Contribution ID: **45** Type: **Oral Presentation**

New progressive particle clogging mechanism by dendritic build-up in porous domains.

Thursday, 22 May 2025 09:20 (15 minutes)

Understanding the transport and deposition of colloidal particles in confined environments is crucial for optimizing natural and engineered systems, such as groundwater remediation and filtration technologies. This study adopts a pore-scale approach, combining microfluidic devices that mimic rock structures with pore-scale flow simulations to investigate clogging mechanisms, uncovering a unique phenomenon termed dendrite clogging. Unlike traditional progressive clogging, dendrite clogging arises from particle buildup at a single deposition site—the dendrite tip—which extends toward adjacent grains to block pathways. We experimentally confirm that dendritic structure formation is highly flow-rate dependent, identifying a critical velocity threshold (Vc), derived from drag-adhesive torque balance, beyond which particle attachment is suppressed. When normalized flow velocity (Vf / Vc) is less than 1, cone-shaped stagnation zones form, enabling particle attachment. Experiments on single-grain collectors validate this criterion, showing dendritic structures when stagnation zones accommodate particles along the collector's centerline. Increasing flow rates compress these zones, limiting attachment. Applying this criterion to porous domains reveals that dendrite formation depends on the accommodation capacity of stagnation zones. We demonstrate that flow behavior is significantly impacted by particle deposition and clogging, as evidenced by the observed increase in experimental and simulated pressure differences alongside porosity decline with increasing pore volumes injected. Interestingly, this trend stabilizes over time, suggesting that fluid velocity eventually surpasses the critical threshold for particle attachment. These findings provide insights into the formation of unique clogging mechanisms by dendrites in porous domains, with practical implications for improving the performance and efficiency of porous systems.

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Session Classification: MS11

Track Classification: (MS11) Microfluidics and nanofluidics in porous systems