Measurements of Thermodynamic Properties of Ice Created by Frozen Sea Spray

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ABSTRACT

A field simulation of ice accretion has been performed in the harbour area of Longyearbyen, Spitsbergen, during the winter of 2011. Cylinders with diameters of 10, 20, 40 and 100 mm were exposed to a freezing artificially created periodic spray. This paper presents the density, crystalline structure and salinity of the accreted glaze ice. Hydrostatic weighing was used to measure the ice density, which is a well-established method in fields not related to ice. The method is simple, does not require special equipment and can be accurate to better than 1%. The dependence of the ice properties from the weather conditions is discussed. The experiments demonstrated that the ice salinity was smaller on the larger vertical objects.

KEY WORDS: Accretion; ice; density; icing; sea spray.

INTRODUCTION

No much data are available in the literature related to the properties of ice formed by freezing sea spray with high concentration. A detailed description of the properties of ice accreted on a real vessel can be found in the work of Ryerson and Gow (2000). Some data on the salinity of ice accretion are available in a study by Fukusako et al. (1989).

The ice salinity is important for the ice adhesion, according to Makkonen (2012). The salinity also defines the ice strength and is important to understand salt entrapment and the growth of saline ice. This knowledge is required for modelling ice accretion, which can be further used to estimate the icing load. The salinity measurements were produced in the given experiments for these reasons.

The measurements were obtained in the harbour area of Longyearbyen, Spitsbergen, and a detailed description of the experimental setup is given in the work of Kulyakhtin et al. (2012). The measurement was conducted for up to 2.5 hours, which is a relatively long time of measurement. The spray inflow resulted in a wet icing formation that was unknown; therefore, the data for this formation were not analysed previously. The recent results in Kulyakhtin et al. (2013) proved that in a “thermally limited” (TL) conditions, the ice accretion is almost independent of the spray’s flow rate and period. Therefore, the experimental results were revised based on the improved knowledge, and an analysis of the ice properties was attempted. The scattering and the limited amount of data complicated the analysis. The results and discussion are therefore combined in this paper; however, a few important observations have been made. The results indicate the ice growth process and the drainage of the salt solution.

ICE ACCRETION RATE THEORY

There are two main scenarios of ice accretion in accordance with the factors limiting the growth rate. The first scenario is the “mass limited” (ML) scenario, in which the total water mass arriving on the cold surface can be frozen due to the cooling; the water mass is therefore the limiting factor for the accretion rate. The second scenario, the TL scenario, represents conditions when the water impingement on the surface is high and the heat fluxes are unable to freeze all of the water; as a result, some of the water runoff representing the “wet” icing conditions. The existence of the unfrozen water and the water-ice interface requires that the temperature of the liquid film equals the freezing temperature. The temperature of the sea water is defined by the water’s salinity, which can be increased due to salt expulsion from the forming ice. The equation describing the ice growth in the TL scenario in the case of continuous spray was given by Makkonen (1987).

Kulyakhtin et al. (2013) showed that in the wet icing case, the accretion rate is independent of the spray period and the water amount arriving per spray event for the conditions in Longyearbyen. This finding is true even if the conditions are TL only on average, i.e., even if most of the ice surface is dry between the sprays. This result means that the “wet formed” ice should be independent of the amount of water that arrived and should depend purely on the heat fluxes. Thus, if the conditions are proven to be TL, the results in the paper by Kulyakhtin et al. (2012) can be analysed based on the freezing conditions. Such an analysis is performed in this paper, and the ice properties are discussed.

Kulyakhtin et al. (2013) simplified the equation from Makkonen (1987) and showed that the main heat flux sources in the experiment were convection and evaporation. It was shown that the radiation can be neglected; however, the heat flux from cooled spray is uncertain. According to Kulyakhtin et al. (2013), the ice accretion growth rate per