Because the recirculating system is integral with the steam generator and independent of other plant equipment, the protection it affords to the furnace-wall system is present in full force not only during normal operation over load range, but also for startup, extremely low loads, and shutdown. The furnace-wall system, therefore, does not require a bypass system and is immune from failures due to controls and interlocks associated with such systems. The recirculating system is independent of pressure above a minimum as determined by load and will maintain circulation for low- and high-pressure operation during steady-state as well as transient conditions.

Basic Design Principles

Protection of tubes against failure through overheating is achieved, then, by these principles:

1) Recirculation of water at the ratio of 4 to 1, designs into the system a large margin of safety for all system circuits under any operating condition.

2) Low steam quality present over the full length of all tubes which are sized for a mass flow adequate for all flux rates, assures nucleate boiling conditions with the bulk fluid temperature at saturation level in every tube at any elevation.

3) A system of orifices establishes and maintains these safety features by (a) Distributing the total flow through all tubes in relation to the heat pickup of individual circuits or groups of circuits, with the possibility of easy readjustment if required and, (b) Stabilizing the flow under transient flux conditions by the nature of inlet orifices with as much pressure drop as is present in the heated circuit.

With these principles, the design is able to control the metal temperature in a tube panel, as it is influenced by the heat flux, and the inside film coefficient.

The temperature distribution for a welded tube panel with heat flux on the furnace side is shown in Fig. 3, isotherms are plotted on a typical tube configuration for a constant flux with different inside film coefficients. With increased inside resistance to the flow of heat, the temperature level in the crown region increases, and more heat flows towards the backside of the panel. The distribution also shows that the thermal loading of the tube by the heat flow from the fin always remains below that experienced by the crown of the tube.

Because the recirculating system establishes a minimum inlet velocity for all tubes under any operating conditions, it protects the tubes against the danger of overheating even at comparatively low flux rates when the film coefficent depends on subcooled water flow without boiling.

While there is heat transfer by film conductance of subcooled water at comparatively low flux near the tube inlets in the lower portion of the furnace, the bulk of the heat absorbed in the furnace is transmitted from the tube to the fluid by nucleate boiling.

The stable and high film coefficient which is produced by nucleate boiling, is established by a steam-water mixture of sufficiently low quality - a mean of 25 percent at the evaporator outlet - and a mass flow wholly adequate for even the highest anticipated furnace flux rates. A large number of the tube metal measurements on Controlled Circulation units and extensive laboratory tests with furnace tubes modeled in a full size loop confirm the predictions based on present knowledge about the thermodynamics of boiling heat transfer. Because of the metal

temperature control exerted by assurance of proper cooling, the thermal loading under any furnace condition is well within the elastic range of the material end completely without influence on fatigue in case of cycling.

Drum Internals

The drum internals are devices used to separate water from steam and to direct the flow of water and steam in a manner so as to obtain an optimum distribution of drum metal temperature in boiler operation.

The drum internals for a Controlled Circulation unit are shown in Fig. 4 with characteristic arrangement of primary and secondary separators as well as the final dryers. Feedwater is introduced below the water level and in this manner mixes with the recirculated, saturated water to produce the subcooled flow to the circulating pumps.

One distinct advantage of the Controlled Circulation design is the internal shrouding in the drum. This water-tight shrouding directs the return flow of steam and water from the furnace around the inside surface of the drum, providing for uniform heating or cooling of the drum and drum heads.

Because of the importance of orifices to the protection of the furnace-wall system, care is taken to prevent their plugging by foreign material. The orifices which are made of austenitic steel are located in the inlet headers and protected by screen plates extending along the entire length of the header. The 3/16-in. openings in these screens are smaller than the smallest orifice dia used in Controlled Circulation units. The range of the orifice sizes and water velocities through the

orifices (in the order of 20 to 30 ft per second) also prevents smaller particles from clogging the orifice proper.

Experience with the very large number of Controlled Circulation units in operation under the widest range of power plant operating conditions has shown that chemical buildup in orifices does not occur if proper feedwater treatment is followed.

In addition, the differential head across the pump which is measured and monitored acts as a reliable and clearly recognizable signal concerning the absence or presence of any deposition in the orifice or heating surface. If deposition does occur, this differential will gradually increase and indicate the need for a remedial action long before the tube circuits themselves fail.

Circulating Pumps

Because circulating pumps are the key element in the furnace-wall system and are essential to tube protection under all operating conditions, a multiple pump arrangement with shutoff valving for each pump is provided. This in itself insures that availability is not impaired by possible failure of any individual pump.

The number of pumps selected for any system may vary between two and four. Because experience with Controlled Circulation units has established the reliability of modern circulating pumps, spare pumps are not normally provided. Each installed pump can be isolated by a motor-operated suction valve and a discharge stop-check valve. In case of failure, a pump may be isolated for a sufficient length of time to effect repairs without impairing the full-load capacity of the unit. It is recommended that for overall safety of the furnace-wall system,