The Effect of Surfactants on the Breakup of an Axisymmetric Laminar Jet

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Abstract

The breakup of a laminar axisymmetric jet is a well studied fluid dynamics phenomenon. However, the impact of surface active agents on jet breakup has received limited attention. Many multiphase contactors, such as rotor-stator mixers function by forcing immiscible fluids through an orifice or slot, or by otherwise destabilizing deformed droplets. Many of these processes can be mimicked on a fundamental level by the discharge of an immiscible axisymmetric laminar jet. Once exposed to the surrounding (matrix) phase, waves form on the surface of the jet causing it to destabilize. At a certain distance from the capillary tip (the breakup length), the jet disintegrates into a series of discrete droplets. Often, the jet breaks up into large primary drops and smaller satellite droplets, resulting in a multi-modal droplet size distribution. In this study, the Expectation-Maximization algorithm is used to decouple these modes and determine separate droplet size distributions for each mode.

Clean and surfactant-laden water jets were injected into otherwise still air; and silicone oils of various viscosity grades were injected into clean water and aqueous surfactant solutions. The capillaries used to form the jets have diameters from 200 to 800 microns and are long enough to assure fully developed flow at the capillary tip. Several non-ionic surfactants, all insoluble in silicone oils, were added in turn to the aqueous phase. It should be noted that our two series of experiments are quite different. In the first series, surfactant must diffuse from within the jet to the water-air interface. In the latter, surfactant must diffuse from within the surrounding matrix phase to the oil jet interface. However, surfactant transport to the interface always occurs within the aqueous phase.

Two distinct CCD cameras were used to image droplets. A low frame rate (30 fps), high resolution camera was used to measure breakup length and to quantify droplet population statistics. A high frame rate (5,000 fps), moderate resolution camera was employed to observe detailed breakup phenomena. An automated image processing algorithm was used to acquire droplet geometry and population statistics. To aid in data interpretation, interfacial tension and other relevant interfacial properties were acquired/estimated using both static and dynamic Pendant Drop techniques.

A parametric study has been performed to explore a wide range of flow rates, capillary diameters, surfactant types, and surfactant concentrations in both the air-water and water-oil systems. We will report the results of this study, and demonstrate the effect of surfactant concentration, jet discharge flow rate, oil phase viscosity and capillary diameter on jet breakup length; and on primary and satellite droplet size distributions and relative population size. The data will be interpreted with respect to the relevant physicochemical phenomena and implications to liquid-liquid dispersion in multiphase contactors will be addressed.