The Influence of Thermal Buoyancy On Vertical Tube Bundle Thermal Density Head Predictions Under Transient Conditions

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The thermal-hydraulic behavior of an LMFBR system under various types of plant transients is usually studied using one-dimensional (1-D) flow and energy transport models of the system components. Many of the transient events involve the change from a "high" to a "low" flow with an accompanying change in temperature of the fluid passing through the components which can be conducive to significant thermal buoyancy forces [1,2,3]. Thermal buoyancy can exert its influence on system dynamic energy transport predictions through alterations of flow and thermal distributions which in turn can influence decay heat removal, system-response time constants, heat transport between primary and secondary systems, and thermal energy rejection at the reactor heat sink, i.e., the steam generator.

In this paper the results from a comparison of a 1-D model prediction and experimental data for vertical tube bundle overall thermal density head and outlet temperature under thermal transient conditions causing varying degrees of thermal buoyancy are presented. These comparisons are being used to generate insight into how, when, and to what degree thermal buoyancy can cause departures from 1-D model predictions.

It has been shown [1,2,3] that when "cold" flow enters the shell side of a previously hot vertical tube bundle from the top and flows downward (if the thermal buoyancy forces are large enough), the cold flow can channel and accelerate down through the hot bundle creating temporary semi-stagnant recirculation zones between the baffles. Hence the axial and radial temperature distributions in the bundle can differ greatly from that which would be presented if the buoyancy forces were negligible and can also differ greatly from those predicted by a 1-D analysis.

Transient, low-flow, nonisothermal water thermal buoyancy experiments are being performed in the Argonne National Laboratory Mixing Components Test Facility (MCTF). Currently a 60° sector, 0.46-scale, reduced length, shell-side hydraulic model of the Westinghouse Intermediate 'A' steam generator is being tested, see Ref. 4 and Figure 1. These studies have led to a generalized correlation for predicting the degree of flow channeling in a vertical tube bundle. Two comparisons between experimental data and 1-D model predictions for this SG test article are presented below. Tests SG50A7, Fig. 2, and SG50CY, Fig. 3, are two thermal downramp tests under constant inlet flow conditions and respectively are cases of insignificant and significant thermal buoyancy based on results from earlier correlation development activities. The tube bundle inlet forcing functions for flow and temperature for the 1-D model were the actual experimental data, shown in the Figures. Presented for each test are predicted SG exit temperature and overall pressure differential along with the experimental data for comparison. For Test SG50A7, negligible buoyancy, both exit temperature and ΔP are reasonably predicted by the 1-D model. However for Test SG50CY, strong buoyancy, both exit temperature and ΔP are not well predicted. The thermal disturbance arrives at the SG exit much earlier than the 1-D model predicts and the 1-D model predicts a much earlier approach to final steady state. This is a result of buoyancy induced flow channeling and the formation of temporary semi-stagnant "hot" zones between baffles. Because the 1-D model fails to correctly predict the temperature variation, is is not surprising that it also fails to correctly predict the pressure differential across the bundle. ΔP has as its main contribution the integrated thermal density head over the length of the bundle, which is a strong function of time due to the thermal transient. The 1-D model over-predicts ΔP and shows a much more rapid approach to steady state. This is a result again of the semi-stagnant, hot recirculation zones formed in the bundle which are very persistent.

In summary the above comparisons are generating valuable information on how thermal buoyancy can invalidate 1-D model predictions of tube bundle thermal hydraulics. Efforts are currently underway to establish criteria for determining when 1-D models become invalid. Similar studies have already been performed for establishing when 1-D pipe flow models become invalid due to thermal buoyancy [5].

References

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FIG. 1 STEAM-GENERATOR 60° SECTOR TUBE-BUNDLE FLOW MODEL

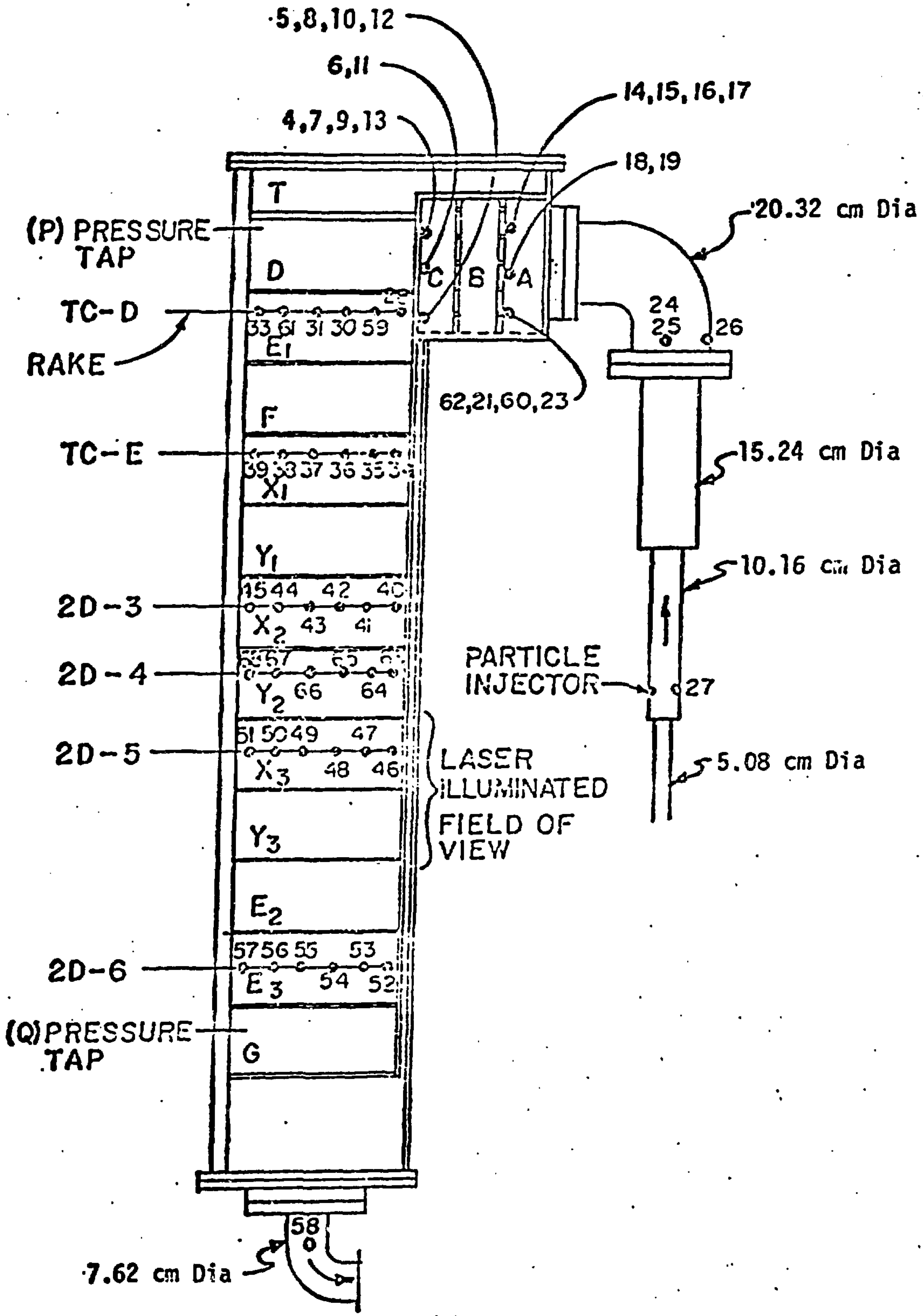

FIG.2A TEMPERATURE & FLOWRATE HISTORIES
SG50A7

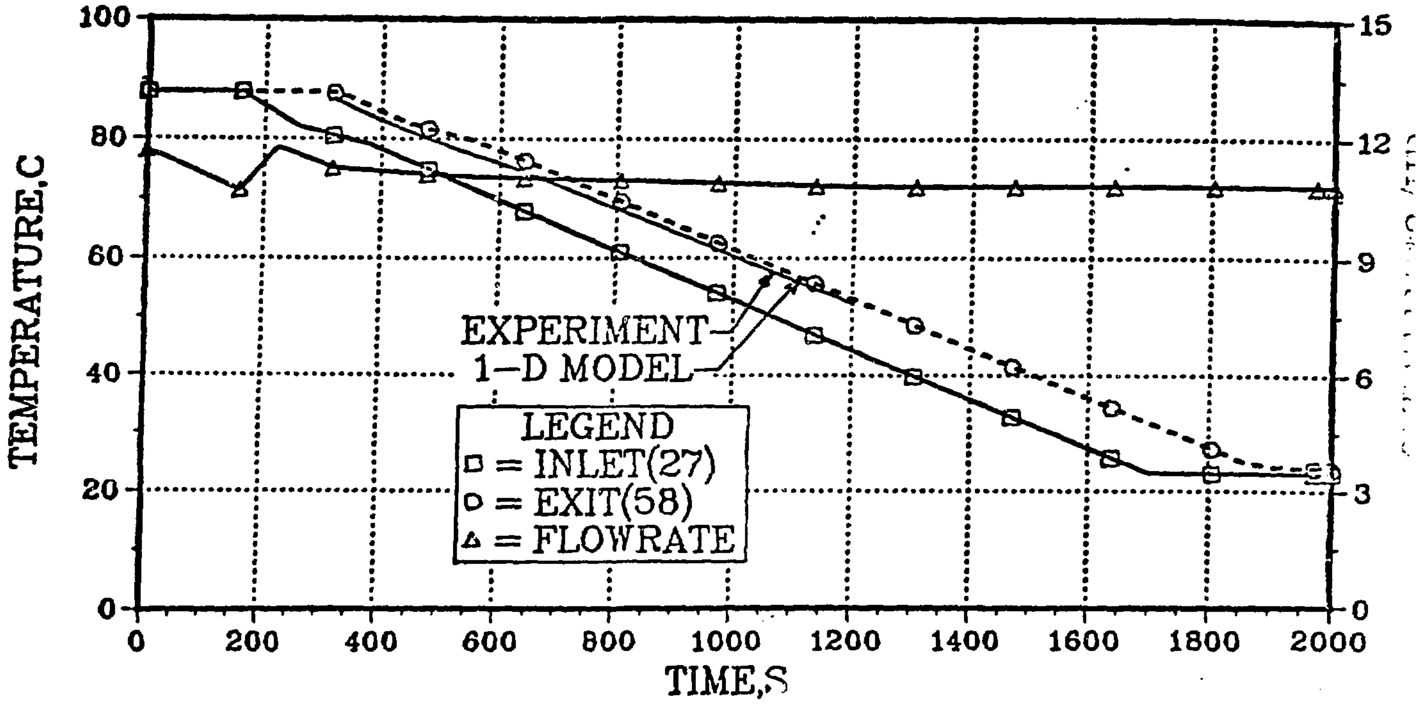

FIG.2B PRESSURE DIFFERENTIAL HISTORY
SG50A7

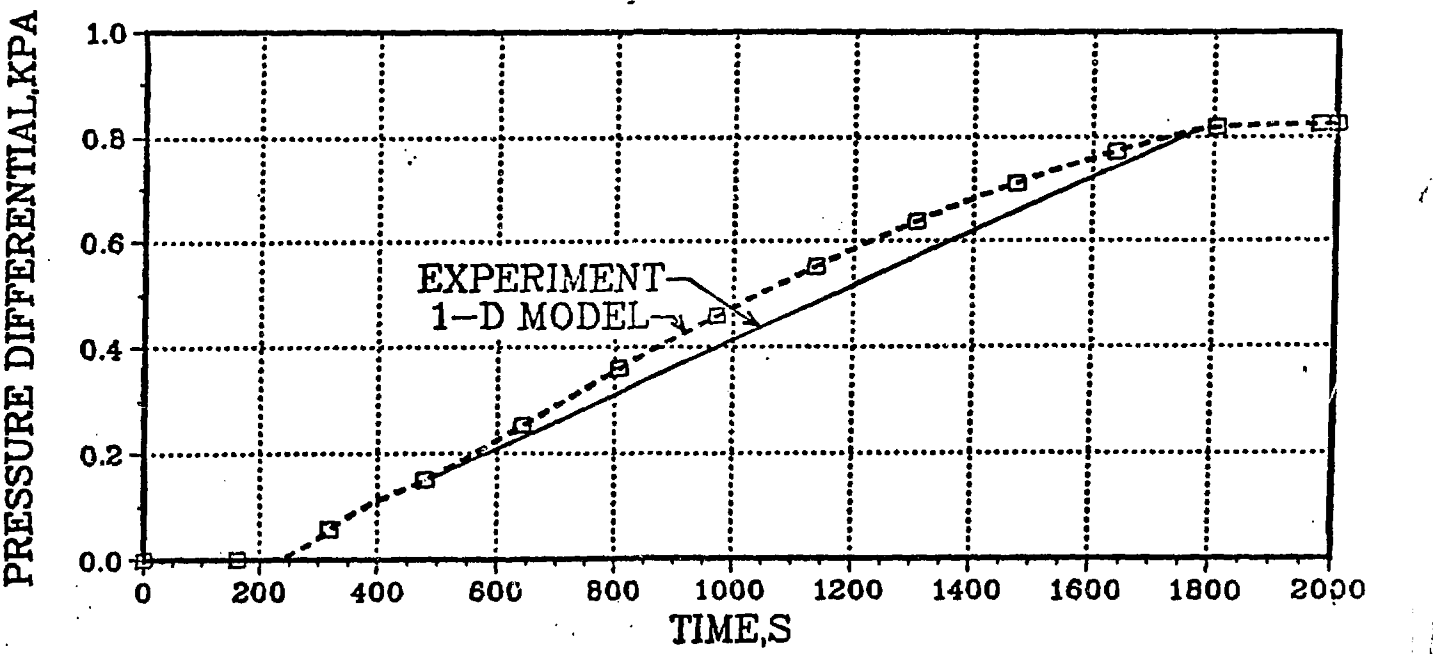

FIG.3A TEMPERATURE & FLOWRATE HISTORIES
SG50CY

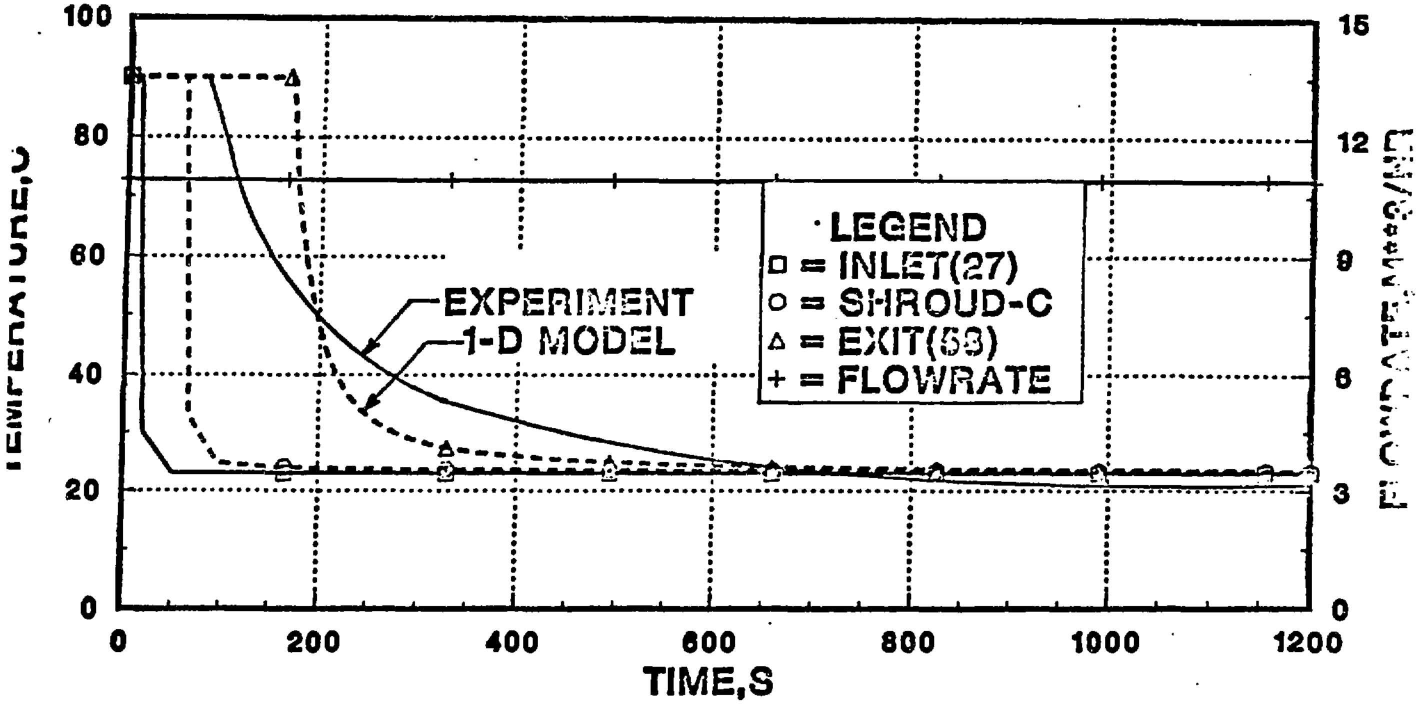

FIG.3B PRESSURE DIFFERENTIAL HISTORY
SG50CY