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DRY COOLING TOWER OPERATING EXPERIENCE IN THE LOFT REACTOR

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ABSTRACT

A dry cooling tower has been uniquely utilized to dissipate heat generated in a small experimental pressurized water nuclear reactor. Operational experience revealed that dry cooling towers can be intermittently operated with minimal wind susceptibility and water hammer occurrences by cooling potential steam sources after a reactor scram, by isolating idle tubes from the external atmosphere, and by operating at relatively high pressures. Operating experience has also revealed that tube freezing can be minimized by incorporating the proper heating and heat loss prevention features.

INTRODUCTION

A dry cooling tower has been uniquely utilized to dissipate heat generated in the Loss-of-Fluid Test (LOFT) pressurized water nuclear reactor, a small experimental reactor used in the United States Nuclear Regulatory Commission's nuclear safety program.

One of the main objectives of the LOFT experimental program is to provide data required to evaluate and improve analytical methods currently used in predicting the response of large pressurized water reactors during hypothetical loss-of-coolant events. The operating experience discussed was obtained during reactor testing conducted to fulfill this main objective.

The use of a dry cooling tower to dissipate heat generated in a power station may be particularly attractive for use in areas beset with water supply shortages. The use of dry cooling instead of evaporative cooling is estimated to save approximately 38 000 m^3 of water per day for a 1000 MW plant.[1] A problem with dry cooling is that it is less efficient and more expensive than wet cooling. A potential merit for cold climates is that dry cooling reduces the freezing problems that evaporative cooling systems encounter.

A description of the LOFT reactor primary and secondary systems, a discussion of the wind susceptibility and water hammer phenomena of the dry cooling tower, and a discussion of the dry cooling tower tube freezing prevention design features and operating precautions are presented.

SYSTEM DESCRIPTIONS

The LOFT facility is a 50-MW (thermal) pressurized water reactor (PWR) that simulates a large PWR under loss-of-coolant accident conditions. The reactor primary cooling and blowdown systems are schematically represented in Figure 1. The reactor fluid volumes and flow areas are generally scaled to simulate a large PWR. The LOFT intact cooling loop, containing the primary coolant pumps, steam generator, and pressurizer, simulates three loops of a four loop, large PWR. The LOFT broken loop, containing the steam generator and the pump simulators, simulates the broken loop of a four loop, large PWR. During most loss-of-coolant experiment testing, the quick opening valves in the broken loop initiate the experiment. The expelled coolant is captured in the suppression vessel depicted in Figure 1. The secondary cooling system, depicted in Figure 2, dissipates the nuclear generated heat to the atmosphere by a dry cooling tower designated the air-cooled condenser.

Secondary Cooling System

The heat generated in the LOFT nuclear fuel is transferred to the LOFT secondary cooling system through a steam generator. The LOFT secondary cooling system is schematically depicted in Figure 2. The steam flows from the steam generator through a main steam control valve to the inlet header of the air-cooled condenser. The steam is condensed consequently dissipating the nuclear generated heat in the condenser by air flowing over a series of finned tubes. The condensate exits the condenser by the outlet header and subsequently flows to a condensate receiver. The condensate is subcooled and ultimately can be pumped to the steam generator by the main feedwater pump to maintain the liquid level on the secondary side of the steam generator.

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[1] "Water: Pinch on Energy Development," <u>EPRI Journal</u>, October 1979.

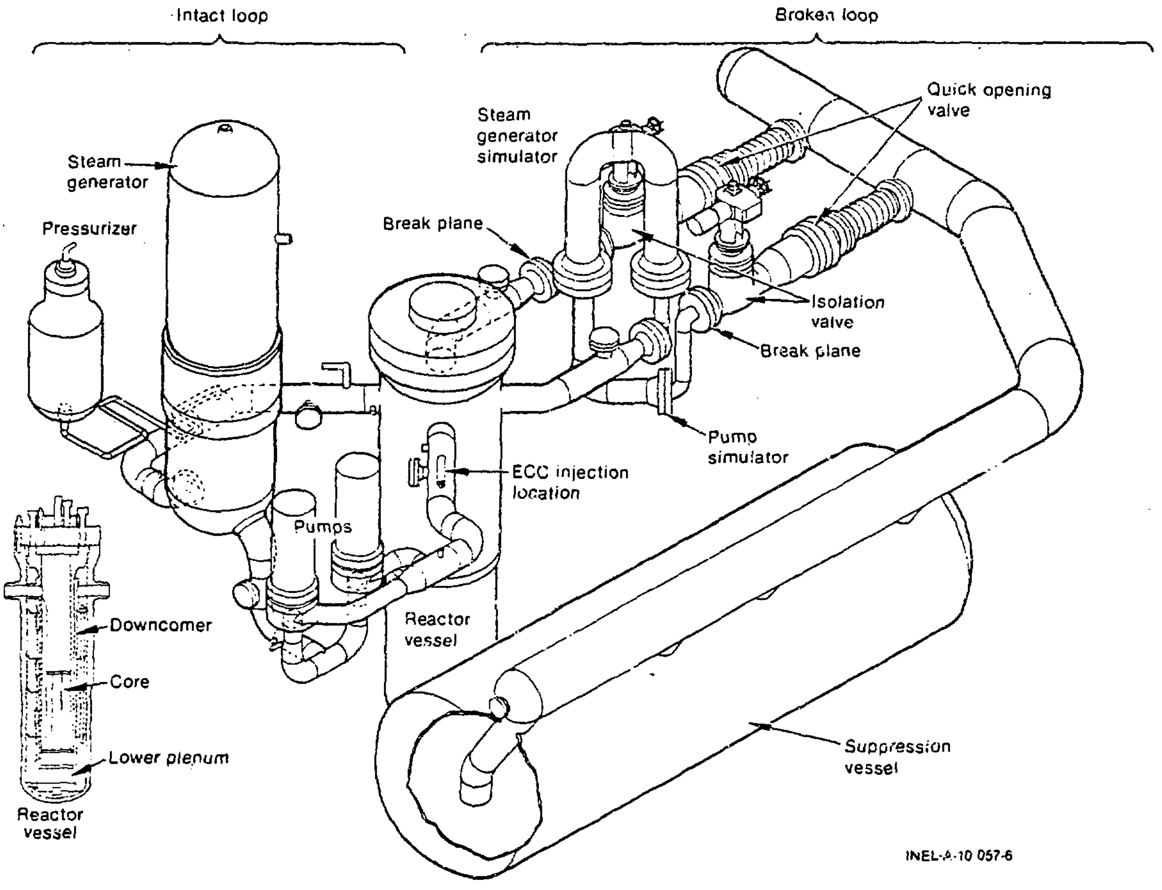

Fig. 1 LOFT primary coolant system configuration.

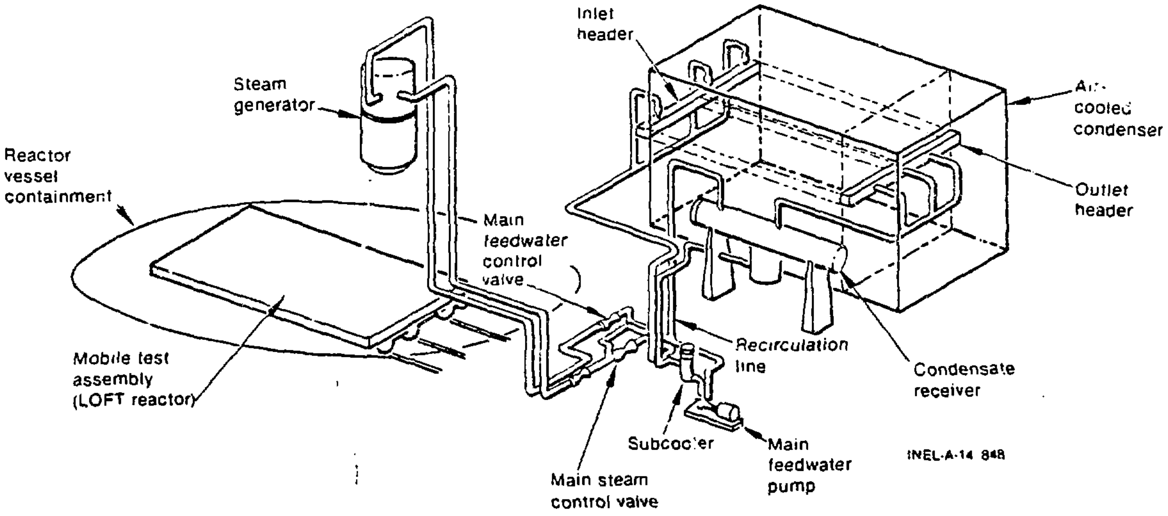

Fig. 2 LOFT secondary coolant system.

Air-Cooled Condenser

The air-cooled condenser which ultimately dissipates the nuclear generated heat to the atmosphere is a high pressure (2 MPa), high temperature (483 K) horizontal dry cooling tower. The unit consists of three bays, and each contains approximately 230 finned tubes distributed in four rows. Each bay also contains two variable pitch fans and inlet-outlet louvers.

Figure 3 shows the steam inlet side of the condenser illustrating the inlet steam piping and one set of inlet louvers. Figure 4 shows one-half of a single bay illustrating the variable pitch fan in the lower portion of the picture and illustrating the lowest of the four rows of finned tubes in the upper portion of the photograph.

The functional relationship of the condenser and the condensate receiver is illustrated in Figure 5. Steam enters the finned tubes in the condenser from the steam inlet header. The variable pitch fans move the air through the inlet louvers, over the tubes, and through the outlet louvers. As the air flows over the tubes, the steam condenses in the tubes, and subsequently the condensate drains to the condensate receiver.

One, two, or three bays can be operated simultaneously depending on the reactor power level. The fan pitch in the operating bays is automatically controlled from the stem position of the main steam valve and from condenser pressure. The louver position can also be remotely manually varied to control the fan pitch within a desired pitch band. The reactor power is ultimately controlled by this system.

OPERATING EXPERIENCE

Operating experience with the condenser addresses wind susceptibility, water hammer characteristics, and tube freezing prevention design features and operating steps for the unit.

Air-Cooled Condenser Wind Susceptibility

Operating experience gained during initial power testing of the reactor established that the condenser was susceptible to wind gusts. The LOFT reactor is located on a flat, high elevation desert which permits the wind to reach each set of inlet louvers on each bay after the wind passes through and over structures shown in Figure 3.

The variation in condenser pressure under gusting conditions is illustrated in Figure 6. Under the gusting conditions shown in Figure 6, one bay was operating, a second bay was idle with the louvers open, and a third bay was idle with the louvers closed. The maximum wind induced pressure variation in Figure 6 is approximately 0.06 MPa. By monitoring the wind velocity, fan pitch position, and ACC pressure, it was established that the pressure variations in Figure 6 were caused by wind gusts. As the wind

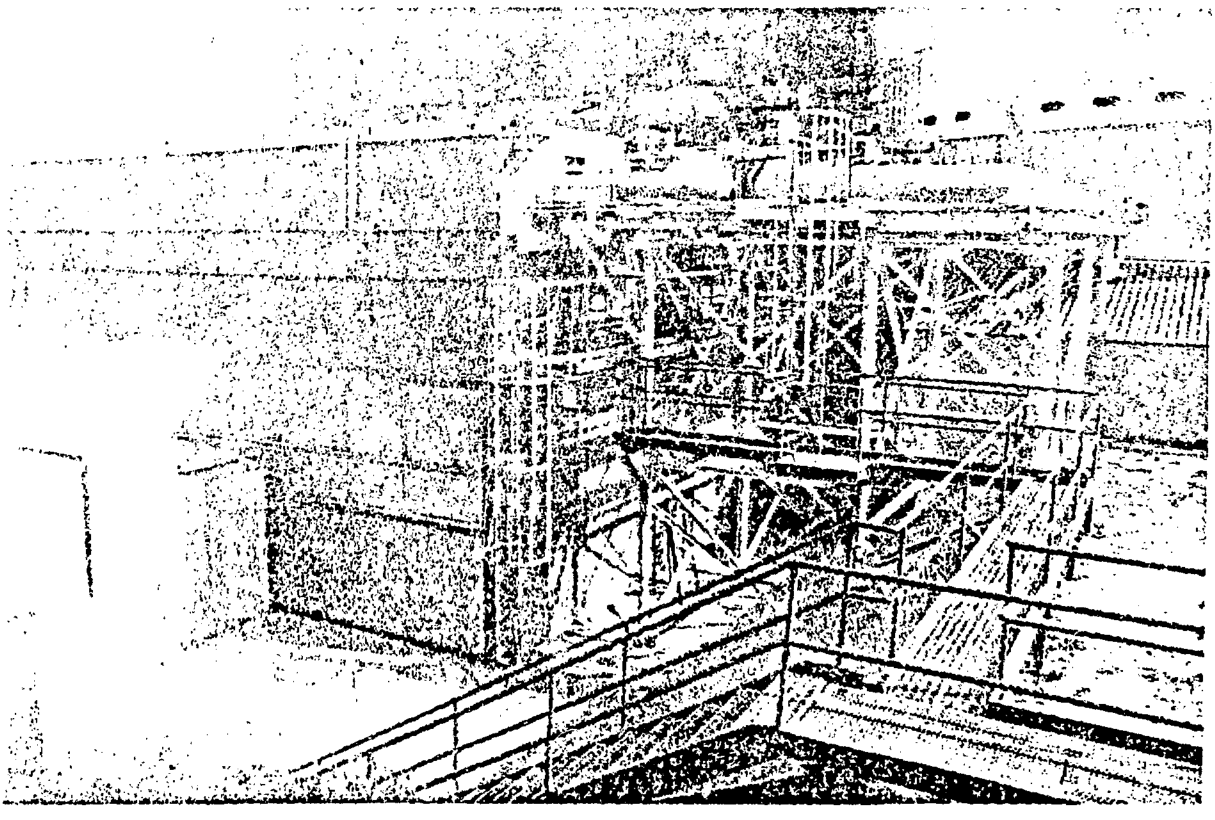

Fig. 3 Air-cooled condenser steam inlet.

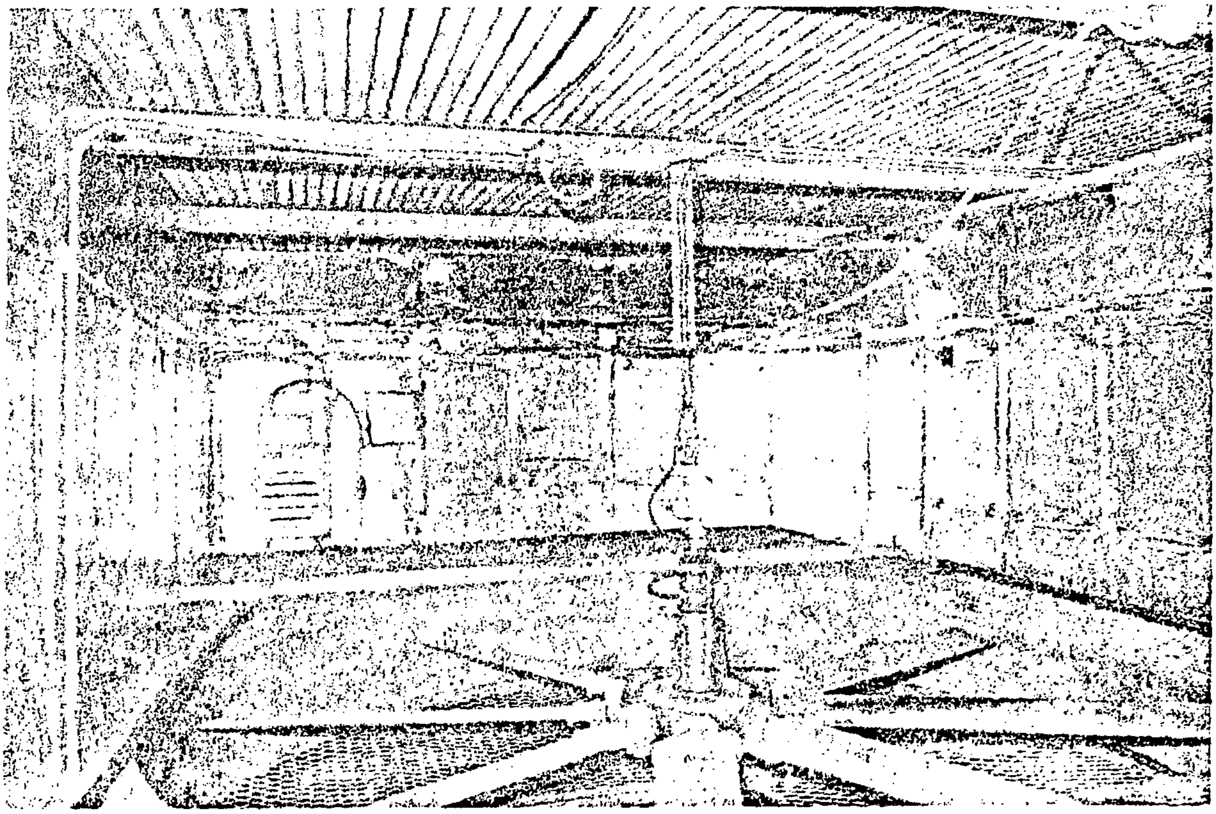

Fig. 4 Air-cooled condenser bay.

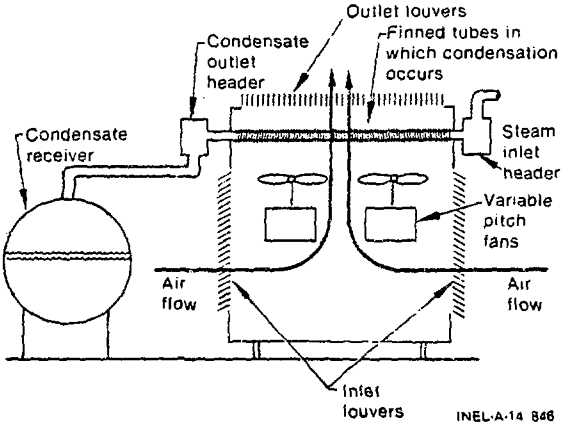

Fig. 5 Air-cooled condenser functional schematic.

velocity increased, the fan pitch and condenser pressure began to decrease. As the wind velocity decreased, the fan pitch and condenser pressure began to increase. The asterisks on Figure 6 represent wind induced condenser pressure changes.

The variation in condenser pressure under gusting conditions is also illustrated in Figure 7 which represents all bays operating. The maximum pressure variation in Figure 7 is approximately 0.01 MPa. Comparison of Figures 6 and 7 indicates that condenser pressure susceptibility due to wind gusts is significantly reduced when all bays are operating and indicates that all bays should be operated to reduce wind susceptibility.

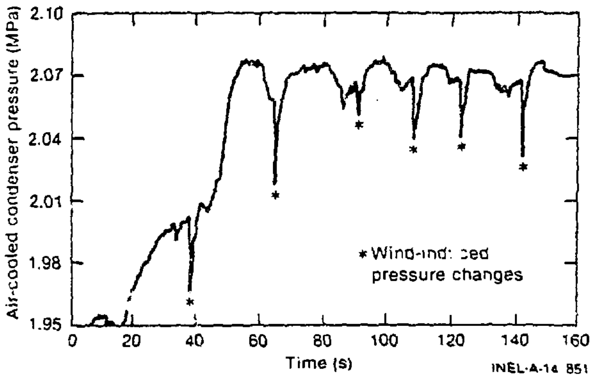

Fig. 6 ACC wind induced pressure variations idle bay configuration.

Water Hammer Phenomena

During condenser operating conditions, water hammer, or pressure wave, related effects were

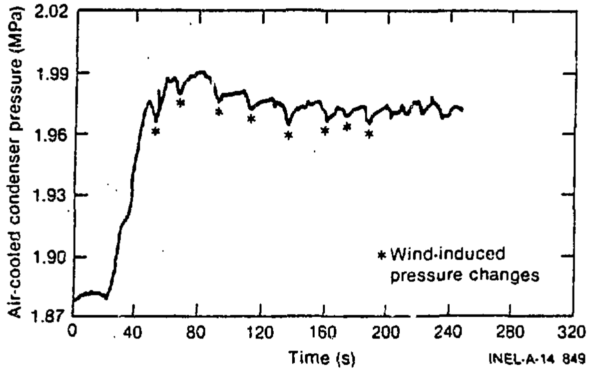

Fig. 7 ACC wind induced pressure variations--full bay operation configuration.

observed in the unit after reactor scram, under low pressure operating conditions, and under wind gusting conditions. The water hammer occurrence is based on qualitative visual and audible observations.

After reactor scram, steam ceases to flow from the steam generator to the condenser. The water in the condensate receiver boils at saturation conditions providing a source of steam which can flow back into the condenser tubes. (Condenser outlet isolation valves are installed which could prevent the backflow of steam, but they are left open on idle bays during normal operations to expedite bringing on-line an idle bay.)

Two explanations are hypothesized for the water hammer observed in the condenser after scram. Figure 8 explains these hypotheses. The first explanation involves phenomena originating inside the tube. As the steam condenses inside the tubes, a low pressure area is created. Water is hypothesized to accelerate from both directions in the tube toward the low pressure region. The colliding masses of water yield a pressure wave.

The second explanation requires that steam from outside the tubes enters the condenser to yield the water hammer. As previously discussed, the condensate receiver boils at saturation conditions after scram. The steam flows back into the condenser through the open outlet isolation valves on the unit. The steam from the condensate receiver and the condensate in the condenser tubes produce a countercurrent flow in the tubes. Surface instabilities are produced on the liquid surface in the tubes by the counterflowing steam. The surface instabilities produce voids in the tubes as depicted in Figure 8. Condensation occurring in the voids yields a low pressure region. The low pressure voids accelerate until they collapse at obstructions like flanges, valves, or pipe elbows which are located at the inlet and outlet of the condenser. The collapse of the voids creates pressure waves. Figure 8 schematically depicts this water hammer phenomenon.

Water hammer severity under the postscram conditions is significantly reduced by recirculating condensate from the condensate receiver back to the condenser after scram through the recirculation line designated in Figure 2. This action cools the condensate receiver and consequently reduces the quantity of steam available in the condensate receiver

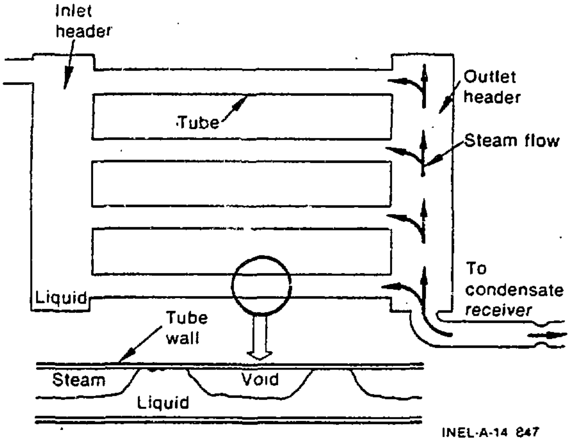

Fig. 8 Air-cooled condenser water hammer schematic.

that is available to flow back into the condenser. This reduction in steam in turn reduces the countercurrent flow instabilities previously described which in turn reduces the formation of voids which reduces water hammer severity.

The louvers on the condenser are also closed while recirculation occurs. This action allows the condensate receiver to cool faster than the condenser. This tends to reduce condenser water hammer severity by tending to reduce the condensation rate in the condenser while simultaneously reducing the steam production rate in the condensate receiver.

Water hammer severity is also observed to be greater when the condenser is operating at lower pressures. Severe hammering is audibly observed when the condenser is operating at 1.4 MPa. When the condenser pressure is increased to 2.0 MPa, the hammering intensity reduces significantly. This reduction in intensity would be anticipated as illustrated by Figure 9 which presents the volumetric contraction of steam to water as a function of steam temperature. Figure 9 indicates that at higher temperatures corresponding to higher saturation pressures in the condenser the volumetric contraction of steam to liquid is greatly reduced below the values at lower temperatures corresponding to lower condenser pressures. Consequently, higher condenser operating pressures yield smaller changes in steam properties when condensation and subsequent water hammer occur than lower condenser operating conditions. Therefore, higher condenser operating pressures yield reduced water hammer severity than lower operating pressures.

A water hammer is also audibly and visually observed in the condenser under the wind gusting conditions depicted in Figure 6. The wind gusts are postulated to have entered the condenser through the open louvers in the idle bays. This action subsequently increased the condensation rate inside the tubes. In turn, increased quantities of low pressure regions were created in the tubes. The collision of accelerating liquid water masses in these voids created pressure waves, or water hammer. The hammer was audibly observed to be more severe in idle bays with the louvers open than in idle bays with louvers

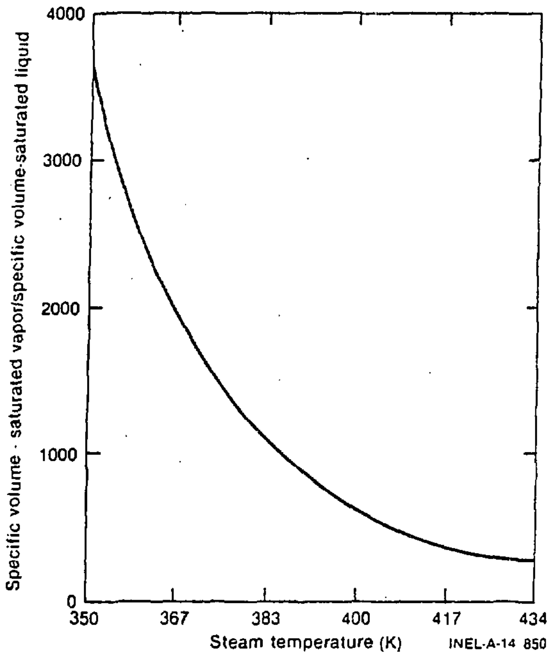

Fig. 9 Volumetric contraction of steam to water.

closed. From these observations, the conclusion was that water hammer severity due to wind gusts is greatly reduced by operating with no idle bays or by closing the louvers on the idle bays.

Cold Weather Operating Features and Experience

During cold weather intermittent operations, tube freezing was a problem. The condenser was originally heated with a propane, volume limited heater. The heater was activated after the reactor was shut down and while condensate was still present in the unit. The propane volume limit of the heater limited the operating time of the heater. The propane system also experienced difficulties maintaining adequate propane pressure to preclude flameouts at low temperatures. Operational inconveniences of the secondary cooling system encountered while performing such system tests as hydrostatic testing between reactor operations permitted water to enter the tubes unobserved by plant operators. During cold weather tube freezing would subsequently occur. These operational difficulties prompted the replacement of the propane heater with thermostatically controlled electric heaters located in each bay. The heater operating time limitation due to the propane volume limit and the other previously mentioned problems were eliminated by this change. The thermostatically controlled electric heaters permit unlimited heater operation.

Additional tube isolation capability has also been created by installing a system of canvas covers that close openings above and below the tubes to reduce heat losses after reactor shutdown. The canvas covers are placed over the tubes after the reactor is shutdown using a motor driven winch system which also is used to remove the covers before reactor startup. Smaller openings below the tubes are covered with canvas which is installed manually.

At present, these modifications have not been subjected to significant operating time during cold weather to assess their effectiveness. The small amount of operating time incurred by the electrical heating system and the canvas cover system does indicate that these systems prevent freezing down to approximately 255 K. Operating experience at lower temperatures in the more severe winter conditions is expected in the near future.

CONCLUSIONS

Operational experience has revealed that horizontal dry cooling towers can be operated on an intermittent basis with minimal wind susceptibility and water hammer occurrences by cooling potential steam sources after reactor scram, by isolating tubes on idle bays from the external atmosphere, and by operating the unit at relatively high pressures. Cold weather operating experience using a new electric heating system and a heat loss prevention canvas system indicates that tube freezing in idle bays during cold weather operation can be virtually eliminated.

ACKNOWLEDGMENTS

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