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MEASUREMENT OF VELOCITY PROFILES IN A STRATIFIED PIPE FLOW RECIRCULATORY SHEAR ZONE USING LASER FLOW VISUALIZATION

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by

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Argonne National Laboratory is studying pipe-flow/plenum thermal-plume interactions induced by a pipe-to-plenum temperature difference. Under these conditions a pipe-flow-generated thermal plume is produced in the plenum and a stratified recirculation zone is produced in the pipe resulting in cold fluid being drawn out of the plenum into the bottom of the horizontal pipe conveying hot fluid into the plenum. These phenomena produce plenum wall and pipe nozzle thermal distributions conducive to detrimental structural thermal stresses. In order to study these phenomena studies are being conducted in the ANL Buoyancy Effects Tank (BET), a 3.41-m^3 plenum containing cold water which is interfaced with a horizontal transparent pipe conveying hot water into the plenum. Details on the test section design, instrumentation and previous results are given in Refs. [1,2,3,4].

DISCLAIMER

Reference [3] highlighted the role of thermal buoyancy in laminarization of a turbulent stratified shear zone in a horizontal pipe. This laminarization phenomenon is important because it influences the pipe-backflow penetration distance of the stratified recirculation zone as well as the thermal oscillations occurring at the stratified interface in the pipe. Since shear layers are found in many reactor components, an effort has been made to generalize the previous results by defining nondimensional parameters (i.e., Richardson number) in terms of local conditions (i.e., temperature and velocity gradients) as opposed to the global conditions (i.e., pipe mean velocity and temperature difference between hot incoming fluid and the cold plenum). This paper summarizes the efforts directed at further study of shear zone laminarization.

Additional tests have been conducted in the BET. At the two pipe axial measurement locations in the stratified recirculation zone, temperature and velocity distributions were measured simultaneously across the pipe diameter in the vertical symmetry plane. The velocity distribution was measured using neutrally buoyant fluorescent particle flow tracers (<50 μm) in conjunction with laser illumination and a Spin Physics Motion Analysis Video System, Ref. [4]. Fluorescent particles were introduced upstream in the stratified pipe flow, and video pictures were taken at 200 frames per second at the primary measurement locations. The camera speed was fast enough to stop each particle. By tracking individual particles over a number of video frames, the velocity at a particular radial position was determined. The velocity distribution and accuracy bounds shown in Fig. I were obtained by tracking individual particles at various radial positions. Some advantages of this visualization technique are the ability to quantitatively measure an instantaneous global velocity distribution (not just a point velocity), to obtain clear, unambiguous images due to the thin plane of illuminated particles and to make nonobtrusive measurements (flow field being measured is not disturbed).

Eastman Kodak has been participating with ANL in developing the most suitable combination of the type of particle (i.e., size and density) and dye (i.e., wavelength of fluorescing optimum for the ANL argon laser and video camera) for the present application. The Spin Physics Motion Analysis System has been connected to the Mixing Components Test Facility data acquisition system and efforts are underway to perform computer analysis of the video images. The current data confirm the workability and strength of this system under development.

Temperature profiles were measured with three fast-response, copper-constantan thermocouples mounted along a 0.31 cm dia. support rod spaced 2.54 cm apart. The rod was moved by means of a micrometer depth gage. Simultaneous laser pipe flow visualization velocity and temperature profiles are shown in Fig. II for the same axial location in the horizontal pipe, near the plenum. The horizontal axis is the radial distance from the pipe centerline nondimensionalized with respect to the pipe diameter. Note that the shear layer (i.e., region of steep gradient in velocity and temperature) extends from a radial location of -0.35 to -0.1 (a quarter of the pipe diameter). Also, the point of zero velocity (i.e., the eye of the recirculation zone) is in a region of large temperature gradient. Both temperature and velocity gradients can be determined from the above data and used to calculate the gradient form of the Richardson number, the ratio of buoyancy to inertia forces.

Results from tests have been analyzed to establish a criterion for determining the conditions for laminarization of a turbulent shear zone.

The observed suppression of turbulence is very important because the oscillatory behavior of the stratified interface can be conducive to thermal striping and under certain conditions it has been shown that the oscillations are completely suppressed by buoyancy forces.

REFERENCES

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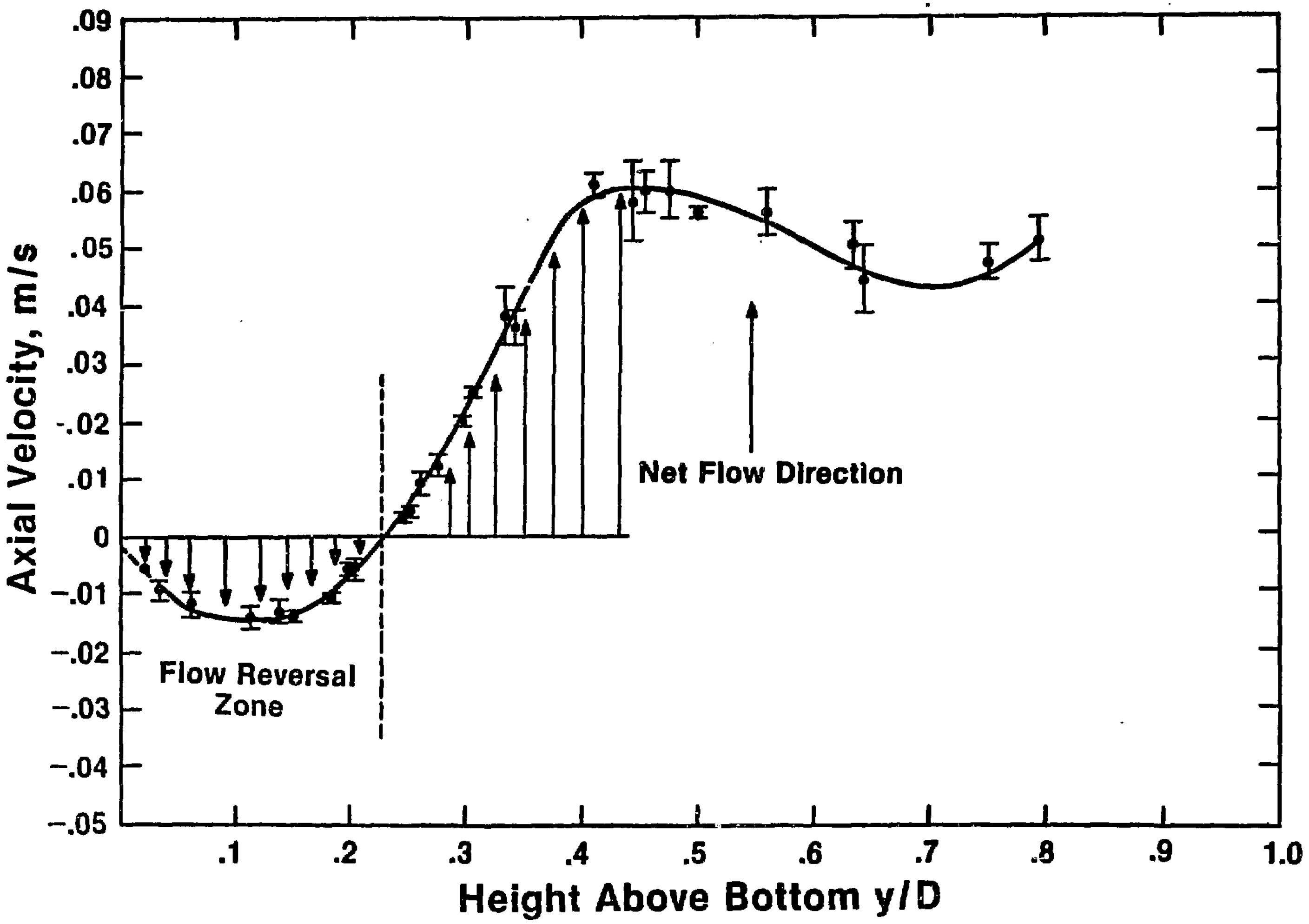

Fig. I. Horizontal Pipe Flow Velocity in Vertical Symmetry Plane in Region of Buoyancy-induced Recirculation Zone, Showing Cold Reversed Flow Region at Bottom of Pipe and Velocity Gradient in Shear Zone.

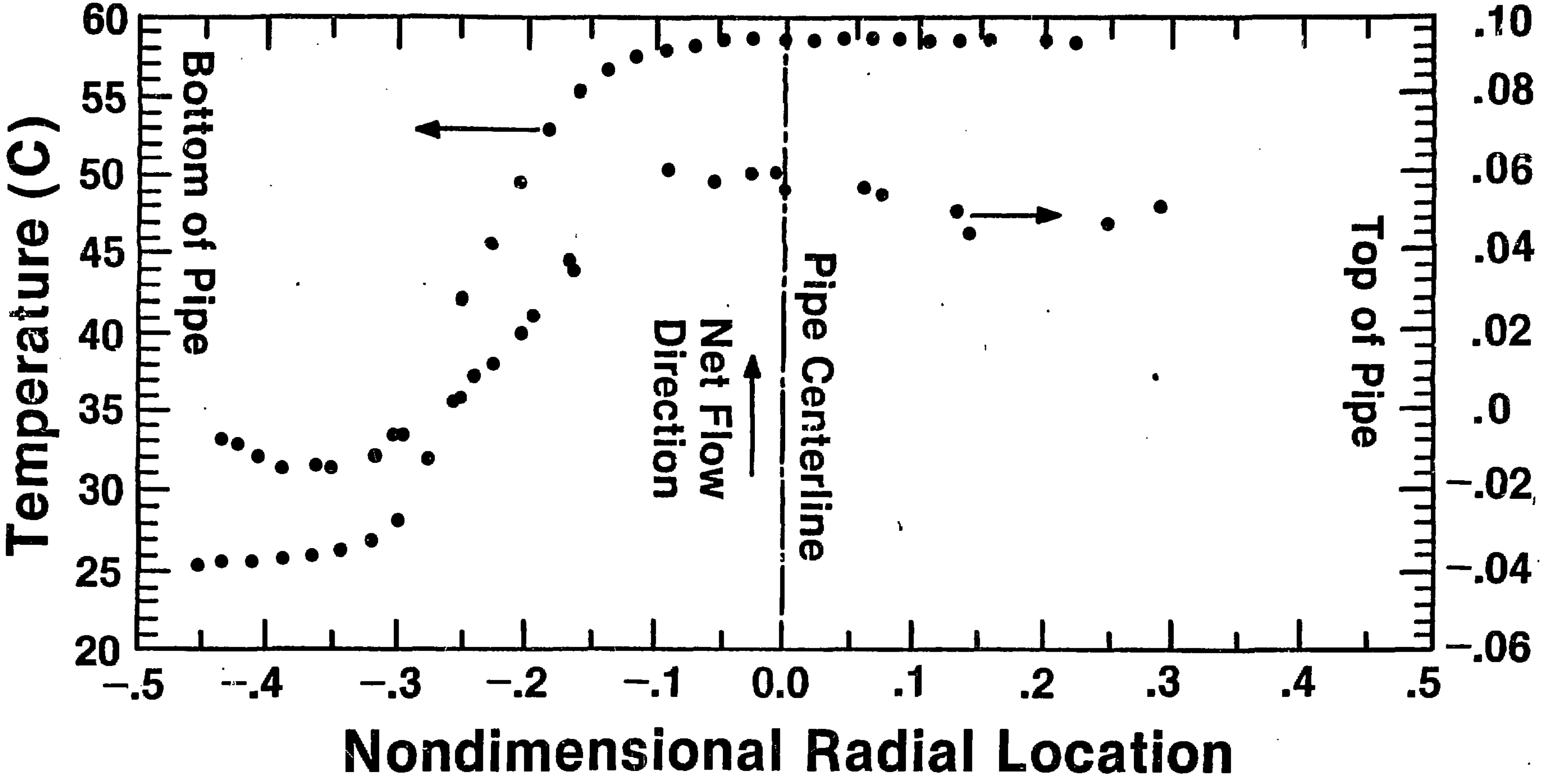

Fig. II. Simultaneous Velocity and Temperature Profiles Occurring in a Stratified Horizontal Pipe Flow, Vertical Symmetry Plane