Frontal Polymerization in Microgravity

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Frontal polymerization is a mode of converting monomer into polymer via a localized reaction zone that propagates, most often through the coupling of thermal diffusion and Arrhenius reaction kinetics. Large temperature gradients occur in the front as the temperature increases 200 degrees C in a few mm. The process is similar to a "liquid flame" of polymerization.

Because of convective instabilities, it is not possible to perform frontal polymerization with many monomers that produce thermoplastics, such as n-butyl acrylate, without the addition of a viscosity enhancing agent because of the Rayleigh-Taylor instability. Performing propagating fronts of n-butyl acrylate polymerization on a sounding rocket, Conquest I, allowed us to determine that the ultrafine silica gel (CAB-O-SIL) used in ground based research may affect the molecular weight of the polymer produced. Samples prepared with CAB-O-SIL did have slightly broader molecular weight distributions that could reflect the decrease in termination because of the higher viscosity. However, the difference could also be caused by differences in front temperature because of the lack of convective heat losses under weightlessness.

Fronts producing a thermoset (rigid product) can be studied easily in one g. The front shape and velocity are sensitive to the reactor orientation. Ascending fronts may cause simple buoyancy-driven convection depending on the viscosity, tube diameter, and the front velocity. The stability boundary for the onset of antisymmetric convection in the viscosity-velocity plane has been determined analytically and experimentally.

Descending fronts propagate faster if the tube is not vertical, and the front reorients to remain approximately perpendicular to the gravitational vector. However, by performing experiments on the KC-135, we determined that the increased surface area of the front is not the cause of the increase in propagation velocity. Instead, a convective roll induced under the front that increases in velocity as tube angle is increased farther from the vertical.

The interactions of bubbles with propagating fronts with a liquid product and with a solid product were studied on KC-135 flights. Bubbles aggregate in microgravity but are dispersed in 1 g. Further investigations are needed to determine the mechanism of this aggregation.

An important question to be answered is how does surface-tension-induced convection (STIC) affect a front with a liquid product without bubbles? STIC should occur if there is a radial temperature gradient caused by heat loss but whether a true Marangoni instability can occur because of the large temperature and composition gradients normal to the front is unknown.