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Numerical Investigation Of Non-Newtonian Emulsion Formation At Microfluidics T-Junction

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Abstract

Microfluidic systems enable exquisite control for drug encapsulation efficiency and release by using emulsion droplets. Current industrial practice and perceptions increasingly demand the use of fluids with more complex rheological behaviours, which result in non-Newtonian behaviour being observed. Nevertheless, the controlled formation of droplets with viscous non-Newtonian fluids in microchannel still remains at an elementary stage. In microfluidics aspect, viscosity is one of the most important factors influencing the droplet formation [1-5]. The main focus of the present study is the parametric investigation of the influence of viscosity on breakup dynamics of the non-Newtonian sodium carboxymethylcellulose (CMC) droplets. It presents the numerical simulations of the fluid dynamics of CMC droplets with shear-thinning properties in an immiscible liquid-liquid system. Computational fluid dynamics (CFD) path is adopted as opposed to a large number of experiments to examine the sensitivity of the viscosities of both dispersed and continuous phases to the formation of droplets and their size distributions. A well-known Carreau-Yasuda rheological model is incorporated with a two-phase conservative Level-Set (LS) approach [6,7] to capture the shear-thinning droplet breakup dynamics and fluid-fluid interface tracking in present study. This was achieved using COMSOL's implementation of the LS method from CFD module. The interface between two immiscible fluids is considered to be sharp and characterized by the 0.5 contour of the LS function (see Figure 1). The fluid interface uses the governing equations, consisting of the incompressible Navier-Stokes equation, continuity equation and coupled with the level-set equation, respectively. An optimal grid resolution containing 7644 mapped mesh elements was adopted based on the grid convergence analysis, with an acceptable relative error of 0.381%. Properties of the dispersed phase simulated has a range of viscosities similar to that of aqueous solutions comprising of 0.02wt% to 1.20wt% CMC in an oil phase that serves as the continuous phase in a microfluidic T-junction. The continuous phase properties were varied to match a range of oils for which experimental data are available for comparison. Prior to a series of numerical investigation, the proposed numerical model was first validated by comparison with laboratory experiments and good agreement was achieved at lower flow rate ratios (see Figure 2). With the applied flow condition, the numerical model predicted that the viscosity effect of both phases has a major influence on controlling the diameter of the trains of CMC droplets in microfluidic flow (see Figure 3 and 4). These findings will provide explicit information on the impact of viscosity on the motion and formation of the microdroplets. Additionally, the proposed model can be served as a practical and predictive tool for simulating the incompressible non-Newtonian and Newtonian two-phase flow in any forthcoming case of studies.

Reference

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Figures used in the abstract

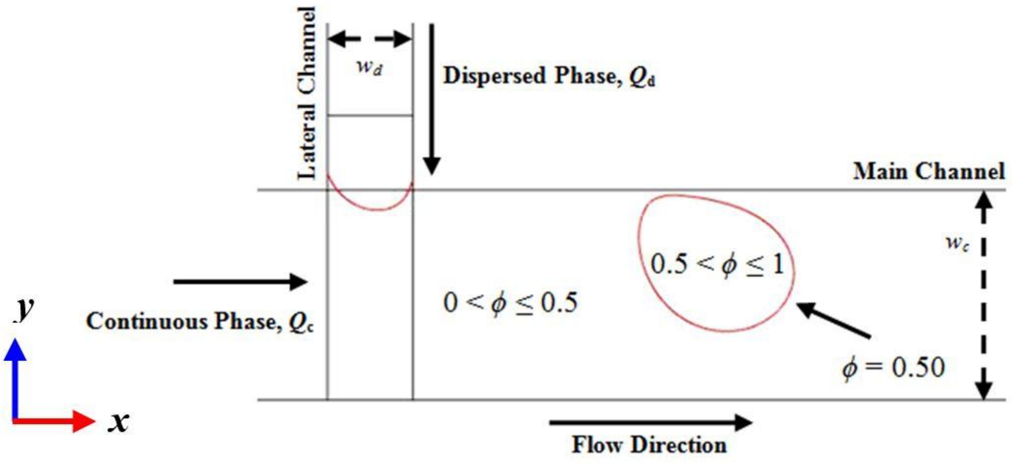

Figure 1: Contour representation of interface location for a droplet generated.

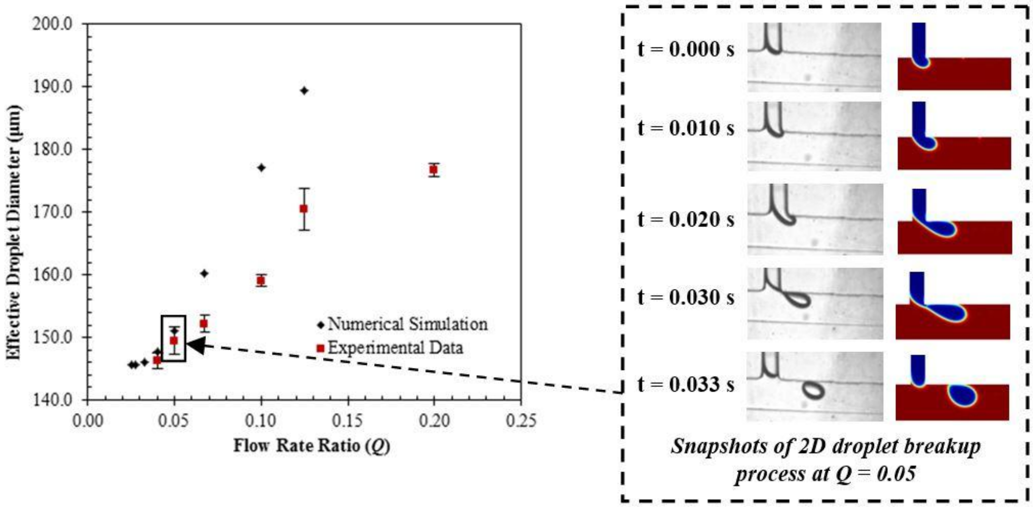

Figure 2: The comparison between numerical and experimental data of effective droplet diameter as a function of flow rate ratio (Q).

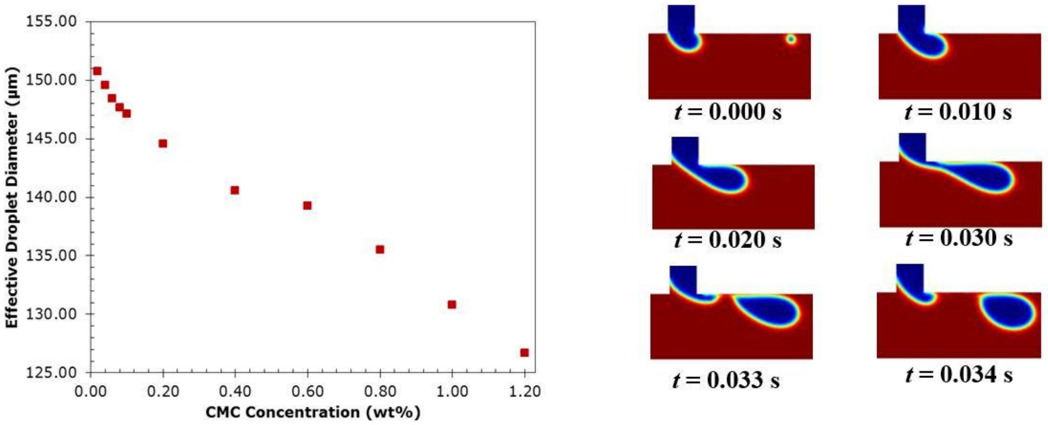

Figure 3: Graph of the effect of CMC concentration on effective droplet diameter and snapshots of droplet breakup process of 0.40 wt% CMC.

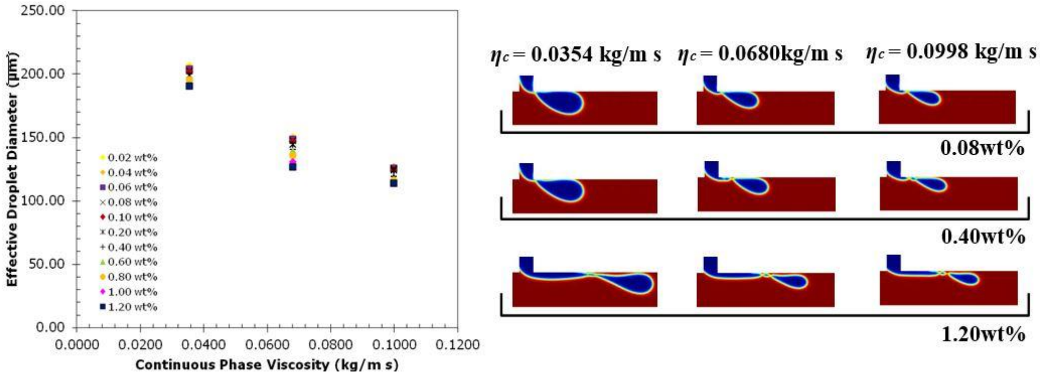

Figure 4: Graph of the effect of continuous phase viscosity on effective droplet diameter of CMC droplets and snapshots of the effect of continuous phase viscosity on flow pattern at different CMC concentrations.