was more developed at a wind speed of 4 m s^{-1} (Fig.4(a)) where the convexity of air-bubble layers was more pronounced than that observed at 8 m s^{-1} (Fig.4(b)). Lobe structure was also observed at -15°C (Fig.4(c)), but at a little higher air speed (15 m s^{-1}), and again at -6°C (Fig.4(d)) but, in this case, only at the lowest air speed used (4 m s^{-1}). Except in Figure 4(d) where the measured deposit temperature was -1°C, ice samples shown in Figure 4 were grown in the dry regime with the deposit temperature varying between -4 and -10°C. Figure 4 also shows, between the lobes, that large radial air bubbles formed which crossed several rings of fine air bubbles. Due to the rotation imposed on the collector, the separation between two adjacent rings of fine air bubbles corresponds to one revolution of the conductor, i.e. 1 min. Observation of the length of the radial air bubbles in Figure 4 shows that the time of formation of these bubbles varied from 10 to about 40 min.

Visual inspection of ice accretions grown in the presence or in the absence of an electric field but presenting cusped-lobe structure (for example, Figs.2(b) and 4(c)) shows protuberances at the outer surface while accretions without such lobe features have rather smooth surface finishes. In the conditions of growth corresponding to the accretions shown in Figures 2(b) and 4(a), (b) and (c), the measured height of these protuberances takes an average value of 2 mm. We estimate the value of the relative surface roughness of these ice accretions to be about 5%; it is defined as the ratio of the rough-

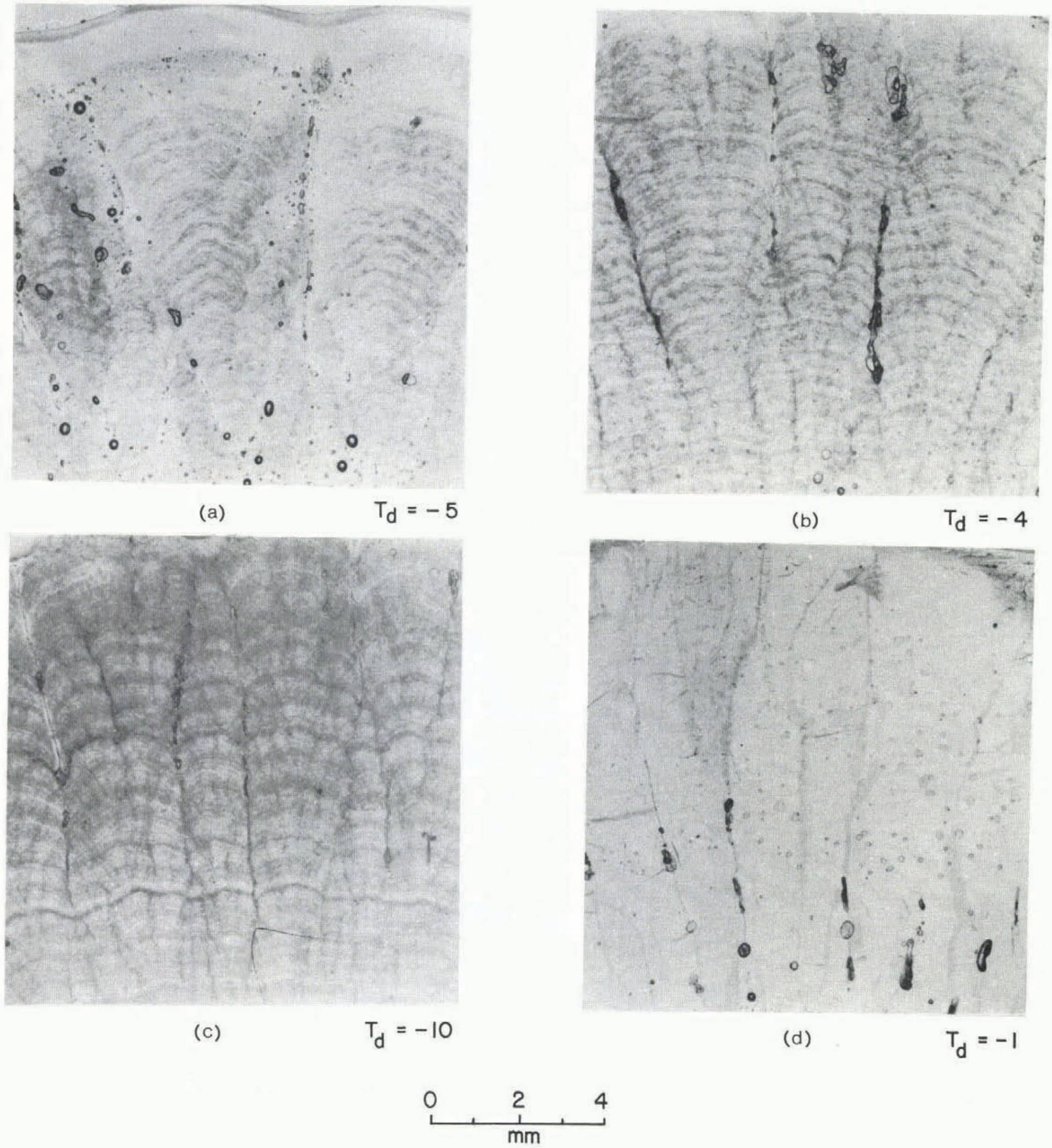


Fig.4. Effects of ambient temperature and air velocity on the lobe structure of ice accretions grown on a rotating cylinder in the absence of an electric field. (T_a = -10°C, V = 8 m s^{-1}, W = 0.6 g m^{-3})

(a) T_a = -10°C V = 4 m s^{-1} (b) T_a = -10°C V = 8 m s^{-1}
(c) T_a = -15°C V = 15 m s^{-1} (d) T_a = - 6°C V = 4 m s^{-1}

ness or protuberance height (about 2 mm) to the diameter of the cylindrical ice accretion (about 40 mm). As will be explained later in the discussion, the heat transfer at the outer surface of the ice accretion is greatly dependent on the relative surface roughness.

On the whole, all these observations are in agreement with Knight and others (1978) who showed that cusped-lobe structure with distinct radial lines of large air bubbles occurs in cylindrical ice accretions grown in dry regime especially when the deposit temperature is not greatly different from the air temperature. In addition, the size of the radially elongated air bubbles measured by these authors in dry accretions was found to vary from several tens to 100 or 200 µm in length. Knight and Knight (1970) also mentioned that the tumbling or wobbling of the hailstone is very likely a necessary condition for the development of the lobe structure. These authors believe that when a bump is formed on the surface of a hailstone during its tumbling, the bump will shield other portions of the surrounding surface from collecting the droplets. As a result, the valleys between the lobes become more and more impoverished, receiving droplets only when the hailstone is oriented in certain small ranges. The results obtained in the present series of experiments are in agreement with Knight and Knight (1970) on the fact that tumbling is an important condition of the development of the lobe structure. In fact, it is observed that, in the case of a stationary conductor (Fig.5) there is only one projection and that the convexity of rings

Fig.5. Bubble features of ice accretion grown on a fixed cylinder. (T_a = -10°C, V = 8 m s^{-1}, W = 0.6 g m^{-3})

of fine air bubbles decreases in comparison with those observed in ice accreted on a rotating conductor in similar atmospheric conditions (Fig.2(a)).

DISCUSSION

The results obtained in the absence of an electric field (Fig.4) show that the formation of a well-developed cusped-lobe structure occurs when the difference between the deposit and the ambient temperatures is small. This can be achieved either by a decrease in the impact speed of the droplets or an increase in the local heat transfer. The relationship between the above-mentioned factors and the droplet charges in an electric field as well as the polarity effects will be discussed in the following sections.

(a) Effect of the droplet charge upon its impact velocity

The charge carried by the droplets in the present experiments may be produced in several ways. Depending on the cloud-producing mechanism, droplets may acquire a charge termed the "natural charge" at the output of the nozzle. Droplets can also be charged in an ionized field: indeed, when a corona discharge is present, the air is ionized and the ions of the same polarity as the applied field, which travel along the lines of force, strike the droplets and impart a charge on them. In addition, cloud droplets are polarized, distorted and can even disintegrate close to a conductor under high voltage.

A Keithley electrometer was used to measure the natural charge of the droplets at -10°C in the absence of an electric field. The results obtained show that droplet charges vary randomly between the positive and negative signs with a predominance of the negative sign. The average value of the charge is about 450 e or 7.2 x 10^{-17} C per droplet.

Concerning the charge q_s that a droplet of radius a can acquire in an ionized field E, its maximal value, called the "saturation" charge, is (White 1962: 129-137)

$$q_s = \frac{3\varepsilon_r}{\varepsilon_r+2} \quad 4\pi\varepsilon_0 a^2 E \ , \tag{1}$$

where ε_r and ε_0 are the dielectric constant of water and the permittivity of air respectively. E is the undisturbed field, i.e. the field far from the particles or the discharge electrode. The charging time is inversely proportional to the space charge concentration, i.e. the corona current. For an applied field of 15 kV cm^{-1}, the undisturbed field at 1 cm from the surface of the conductor is about 10 kV cm^{-1} and the maximal charge of a droplet of 40 µm in diameter is about 1 x 10^{-13} C. Thus the charge acquired by a droplet in a corona field is much more important than that carried by the droplet at the output of the nozzle.

The polarization or dipolar charge q_0, i.e. the charge carried in each hemisphere of a droplet in a uniform electrostatic field E_0, is

$$q_0 = 6\pi\varepsilon_0 a^2 E_0, \tag{2}$$

where a is, again, the droplet radius. In a cylindrical configuration, q_0 is a function (Phan and Mansiaux 1975) of the separation D between the droplet and the conductor, and the radii R_1 and R_2 of the conductor and the mesh cage, respectively:

$$q_0 = \frac{12\varepsilon_0 V}{\ln R_2/R_1} \quad [D\ln \quad \frac{D}{D-a} - a], \tag{3}$$

where V is the applied voltage. For a field of 10 kV cm^{-1}, with a = 20µm, the value of q_0 is about 4 000 e or 6.4 x 10^{-16} C. This polarization charge is larger than the natural charge but still very small compared to the charge imparted to the droplet by an ionized field. Despite its small value, the polarization charge is the cause of the spark between the droplet and the conductor. Akazaki and Hara (1971) and Phan and Mansiaux (1975) have photographed the deformation and the spark between water drops with diameters of 3 mm falling close to a conductor under high voltage. After the spark or violent coronas the drops are usually blown off from the conductor with a remaining charge of the same sign as that of the conductor.

Owing to the high value of the electric charge imparted by an ionized field to the droplets, its impact velocity may be reduced. The electric repulsive force corresponding to a maximal droplet charge of -10^{-13} C in an undisturbed field of -10 kV cm^{-1} is 10^{-7} N. This force is independent of the polarity of the applied field. In our experimental conditions, with an air velocity of 8 m s^{-1}, the viscous force acting on a spherical droplet with radius of 20 µm is about 5 x 10^{-8} N. Thus the maximum electrical force is slightly larger than the viscous force and this can cause a decrease in the impact speed of the droplet carrying a maximum charge. However, in these experiments, the small (between 2 and 12 µA) corona current is produced by some projections on the outer surface of the ice accretion. In other words, the ionization is not uniform along and around the ice accretion with the result that all the droplets do not acquire a maximum charge. Moreover, it is not easy to measure the droplet charge in the presence of an ionizing field, and consequently not easy to know the exact value of the decrease in the droplet impact speed. Concerning the difference between the effects observed under negative and positive fields, it may be recalled that no lobe structure is observed under a positive field up to +15 kV cm^{-1}. Although the maximum repulsive force is the same under both polarities, it is expected that the number of negative droplets would be larger than the positive droplets. In fact, as the charging time t_0 is inversely proportional to the corona current I, the values of t_0 under a negative field of 15 kV cm^{-1} (I = 12 µA) should be six times lower than that corresponding to a positive field of the same strength (I = 2 µA).

To summarize, the high value of the charge imparted to the droplets by a corona field may reduce the impact speed of the droplets and consequently the collection efficiency. As a result the deposit temperature may be closer to the ambient temperature, which, as previously mentioned, is a condition for lobe-structure formation. Meanwhile the decrease in the impact speed due to the charged droplets is probably not the only cause of the formation of the lobe structure observed under an electric field.

(b) Effect of an electric field upon the local heat transfer

The local heat transfer at the outer surface of the ice accretion depends on many factors such as the roughness of the surface and the convection of the air flow. The electric field may influence the above factors and enhance the observed lobe structure.

Effect of the electric field upon the roughness of the surface of the ice accretions

Various types and degrees of surface roughness were observed with hailstones containing a lobe structure. The presence of the depressed areas or dimples between the projections of a rough surface influence the air flow so that fewer droplets are deposited on them than elsewhere (Kidder and Carte 1964). According to Bailey and Macklin (1967), the radial air bubbles observed between the lobes appear when there is a local variation in the collection efficiency of water droplets. Thus there is an interesting relationship between the formation of the lobe structure and the roughness of the surface.

Schuepp (1971) has shown that the heat and mass transfer of a sphere with a relative roughness k of 5 to 15% at a Reynold's number Re over 1.5×10^4 are about 1.7 times larger than those corresponding to a smooth sphere of equal volume. The examination of the outer surface of a cylindrical ice accretion with diameter of 40 mm grown in the present experiments under a DC negative electric field ($E = -15$ kV cm^{-1}) at 8 m s^{-1} ($Re = 2.4 \times 10^4$) gives a value of k equal to 5%. Ice accretions formed in the same atmospheric conditions under a positive field (15 kV cm^{-1}) or in the absence of a field present rather a smooth surface. This means that the heat transfer of ice grown in the presence of a DC negative electric field would be expected to be higher than that of accretions formed in the same atmospheric conditions but in the absence of a field or in a positive field due to an increase in the relative roughness.

The observed increase in the roughness of the ice accretions grown under a negative field may be a consequence of the decrease in the deposit temperature due to the reduction of the impact speed of the charged droplets discussed in section (a). In addition, there is also a possibility that an electric field, especially if negative, could enhance the production of protuberances at the surface of the ice accretion. It may be possible that the supercooled liquid droplets would be stressed and deformed under the action of an electric field. Direct evidence of such deformation has been shown during the freezing of water liquid drops hanging below a high-voltage conductor. Phan-Cong and others (1974) have reported that large hanging water drops become unstable and the excess water is ejected. The remaining volume, called the optimal volume of the drop, is independent of the initial volume of collected water but it depends on the polarity of the applied electric field and the size of the conductor. For instance, with a smooth cylinder with a diameter of 3 cm the optimal volume of the water drop is 20 µℓ under a positive field while the corresponding volume under a negative field of the same amplitude is about 60 µℓ. These results were confirmed by Jordan (1974) in an independent study. This means that the deformation or the distortion of the hanging drops is more important under a negative field than under a positive field. Assuming that these observations are applicable to small drops (droplet of 40 µm in diameter) freezing rapidly, it is possible that the supercooled liquid water droplets are also deformed before freezing completely on the surface of the conductor. In addition, the fact that a larger deformation of the droplets is expected to occur under a negative electric field would correspond to a decrease of the freezing time of the supercooled droplets, which is probably the cause of the polarity effect observed upon the roughness. Meanwhile, more work with small drops is needed to confirm the above explanation.

Effect of an electric field upon the modification of the convection of air flow around the ice accretions

It is known that the discharge current, such as that measured during the accretion test under an electric field, gives birth to a corona wind or electric wind. The velocity of the corona wind was measured by several authors, including Robinson (1961), using a point-to-cylindrical-screen configuration, and, more recently, Ballereau (unpublished) using the Doppler-laser method in a point-to-plane configuration. Whatever the configuration used, the corona wind in both polarities is directed from the point toward the ground electrode and the order of magnitude measured near the point is about 6 m s^{-1}. In the case of ice accretions showing a cusped-lobe structure, protuberances at the outer surface should be expected to act as ice points. Indeed, corona activities should be rather important at these points, compared to those expected with a smooth surface which do not present such ice protuberances. These surface protuberances may then be considered as discharge points with regard to the cylindrical mesh cage and the configuration is similar to that used by Robinson (1961). Owing to the large radius of the mesh cage, the same equipotential patterns around the conductor would be obtained if the cylindrical cage is replaced by four tangential grounded planes. Thus the configuration of ice points and mesh cage is also comparable to the point-to-plane configuration. Whatever the configuration used, the velocity of the corona wind is proportional to the square root of the DC component of the corona current. According to Marco and Velkoff (1963), the average heat-transfer coefficient is proportional to one-quarter power of the total discharge current. As a result, the heat-transfer coefficient produced by a current of 12 µA ($E = -15$ kV cm^{-1}) would be about 1.6 times larger than that corresponding to a current of 2 µA ($E = +15$ kV cm^{-1}). In other words, a negative electric field of 15 kV cm^{-1} produces a cooling effect 1.6 times more efficient than a positive electric field of the same strength.

Although an electric field may influence the formation of a lobe structure in ice in different ways, its effects may be interdependent. For example, the formation of initial protuberances increases the surface roughness and consequently the local heat transfer; at the same time, they form discharge points which ionize the air and impart high electric charges to the droplets. The protuberances also give birth to a corona wind, always in the opposite direction to the impact droplets. These two factors would contribute to a decrease in the droplet impact speed and consequently in the deposit temperature. On the other hand, the corona wind, being more important at the protuberances, would increase the local heat-transfer coefficient and thus enhances the above-mentioned effect of the surface roughness.

CONCLUSION

An experiment has been conducted to simulate the formation of ice on power-line conductors. For the atmospheric conditions used, a negative electric field of 15 kV cm^{-1} enhances the formation of a well-developed cusped-lobe structure with large radially elongated air bubbles and outward convex rings of fine air bubbles. In the same atmospheric conditions, ice accretions formed in the absence of an electric field or in the presence of a positive electric field of 15 kV cm^{-1} do not present a lobe structure. On the other hand, in dry growth, lobe structure is observed in the absence of an electric field only when the difference between the deposit temperature and the ambient temperature is small. The latter condition may occur with ice grown in the presence of an electric field when there is a reduction of the impact speed of charged droplets or an increase in the local heat transfer at the outer surface of the ice accretion. Corona wind from ice points, always in the opposite direction to the impinging droplets, may also reduce their impact velocities. In addition, corona wind and roughness of the surface may contribute to a better evacuation of the latent heat and thus decrease the deposit temperature. The difference between the effects of a negative DC field and those of a DC positive field of the same strength comes from a stronger ionization intensity and/or a stronger deformation of water drops in the negative electric field.

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