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Thermal Laminarization of a Stratified Pipe Flow

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The present work constitutes a new program that grew out of a scoping assessment by ANL to determine the propensity for pipe stratification to occur in the reactor outlet nozzles and hot-leg piping of a generic LMFBR during events producing reverse pipe flow. The scoping assessment, guided by stratification information already produced by ANL [1], showed that stratification can occur, producing potentially troublesome structural thermal stresses, when flow leaks back past a check valve during several postulated reactor transients (for example, in a down loop during N-1 loop operation). Reactor events of this nature cause stratified flow to be convected back into the reactor outlet nozzle/piping region and to be backflushed into the reactor upper plenum, producing a pipe-flow-generated thermal plume in the plenum and

a stratified recirculation zone in the pipe, which influences plenum-wall and outlet-nozzle thermal distributions. [2,3] Three phenomena have been highlighted as having a direct bearing on a quantitative assessment of the potential problem and for which adequate technical information is not available.

- Steady-state initial thermal distribution in the down loop is very important to proper interpretation of the ensuing stratification after the backflow transient begins. The initial thermal distribution in the piping falls into a class of steady-state pipe stratification problems resulting from differentially heated pipe ends with both zero and nonzero net flow.

- The behavior of a stratified pipe flow discharging into a large reservoir is not well understood, both from the viewpoint of how the pipe/reservoir interaction influences the pipe stratification itself (being the boundary condition on one end of the pipe), and from the viewpoint of how,

- The plume generated by the back-flushed pipe flow into the plenum influences the thermal distribution in the outlet-nozzle/plenum-wall region.

This paper focuses on the role that thermal buoyancy plays relative to being able to laminarize a turbulent stratified shear zone in a horizontal pipe. The preceeding can influence the behavior of a pipe stratified-backflow-recirculation zone (cold plenum water down into the hot pipe flow) which developes as the result of a temperature difference between the pipe flow and the plenum.

The laminarization phenomena 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. The thermal oscillations are of potential concern due to possible thermal striping induced thermal fatigue of the pipe walls. Tests were conducted in the ANL Buoyancy Effects Tank (BET) which consists of a 3.41-m^3 plenum, containing cold water, interfaced with a horizontal transparent pipe conveying hot water into the plenum.

For a typical series of tests, at a fixed value of Grashof number (Gr), (i.e., a fixed temperature difference between the plenum and the pipe flow), the pipe flow rate was varied over a wide range and dye was injected into the bottom of the pipe in the recirculation region. The dye allowed determination of pipe-backflow recirculation-zone penetration distance, Z_p, and study of flow oscillations in the stratified shear zone.

The variation of Z_p/D, where D is pipe diameter, as a function of bulk flow Reynolds number is shown in Fig. 1. The seven curves are for different values of Gr. In general, as Re is decreased (i.e., the pipe flow rate Q is reduced), Z_p/D increases. When Re is sufficiently reduced, the recirculation zone can penetrate upstream to the pipe entrance. The knee found in each Z_p/D curve is related to the fact that pipe turbulence is being suppressed locally by the buoyancy forces in the stratified interface (i.e., laminarization is taking place) at Re below the knee value. Note also that with increasing Gr, the knee occurs at larger values of Re (i.e., the local stratified shear zone laminarization can occur under higher turbulent pipe flow conditions with increasing buoyancy force strength).

Figures 2 and 3 show circumferential fluid/wall interface thermocouple responses for two different tests, at a location one pipe diameter upstream from the pipe exit. Both tests are characterized by a turbulent pipe Reynolds number. After start-up transients have disappeared, time > 400s, a well defined hot-cold interface lies in the bottom of the pipe for both tests, i.e., the stratified shear zone. Test BETC2 which lies above the knee in the Z_p/D curve (see Fig. 2), exhibits no thermal oscillations associated with the shear zone. However test BETC5 which lies below the knee exhibits thermal oscillations at the shear zone. Hence the buoyancy forces were large enough in test BETC2 to suppress turbulence in the shear zone. Where as for test BETC5 the buoyancy forces were not large enough to cause laminarization. The observed suppression of turbulence is very important because the oscillatory behavior of the stratified interface can be conducive to thermal striping. The preceding experimental observations indicate that even with turbulent bulk-pipe flow there are circumstances (i.e., strength of thermal-buoyancy forces) that can cause thermal striping to be mitigated. Efforts are underway to quantify the conditions under which turbulence and possibly gravity waves at the stratified interface are suppressed. Note that these are very generic phenomena, and a fuller understanding of them will greatly increase the understanding of stratified interface behavior in other reactor components.

References

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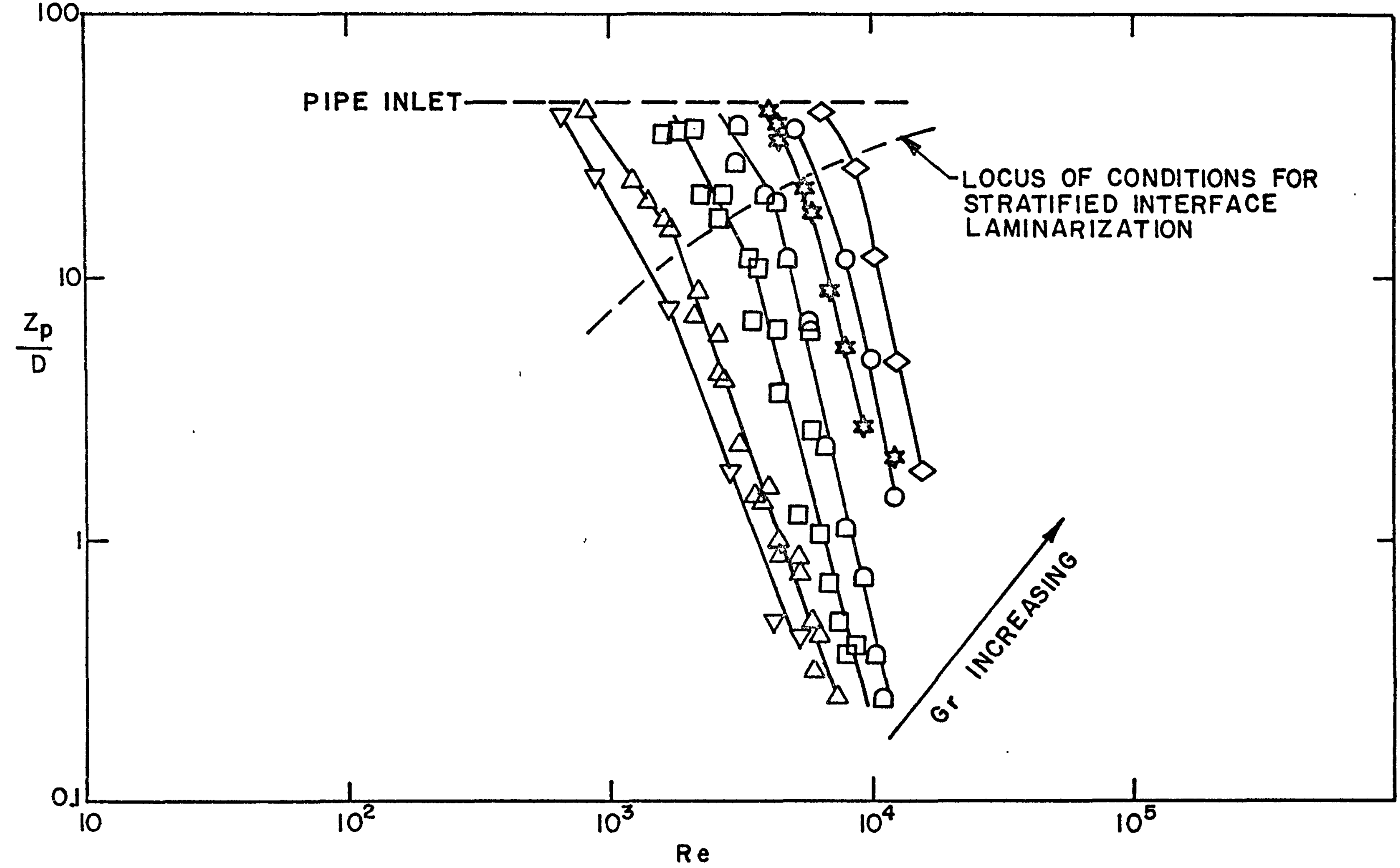

Fig. 1 Variation of Pipe-backflow Recirculation-zone Penetration (Z_p/D) with Reynolds number (Re) for Various Values of Grashof Number (Gr)

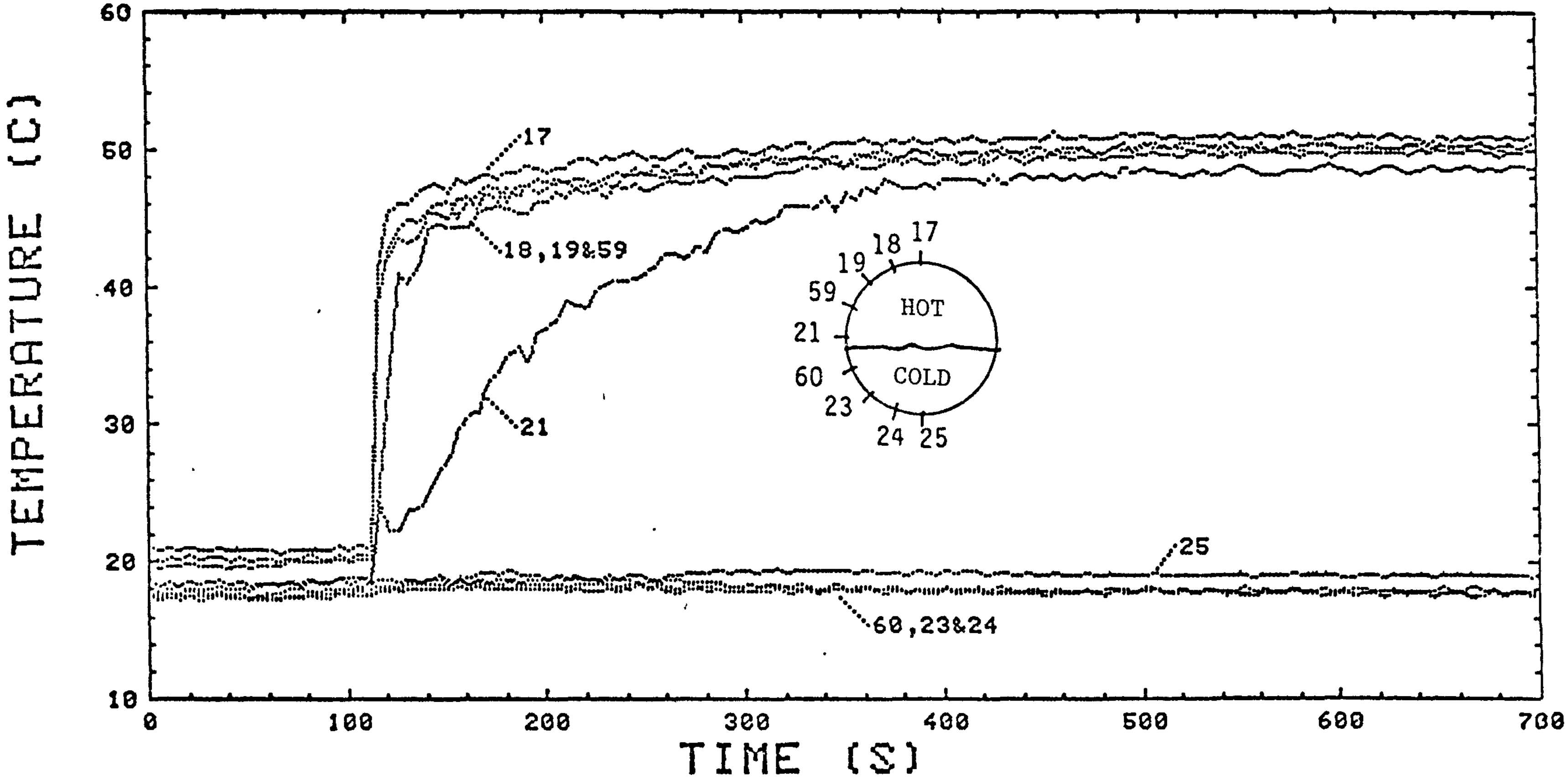

Fig. 2 Pipe Circumferential Temperature Distribution During Approach to Steady-State for BETC2

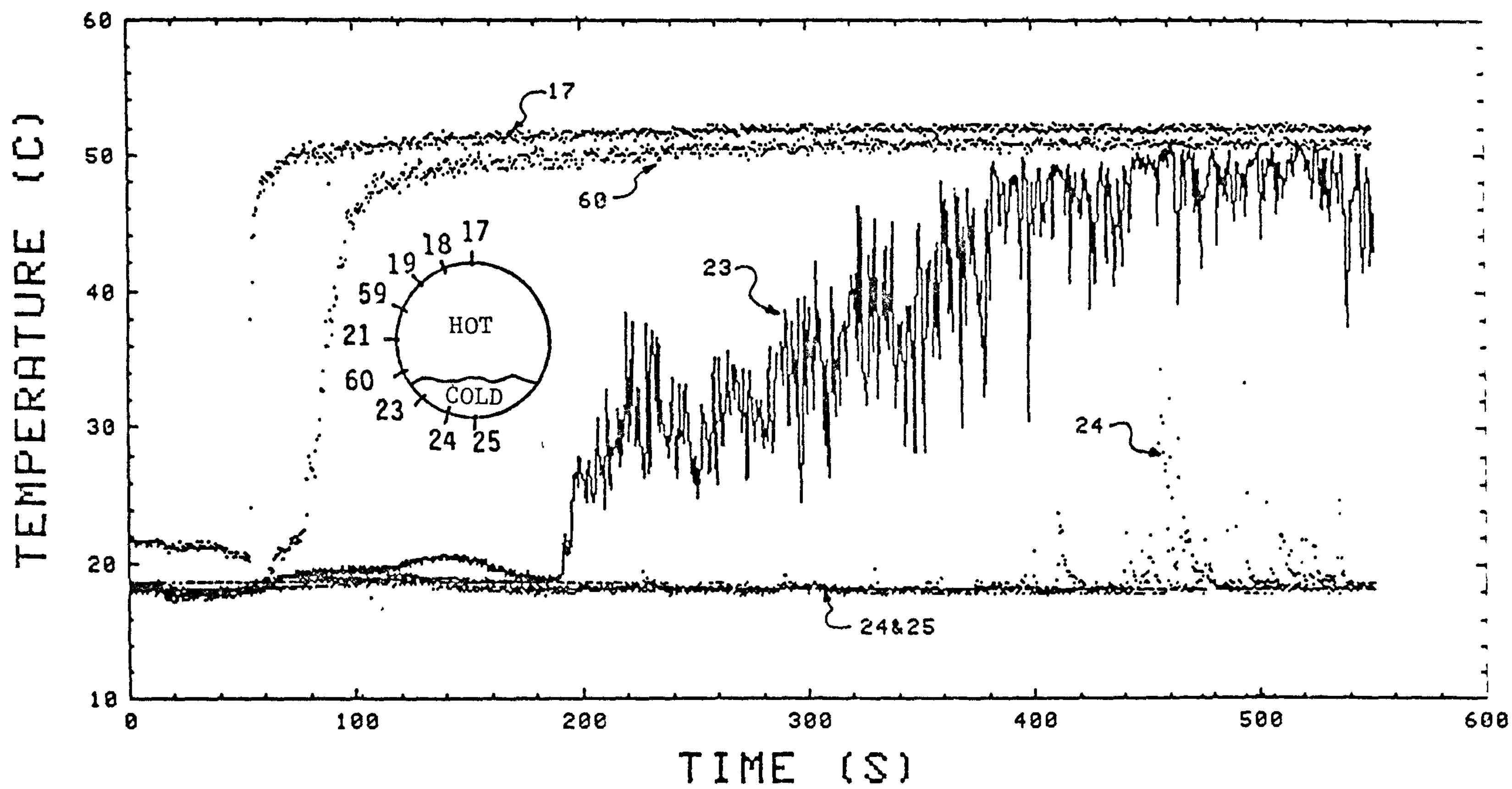

Fig. 3 Pipe Circumferential Temperature Distribution During Approach to Steady State for BETC5