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Post-nucleation conversion of an air bubble to clathrate air–hydrate crystal in ice

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Abstract

We present an attempt to model the process of conversion of an air bubble, trapped in ice, to clathrate air–hydrate crystal after its nucleation on the air–ice interface. Both counterparts of the transformation are considered: diffusion of interstitial water and air molecules through the growing hydrate layer that coats the bubble surface, and compressive deformation of the three-phase (air–hydrate–ice) system at a given temperature and load pressure. The mathematical model is constrained by laboratory experiments covering a wide range of thermodynamic conditions. Computational tests show that either diffusion or bubble compression can be the rate-limiting step in the post-nucleation growth of air–hydrate crystal. As a plastic material, air–hydrate appears to be, at least, one order harder than ice. The mass transfer coefficient for the diffusion of air and water molecules in air–hydrate is estimated to be 0.6–1.3 mm^2/yr at 263 K with the activation energy not higher, than 30–50 kJ/mol. The mass flux of air, although small in comparison with that of water, plays an important role in the conversion. Special attention is paid to the case of air–hydrate growth in air bubbles in polar ice sheets.

Keywords: Clathrate air–hydrate; Polar ice; Post-nucleation growth; Mathematical model

1. Introduction

Preliminary study of the first deep ice core recovered in Antarctica at Byrd Station [1] has revealed that air bubbles, trapped in polar ice at the pore closure depth, completely disappear below 1200 m. Miller [2]

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