Wet Snow Shedding from an Overhead Cable Part 1: Experimental Study

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***Abstract*— Severe wet snow events lead to the formation of cylindrical sleeves on overhead cables. Wet snow sleeves shed naturally when subjected to a positive heat gain, when their liquid water content (LWC) reaches a critical value. A short account of the heating and cooling factors acting on a wet snow accretion, as well as a qualitative description of the creep phenomenon leading to natural shedding are provided. It is often impractical to study wet snow accretions on site since they are rare and since their physical properties may evolve rapidly under the influence of meteorological factors. A simple and inexpensive method developed to reproduce wet snow accretions on a cable is explained. The technique was used in a controlled environment to recreate wet snow sleeves up to 5 meters in length, with initial density ranging from 0.4 kg/m³ to 0.6 kg/m³. The evolution of snow sleeves is described for two different scenarios: left to thaw in still air, and subjected to radiation heating.**

I. Introduction

WET snow accretion on overhead transmission line conductors and ground wires can lead to a number of serviceability, safety and mechanical reliability issues. Wet snow accretions typically occur at air temperatures slightly above the freezing point. Similarly to rime ice accretions, wind-borne wet snow particles adhere to the windward side of overhead cables. As demonstrated by Wakahama *et al.* [1], the accreted mass grows into the wind, causing the cable to rotate under the eccentric load. Cable rotation leads to the formation of cylindrical snow sleeves that are unlikely to shed from wind loads alone [2].

Wet snow accretions are difficult to study. They are rare and often limited to specific locations with special topography or microclimate. Field observations are typically done during the hours or days following a storm. However, wet snow sleeves may undergo rapid changes in LWC and strength and/or even shed before samples can be collected [3]. As it is the case for most atmospheric icing studies, experiments performed in a controlled laboratory environment are best suited to study the evolution of these accretions along their lifespan.

The recent partnership between Électricité de France (EDF), the CIGELE Industrial Chair on Atmospheric Icing of Power Network Equipment at Université du Québec à Chicoutimi (UQAC) and McGill University has resulted in a number of studies on the subject of wet snow. This paper summarizes some of the experimental work performed by M. Roberge within the framework of his master's thesis on the topic of wet snow shedding from an overhead cable [4].

II. Properties of Wet Snow Sleeves

A. *The Nature of Wet Snow*

Wet snow particles are an agglomeration of snowflakes and a mixture of ice, liquid water and air. The physical properties of wet snow are extremely variable, as different ratios of ice, water and air produce microstructures with different densities and LWC. This, in turn, leads to a wide range of adhesive properties and strengths [5]. Moreover, the microstructure of wet snow is continuously undergoing metamorphism with changes in LWC, temperature and/or temperature gradient [6], [7].

Wet snow is characterized by two basic modes of liquid water saturation: the *pendular* and the *funicular* regimes. At low LWC values, air spaces are contiguous throughout the microstructure and snow is said to be in the pendular regime. The funicular regime occurs at higher LWC values, and is achieved when liquid water becomes contiguous throughout the pore space. In the pendular regime, wet snow exhibits increasing cohesive strength as its LWC increases. Once the transition to the funicular regime is achieved the cohesive strength of wet snow decreases with increasing LWC [8].

Natural shedding of wet snow sleeves from overhead cables occurs in the funicular regime when the combined gravitational and aerodynamic loads exceed the weakened internal forces holding the sleeves together and on the cable [5], [9].

B. *Heat Balance of a Wet Snow Sleeve*

The components of the thermodynamic equilibrium of a wet snow sleeve are illustrated in Fig.1. The heating and cooling factors were identified by previous researchers while attempting to model the complex wet snow accretion process [5], [9]. Inside the snow mass, the following heating and cooling effects are balanced by the melting or freezing of water, i.e. by a variation of the LWC:

- Q_{conv}: Heat supplied or removed by forced convection. During the accretion stage, air temperature is slightly above the freezing point and heat is supplied to the snow sleeve. After the accretion stage, air temperature may drop below the freezing point: in that case heat is removed by convection.

- Q_{evap}: Heat removed by evaporation/sublimation at the surface of the accretion. This effect should be neglected during the accretion stage since wet snow events usually occur at relative humidity close to 100%, which prevents evaporation.
- Q_{cond}: Heat supplied by condensation at the surface of the accretion. Condensation also increases the amount of liquid water in the snow sleeve.
- Q_{rad}: Heat supplied by ambient radiation and solar radiation. The amount of heat from ambient (air-snow) radiation is negligible and the model established by Grenier *et al.* neglects these effects [5]. It is acceptable to disregard solar radiation during the accretion stage when precipitations are heavy. However, it should be included when modeling a snow sleeve during the persistence and shedding stages.
- Q_{joule}: Heat supplied by Joule effect if the conductor is energized. Under rare meteorological conditions, the LWC of a wet snow sleeve can be kept constant in the pendular regime. During such exceptional events, unrestricted growth of snow sleeves may occur, possibly leading to severe overloads and damages to overhead cables and structures [9]. In such circumstances, Grenier *et al.* suggest that Joule heating of the conductor could be used to increase the LWC of the snow matrix and promote snow melting and shedding [5].

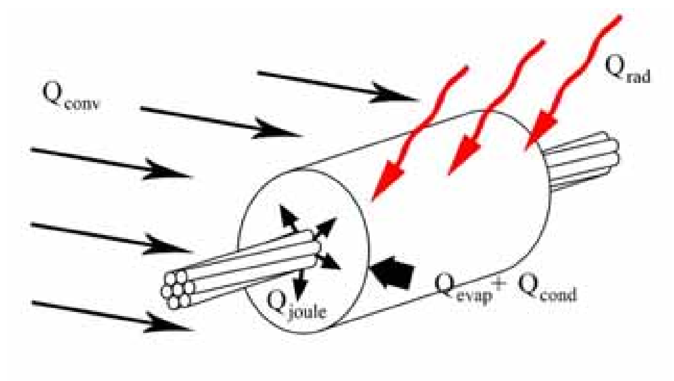

Fig.1. Heating and cooling effects on a wet snow sleeve

C. *Shedding of Wet Snow Sleeves*

Observations of natural wet snow shedding from an overhead cable are rare and not well documented. Very few people have actually witnessed the phenomenon in the field and observations are varied and scattered. In general, cylindrical sleeves appear to shed partially and randomly over their span, in segments up to 30 meters long (rough approximation) [10]. Admirat claims that, once partial shedding is initiated, total unloading may take place in only a few minutes [10].

Shedding occurs following an increase of the LWC of a snow sleeve, governed by its thermal equilibrium. The exact LWC at which shedding occurs is difficult to predict: it appears to depend on the density of snow and on external factors (for example, snow shedding on a conductor may be triggered at a lower LWC if it is subjected to a sudden transverse acceleration). The range of LWC values reported at the time of shedding varies between 20% and 40%, by mass [10], [11].

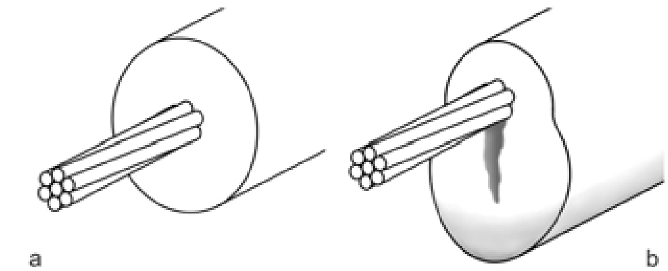

Fig.2. Wet snow creep in a wind-tunnel experiment at high LWC (Density 0.4 ~ 0.7 g/cm³, LWC ~ 40% by mass; adapted from [12])

Previous wind-tunnel and *in situ* observations indicate that snow sleeves exhibit significant creep prior to shedding. As illustrated in Fig.2, snow sleeves flow under the effect of gravity when their LWC approaches a critical value. The initial cross-sectional profile (Fig.2a) becomes elongated and a cavity forms below the cable as the snow migrates (Fig.2b). Snapshot “b” was taken 20 minutes after snapshot “a”, and only instants before shedding.

Natural shedding strongly depends on the weather conditions during and following the accretion. For example, if a wet snow sleeve is subjected to overnight freezing it is unlikely to shed by the mechanism described above. Instead, it will remain on the cable and shed by slow sublimation and/or melting, as would rime ice or glaze ice. In Iceland, such hardened snow accretions have been reported to persist for many weeks on cable spans [13].

Since wet snow is a highly plastic material it is unlikely that an applied deformation could trigger its shedding. However, it is reasonable to assume that any accretion can be removed from a cable by subjecting it to a sufficiently large acceleration resulting from a combination of gravity, wind and inertia effects. In such a scenario, the resultant load may impose stresses as large as the cohesive strength of the snow sleeve, causing the cable to punch through the accretion.

III. Wet Snow Experiments in a Climate Room

A. *Experimental Setup*

Experiments were performed at the CIGELE laboratories in March 2006 to assess the feasibility of reproducing wet snow sleeves by using fresh dry snow collected on the campus grounds.

The experimental setup used to simulate wet snow accretion shedding is shown schematically in Fig.3a. Two stranded 5 m-long conductors (ALCAN Pigeon 6/1 ACSR, 12.75 mm diameter) were suspended approximately 1 m above the floor (Fig.3a, b). The cables were tensioned using hoists to remove most of the sag due to the snow load. The large climate rooms of the CIGELE facilities were ideal to perform such a study.

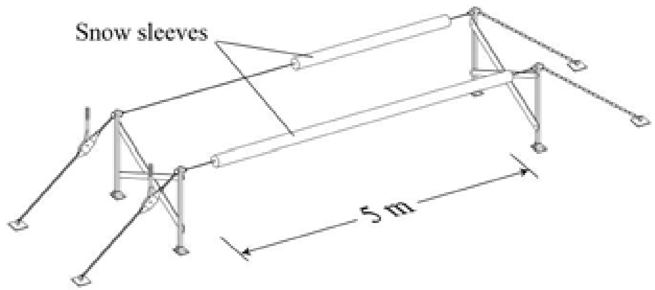

Fig.3a. Cable setup schematic

Fig.3b. Actual setup in climate chamber, with 5 m snow sleeve

B. Wet snow sleeve molding

An inexpensive technique was developed using simple tools to produce wet snow sleeves around a cable. For all experiments, wet snow was obtained by bringing fresh dry snow from campus grounds into a climate room and spreading it evenly, 1 cm to 2 cm thick, on sheets of polystyrene insulation board. The dry snow was collected from the top layer of snow banks and had accumulated less than 12 hours earlier. The LWC of the snow thus processed approached that of precipitating wet snow after being exposed to warmer air at 3°C for one hour. This method, based in part on the recommendations of Sakamoto [2], [3], produced a wet snow material with adequate LWC and density uniformity.

Fig.4 illustrates how the sleeves were molded. Wet snow was laid in a semi-cylindrical mold and compacted evenly in a succession of layers (Fig.4b to d). Once the bottom half of the sleeve was formed the mold was placed under the cable and raised until the snow touched the cable (Fig.4e). Using a semi-cylindrical hand tool, the top half of the sleeve was formed by compacting successive layers of wet snow (Fig.4f to i). After molding, the resulting snow sleeve had a uniform diameter of 10 cm and a length up to 5 m.

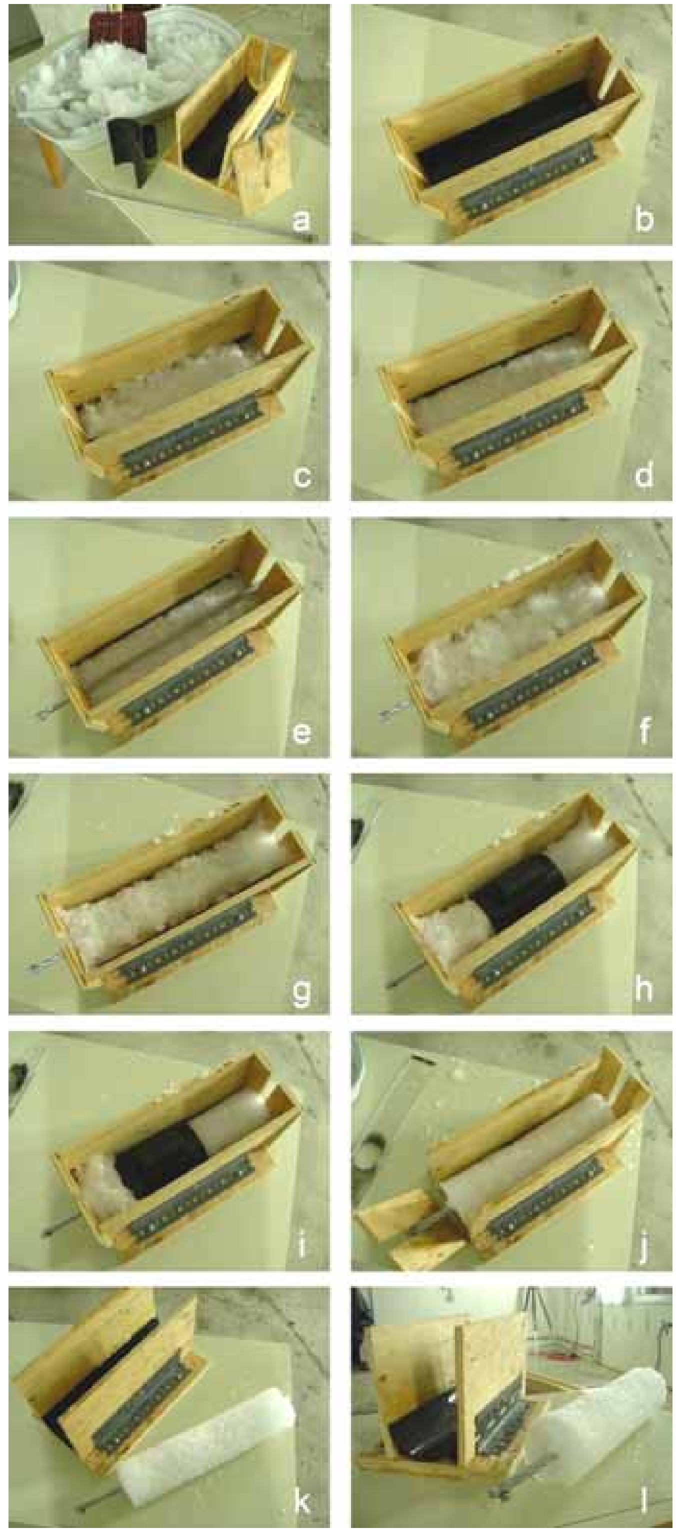

Fig.4. Molding a snow sleeve around a cable segment

C. Observation of wet snow sleeves in still air

The objectives of these experiments were to reproduce wet snow sleeves and to observe how they shed naturally when ambient temperature is controlled and held constant.

As melting progressed, it was observed that the bottom of the accretion became saturated with water: it became translucent and liquid water dripped to the floor after a few hours (Fig.5a); this is consistent with the observations reported during the wind-tunnel experiments of Wakahama *et al.*[1] and Sakamoto *et al.* [3], for snow sleeves of similar density. Measurements showed that the density and LWC of the accretions increased significantly as melting progressed and that the bottom part of the snow sleeves had LWC values almost twice as high as the top part (Fig.5b). The wet snow sleeve also became slightly eccentric with respect to the cable due to the migration of melt water from the top to the bottom (Fig.5c). Snow grains in the top part of the accretion had good cohesion, even when the LWC reached 25% to 28%. Some of the top grains were even found to be frozen onto the cable.

Fig.5a. Liquid water migration: water droplets (+8 hours)

Time	0h	+3h	+6h
Density	0.36 g/cm^3	0.57 g/cm^3	0.67 g/cm^3
LWC	8.3%	16.5% (top)	26.9% (top)
		31.8% (bottom)	50.5% (bottom)

Fig.5b. Sample measurements: Evolution of LWC and density

Fig.5c. Cross-sectional cut (+11 hours, 25% LWC top, 44% LWC bottom)

It was also observed that the artificially reproduced snow sleeves left to thaw in still air did not exhibit the expected behavior of random partial shedding on long segments, as described by field observers. Instead, shedding progressed very slowly from the bare cable ends, even if the climate room was set to a higher temperature (e.g.10°C to 15°C). It took more than 12 hours for the snow sleeve to melt and shed from the cable at an ambient temperature of 3°C (Fig. 6).

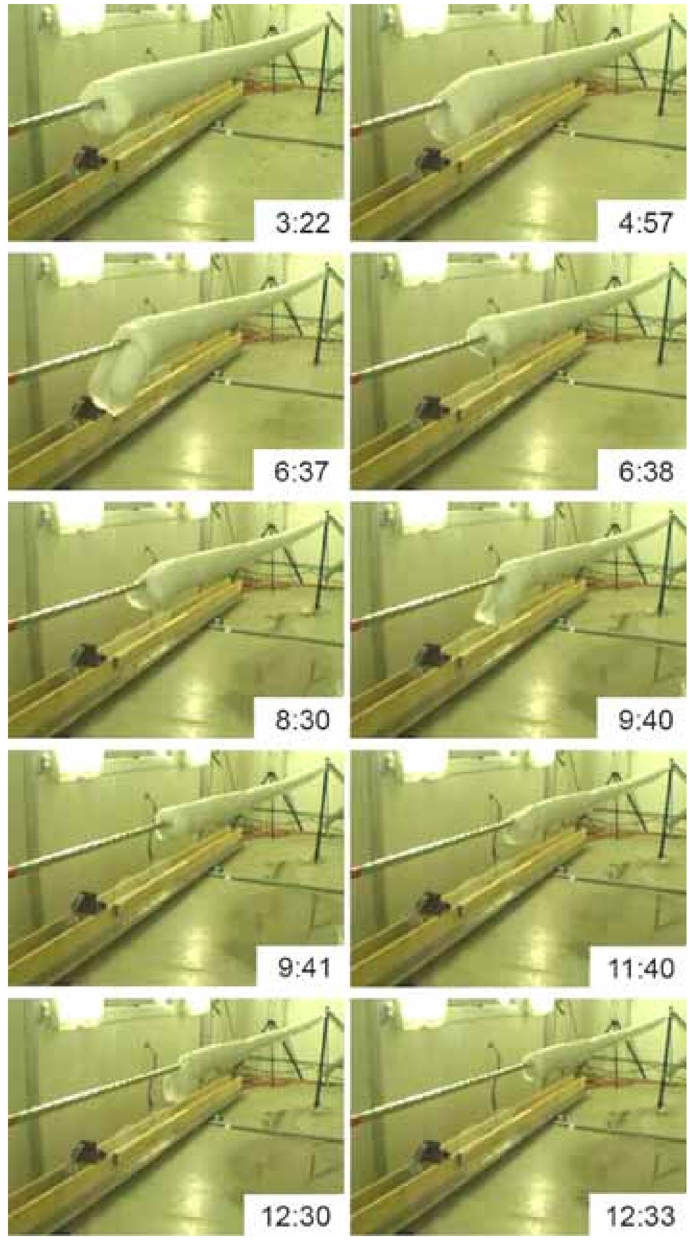

Fig.6. Slow melting and shedding snapshots

Natural wet snow sleeves are created by sustained precipitations and wind. The amount of heat supplied by forced convection is not negligible and other heating sources such as solar radiation and Joule effect also contribute to increase the LWC of the accretions.

During this first series of experiments, LWC values up to 28% were observed in the top half of the snow sleeves without any sign of creep. It appears that the LWC in the top half of the accretions never reached a critical value, thus preventing creeping of the snow sleeves. Liquid water migrates easily inside the snow mass under the effect of gravity; melt water in excess of what the microstructure can retain escapes in the form of droplets, keeping the top of the accretion relatively dry.

D. *Wet snow sleeves subjected to radiation heating*

In a laboratory environment, it would seem that some heating is required to increase the LWC of the top of a snow sleeve and recreate the conditions leading to natural shedding, as witnessed by most observers. Solar radiation heating on the top of the snow sleeves was simulated by adding halogen spotlights to the experimental setup (20 W/m to 25 W/m estimated). This realistic solar radiation effect caused the accretions to creep and changed the shedding behavior significantly. Under radiation heating, snow sleeves took approximately 2 hours to shed in an "unzipping" manner along their entire length. No sleeve was observed to shed spontaneously: shedding was initiated at one point along the cable segment, and progressed at speeds measured between 12 m/s and 14 m/s (Fig.7). Further investigations would be necessary to demonstrate whether this shedding speed is constant or if it depends on the cable diameter, the density and/or the microstructure of the snow accretion.

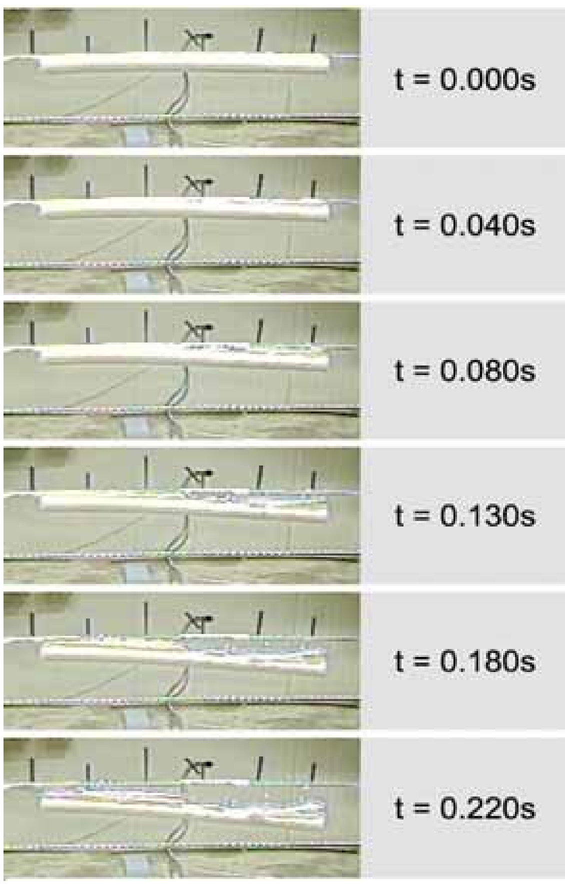

Fig.7. "Unzipping" shedding of a wet snow sleeve, progressing at 12.5m/s

The speed of propagation of the unzipping effect has been used as input in finite element analysis to evaluate the effects of wet snow shedding from a suspended cable. A numerical modeling technique has been developed during this study to evaluate the response of an overhead ground wire subjected to different types of snow shedding [14].

IV. Conclusion and Future Developments

Experimental production of wet snow sleeves using simple and inexpensive tools is possible. In future work, the microscopic aspects of these simulated sleeves should be studied and compared to those observed in the field. Because of the short-lived nature and rarity of wet snow sleeves, artificial production of wet snow accretions of good quality in a controlled environment may be the only way to study their mechanical properties.

When a snow sleeve loses its cohesion, creeps and breaks off from a cable, the rupture propagates along the accretion at a measurable speed. Good quality wet snow sleeves could be used to observe the influence of various heating effects on their properties, and on the speed at which shedding fractures propagate.

In the current study, snow sleeves were subjected to an added heat flux in order to recreate the conditions leading to natural shedding. A radiation heat flux applied to the top of a short snow sleeve successfully caused the accretion to creep and shed along its entire length. This also demonstrated that wet snow sleeves surrounded by warm still air melt slowly and shed gradually, without causing noticeable cable motion.

Further experimental research is needed for a more rigorous study of the heating effects that influence the LWC of wet snow sleeves. Such a study could be combined with a validation/revision of the thermodynamic accretion models proposed by Grenier and Admirat during the 1980's and by Poots in the 1990's.

V. Acknowledgment

This study is the first of a series of wet snow investigations emerging from a partnership between Électricité de France (EDF) and the CIGELE Industrial Chair on Atmospheric Icing of Power Network Equipment at Université du Québec à Chicoutimi (UQAC), in collaboration with McGill University. Funding for this study was provided by EDF within the framework of this partnership.

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