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Modeling Invasion Percolation in Granular Media with Evolving Rheology: The Case of Rice Cooking.

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The rice cooking process represents a complex physical system where phase transition thermodynamics, biopolymer leaching, and granular media mechanics converge. In this work, we present a cellular automaton model based on the Invasion Percolation (IP) algorithm to simulate the dynamics of nucleation and water vapor transport through a grain bed. Unlike standard IP models, our approach incorporates a thermo-rheological coupling: the heat flux at the base induces a thermal gradient that governs starch gelatinization kinetics via an Arrhenius-type relationship. The subsequent leaching of amylose and amylopectin modifies the viscosity of the continuous phase following the Quemada model, leading to a viscosity divergence as the solvent is depleted. Simultaneously, the mechanical transition of the grains is modeled through a critical invasion radius (R_c), which discriminates between the physical displacement of the grains (piston-like regime with geometric memory) and capillary flow (channeling). Preliminary results suggest that the competition between bubble buoyancy and the hardening of the polymeric gel defines the morphology of the vapor channels, explaining the formation of the tubular structures ("rice holes") observed macroscopically during cooking. This model provides a framework to understand how local heterogeneities in friction and dynamic surface tension dictate the final transport state in saturated granular systems.

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