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“Modeling the Position-dependent Inner Drop Velocity for a Millimeter-size Core-Shell Drop as it Approaches Failure at Low Reynolds Numbers”

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ABSTRACT

Co-axial dripping is one of the many ways to make drops with a core-shell structure for encapsulated materials. However, in systems where the capsule components are not density matched or surfactants are not used, the shell will eventually thin and break if not solidified in time. If the shell fails before solidifying, the core will leak out and result in a non-functional capsule. This study assumes that all capsules will fail once the core has reached 80% eccentricity, meaning a shell region has thinned to 20% of its original thickness (~60 microns). In reality, the rupture event depends more on stochastic defects and disturbances, but locally decreasing the shell thickness will increase the probability of capsule rupture. With this assumption, the survival time of a core-shell drop is inversely proportional to the relative velocity of the inner drop, where the greater this relative velocity, the faster the shell phase will thin. Stoke's law is generally used to approximate the speed of a sphere in a fluid. However, this study demonstrates that Stoke's law is insufficient for predicting the inner drop's motion for a compound drop. This is due to internal flows that develop within all fluid drops since there are shear forces on the drop’s external face during freefall. For core-shell drops, prior studies report how the inner drop velocity can change in magnitude and direction as a function of its eccentricity, meaning its position within the outer drop. Since previous studies did not analyze this core-shell drop relationship with a 50 vol% core and a high viscosity shell, a model was built in COMSOL Multiphysics to understand how the claims from literature would apply to a previous encapsulation study (Betancourt, 2021). The model was also put through a series of validation tests that confirmed the model’s ability to accurately represent the speed and direction of inner drop motion. The final model configuration was then used to identify the transition point between buoyancy-driven and flow-driven failure modes observed during the production of core-shell drops in a previous encapsulation study for phase change materials (Betancourt, 2021). The model results showed how the estimated inner drop velocity was significantly reduced once accounting for the internal flows within the shell phase of a compound drop. The results also showed at what critical eccentricity position the inner drop’s drop could reverse its direction and eventually cause the less dense core phase to be pushed through the bottom of the falling compound drop.

Daniela Betancourt-Jimenez, Brandon Wells, Jeffrey P. Youngblood, and Carlos J. Martinez, "Encapsulation of biobased fatty acid amides for phase change material applications,” Journal of Renewable and Sustainable Energy 13, 064101 (2021) https://doi.org/10.1063/5.0072105

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