Crystallization in a thermal plume

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Résumé

The dynamics of multiphase reactive plumes, which govern geological and environmental processes such as cloud formation, volcanic eruption columns, and hydrothermal vent systems, rely on the coupled interplay between turbulent mixing, phase transitions, and chemical reactions. To investigate these mechanisms under controlled conditions, we conduct laboratory experiments on crystallization dynamics within a buoyant reactive plume in a two-dimensional tank. Butyramide is selected as the working solute because its saturated solution density is close to that of water, while its solubility exhibits a strong temperature dependence. To suppress interfacial crystallization at the air–water interface, the ambient solution is stratified into two layers by dissolving NaCl in the lower layer. A buoyant plume is generated by injecting preheated butyramide solution (Tb = 50–60 ∘C) into the cold lower layer (10 ∘C). Two synchronized cameras simultaneously record the crystal phase and the concentration field. Crystals nucleate within the mixing zone and develop into a cloud-like structure. Quantitatively, the total projected crystal area increases with both the injection temperature (Tb) and the initial ambient concentration ($C0$). The latter plays a role analogous to moisture content in cloud formation. Particle tracking reveals that each crystal undergoes a rapid growth episode of duration
taug, which correlates with both its spatial position and the local saturation level (defined as the ratio of concentration to saturation concentration). These measurements directly demonstrate that localized supersaturation generated by mixing is the primary driver of crystal growth. Importantly, Tb and $C0$ influence crystallization through distinct physical pathways. Increasing Tb primarily enhances the crystal number density, indicating stronger local supersaturation and intensified nucleation. In contrast, increasing $C0$ prolongs
taug and produces larger crystals, consistent with the expansion of the supersaturated region. This study establishes a direct quantitative link between mixing-induced supersaturation and crystallization dynamics in reactive plumes, providing new insight into the universal mechanisms governing both natural and engineered multiphase systems.

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