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Thermal Oscillations Downstream Of An Elbow In Stratified Pipe Flow*

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by

T. M. Kuzay and K. E. Kasza

Components Technology Division
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

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In previously published papers [1 and 2], the test geometry, test methodology and the scope of the thermal transient-induced pipe stratification studies at Argonne National Laboratory (ANL) were explained. In these prior studies, limited fluid temperature data from elbow inlet and exit plane thermocouples indicated the presence of large-amplitude thermal fluctuations for conditions in which the horizontal pipe upstream of the elbow developed stratified flow induced by a pipe entrant thermal transient. Under severe transient conditions, thermal oscillations of amplitude of almost 70 percent of the pipe inlet transient temperature change, ΔT_{IN}, were observed in the bulk flow. TC data and accompanying flow visualization test results showed that the largest near wall thermal oscillations were located within and immediately downstream of the elbow. The thermal oscillations if they are of large enough amplitude, of the appropriate frequency, and of sufficiently long duration can cause thermal striping and thermal-fatigue stress cracking in the elbow region.

To address these concerns, a specially instrumented test section has been fabricated using a sweep elbow (d/R = 0.5) similar to the glass elbow utilized in the earlier studies [1]. The test section is shown schematically in Fig. 1. The dark circles and the accompanying numbers indicate thermocouple locations. The four instrumented cross-sections are located 13 mm before the elbow exit and 25,101 and 177 mm after the exit, respectively. The thermocouples shown at the fluid/wall interface protrude from the wall only to the extent that they are "feelable" by the touch of fingertip. These TCs are thus assumed to measure approximately the interfacial temperature fluctuations. The vertical centerline rake TCs are located in the same cross-sectional plane as the wall TCs. Thus simultaneous recording of the interfacial and bulk fluid thermocouples allows cross correlation of the thermal disturbances in each region. All TCs are of the exposed junction type and typical response time is of the order of 20 ms, which is more than adequate for following the low frequency oscillations encountered.

To date a battery of tests have been conducted with pipe Reynolds number (Re) ranging from 15,000 to 30,000, Richardson number (Ri) from 5 to 21 and the thermal transient duration time ranging from 10 s to 120 s. Because the pipe and elbow stratification once developed persists a long time under severe conditions [1,2], data was recorded, even for the short transients, in excess of 1200 s to record fully the duration of the thermal oscillations in the elbow.

Figures 2 and 3 are typical examples of the wall TC data in the area observed to be subjected to the largest thermal oscillation. The region of largest fluctuations is located at the second instrumented section downstream of the elbow exit as shown in Fig. 1. The locations upstream and downstream of this section are subject to much smaller temperature oscillations. Furthermore, at the axial location of largest oscillations, it is the inner radius upper quadrant thermocouples, Fig. 3, which are subjected to the largest thermal oscillations. From Fig. 3, it can be seen that the maximum amplitude of the oscillations is of the order of 30-40 percent of the imposed transient temperature change at the pipe inlet, ΔT_{IN}. In conclusion the thermocouple data indicates that the potential for thermal striping is the greatest along the elbow inner radius within one pipe diameter downstream of the elbow exit.

Work is currently in progress to quantify the data in terms of amplitude and the frequency content of the oscillations. This will allow the thermal striping potential to be related to the strength of buoyancy and the degree of stratified flow developed in the horizontal pipe immediately upstream of the elbow.

References

1. Kasza, K. E. and Kuzay, T. M., "The Influence of an Elbow on Horizontal Pipe Flow Thermal Stratification," Am. Nucl. Soc. Trans. Vol. 43, p. 781 (1982).

2. Kuzay, T. M. and Kasza, K. E., "Persistence of Horizontal Pipe Thermal Transient Induced Flow Stratification," Am. Nucl. Soc. Trans. Vol. 45, pp. 207-209 (1983).

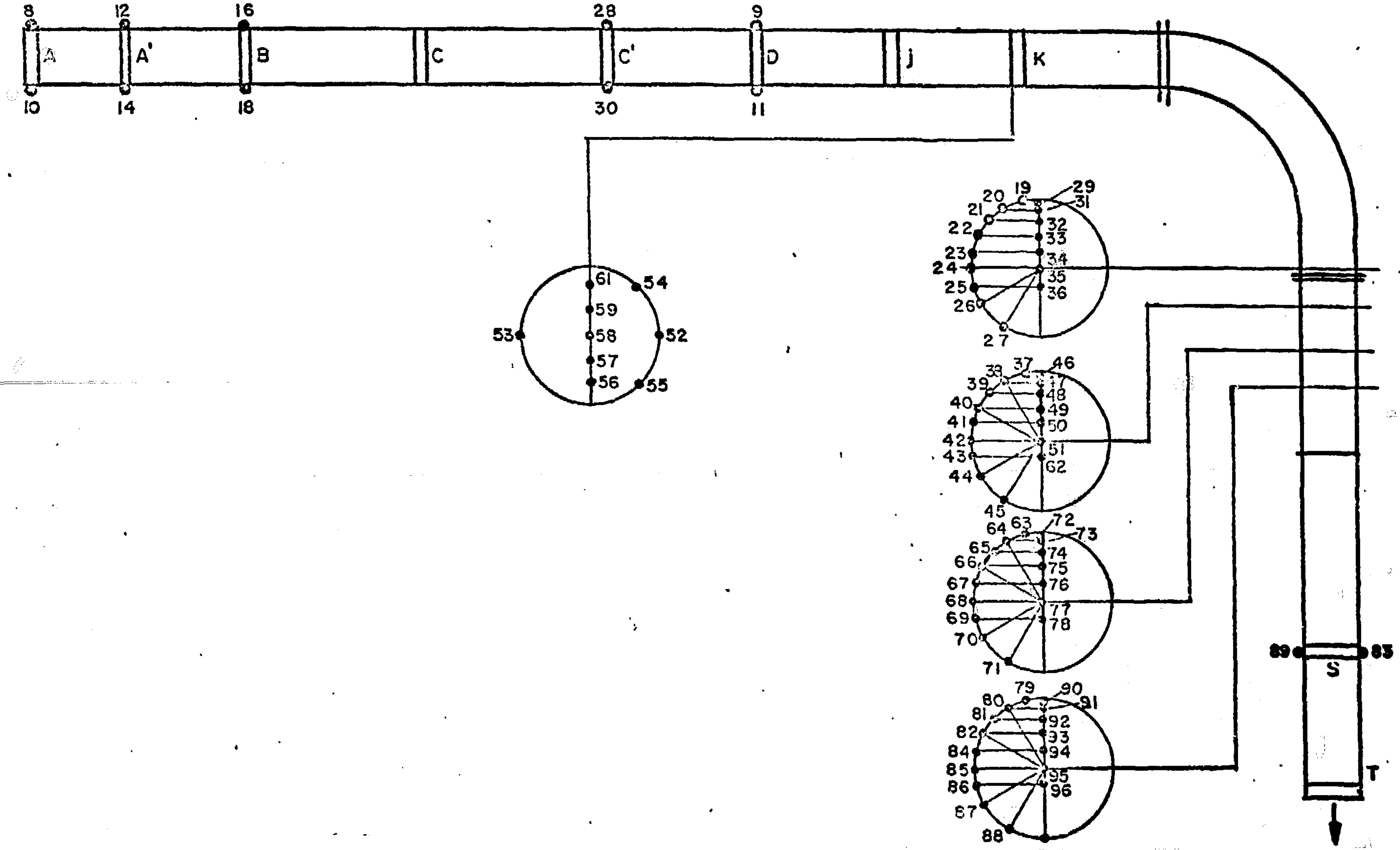

Fig. 1. Elbow Thermal Striping Test Section TC Locations and Channel No's

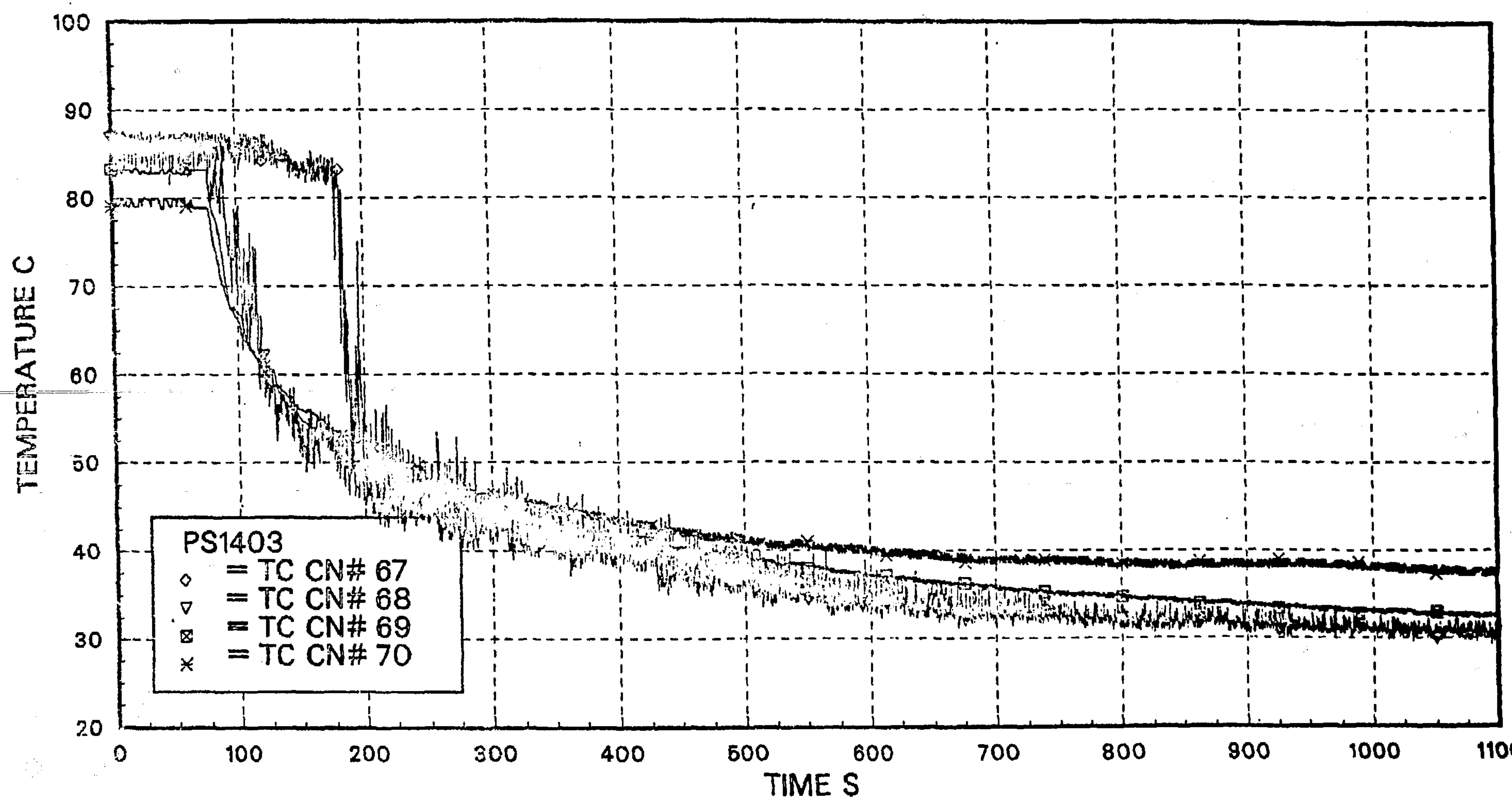

Fig. 2. Fluid/Wall Interface Thermal Oscillations One Pipe Diameter Downstream of Elbow Exit: Inner Radius, Bottom Quadrant

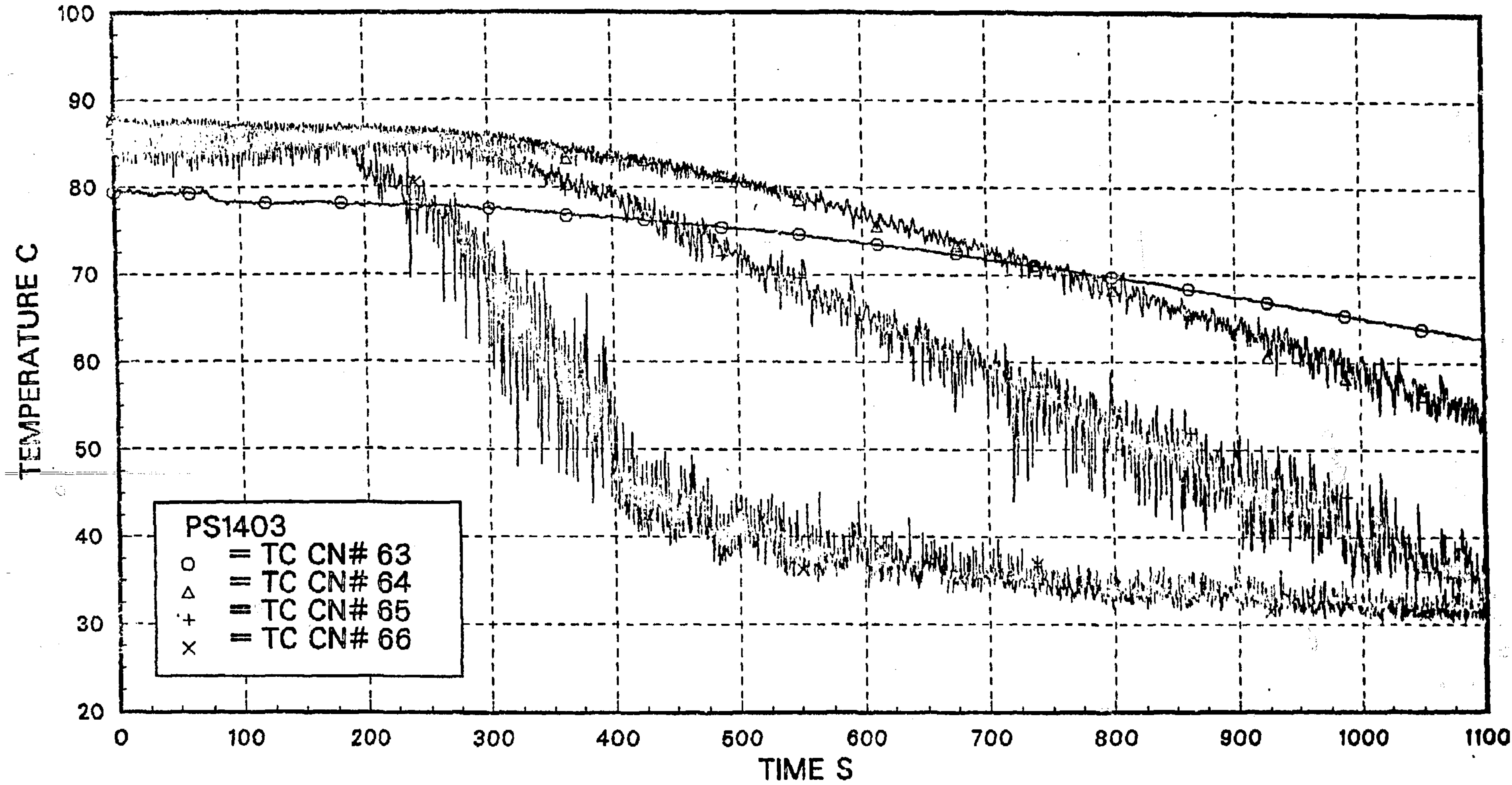

Fig. 3. Fluid/Wall Interface Thermal Oscilaltions One Pipe Diameter Downstream of Elbow Exit: Inner Radius, Top Quadrant