Chair: Physics of Fluids group

What shape of ice melts the slowest in water?

Description

Melting ice is frequently found in nature, where it can result in some very interesting geometries and it is also an important indicator for climate change. Ice melting has great relevance in oceanography, meteorology, and geophysics. The most relevant examples may be the melting of ice in rivers and lakes and polar regions, e.g. glaciers, subglacial lakes, icebergs, ice floes, icy moons, and melt ponds. The interaction between melting processes and turbulent flows is thus an interesting and complicated problem, see the intricate structures displayed in figure 1 for melting and dissolution problems.

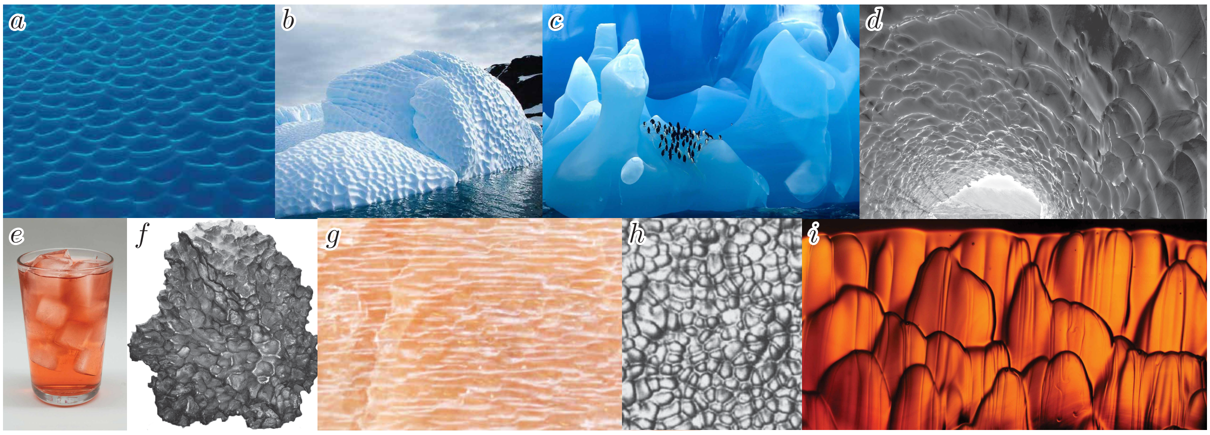

Figure 1: Patterns in melting, dissolving, and ablation: *a*: Submerged side of a freely-floating iceberg (size of a scallop (dimple) ≈ 10 cm) [1]. *b*: Overturned iceberg revealing scalloped surface [2]. *c*: Blue ice of Antarctica (penguins for scale) [3]. *d*: Ice tunnel with ≈ 1 m features [4]. *e*: Beverage cooled by melting ice cubes. *f*: Meteorite shows regmaglypts [5]. *g*: Dissolution by free convection of a salt block in water, striped instability visible (≈ 50 cm view) [6]. *h*: Surface morphology of salt surface exposed to water (≈ 1 cm features) [7]. *i*: Caramel block dissolving into water (5 mm features) [8].

It has long been known that flows tend to enhance melting (or dissolution) rates, as is familiar from the everyday example of stirring sugar into coffee or tea. The non-uniform melting continuously changes the morphology and this modifies the surrounding flow, resulting in very complex coupling between the flow and the melting/dissolving body. Moreover, the dependence of the initial shape on the dynamics of this melting process is mostly unknown.

We aim to study the ice melting within a simple setup of an ice object immersed in hot and initially quiescent water, one observes how the evolution of ice shape depends on the initial geometry. The shape that melts the slowest (for fixed mass) is obviously a very long elongated shape such as to maximize the perimeter (surface area). However, a more interesting question is: what is the shape that melts the slowest. It is known that for a fixed area (volume) a disk (ball) melts the slowest when there is no ambient flow because of the smallest perimeter (surface area). However, when the ice starts to melt, the melted fluid will generate natural convective flow patterns (colder liquid is more dense and will create a flow), which in turn affects the morphology and with that the melting rate. The slowest-melting shape is therefore not known and this shape likely depends on the temperature difference (Rayleigh number), but also on the absolute temperatures of the ice and the water, since the density of water has a non-linear density dependence with a density maximum around 4 °C. By investigating this problem, we can increase our understanding of the fluid-solid interaction and phase transition process, and their relevance to global warming.

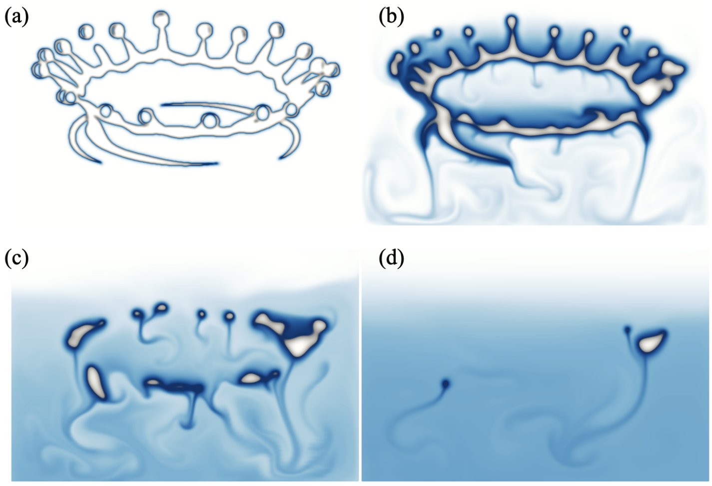

Figure 2: (a-d) Simulation of a melting Physics of Fluids logo in a closed box. See also https://www.youtube.com/watch?v=dav0Qh5CvFg for the video.

Assignment

In this assignment, we conduct direct numerical simulations (https://github.com/PhysicsofFluids/AFiD) for the turbulent flow and couple it with a phase field method for the solid-liquid phase transition. The code has been written has been validated already, an example is shown in figure 2 where we melt our group logo. The main control parameter is the initial shape of the ice while keeping the volume of the ice fixed. One could think of adding Fourier-mode disturbances to the initial shape, or making partially concave-shaped objects and so on to minimize the melting rate. During the assignment, you will learn to perform numerical simulations. Most simulations will be performed on supercomputers. You will learn how to run simulations on the supercomputers and also learn data analysis techniques for post-processing the data from the simulations. Finally we hope you can 'design' the longest-surviving ice cubes to keep our summer beverages cold.

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References

[1] B. W. Hobson, A. D. Sherman and P. R. McGill, Deep Sea Research Part II: Topical Studies in Oceanography **58**, 1311 (2011).

[2] S. Weady, (2020).

[3] E. Rock, Daily Wild Life Photo (2014).

[4] P. Claudin, O. Durán and B. Andreotti, J. Fluid Mech. **832**, (2017).

[5] G. Kurat, Personal photo (2016).

[6] C. Cohen, M. Berhanu, J. Derr and S. C. du Pont, Phys. Rev. Fluids **5**, 053802 (2020).

[7] T. S. Sullivan, Y. Liu and R. E. Ecke, Phys. Rev. E **54**, 486 (1996).

[8] C. Cohen, M. Berhanu, J. Derr and S. C. du Pont, Phys. Rev. Fluids **1**, 050508 (2016).