Blending of liquids with density differences

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Abstract

We have conducted direct numerical simulations of blending of two miscible liquids with different density (by an amount $\Delta\rho$**)** and equal kinematic viscosity (ν**)** in a mixing tank equipped with an axial impeller (a 45^{o} pitched-blade turbine). As the starting point of each simulation the denser liquid occupies the lower half of the tank volume, the lighter liquid the upper half, and the flow velocity in the tank is zero everywhere. Since the impeller is placed with a bottom clearance *H*/3 it initially is fully surrounded by the heavier liquid. At *t*=0 we switch on the impeller and monitor the development of the flow and mixture fraction field in the tank.
This flow system is governed by two dimensionless numbers: a Reynolds number $\mathrm{Re}=\frac{ND^2}{\nu}$, and a Richardson number $\mathrm{Ri}=\frac{g\Delta\rho}{\rho D N^2}$ with *N* the impeller speed (in rev/s) and the diameter of the impeller *D* as length scale. Reynolds numbers are in the range 3,000 to 12,000 so that we cover transitional and mildly turbulent flow regimes and are able to fully resolve the flow (*direct* simulations) without the use of a turbulence closure or subgrid-scale model.
The results show interesting trends with respect to the Richardson number. At low values of Ri ($\mathrm{Ri}\leq 0.15$ for Re=6,000) mixing patterns are akin to what is observed for Ri=0: the interface between light and heavy liquid is sucked into the impeller swept volume (see Figure 1) and macro-mixing occurs relatively quickly with somewhat longer mixing times (compared to the situation with Ri=0). If $\mathrm{Ri}\geq 0.5$ (at Re=6,000) the impeller is no longer able to draw down the interface. In these situations mixing is largely due to erosion of the interface between light and heavy liquid (Figure 2) which results in dramatically longer mixing times. The range $0.15\leq \mathrm{Ri}\leq 0.5$ shows intermediate behavior.

keywords: blending, buoyancy, mixed convection, simulations, transitional and turbulent flow, active scalar

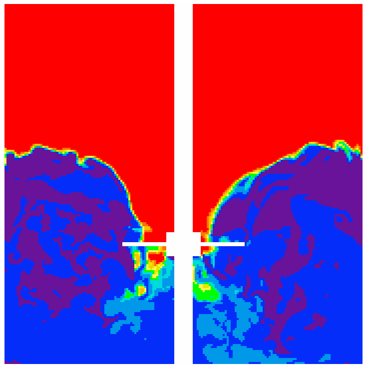

Figure 1. Mixture fraction in the mid-baffle plane for Re=6,000 and Ri=0.125 after 10 impeller revolutions. Red: light liquid; blue: heavy liquid.

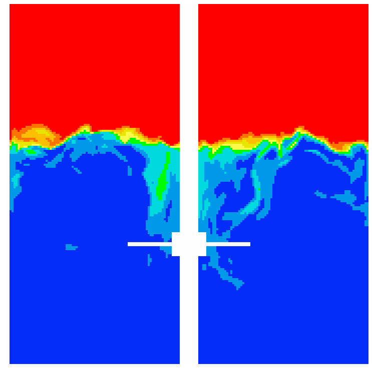

Figure 2. Mixture fraction in the mid-baffle plane for Re=6,000 and Ri=1.0, 50 impeller revolutions after startup. Red: light liquid; blue: heavy liquid.

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