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PRACTICAL HEAT RECOVERY

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FORCED RECIRCULATION

This form of steam generation for heat recovery applications deserves separate comment because there are instances, as cited in the foregoing discussion, that demand forced recirculation.

Reliability and durability are gained by the use of forced recirculation systems, which prevent vapor separation within the steam generating tubes. The rate of recirculation is usually 5 to 10 times the maximum steaming rate of the boiler. Forced recirculation makes possible the use of smaller-sized tubes, which reduce boiler size and weight and reduce the time required for steam up. Only one drum is required. Some forced recirculation boilers, particularly smaller ones, have only a cyclone steam separator with an enlarged lower section for water level control, instead of a steam drum. Boilers having only a cyclone separator are particularly adaptable to shipboard use because they are not particularly sensitive to pitch and roll.

The primary advantage of forced recirculation is probably the assurance that there is always forced water circulation in all boiler tubes. Since heat recovery boilers very often have limited space, there may not be sufficient distance between the upper and lower drums to promote effective natural circulation. Forced recirculation is usually the solution in such circumstances.

A forced recirculation boiler is nearly always more compact than a comparable natural circulation boiler, since the former does not require a fixed relationship between the drum and the heating surfaces. The drum or separator can be located almost anywhere adjacent to the heating surface assembly.

Heating surface design can be quite flexible. Vertical or inclined tubes are not required. The heating surfaces can be arranged in a horizontal return bend configuration or a circular shape consisting of flat, spirally formed coils or other shapes. It is always preferable to have a drainable coil assembly.

External clean out plugs permit internal cleaning of individual tube circuits either chemically or mechanically, without disassembling the boiler casing. Cleaning of external surfaces of the tubes is by conventional soot blowers, operated either by air or steam.

No internal baffles are required in forced recirculation. Internal baffles are difficult to install and maintain and can cause ash accumulation unless they are steeply inclined or vertical. Even inclined baffles require some blowing to keep them clear of soot and ash.

Forced recirculation boilers are generally lighter than comparable natural circulation boilers, requiring less supporting structure and being easier to install.

Probably the most criticized part of a forced recirculation boiler is the recirculating pump. Obviously, if the pump fails, all water circulation ceases in the boiler tubes and the boiler must be immediately removed from service and isolated from its source of hot gas. However, a pump properly selected for service, particularly as to its mechanical shaft seal, will provide long, trouble-free service. The shaft seal and its environment is one of the most critical parts of the system. For operating temperatures above 250°F, it should be water cooled. If the pump is to handle water containing any foreign matter, the seal faces must be flushed. It is advisable to install a duplex strainer ahead of the pump to eliminate larger particles. In some critical applications, a stand-by pump is included. Another important item in the proper selection of a pump is NPSH. This could be important on close coupled systems with only a few feet of head on the pump suction. Failure to consider this factor could result in severe cavitation and consequent recirculation failure. Recirculation pumps for capacities up to about 30 gpm may be regenerative turbine pumps. These pumps are particularly sensitive to dirt because of the close running clearances between the casing and the impeller. For flows in excess of 30 gpm, a single-stage centrifugal pump is used. The differential head on a typical recirculating pump can vary from 50 to 75 ft, depending on pressure drop through the tubes, tube inlets, and steam separator nozzle, if used. For best results, the pump should be operated as close as possible to the design points on its performance curve.

Water and steam velocities in the tubes of a forced recirculation boiler vary with load and pressure. As a general rule, the recirculating pump is sized to produce a water velocity of 2 to 4 fps at the entrance to the tubes where the fluid is all water. Velocity increases as heat is absorbed by the water and steam is generated. At the point where the water-steam mixture discharges into the steam drum or separator, there will be approximately 10% steam and 90% water when the boiler is at full load and the recirculation rate is 10 to 1.

The selection of tube diameter depends on boiler size, configuration, and end use. Tube sizes may vary from $\frac{3}{4}$- to 2-in. o.d. Small, high performance boilers have smaller tubes. However, in making this choice, feedwater quality must be considered. It is advisable to provide for individual tube circuit cleaning by having removable plugs opposite each tube termination at the inlet and outlet headers. Provision can be made for chemically cleaning any tube size. Mechanical cleaning by a pneumatic tube cleaner is generally restricted to tubes of 1-in. I.d. and larger. The mechanical method of reaming out boiler tubes has proven to be very practical even in bent or circular coil designs having at least an 8-in. minimum radius of curvature.

A forced recirculation heat recovery boiler can be built in a variety of configurations, depending on service requirements. Therefore, it is difficult to specify a typical design. Figure 63 illustrates one schematic of a forced recirculation boiler system having an economizer and a superheater section. Many such systems consist only of an evaporative surface assembly, a recirculating pump, and a steam drum or separator. If a steam drum is used, the same design criteria for a natural circulation system may be used. If a separator is used, it can be either a cyclone or baffle type, although the cyclone produces higher quality steam but requires a higher pressure drop (usually 6 to 10 psi). Figure 81 illustrates a cyclone steam separator design that has been extensively used on forced recirculation steam generators and heat recovery boilers. The water-steam mixture enters the cyclone body through a tangential nozzle, than proceeds downward guided by a helical ribbon. The mixture emerges over a spin plate in the bottom of the separator. A high velocity cyclone is formed on the spin plate, which flings water out toward its periphery, where it is captured by radial vanes that direct the water downward and into the recirculating pump. Steam rises, still spinning to the dry pipe. Water particles are continuously flung toward the wall, where they drain into the pump. The result is steam quality of the order of 99.4 to 99.6%. If higher quality is required, two cyclones can be used in series.

Hydrodynamic or flow instability is a potential problem in forced recirculation evaporators. Instability can result in periodic oscillations in steam drum water level (slugging), steam flow, and steam pressure. Instability may be either static or dynamic. Density wave instability is the most common type of dynamic instability. The effect of various parameters have been studied, and the more pertinent ones are as follows:

1. An inlet restriction increases stability.
2. An exit restriction decreases stability.
3. An increase in two-phase flow pressure drop decreases stability.
4. An increase in steam pressure increases stability.

On forced recirculation systems, inlet subcooling appears to be the most useful single independent variable in determining whether the flow will oscillate. For any particular heat flux, loop geometry, and liquid flow rate, there is a definite range of inlet subcooling within which the flow oscillates. If inlet subcooling is outside this range, the flow is steady.

saturated steam, this problem cannot arise. It is also better than a system that controls steam temperature by varying firing rate because it responds more rapidly to load swings.

Stability in the superheater and economizer can be accomplished by designing these sections for a reasonably high pressure drop: 10 to 20 psi for the superheater and approximately 15 psi for the economizer. Economizer outlet temperature is controlled by constant flow to the economizer, bypassing the portion not required to satisfy the demand diverted back to the deaerator. Steaming in the economizer must be avoided because it causes stagnation in some tubes that begin to steam with an accompanying increase in pressure drop, which, in turn, leads to less flow, more steaming, and ultimately stagnation. With a high pressure drop across the entire economizer in the beginning, the increase in pressure drop caused by steaming in some tubes is small compared to the total, resulting in significant changes in flow and thereby preventing stagnation.