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Microfluidic Approach for Template Free Microcapsule Fabrication

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ABSTRACT

Microcapsules fabricated in completely aqueous environments are attractive for encapsulation applications because they offer mild processing conditions, good compatibility with aqueous formulations, and avoid the use of organic solvents. So far, the most established strategies for water-in-water (w-w) capsule fabrication rely on aqueous two-phase systems. These systems enable compartment formation through phase separation, but restrict formulation design because capsule generation depends on preserving immiscibility between the two aqueous phases. Here, we propose an alternative route based on aqueous one-phase systems, where water-in-water capsules are formed directly from miscible polymer and surfactant streams. This approach preserves the benefits of fully aqueous processing while broadening the range of materials and formulations available.

In this study, we adapted a needle-assisted flow focusing geometry into a 3D-printed microfluidic platform for the direct formation of w-w capsules without a two-phase interface [1]. By bringing the separate polymer and surfactant streams into controlled contact within a tailored flow geometry, the device eliminates the need for a separate templating phase [1]. Its 3D-printed design also allows channel dimensions and device architecture to be readily adapted for different formulation systems, enabling reproducible production of microscale capsules with storage stability of up to six months.

Capsule formation is driven by polymer-surfactant coacervation, which generates a shell around the inner aqueous stream and achieves encapsulation. Surfactant addition further improves colloidal stability and reduces aggregation during storage. SEM and AFM results showed that the capsule shell remained continuous and intact across both the micro- and nanoscale. In addition, particle accumulation tests using 1 μm polystyrene particles dispersed in the inner stream showed that, after storage, the particles accumulated along the inner surface of the capsule shell while the surrounding continuous phase remained clear. These observations indicate that the capsules maintained their encapsulation integrity and effectively confined the particles within the shell boundary.

Overall, this work establishes a practical strategy for generating stable and tunable w-w capsules in an aqueous one-phase environment. While further optimisation is required to minimise minimize incidental polymer–surfactant complex deposition in the microfluidic channel, the integration of controlled microfluidic assembly and polymer-surfactant complexation provides a versatile platform for developing all-aqueous capsule systems with potential applications in personal care, food, and drug delivery.

References

1. Li, M., et al., Template-Free Microfluidic Fabrication of Water-in-Water Microcapsules for Controlled Release. ACS Applied Materials & Interfaces, 2026. 18(7).

KEY WORDS

Encapsulation, Microfluidics, Formulation

BIOGRAPHY

Raymond Dagastine is a Professor of Chemical Engineering at the University of Melbourne, leading research in colloidal and interfacial phenomena and nanoscale measurement technologies. After his B.Eng (Uni. Delaware) and PhD (Carnegie Mellon, 2002) he has been an ARC Future Fellow and MCN Technology Fellow. His research pioneered methods to study surface forces between drops, bubbles and soft colloidal particles and developed a label-free, sub-diffraction microscopy technique capable of resolving objects down to the scale of a virus. This technology is now commercialised through his start-up, Tiny Bright Things. He also co-hosts Einstein a Go-Go on Triple R 102.7 FM

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