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Morphogenetic Modelling of Wet Ice Accretions on Transmission Lines as a Result of Freezing Rain

Krzysztof Szilder and Edward P. Lozowski
University of Alberta, Edmonton, Canada

Masoud Farzaneh*
Université du Québec à Chicoutimi, Chicoutimi, Canada

ABSTRACT

When water droplets encounter an object and the atmospheric conditions are sufficiently cold, ice will accrete. In this paper, we examine ice accretion due to freezing rain on a cylindrical surface representing a transmission line cable. A 3-dimensional random walk model is used to predict the morphology and mass of the ice accretion. In this method, the motion of each drop or of drop ensembles is followed individually. The main advantage of the random walk approach is that it models realistically and with numerical efficiency the flow of water along the surface of the accretion. This model calculates not only the accretion on the side exposed to impinging droplets, but also the accretion below the object, including the possible formation of multiple icicles. The model prediction of the shape and mass of the ice accretion on a cylinder has been analyzed as a function of the convective heat flux and the precipitation rate. While used here to simulate accretions on ground wires, the morphogenetic model could also be used to simulate ice accretion on other elements of electrical power transmission lines.

INTRODUCTION

When raindrops encounter an obstacle in their path at atmospheric temperatures that are sufficiently low, ice will accrete on the object. Numerical models that are based on differential forms of the conservation of momentum, energy and mass equations have been used previously to predict the ice accretion load. These models are called continuous since they are based on the assumption of continuous changes of all the physical parameters. Two main categories of such models can be distinguished: time-independent and time-dependent. In time-independent models (e.g., Lozowski et al., 1983), the calculations are based on the assumption that the initial growth rate remains unchanged during the simulation. The time-dependent models take into account, to varying degrees, the fact that the growing accretion changes the fluid flow around the object, the trajectories of the incoming droplets, the area exposed to drop impingement and the heat transfer conditions (e.g. Szilder et al., 1987).

In spite of significant progress in their development, the majority of the continuous models require a priori assumptions about the accretion shape. The model ice shape may vary from circular, to elliptical to noncircular (McComber, 2000). However, in the continuous approach the relation between icing conditions and the assumed accretion shape is uncertain. In this paper, instead of using a continuous approach, a 3-D random walk model is used to simulate the formation of an ice accretion, including cases when liquid flows along the accretion surface prior to freezing. Because the model predicts the accretion shape, we call it a morphogenetic model, borrowing a term from the biological sciences where morphogenesis has to do with the development of shape and form. Such models are also referred to as random walk or Monte Carlo models.

Monte Carlo models have been used previously in ice accretion research as an alternative to continuous models. In this method, the motion of each drop or of drop ensembles is examined discretely. This approach has been applied successfully to predict accretion under riming conditions when impinging small droplets freeze on impact. Gates et al. (1988) examined the accretion on a fixed cylinder and Personne et al. (1990) on a rotating cylinder. A limited mobility of the droplets after impact was proposed by Lozowski et al. (1991) in the simulation of hailstone growth. Szilder (1993) introduced the random walk method into ice accretion research allowing simulation of wet cases, when unfrozen water flows along the surface of an ice accretion before freezing. The random walk model allows the representation of water flow over the surface of an accretion. Fluid elements can move considerably away from their location of initial impact. The random walk model also adds some randomness to accretion shapes in keeping with experimental observations. A 2-dimensional analysis of the ice accretion on a cylinder using a random walk model was undertaken by Szilder (1994). A version of the model that allows the prediction of ice accretions on complex 3-D objects has also been developed (Szilder and Lozowski, 1995a). However, that analysis was performed as a function of the model parameters, and the relation with atmospheric conditions was not explored. A wind-tunnel verification of the model for the formation of a single icicle was described by Szilder et al. (1995c).

During wet icing conditions when there is a lot of available water, a pendant ice formation may be found under the cylinder. Makkonen (1988) presented a model of fresh water icicles and Chung and Lozowski (1990) a model of marine icicle growth. Makkonen (1996) has also recently presented a continuous hybrid model of transmission line icing with multiple icicle formation. The CRREL model (Jones, 1996) also attempts to take icicle for-

*ISOPE Member.

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