STRATIFIED EXTERNAL MIXING AT MODERATE RICHARDSON NUMBER.

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Abstract Stratified turbulent mixing remains an unsolved problem. Turbulent mixing is complicated by its intermittent nature, its highly vortical motion and the large range of scales of its coherent structures. In order to help reduce the problem to a more tractable form, we consider vortex rings as a reproducible, idealized form of a turbulent coherent structure of a defined length and velocity scale. We generate vortex rings in a stably stratified two-layer fluid of varying Richardson number and observe the vortex ring induced mixing. While previous work has looked at the effect of individual vortex rings on the stratified interface, we analyze the aggregate mixing induced over many vortex ring generations. Over successive vortex rings collisions, the mixing rate converges to a constant for a range of Richardson numbers.

EXPERIMENTS

The current experiments were performed within a 0.2m x 0.4m x 0.5m tank. This tank was filled with a two-layer salt-water stratification with a sharp density interface. A fresh-water layer was generated above a layer of salt water, the density of which was varied between experiments. A 3.9cm hollow cylinder is then inserted into the fluid and attached to a linearly-actuated cycle pump. The working of the pump generated vortex rings at the base of the cylinder which propagated downward, impacting the density interface vertically. Figure 1 is a picture of the experimental setup near the completion of a run.

Particle Image velocimetry (PIV) was used to quantify the velocity field of each vortex ring along a two-dimensional vertical slice of the water tank. Data was collected through the centre of the vortex rings. PIV provides us with the vortex ring diameter, the propagation speed of the vortex ring, and an estimate for the total kinetic energy contained in the vortex ring. The formation number of these vortex rings was such that only a single, clear vortex ring was observed.

Similarly, we use a conductivity probe to analyze the density profile of the flow over the course of many vortex ring interactions. A single vortex ring was generated every 75s in order to allow for the macroscopic motion associated with each ring to dissipate before a new ring was generated. Every ten such vortex ring generations, the conductivity probe measured a single density profile. The sensitivity to the intergenerational time was established by varying the temporal inter-vortex ring spacing to ensure that the residual motion within the tank was negligible. The conductivity probe moved at a rate of $\sim$0.5cm/s with a density measurement acquisition rate of 50Hz. For each experiment, 61 density traverses were taken over a total of 600 vortex ring generations.

RESULTS

In order to estimate the energy injection into the system, we approximate the vortex rings as spherical vortices with all of their energy in translational motion (not a Hills vortex). That is, the kinetic energy (KE) is given as

$$\mathrm{KE} = \alpha \left[\frac{1}{2}\rho_0 U^2\right]\left[\frac{4}{3}\pi\left(\frac{a}{2}\right)^3\right].$$

This kinetic energy approximation provides an order of magnitude estimate of the kinetic energy of a single vortex ring injected into the stratification. Figure 2 plots the normalized mixing rate after an initial adjustment period versus the transition Richardson number (Ri_T). We see clearly that the scaled mixing rate is constant over a range of vortex ring parameters and Ri.

References

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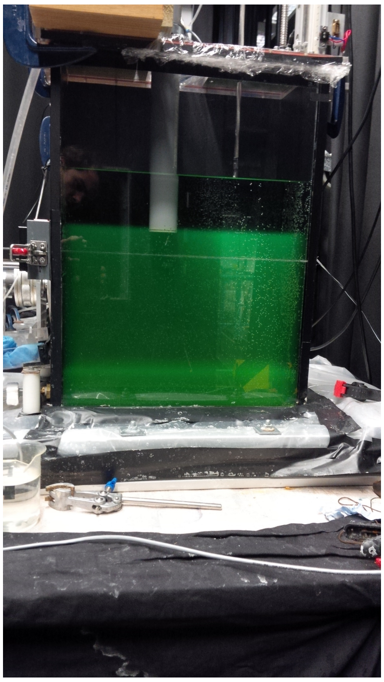

Figure 1. Picture of the experimental apparatus. Vortex rings are generated at the base of the grey tube within the tank. The dye intensity corresponds to the fluid salt concentration.

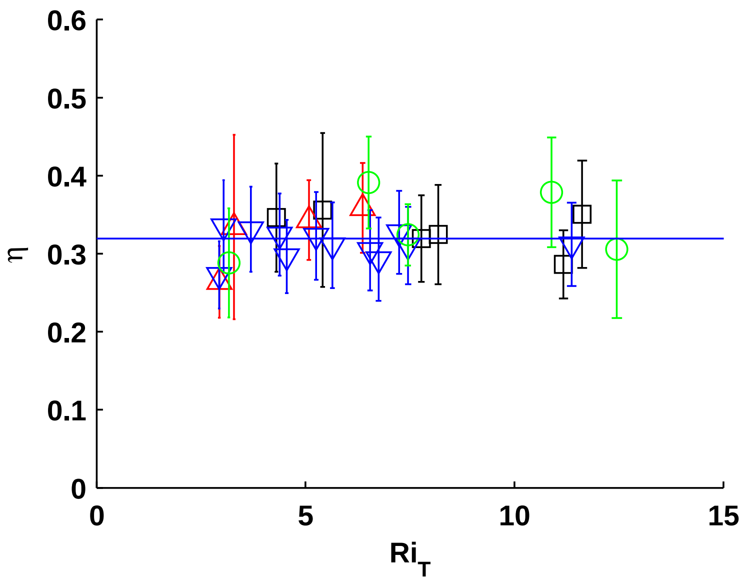

Figure 2. Plot of the mixing efficiency vs. Ri_T. A constant fit is also plotted as the solid back line with value 0.319.