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Melting Kinetics of Permafrost under Overlaying Saline Water

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We experimentally investigate ice melting in porous media under overlaying saline water. Its kinetics provide key information to evaluate the consequences of seawater invasion into permafrost zone caused by global climate change, as melted permafrost may release significant amount of underground methane that further exacerbates the global warming.

Model permafrost is fabricated by glass bead-pack saturated with ice, at the temperature of -5℃. Excessive NaCl aqueous solution initially lays above the model permafrost which further induces melting. We vary glass bead diameter from 0.1-1 mm and salinity up to 25 wt%. Saline water is dyed, so the melting front evolution can be recorded by camera. The fluid system is characterized by its Rayleigh number, $Ra=(k\triangle\rho gH)/(\varphi\mu D)$, where $\triangle\rho$ is the density contrast between overlaying saline water and the diluted saline water that equilibrates to the ice under the experimental temperature. The melting kinetics is evaluated by the Sherwood number, Sh, which is acquired by image analysis.

Surprisingly, we identify three distinct modes of the melting kinetics, which are governed by the value of Ra (Fig. 1):

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1) The stable mode, in which case the melting front is horizontal and stably moving downward. The concentration of the saline water is uniform, indicating good mixing in the melted zone. This mode emerges when Ra > 1500, namely at high salinity and high permeability.
2) The critical mode, in which the melting front is flat but the concentration of the brine in the melting zone is obviously non-uniform. Typical Rayleigh-Darcy convection can be identified in the melted zone. This mode emerges when 330 < Ra < 1500.
3) The unstable mode, in which case fingers develop at the melting front. This mode emerges at low salinity and low permeability that Ra < 330. We note that this low Ra is very common in practical scenario for seawater invasion into permafrost zone.

We hypothesize that the emergence of these three modes is a result of the interplay between the Rayleigh-Darcy convection and the dispersion kinetics. Stability analysis and numerical simulation validate this hypothesis.

In the context of global warming, the unstable melting with fingering implies that seawater can penetrate down through frozen layer of permafrost much deeper than previously estimated. It thus brings higher risk for underground methane to be released into the atmosphere.

Participation

In-Person

References

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