Buoyancy Driven Mixing by Turbulent Shear Dispersion

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Introduction

A series of experiments have been carried out to explore the mixing in a long inclined tube, subject to a supply of negatively buoyant fluid at the top of the tube, and the removal of an equal volume of fluid at the base of the tube. The transient mixing of the buoyant fluid with the original fluid in the tube is studied to determine the rate of mixing along the tube, and the concentration profile as a function of time. The data reveal that there is an unstable stratification along the tube and a weak stable stratification across the tube. The turbulent eddies produced by the flow along the tube lead to mixing across the tube, and a balance is established between the along slope shear flow associated with the density gradient across the tube and the cross-tube mixing produced by the eddies. This mixing has analogies with shear dispersion, but for a buoyancy driven turbulent flow, so that the along slope buoyancy gradient continually evolves.

Model

A quantitative model is developed to describe the above mixing regime, by working with the slow evolution of the buoyancy field, averaged over the eddy turnover time, and by characterizing the mixing in terms of the speed and size of the eddies. This leads to a dependence of the mixing rate given by an ensemble averaged equation of the form

$$\frac{\partial b}{\partial t} = A \frac{\partial}{\partial z}\left[\frac{\partial b}{\partial z}\right]^{3/2}$$

where b is the cross-tube averaged buoyancy and A is a constant which depends on (i) $d^{5/2}$ where d is the width of the tube, and (ii) the angle of inclination of the tube.

Experimental data for the cross-tube averaged buoyancy are in very good agreement with the predictions of the model in terms of the evolution of the buoyancy, and also in terms of the mean shear flow which develops in the tube.

Experiments

The experiments were carried out in a 2 m long tube, of cross-sectional area 25 cm^2 , with angles of inclination ranging from 0 to 45 degrees relative to the vertical (see [1]). The concentration is measured using a light attenuation technique, by including dye in the injected negatively buoyant fluid, and comparing the concentration of dye at each point in the tank at each time with a series of calibration curves for the dye concentration as a function of the buoyancy, in this case associated with relatively saline fluid. This provides a picture of the evolution of the mixing of the buoyancy along the tube.

Summary

Data will be presented which provides a very good match to the theoretical model, illustrating the importance of turbulent shear dispersion in such buoyancy driven mixing. Various generalizations of the modeling approach will be discussed building from these fundamental results.

References

[1] van Sommeren, D., Caulfield, C. and Woods, A., J Fluid Mech., 701, pp 278-303.

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