Synthesis of Temperature-Responsive Hydrogel Particles for Hydraulic Control of Cooled Short Circuits

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Primary CNF Tools Used: Heidelberg DWL2000, ABM Mask Aligner, AMST MVD100

Abstract:

The "short circuit" issue is one of the major challenges that prevents Enhanced Geothermal Systems (EGS) from being commercially successful. In this work, temperature-responsive poly(N-isopropylacrylamide) (pNIPAM)-based hydrogel particles were designed to mitigate the issue by reducing the local permeability of "short circuit" regions. To understand the particle jamming behavior, we fabricated a parallel step emulsifier device at CNF to produce particles with narrow size distribution to conduct fundamental rheology tests.

Summary of Research:

The "short circuit" issue arising from uneven permeability distributions within fracture systems is one of the major challenges in Enhanced Geothermal Systems (EGS). When a fluid gets injected underground, it preferably flows through highly permeable paths. As a result, these regions are rapidly drained of heat, leading to a premature thermal breakthrough and system failure [1]. To alleviate this problem, we designed temperature-responsive nanocomposite poly(N-isopropylacrylamide) (pNIPAM)-based microgel particles. As one of the most studied thermosensitive hydrogel, pNIPAM exhibits a reversible entropy-driven volume phase transition, leading to particle expansion at low temperatures and particle contraction at high temperatures [2]. With careful design, these pNIPAM-based particles can expand to up to several hundred times their original volume when the temperature of their local environment falls below a threshold. This could effectively diminish short circuits by decreasing local channel permeability.

Particles with varying compositions were successfully synthesized through inverse suspension polymerization (Figure 1a). Single-particle studies conducted under an optical microscope demonstrated the particle's responsiveness to temperature changes (Figure 1b). However, studying the rheological property of jammed particles remained challenging since inverse suspension polymerization yields highly polydisperse particle sizes (Figure 2). With the aim of better understanding this complex hydrogel particle system, it is desirable to also study a simpler case consisting of monodisperse particles. To facilitate particle production with a narrow size distribution, we fabricated a parallel step emulsifier device using CNF tools.

At CNF, the Heidelberg DWL2000 was used to create photomasks based on the CAD design (Figure 3) adapted from Stolovicki, et al. [3]. Next, a two-layer SU-8 master mold was fabricated in the Class II photoresist room following the procedure described in Figure 4. The resulting mold was subsequently treated with (1H,1H,2H,2H-perfluorooctyl) trichlorosilane (FOTS) to increase its hydrophobicity. Lastly, the device was obtained by casting PDMS onto the master mold. In the next step, microgels with different compositions will be produced using this device for rheology tests.

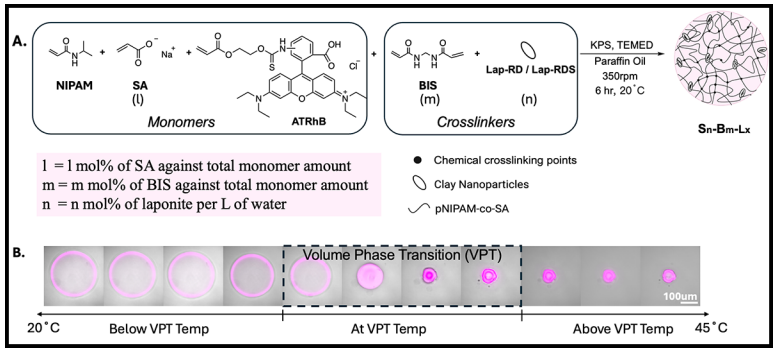

Figure 1: Synthesis of the poly(N-isopropylacrylamide) (pNIPAM)-based nanocomposite microgel. (A) General synthesis scheme of the hydrogel particles. (B) Typical volume phase transition observed under the confocal microscope.

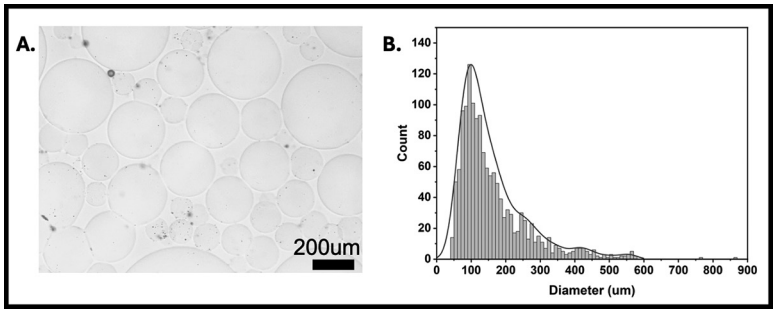

Figure 2: Particle size distributions from batch synthesis. (A) Typical optical images of resulting microgels (Scale bar: 200 µm). (B) Typical size distribution of microgels.

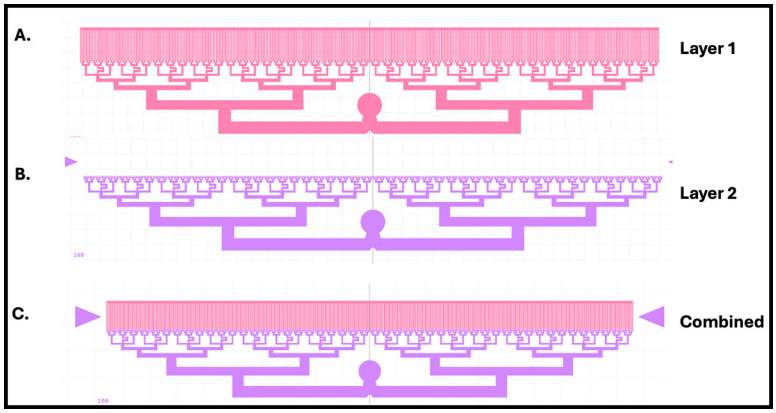

Figure 3: CAD design of the parallel step emulsifier device adapted from the Weitz group [3]. (A) Layer 1; (B) Layer 2; (C) merged images.

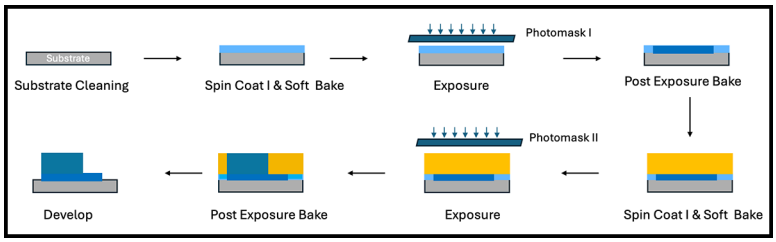

Figure 4: General process flow of the double layer SU-8 master mold fabrication.

Conclusions and Future Steps:

Overall, we synthesized hydrogel particles via inverse suspension polymerization and demonstrated their temperature responsiveness under the microscope. To further understand how individual microgel particles' properties affect the macroscopic rheology properties of the jammed particles, a simple system composed of monodispersed particles was proposed as an alternative. At the CNF, we were able to fabricate an emulsifier device to achieve this goal. In the future, particles with varying compositions will be produced using this device and studied for their rheological behavior.

References:

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