Flux Enhancement by Shear Free Surfaces in a Turbulent Convection

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Abstract: In experimental study of a new type of turbulent flow that is driven purely by buoyancy. The flow is due to an unstable density difference, created using brine and water, across the ends of a long (length/diameter=10) vertical pipe. The Rayleigh number (Ra) based on the density gradient and diameter is about 10^8. Under these conditions the convection is turbulent, and the time-averaged velocity at any point is 'zero'. The pipe is long enough for there to be an axially homogeneous region, with a linear density gradient, about 6-7 diameters long in the midlength of the pipe. In the absence of a mean flow and, therefore, mean shear, turbulence is sustained just by buoyancy. The flow can be thus considered to be an axially homogeneous turbulent natural convection driven by a constant (unstable) density gradient. We characterize the flow using flow visualization and particle image velocimetry (PIV). Measurements show that the mean velocities and the Reynolds shear stresses are zero across the cross-section; the root mean squared (r.m.s.) of the vertical velocity is larger than those of the lateral velocities (by about one and half times at the pipe axis). The flow away from the wall, affected mainly by buoyancy, consists of vertically moving fluid masses continually colliding and interacting, while the flow near the wall appears similar to that in wall-bound shear-free turbulence. obtain the results when the shear free surfaces introduce in vertically concentric with the pipe.

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1. Introduction

Turbulent flows are ubiquitous. Vastly increased transport compared to molecular effect within them is a main characteristic of turbulent flows. This leads to a few undesirable effects such as an increased skin friction drag. Consequently, drag reduction studies are an important focus of turbulent research. Both active (intervening in a turbulent flow based on a trigger event) and passive (modification of boundaries such as use of compliant surfaces or riblets; or use of additives) techniques abound. See Lumley *[1]* for a review of the drag reduction techniques by the use of additives.

Kathuria and Shukla *[2]* Raja Vamsi *[3]* and Tarak Sahoo *[4]* investigated a novel drag reduction technique, based on the attenuation of lateral transport in turbulent flows. Reducing the lateral transport of momentum reduces the drag. Kinematic wall blocking In the presence of solid surfaces can cause the attenuation of lateral transport. To avoid the increase in the drag due to shear boundary layers, the surfaces had to be introduced as a shear free. *[2], [3] & [4]* demonstrated that drag reduction was possible by this approach. Momentum is not the only quantity transported in a turbulent flow. Many other passive or active scalars are also transported at much greater rates when compared to molecular effects. In this thesis, we study the effect of kinematic wall blocking on the transport of salt in a buoyancy driven turbulent flow.

The basic flow chosen is a purely buoyancy driven turbulent flow in a vertical pipe *[5]*. The flow is generated due to unstable density difference across the ends of a vertical pipe. The flow is having zero mean flow, and is random, and hence the mean shear is zero. The turbulence production due to shear $<u_iu_j>\partial U_i/\partial x_j$ is zero, and the buoyancy production $-g_i<u_ic>$ is the only source of turbulent energy. An important consequence for our purpose of zero mean flow here is that as long as the random nature of the flow is not altered, any surface placed within the pipe is a shear free surface (SFS), and thus it should be possible to attenuate the lateral transport. Attenuation of lateral transport would reduce mixing and enhance the axial flux of salt. Thus the effect of placing SFSes into the pipe should be to enhance the axial flux of salt. This thesis is concerned with the effect of SFSes in flux of salt along a vertical pipe containing a shear free pure buoyancy driven convection.

2. Experimental Setup

The experimental setup consists of an arrangement of two tanks, of 20cmX20cmX15cm volume, made of perspex and glass, and connected to each other with the help of a pipe of circular cross section (50mm diameter). The tank which is kept below is closed from all sides, and is open only at the junction which connects it to the above tank through the pipe. There are no other openings connecting the two tanks. The tank openings are sealed by rubber stoppers with the help of a jack which is placed below the lower tank. The schematic of the setup is shown below:

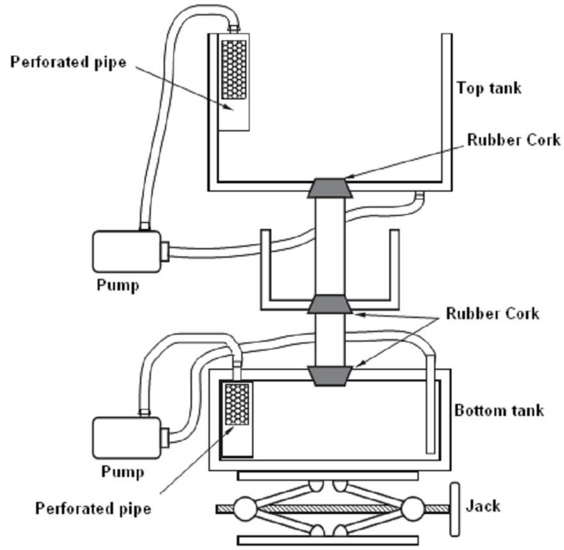

Figure 1: Schematic of experimental setup

At the start of the experiment, fresh water is put in the lower tank and the pipe, while the upper tank is filled with saline water. The two fluids are separated from each other with a stopper. The experiment is initiated by removing the stopper. After the initiation of the experiment, the fluids start mixing with each other because of the flow in the pipe. Because of density difference the saline water will try to move to the lower tank. Since water is incompressible, the salt water flowing to the lower tank will displace an equal volume of fresh water from the lower tank. These interact and mix within the pipe, generating turbulence. A net transport of salt takes place from the upper to the lower tank. Because there is no net flow within the pipe, the mean flow and hence the mean shear within the pipe is zero. Eventually, the density difference across the pipe reduces and the flow first becomes laminar and then finally stops. We are interested in the turbulent part of the flow. Figure 2. is the photograph of the actual setup. Two aquarium pumps are connected separately to the upper and the lower tanks. These pump the water from the bottom of each tank to provide uniform boundary conditions to the pipe by avoiding stratification of fluid in each tank. The flow rate is low enough not to disturb the flow at the pipe exit.

We start by first measuring the volume of the setup just below the upper tank, i.e. volume of the lower tank and the pipe. Then fresh water was filled in the tank to the double of the volume measured before. The pumps connected to the upper and lower tanks were always in running conditions ensuring uniformly mixed conditions in the tanks and thus avoiding stratification. We take the readings of concentration of this plain water using the conductivity probe (*ORION 3 STAR BENCHTOP, MODEL 013005MD*). 0.1% salt by weight of the volume of water in lower tank was used to mix in the upper tank. The upper and lower tanks were separated using a stopper. After adding the salt in upper tank, the concentration of this solution was measured. The experiment is then started by removing the stopper. These experiments lasted for about 3 hours and eventually the turbulent flow in the middle section of the pipe decays. The pumps are running throughout the experiment.

Once the experiment is over, all of the fluid in the setup is collected in another tank and mixed thoroughly. The concentration of this solution is then measured. This completes one full experiment, in the absence of any inserts, to measure the base condition of the flux. We have taken a large set of readings so as to compare these and study the effects of changing the experimental conditions of the experiment. The experiments are done with shear free surfaces. Since the flow is with zero mean, any stationary surface in the flow is a shear free surface, as long as the flow remains random. We have used cylindrical rods as inserts along the pipe axis as shear free surfaces. Rods of 2mm, 5mm and 10mm are used as inserts. The insert is placed within a few seconds of the removal of the stopper.

The above details are given in the following table:

Table 1: Summary of experimental conditions

Sl. No.	Condition	Number of Experiments
1.	No Inserts	10
2.	2 mm Insert	10
3.	5 mm Insert	10
4.	10 mm Insert	13

Details of Experiments

We compare the results of these experiments by processing the data obtained by all the above experiments.

3. Result

Table 2: Normalized flux and relative blockages for various inserts

Sl. No.	d_i/d	Relative blockage $(d_i/d)^2$%	F/F_T, Normalized flux %
1	2/50	0.16	10
2	5/50	1	12
3	10/50	4	15

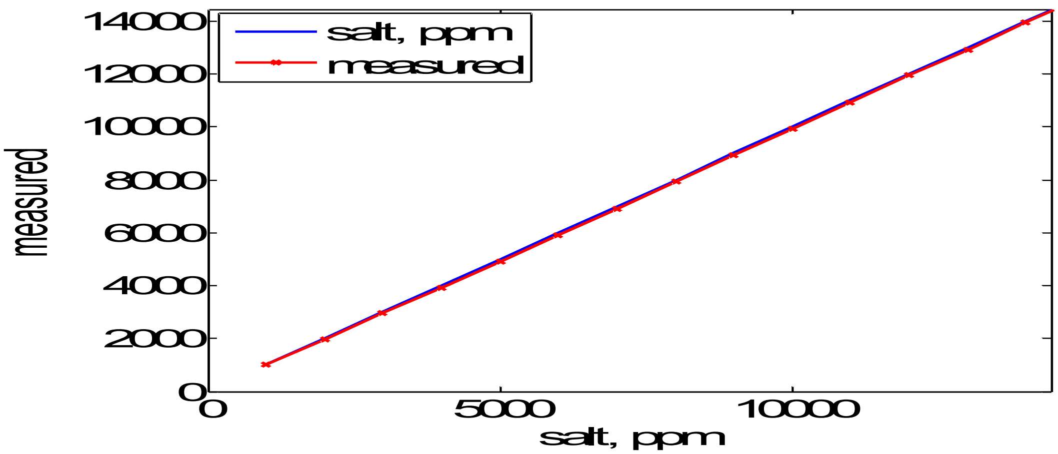

Figure 2: Measured salt vs dissolved salt, plain water

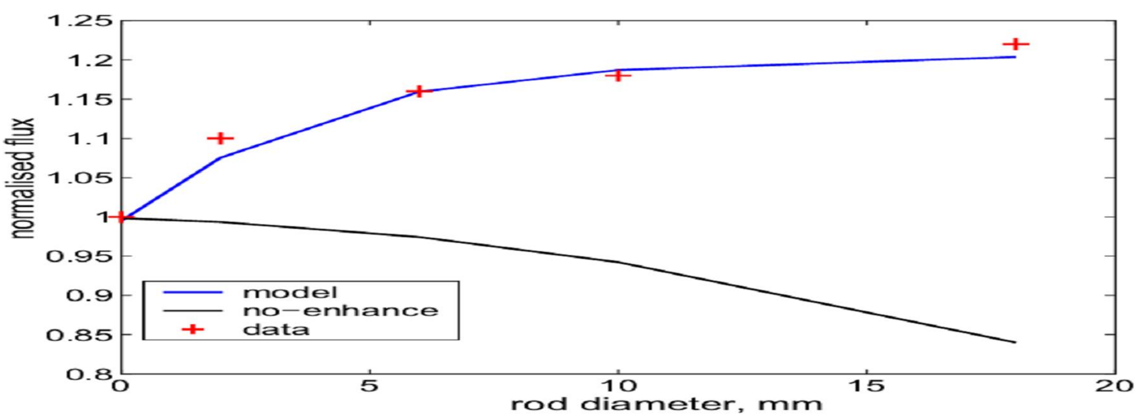

Figure 3: Variation of flux enhancement with size of the insert

4. Conclusion

To summarize, these results show the evidence of flux enhancement due to the presence of SFSes. These affect the large scales of the flow, and through kinematic wall blocking, attenuate the lateral transport and hence enhance the axial transport of flux. Measurements show an increase of upto 20% in flux for a blockage ratio of 16%. Smaller blockage ratios have a surprisingly larger relative enhancement. A simple model describing the flux enhanced flow to occur in three distinct regions captures the trend reasonably well.

References

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