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Prize to a Faculty Member for Research in an Undergraduate: Chaotic mixing and front propagation[1]

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We present results from a series of experiments – all done with undergraduate students – on chaotic fluid mixing and the effects of fluid flows on the behavior of reaction systems. Simple, well-ordered laminar fluid flows can give rise to fluid mixing with complexity far beyond that of the underlying flow, with tracers that separate exponentially in time and invariant manifolds that act as barriers to transport. Recently, we have studied how fluid mixing affects the propagation of reaction fronts in a flow. This is an issue with applications to a wide range of systems including microfluidic chemical reactors, blooms of phytoplankton in the oceans, and the spreading of a disease in a moving population. To analyze and predict the behavior of the fronts, we generalize tools developed to describe passive mixing. In particular, the concept of an invariant manifold is expanded to account for reactive burning. "Burning invariant manifolds" (BIMs) are predicted and measured experimentally as structures in the flow that act as one-way barriers that block the motion of reaction fronts. We test these ideas experimentally in three fluid flows: (a) and chain of alternating vortices; (b) an extended, spatially-random pattern of vortices; and (c) a time-independent, three-dimensional, nested vortex flow. The reaction fronts are produced chemically with variations of the well-known Belousov-Zhabotinsky reaction.

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