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Experimental and computational study of solidification of flow in a Hele-Shaw cell

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The warming climate is inducing changes in hydrological processes in the cryosphere that are not well understood. In this context, the proposed work seeks to advance our understanding of the pore-scale physics of fluid flow through subfreezing porous material such as snow, firn and permafrost. Such flow involves the complex interplay amongst interfacial flow (e.g. air-water), phase change (e.g. freezing/melting), and thermal transfer between liquid-liquid or liquid-solid phase boundaries, giving rise to a myriad of non-equilibrium phenomena from pore to field scales.

Here, we couple novel laboratory experiments and high-resolution simulations to characterize this type of flow in the simplified configuration of a Hele-Shaw cell. To conduct the experiments, we radially inject water at 0℃ and a constant flow rate into a Hele-Shaw cell that is being cooled by an aluminum plate placed in a freezer at -80℃ for 24 hours to induce solidification in the cell. We systematically vary the initial gap thickness and flow rate to observe changes in the solidification dynamics and flow.

Next, we simulate the experiment with a continuum model, where we couple the single-phase Hele-Shaw flow equations with a gap-averaged formulation of heat transfer and phase change that accounts for reduction in gap thickness due to freezing. We perform numerical simulations of the model in both 1D and 2D and study the role of injection rate, initial thermal conditions and initial gap thickness on the temperature evolution and pattern formation of the flow. Finally, we provide preliminary results that validate the model with experiments.

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References

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