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A disaggregation theory for predicting concentration gradient distributions in heterogeneous flows

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Many transport processes occurring in fluid flows depend on concentration gradients, including a wide range of chemical reactions, such as mixing-driven precipitation, and biological processes, such as chemotaxis. A general framework for predicting the distribution of concentration gradients in heterogeneous flow fields is proposed based on a disaggregation theory. The evolution of concentration fields under the combined action of heterogeneous advection and diffusion is quantified from the analysis of the development and aggregation of elementary lamellar structures, which naturally form under the stretching action of flow fields. Therefore spatial correlations in concentrations can be estimated based on the understanding of the lamellae aggregation process that determine the concentration levels at neighboring spatial locations. Using this principle we quantify the temporal evolution of the concentration gradient Probability Density Functions in heterogeneous Darcy fields for arbitrary Peclet numbers. This approach is shown to provide accurate predictions of concentration gradient distributions for a range of flow systems, including turbulent flows and low Reynolds number porous media flows, for confined and dispersing mixtures.