Fauske & Associates, Inc.
16W070 West 83rd Street, Burr Ridge, Illinois 60527
Phone: (630) 323-8750 • Fax: (630) 986-5841 • email: info@fauske.com

Technical Bulletin **No. 1196-1**

WATERHAMMER, COLUMN SEPARATION, AND BOILING INSIDE COOLING WATER SYSTEMS

BACKGROUND

Recently, the U. S. NRC has issued three documents addressing potential waterhammer and two-phase flow conditions which could be present in the cooling water systems of PWR and BWR power plants:

1. *NRC Generic Letter 96-06: Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions (September 30, 1996).*

2. *NRC Information Notice 96-60: Potential Common-Mode Post-Accident Failure of Residual Heat Removal Heat Exchangers (November 14, 1996).*

3. *NRC Information Notice 96-45: Potential Common-Mode Post-Accident Failure of Containment Coolers (August 12, 1996).*

The first issue of concern is that the hydrodynamic loads imposed by waterhammer could be large enough to challenge the integrity of safety-related piping in the cooling water system. For PWR plants, during postulated LOCA's with loss of offsite power, flow to the containment air coolers could be temporarily interrupted leading to column separation in the air cooler inlet and return piping as well as boiling in the air cooler cooling tubes, themselves. Upon restoration of cooling water flow, dynamic loading may occur as steam condenses and water columns rejoin.

For BWR plants, during design-basis LOCA conditions, cooling water in the RHR heat exchangers may be initially stagnant and at subatmospheric conditions. When the relatively hot suppression pool fluid is then pumped through the RHR heat exchanger, it could lead to boiling of the stagnant, low pressure service water. Then, upon manual initiation of RHR service water flow, steam voids could collapse leading to hydrodynamic loads.

The second issue of concern is the effect of long-term transient two-phase flow on the heat removal capability of the safety-related heat exchangers.

Recent experimental and theoretical investigations at the FAI facilities have provided crucial information regarding the relevant physical processes surrounding the voiding and refilling of heat exchanger piping. These investigations have also led to insights on the potential dynamic loads resulting from waterhammer events.

EXPERIMENTAL STUDIES

Figure 1 depicts one arrangement of the test apparatus used at the FAI facility to perform scaled experiments of

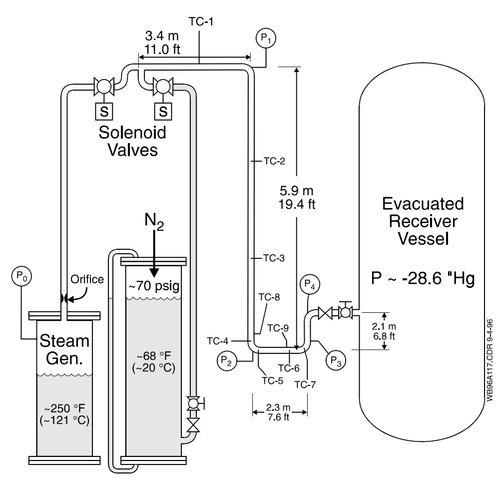

Figure 1

containment air cooler two-phase flow and waterhammer phenomena. This configuration represents an air cooler located at an upper elevation in containment, thus the supply and return piping are shown to undergo significant elevation changes. By alternately injecting cold water and steam into the elevated sections of the test apparatus, FAI was able to successfully create the column separation, column rejoining, and steam condensation process for a range of realistic, scaled accident conditions.

These studies indicate that due to the geometry, cooling water flow rate, and steam condensation rates that could be expected under accident conditions, the waterhammer pressure loads would not be large enough to threaten the structural integrity of safety-related piping.

ANALYTICAL STUDIES

The TREMOLO computer code has been used to analyze two-phase flow in the service water piping of containment air coolers. TREMOLO was originally developed at FAI to address two-phase pressure transients resulting from closure of motor-operated valves (MOVs) in response to Generic Letter 89-10 (see FAI Technical Bulletin 0594-1).

The current analyses have focused on determining the degree of flow degradation which would occur due to boiling in the cooling water downstream piping and its effect on air cooler performance. Although these studies are dependent on plant-specific geometry, air cooler capacities, and peak design-basis containment conditions, preliminary calculations indicate that even with the expected decreases in flow rate through the air coolers, substantial heat removal can still be obtained and that two-phase flow will be limited to sections of the downstream piping, only.

Figure 2 compares typical steady state pressure profiles in a 750 ft segment of a service water supplying a

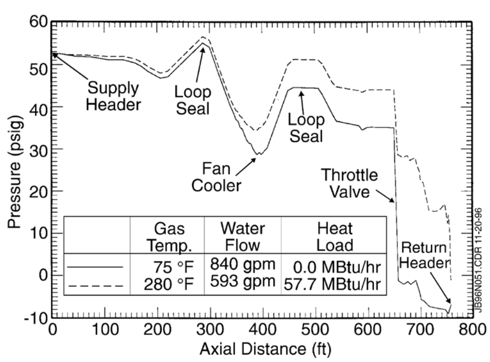

Figure 2

containment air cooler under normal and design basis accident conditions. Figure 3 illustrates the subcooled margin for the same piping and accident conditions. Note that the water pressure is maintained above the saturation pressure throughout the elevated air cooler region and that steam formation does not occur until after the heated fluid

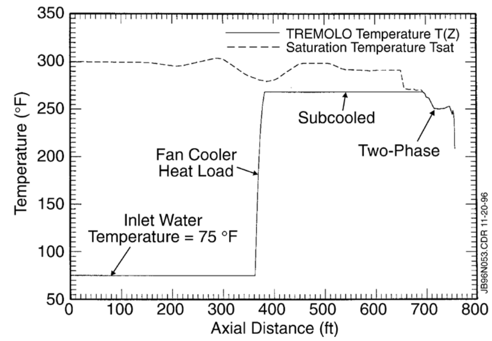

Figure 3

passes through a flow control orifice downstream of the air cooler.

SUMMARY

Experimental and analytical studies performed at FAI indicate that waterhammer and two-phase flow events can be tolerated in the service water piping associated with safety-related containment air coolers. Although these studies are plant specific, the general indication is that even though two-phase flow conditions may be present in the cooling water piping under very specific accident conditions, safety-related heat exchanger operation should not be adversely affected.

Technical Contact:

Damian Stefanczyk (630) 887-5208
email: stefanczyk@fauske.com

Visit our website at www.fauske.com to view additional FAI Technical Bulletins.