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DESIGN AND MODELING CONSIDERATIONS RELATIVE TO THE PHENOMENA ASSOCIATED WITH FLOW RECIRCULATION IN BRANCHED PIPING SYSTEMS

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BSTRACT

Design and analytical modeling considerations associated with ecirculating flow in piping systems with tee and "Y" connections are resented. Flow recirculation, in many process piping networks, can roduce nonsteady flow and associated thermal conditions. In the low recirculation discussion, experimental data is presented for a 90 egree branch piping (tee connection) using four different branch ipe sizes over a wide velocity range [Coffield and Kolar (1990)]. The discussion also includes recent test data for a 45 degree, Y onnected, branch piping design. Designers can use this information y directly applying the limiting conditions that are presented at the lesign stage, or in evaluating the performance of existing systems. For example, although flow recirculation may result in complicated low patterns, it often can have the beneficial effect of mixing low elocity branch line fluid with the primary system fluid as it pproaches the intersection. In branch pipe systems where flows are it different temperatures this recirculation helps attenuate the otential for large thermal stresses. The recirculation flow patterns re strongly affected by the branch angle and thus they are presented s a function of the branch angle.

NTRODUCTION

Many different size auxiliary lines (branches) are tied into the heat transport piping of many systems. Often these lines are valved closed or have very small flows so that the contained fluid is either stagnant or flowing at low velocity due to free convection or small amounts of leakage (across valves). The characterization of the axial temperature distributions in these lines is important because of potential structural consequences to the pipe. For example, in addition to being required for determining basic thermal expansion allowances in piping networks, the temperature distribution is needed relative to other considerations such as thermal fatigue which could occur due to leakage attaining a different temperature than that of the header pipe that it flows into. As would be anticipated, conditions which result in larger fluid temperature differences at a particular network juncture or other axial positions generally result in more severe structural impact (e.g., thermal stratification/striping assessments may become necessary). Recirculation of the main heat transport system fluid into the branch results in mixing of the two fluids which helps to attenuate the magnitude of the differential temperatures and decrease axial piping temperature gradients.

This paper addresses the phenomena of flow recirculation relative to methods of modeling the thermal-hydraulic effects on the spatial temperature distributions. The information presented is based on experiments which were performed to characterize the phenomena for branch lines tied into a header pipe. The typical angles of 45 and 90 degrees between the main heat transport piping and the branch line are investigated. Flow field characteristics, using water as the fluid, were obtained by visually observing (through the clear plastic piping components) the temporal and spatial distribution of blue dye injected into the flow streams.

FLOW RECIRCULATION TEST DATA

Recirculation data for both 90 and 45 degree piping angles is presented. The vortex flow patterns in the recirculation region are significantly different for the two orientations, but the resultant impact on thermal design conditions in the piping system would be very similar.

90 Degree Branches

For the 90 degree orientation, an experimental study reported by Coffield and Kolar (1990) defines the flow recirculation pattern in four different diameter closed ended pipes branching from a header pipe. A sharp edged corner was used for the internal intersection of the two pipes. A schematic of the test set-up of clear PVC piping (Schedule 40) is shown by Figure 1. No pumped flow existed in the branch lines.

All tests indicated that three distinct recirculation regions exist in the branch pipe for the 90 degree case:

- Region 1 is a highly turbulent corkscrew vortex on the inside surface of the branch pipe with return flow back through the center.
- Region 2 is similar to Region 1 but of lower intensity.
- Region 3 is a buffer zone between the vortexing regions and the stagnant water region toward the closed end. This zone is characterized with a mild, nearly uniform axial vortex on the inside surface of the pipe with axial flow back through the center.

Data for the recirculation distance measured along the branch pipe center line from the inside surface of the header pipe were measured as a function of the header pipe flow velocity. Velocities up to 4.7 m/s (15 ft/sec) were tested. Figure 2 shows the data for the 2.54 cm (1 inch) nominal branch pipe size which typifies the data trends for the other pipe sizes. The data indicated that a maximum penetration depth was being approached at higher header pipe velocities. Estimations of the maximum penetration depths (distance independent of main flow velocity) for the various size pipes are provided in Table I.

It is suggested that the Table I data may prove useful for validating computational fluid dynamics (CFD) computer codes which are being developed for performing this type of analyses. A literature review indicates that no other source of this type of data exists.

A major conclusion of this study relative to design applications is that very little potential exists for low velocity flow approaching a main header pipe at a significantly different temperature (e.g., from valve leakage) to penetrate the high energy Region 1 vortex emanating from the main line. Rather, the vortex should result in an intense mixing of the flow which would tend to produce more uniform temperatures and thus greatly mitigate the potential for both nozzle and trunk line thermal fatigue damage.

45 Degree Branches

A experimental study similar to that for the 90 degree intersection was performed for 45 degree pipe branches. A sharp edged corner was used for the internal intersection of the two pipes. Figure 3 shows a sketch of the test section in the various orientations that were investigated relative to the branch and main header flow directions. Figure 4 shows the penetration of the main flow into the branch pipe for flow directions from A to B and A to C, as defined by Figure 3. Zero pumped flow existed in the corresponding branch lines for the Figure 4 information. A summary of the maximum penetration distance into the non-pumped branches is provided in Table II.

TABLE I
SUMMARY OF MAXIMUM PENETRATION DISTANCES FOR 90 DEGREE BRANCHES

Nominal Branch Pipe Size (in.)	Estimated Maximum Penetration*		
	L_1	L_2	L_3
2	<7D	<15D	<27D
1-1/2	<7D	<15D	<24D
1	<7D	<11D	<21D
1/2	<6D	<9D	<12D

* In diameters of branch pipe

TABLE II
SUMMARY OF MAXIMUM PENETRATION DISTANCES FOR 45 DEGREE BRANCHES

TEST CONFIGURATION	HEADER FLOW DIRECTION	ZERO FLOW BRANCH	ESTIMATED MAXIMUM PENETRATION*
Fig. 3(a)	A to C	O to B	< 8D
Fig. 3(a)	A to B	O to C	< 7D
Fig. 3(b)	A to B	O to C	< 5D
Fig. 3(b)	C to B	O to A	< 4D

* In diameters of branch pipe

The three regions of recirculation did not occur as found for the 90 degree intersection. Rather a single vortex was seen that was countercurrent in nature with flow up one side of the pipe and returning back the opposite side. Similar to the 90 degree intersection, the resultant mixing would tend to mitigate large temperature differences between the branch line and header pipe flows.

Testing also studied the effect of very low flow rates in the branch pipe flowing toward the intersection. Only small fractions of the main header flow rates were investigated. It was found that this forced back flow significantly attenuated the axial penetration of the recirculation. For example, a branch-to-header velocity ratio of 0.10 was found to almost completely eliminate the penetration. Velocity ratios of approximately 0.02 were found to reduce the penetration distance by about 10 percent.

SUMMARY AND CONCLUSIONS

This study addresses modeling considerations relative to flow phenomena associated with flow recirculation in branch piping for 90 and 45 degree angles of the branch piping.

The experimental data presented is not only important for correctly predicting temperature distributions in piping networks, but it also provides a database for validation of computational fluid dynamics (CFD) computer codes used for performing these type of analyses.

For both branch angles, the experimental data shows that very little potential exists for low velocity flow (approaching a main header pipe) to penetrate the high energy vortex emanating from the main line. Rather, the vortex would result in an intense mixing of the flow which would tend to produce more uniform temperatures for cases where the approaching flow is at a significantly different temperature. Thus, the recirculation phenomena will greatly mitigate the potential for thermal fatigue damage in both the nozzle and the header pipe.

REFERENCE

1. R. D. Coffield and M. J. Kolar, "Modeling Considerations Relative to Non-Steady Flow Phenomena Associated With Flow Recirculation and Flow Stratification/Thermal Striping", CSME Mechanical Engineering Forum 1990, University of Toronto, pp. 71-74, June 1990.

FIGURE 1: TEST CONFIGURATION FOR THE MEASUREMENT OF BRANCH NOZZLE VORTICES

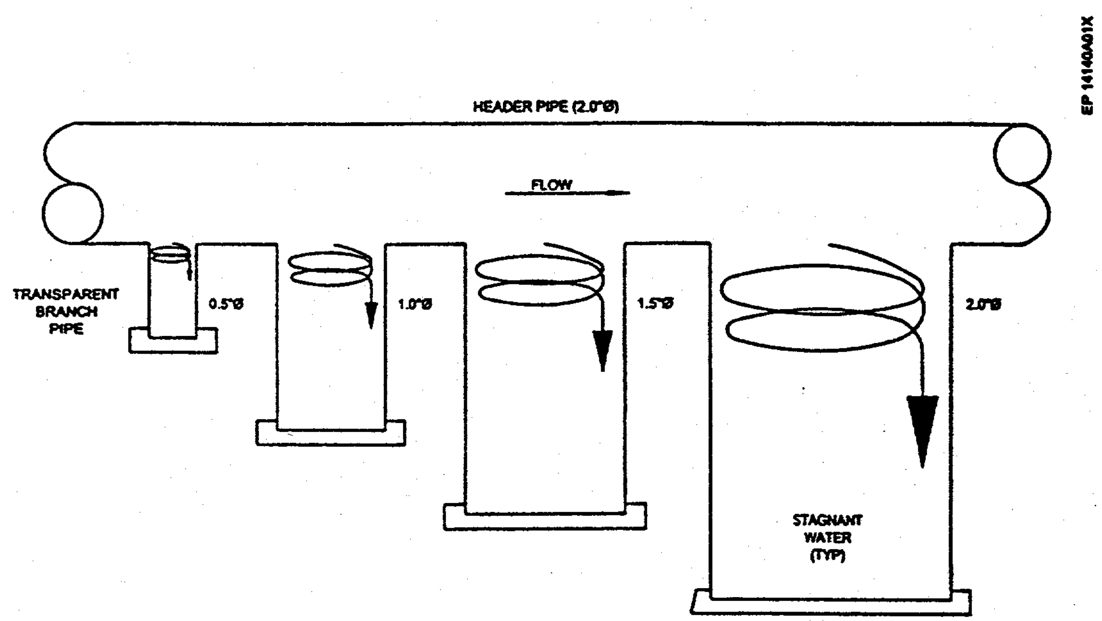

FIGURE 2: FLOW RECIRCULATION TEST DATA FOR 1" NOMINAL BRANCH PIPE SIZE
(90 DEGREE INTERSECTION)

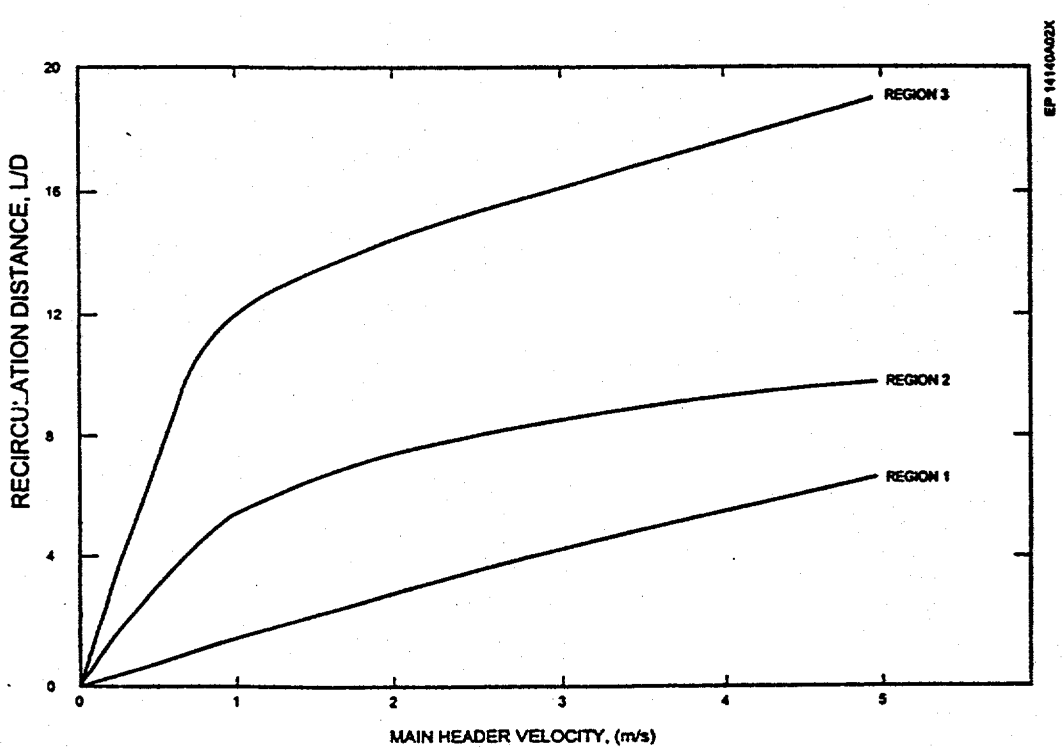

FIGURE 3: SCHEMATIC OF 45 DEGREE INTERSECTION CONFIGURATIONS TESTED

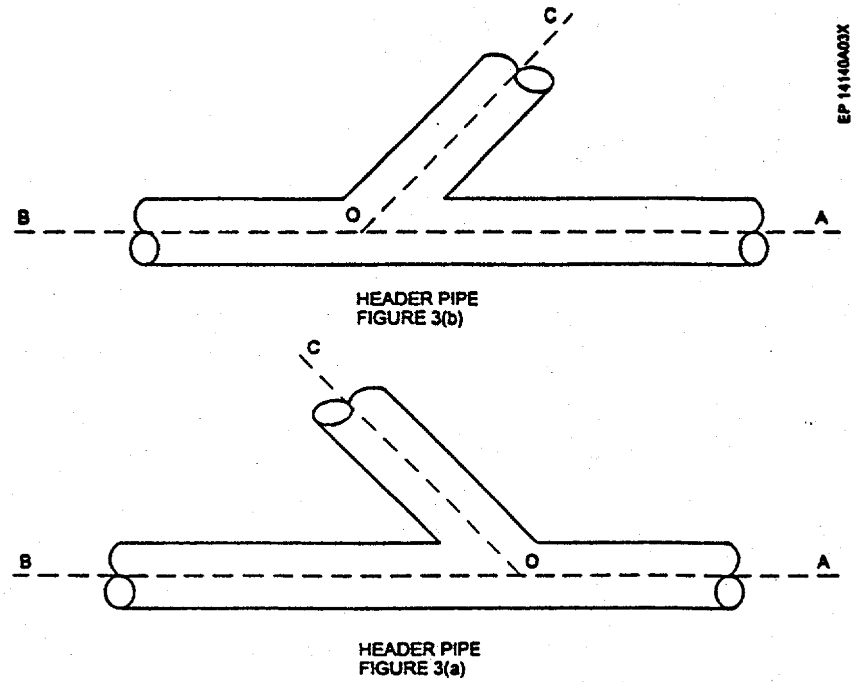

FIGURE 4: FLOW RECIRCULATION FOR 45 DEGREE INTERSECTION