SYNCHRONIZATION IN MULTI-INJECTOR DROPLET GENERATION DEVICES FOR THE SCALE PRODUCTION OF EMULSIONS

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We investigate collective dynamics in a parallel droplet-generation system designed for the scalable production of monodisperse chitosan gels. These gels are used as containers for liquid diets of biological control insects in intensive agriculture [1, 2]. The device consists of a 19-injector array arranged in a honeycomb geometry, where droplets are formed by flow-driven injection and subsequently polymerized under UV light. While parallelization increases throughput, hydrodynamic interactions between injectors introduce coupling that can lead to synchronization of droplet formation, potentially affecting size uniformity and stability.

We perform time-resolved measurements of droplet creation and detachment events across the injector array and analyze the temporal correlations between injectors. We quantify pairwise synchronization using event-based metrics and construct synchronization matrices and networks. To distinguish genuine coupling from coincidental alignment due to similar dripping rates, we compare the experimental data against interval-preserving surrogate datasets. This analysis reveals statistically significant synchronization regimes that depend on the imposed flow rate.

We observe the emergence of partially synchronized clusters across the injector array, indicating hydrodynamic coupling mediated by shared flow and pressure fluctuations. These results show that multi-injector droplet generators behave as systems of coupled oscillators, where collective dynamics can be tuned through control parameters such as flow rate and geometry.

Our findings provide insight into collective effects in microfluidic soft matter systems and offer guidelines for the design of scalable droplet-based fabrication devices.

References:

[1] J. Chem. Phys. 163, 054904 (2025), [2] J. Vis. Exp. (182), e63376 (2022)