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EFFECT OF BODY FORCES ON MOTION AND HEAT TRANSFER OF CONFINED FLUIDS

FINAL SCIENTIFIC REPORT

Grant AFOSR-77-317

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Despite the numerous natural and technological occurrences of transport processes due to complex driving forces little detailed information about them is available. Under the subject grant study was started of several different coupled convection problems. In each case the problems not only were of fundamental scientific importance but each also has practical implications. The new aspects and phenomena that are addressed and have been identified and described since the last Interim Progress Report will be summarized below. Not as much progress was made on some phases of the work as was anticipated because it was necessary to orient new students in these complex research areas.

I. Combined Thermal and Hydrodynamic Instability.

There are two sources of instability for a flow over a heated concave wall like a reentering nose cone. One is the Taylor-Goertler instability that occurs on a concave wall, and the other is the thermal instability for a flow heated from below. Both have been studied separately in the past. The present work investigates the combined instabilities. The study will determine: (1) the conditions for the onset of instability (specifically the effect of the Goertler number on the critical Grashof number and critical wavelength), (2) the flow structure in the post critical region, especially the structure of the secondary cells, (3) heat transfer rate changes due to the combined instability.

There are two important dimensionless parameters in the problem. The Goertler number and the Grashof number. From the past work on the Taylor-Goertler instability it is known that the critical Goertler number is about 10 (without heating), and from

the work on the thermal instability in the boundary layer over a heated flat plate the critical Grashof number is known to be on the order of $10^7 \sim 10^9$ depending on the distance from the leading edge. Based on these numbers we have designed to test setup which is sketched in Fig. 1. The setup covers the range of $G \leq 60$ and $0 \leq Gr \leq 1.2 \times 10^7$. To obtain a smooth uniform flow at the entrance of the test section air from a compressor goes through a settling chamber (with screens and honeycombs) and a contraction. The bottom plate of the test section is a curved aluminum plate which is heated by electrical heating mats. The setup is currently being constructed.

The onset conditions and flow structure are to be studied using a flow visualization method. Smoke is injected from a small tube placed in the settling chamber. The temperature distributions are measured by a thermo-couple probe inserted from the open end of the test section. The heat transfer rate is computed from the net input to the heaters.

II. Effects of Stabilizing Temperature Gradients on Confined Natural Convection Flows

This work is an extension of the earlier one by Raghavan and Ostrach (Ref. 1). In that work the effects of stabilizing temperature gradients on natural convective flows in an enclosure were investigated mainly qualitatively using a flow visualization method. The streamline patterns were determined by following small plastic particles mixed in the fluid (silicone oil). Later it was found that the particles did not follow the streamlines exactly (especially around the corners) mainly because of a difference in density (specific gravity 1.05 for the particles compared to .978 for the oil). Nevertheless the work demonstrated significant reductions in the flow velocities under stabilizing temperature gradients, and it also showed that the overall flow patterns were altered by the vertical temperature gradients. This provides

an important design option to reduce undersirable natural convection.

In the present work those effects are investigated quantitatively, that is, the velocity and temperature distributions in the container are measured in detail under various conditions. The experimental setup, the container design and the fluid are the same as in the earlier work by Raghavan and Ostrach. The velocity fields are investigated using the similar method as in the earlier work, but to avoid the aforementioned density difference effect, a colored solution (a colored substance dissolved in silicone oil) is used. The solution is injected into the fluid by a hypodermic needle at a desired location. After some preliminary investigations it was found that the solution follows the streamline patterns more accurately and reveals more detailed flow structures than the plastic particles. This method is used to study the overall flow patterns and measure locally-averaged velocities. The temperature distributions are measured by traversing a thermocouple probe in the container. The hypodermic needle and the thermocouple probe are held by a traversing mechanism, and inserted into the container through a slit cut along one end well.

For a given fluid the important experimental variables are container aspect ratio and four side wall temperature levels. Since only relative temperature levels are important in the problem, only three side wall temperatures are changed independently for a given aspect ratio. The present experiments are conducted for various aspect ratio and relative side wall temperature levels.

So far we have completed setting up the system and preliminary studies on the experimental techniques used herein. The main experiment will be conducted shortly.

- Ref. 1 Raghavan, C. and Ostrach, S., "Stabilizing Thermal Gradients on Confined Natural Convection Flows," Report FTAS/TR-76-118, Case Western Reserve University, 1976.

III. Convection Induced by Combined Horizontal Temperature and Concentration Gradients

This work is to study the flow field (distributions of velocity, temperature and concentration) caused by combined horizontal temperature and concentration gradients in a closed container. Since the main motivation of the present work is to investigate the convection effects associated with the crystal growth process known as closed-tube vapor deposition, the orders of magnitude of the important dimensionless parameters in the problem are chosen such as to simulate the process as closely as possible. The important dimensionless parameters have been found from the governing equations (aspect ratio, thermal and solutal Grashof numbers, Prandtl number and Schmidt number). The selected aspect ratio (height/width) range is $.05 \sim .2$, and thermal Grashof number $10^6 \sim 10^8$. Since there is not much information available on confined natural convection induced by temperature gradients alone for each small aspect ratio and high Grashof number cases, it has been decided to investigate those cases as a first step. The selected fluids are water and polyethylene glycol.

The overall flow structures under various experimental conditions have been studied mainly qualitatively using a flow visualization method. The method is very similar to the one used in Project II. Under certain conditions secondary cells are found to appear along the vertical walls (Fig. 2). The conditions for the appearance are found to be related to the aspect ratio, Grashof number and Prandtl number. Since the appearance of the secondary cells is a very important feature of the problem (once they appear, the flow structure is significantly altered), the conditions for the appearance are currently being investigated in detail.

As for the combined effects of temperature and concentration gradients, it was originally planned to place a soluble material along a vertical plate (either hot or cold wall) and observe the convection patterns under a quasi-steady state condition.

However, there are some difficulties in finding an appropriate material that dissolves slowly enough and still causes a significant density change. We are still in a preliminary stage for the study of the combined effects.

IV. Waste Heat Disposal into a Stratified Environment

This is a continuous effort from the earlier work by Tong and Ostrach (Ref. 2) trying to find an effective way to discharge waste heat into stratified lakes or oceans. In the earlier work waste heat was discharged from a small hole as a jet. Investigations of the jet trajectories showed that the heat did not disperse into a wide region because of density stratification. In the present work we consider cases where heat is discharged from a larger area. In this way thermal convection can disperse the heat into a wider region.

At first to study the complex interaction between the thermal convection and stratified environment, we constructed an experimental setup sketched in Fig. 3. The stratified environments are obtained by varying salt concentrations in the vertical direction. A heated plate of 5 cm diameter is placed at the center bottom of the container (square section, 30 cm wide). In the present work no material is discharged from the plate. Using the system, the flow structures are investigated by measuring the velocity and temperature distributions under various plate temperatures and stratification levels (uniform, 2-layer model, multi-level stratification). The velocity is measured using the Ph indicator method, and temperature by a thermocouple rake.

We are also trying to find the important parameters in the problem. The problem is very complex because the convection is induced by a thermal instability due to heating from below, heating from the side and double-diffusive mechanism (combined effect of heat and salt diffusion). Therefore, we may restrict ourselves to mainly qualitative

studies at first to see how those mechanisms interact and to see what parameters are important in determining the dispersion of heat.

- Ref. 2 Tong, T. and Ostrach, S., "The Discharge of Submerged Buoyant Jet into a Stratified Environment," Report FTAS/TR-77-128, Case Western Reserve University, 1977.

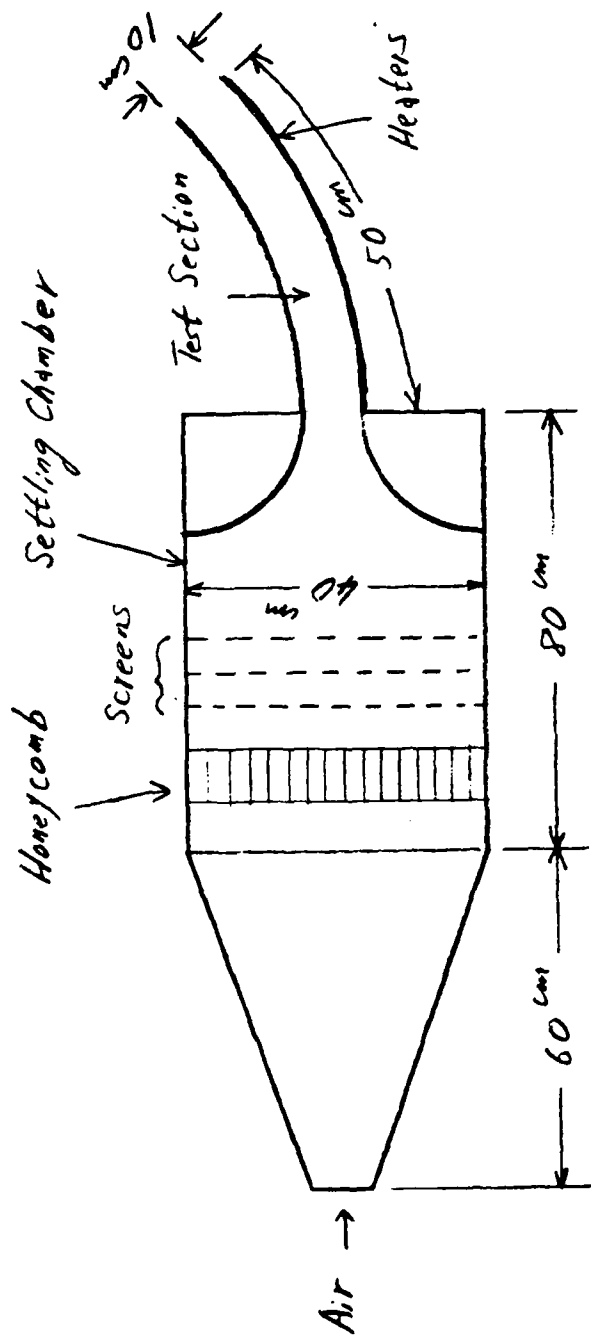


Figure 1. Sketch of Experiments 1 Setup for Project 1.

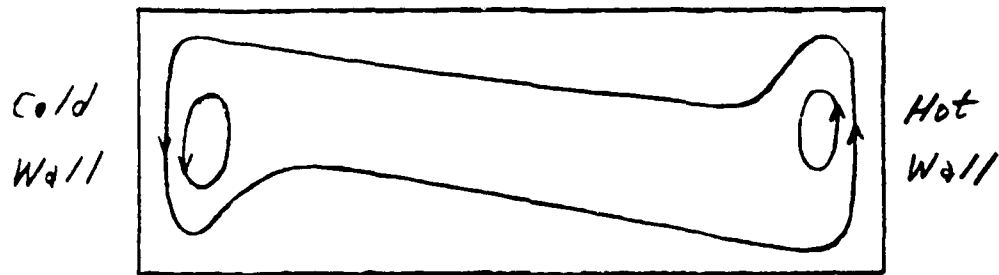


Figure 2. Streamline Patterns (Project 3)

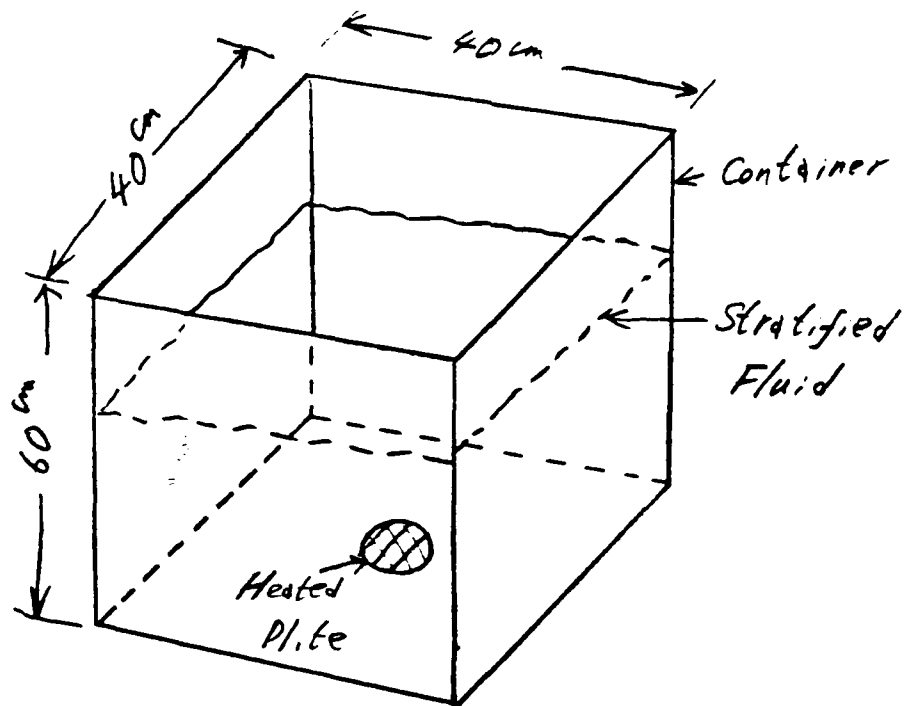


Figure 3. Sketch of Experimental Setup for Project 4.