13th Australasian Natural Convection Workshop (13ANCW)
Canberra, Australia, 1st and 2nd December 2025

TURBULENCE PROPAGATION AND ENTRAINMENT ACROSS DENSITY INTERFACES IN OSCILLATING GRID STRATIFIED FLOWS

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1. INTRODUCTION

Turbulent entrainment across sharp density interfaces is central to geophysical flows such as lakes, estuaries, and the atmosphere. Using oscillating grid turbulence (OGT) in a two-layer stratified tank, we investigate how turbulence evolves above a stable interface and drives mixing in the absence of mean shear.

2. EXPERIMENTAL SETUP AND MEASUREMENT TECHNIQUES

Experiments are conducted in a two-layer stratified tank using an OGT facility. A schematic of the tank and grid configuration is shown in Figure 1. A square grid ($M = 5$ cm) oscillates vertically with fixed stroke of 5.5 cm and frequency of $f = 1$ Hz or $f = 3$ Hz, generating approximately isotropic, shear-free turbulence. Particle image velocimetry (PIV) and planar laser induced fluorescence (PLIF) techniques are used separately to measure velocity and density fields. The field of view is shown by a blue dashed box in Figure 1.

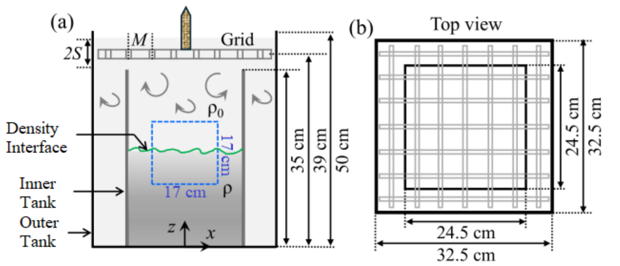

Figure 1. Schematic of the oscillating grid setup: front view (a) and top view (b)

3. RESULTS

Figure 2 shows the entrainment coefficient $E = w_e/u_*$ (where w_e is the interface propagation speed and u_* is the root-mean-square (rms) velocity induced by the grid) versus Richardson number $Ri = g\Delta\rho H/(\rho_0 u_*^2)$ (where g is the gravitational acceleration, $\Delta\rho$ is the density difference between the bottom and the top layer, ρ_0 is the density of the lighter fluid, and H is the initial depth of the fresh-water layer) revealing a transition from $E \propto Ri^{-1}$ at low Ri to $E \propto Ri^{-3/2}$ at high Ri. This scaling is consistent with earlier studies [1-5] and confirms that stratification strongly governs mixing dynamics.

Figure 3 shows the time evolution of the total kinetic energy (TKE) for two density ratios (DR = $\Delta\rho/\rho_0$): $DR = 0\%$ and $DR = 0.3\%$. In both cases, TKE increases over time due to continuous input from the oscillating grid. The stratified case maintains significantly lower TKE throughout, reflecting the dampening effect of buoyancy, with the remaining energy contributing to potential energy gain.

Snapshots in Figure 3 support this interpretation: at $t = 20$ s, turbulence is confined above the interface; by $t = 100$ s, it has propagated downward, visibly eroding the interface.

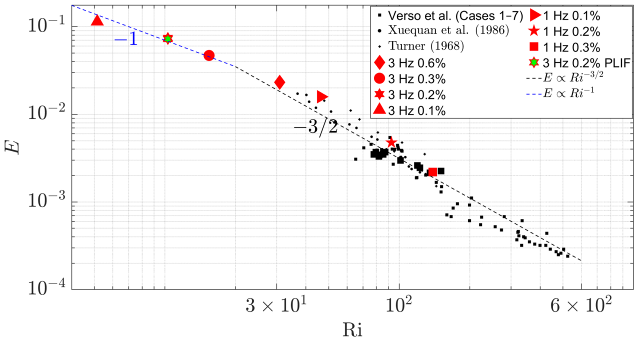

Figure 2. Entrainment rate E vs Richardson number Ri.

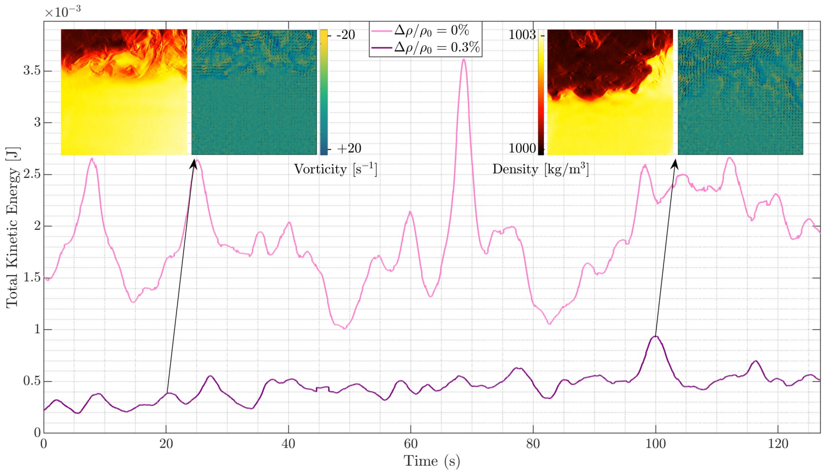

Figure 3. Total kinetic energy over time for the unstratified and the $DR = 0.3\%$ case.

4. CONCLUSIONS

This study highlights the role of stratification in modulating turbulence growth and entrainment across sharp density interfaces. Future work will combine simultaneous PIV and PLIF to resolve velocity and density fields together, enabling direct tests of the physical basis for the observed $E \propto Ri^{-1}$ scaling. In particular, we will examine whether the rate of potential energy increase is truly proportional to the rate of kinetic energy input as suggested in [6].

Building on these measurements, we aim to refine and extend existing models [7] by explicitly accounting for temporal energy build-up and interface crossing in shear-free stratified flows.

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