Coil-Type Steam Generators for

Heating Plant Applications

Design and feedwater considerations for coil-type steam generators

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Because, historically, coil-type steam generators have not been commonly used in "typical" steam heating plants, many engineers are unfamiliar with the technology. A coil-type steam generator, as described in this article, is a forced-circulation, watertube boiler in which water under pressure circulates at high velocity, in either series or parallel flow, through sets of coils—while forced draft combustion gases travel across the coils. The hot gases envelope the entire tube surface making maximum use of both radiant and convective heat to achieve very high heat-transfer rates.

Coil-type steam generators have been used primarily in industrial process applications. They have long dominated the very high-pressure (above 400 psig) requirements of process steam users and the extremely high-pressure (over 3100 psig) demands of valve testers and similar industries. However, there are other instances where a packaged coil-type generator should be considered, including:

- Retrofit situations where there is a need for additional steam capacity, and either available floorspace, headspace,

[1] Superscript numerals indicate references listed at end of article.

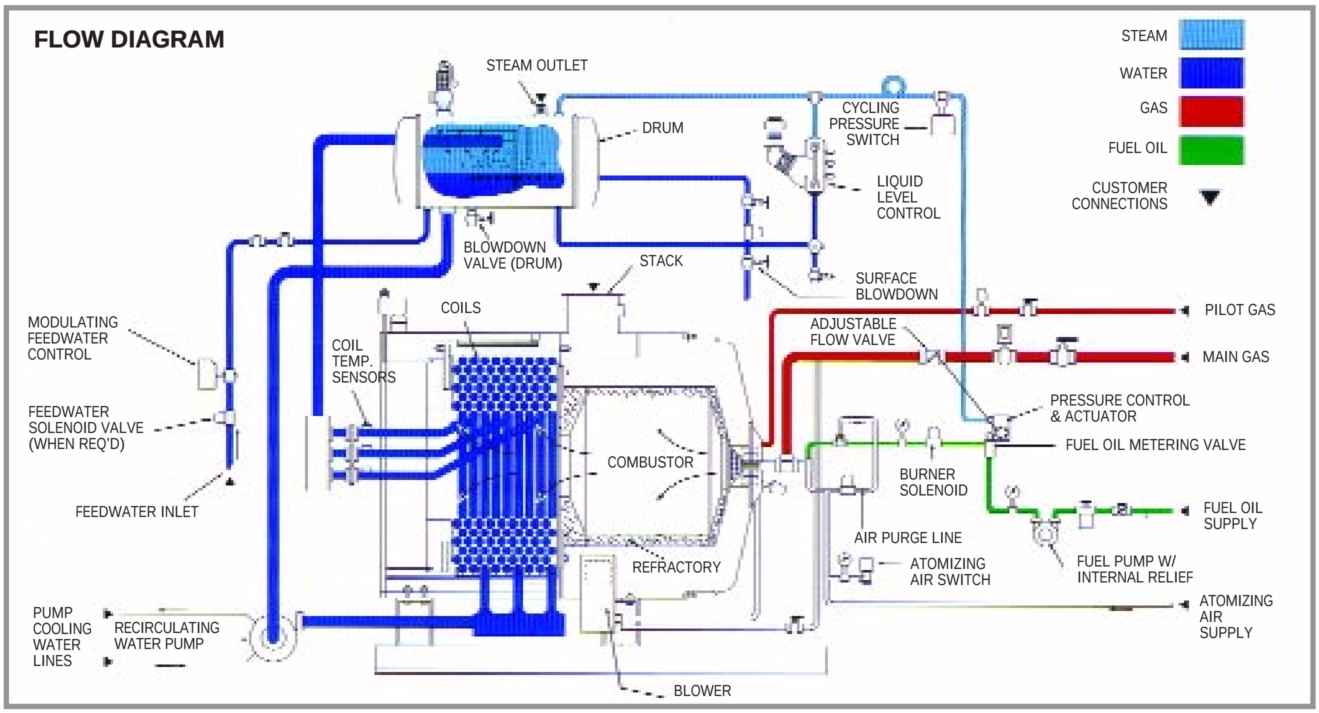

FIGURE 1. Recirculating steam generator flow diagram.

FIGURE 2. 200 bhp recirculating coil-type steam generators in basement of Fourth & Vine Tower, Cincinnati, Ohio.

or physical access (or perhaps all three) are limited or restricted.

- Those applications in which there are significant cyclical or seasonal load fluctuations such as facilities that experience drastically reduced summer loads as well as operations that may experience relatively short-duration load swings.

This article examines the various characteristics of coil-type steam generators used in a high-pressure steam heating plant. Definitions and descriptions are presented along with rules-of-thumb for steam-generator selection and sizing.

COIL-TYPE STEAM GENERATORS

There are two general styles of coil-type steam generators: recirculating and once-through. In the case of the recirculating coil-type steam generator (Figures 1 and 2), water at saturation temperature is drawn from a steam drum and pumped through a set of nested, parallel-connected coils at several times the maximum desired steaming rate. The water is then carried back to a steam lance, in the top of the same drum, where steam is released and effectively separated. Dry steam, which has a dryness fraction greater than 0.99 (less than one percent water droplets), is withdrawn from the drum—leaving a reservoir of heat-saturated feedwater.

The once-through coil-type steam generator (Figure 3) differs significantly from the recirculation design in that the water is pumped through a series-connected multiple coil assembly and then into an integral cyclonic separator. This results in approximately 90 percent of the water being converted to steam with a dryness fraction greater than 0.99. The remaining 10 percent (approximate) un-evaporated water can then be blown down or reused. Because the water flowing through the tubes and the combustion gases outside the tubes are traveling at high velocities, turbulent flow is created. This reduces the film resistance to heat transfer and results in a high overall heat-transfer coefficient, as described below.

Physical size, operating weight, and speed for getting full-steam output are characteristics of boilers and generators that engineers need to consider during the design process.

Coil-type steam generators provide an average of six Btu per sq ft per F, which translates to a heating surface requirement of approximately 1.67 sq ft to produce one boiler horsepower (bhp). The result is a relatively small footprint for the coil-type steam gener-

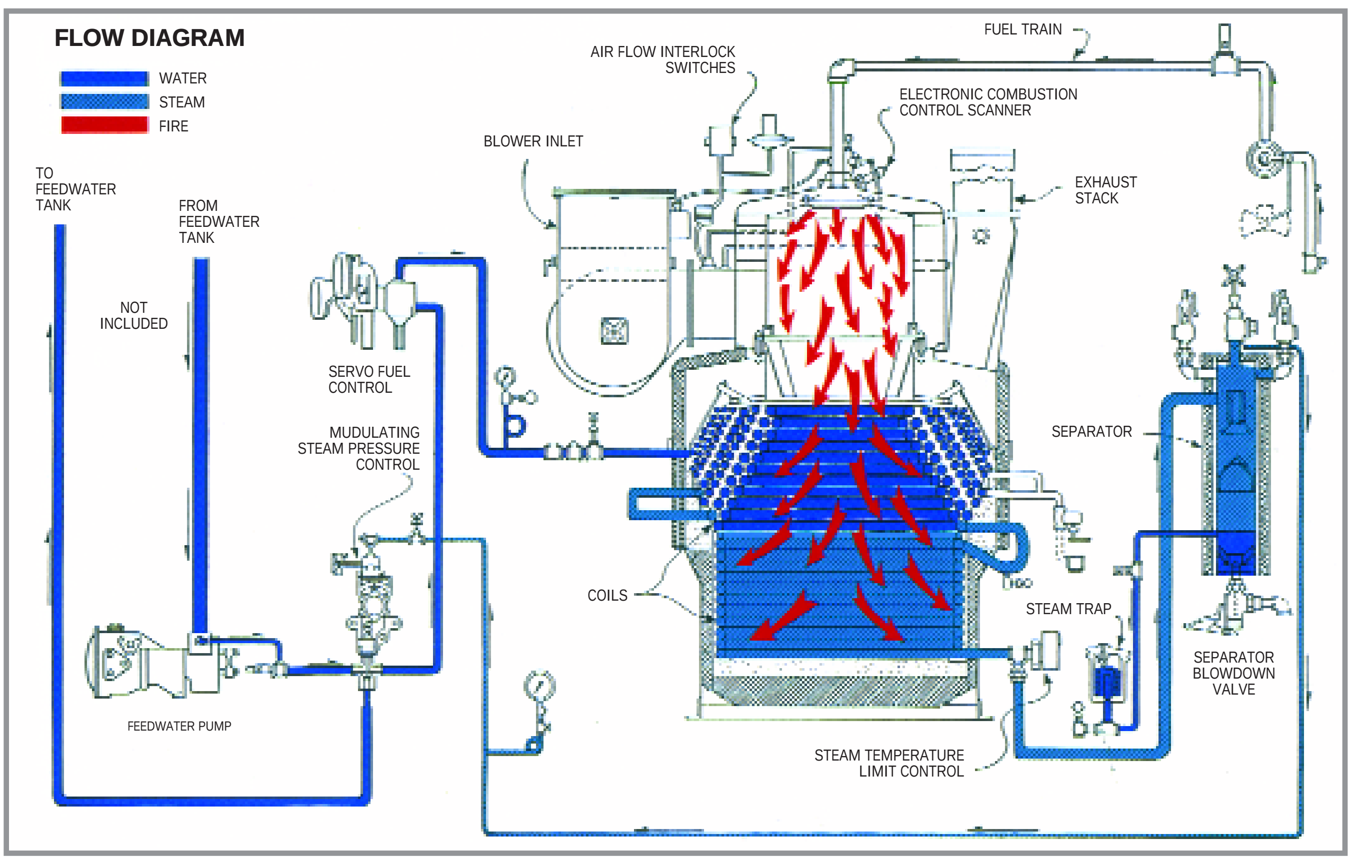

FIGURE 3. Once-through steam generator flow diagram.

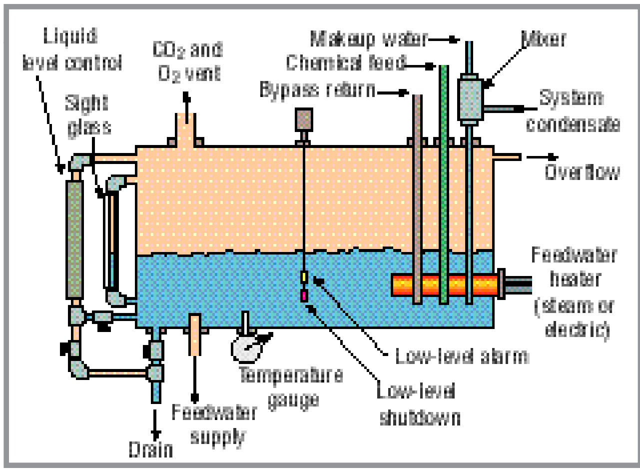

FIGURE 4. Recommended feedwater tank design.

ator package. A 350 bhp recirculating generator in a horizontal arrangement has footprint dimensions of 146 in. long by 92 in. wide. An additional 60 in. is required along the length dimension for tube-removal.

The small physical size also results in lower weight. The operating water content of the 350 bhp generator described above is only 56 gal, which is about 97 percent less water by weight than a typical boiler configuration for the same steam requirement.

The relatively small water content of the coil-type enables it to go from cold startup to full steam output in approximately 5 min—hence the use of the term *steam generator* instead of boiler, reflecting its ability to produce dry steam very quickly.

SAFETY CODES

All steam boilers, regardless of design, manufactured and sold in the U.S. must meet certain codes and standards that ensure safety for the operators and users. And, coil-type steam generators are certainly no exception. As mentioned earlier, they generally come in two styles: once-through and recirculating. The once-through design is capable of much higher operating pressures—up to 3100 psig or higher—than are the recirculating models that are usually rated for 530 psig design. However, even in lower pressure-rated units, the coils should be designed for a minimum working pressure of 1000 psig. Should a coil failure occur because of the very small water content, the result would be similar to a rupture in a steam or condensate return line—there is no explosion. In fact, there has never been a National Board reportable incident[1] involving a U.S.-manufactured coil-type steam generator.

Several state and local boiler codes recognize the coil-type steam generator's inherent safety, which is a function of its low-water content, by allowing unattended (or reduced supervision) operation. In those jurisdictions where such exemptions to the boiler code have been granted, substantial reduction in personnel costs can be realized. For example, in Ohio,[2] all coil-type steam generators (of the design on which this article is focused) up to and including 300 bhp may be used without a licensed operator. By merely isolating (with appropriate valves) the steam drum from the coils, the recirculating steam generator becomes a hot water generator and is, then, also exempt from the boiler code in sizes up to and including 600 bhp. The exemption for the once-through steam generator is based on a total heating surface area of less than 360 sq ft.

Another example of a code advantage is found in the City of Detroit, Mich.[3] That exemption from the definition of a boiler and, therefore, from the requirement for licensed operation is based on the fact that a coil-type steam generator, unlike a natural circulation boiler, has no fixed-water (or steam) level. The Province of Ontario, Canada[4] takes a different approach with its operating engineer exemption for coil-type

Using coil-Type steam generators in conjunction with natural circulation boilers

Natural circulation firetube and watertube boilers have long dominated the high-pressure steam-heating market—and with good reason—because they can provide the high-steam capacities required in many institutional steam plants. So, when (and why) would you need a coil-type steam generator in the same plant?

- **Retrofit applications—**Where additional steam capacity is needed and either available floorspace, headspace, or physical access (or perhaps all three) is limited or restricted such as in older plants. Not only does the coil-type steam generator have a 40 to 60 percent smaller footprint, it can be disassembled and re-assembled on site without any field welding.
- **Summer loads—**In situations where there are significant cyclical or seasonal load fluctuations, such as facilities that experience drastically reduced steam loads during the summer, the coil-type steam generator alone can often carry the reduced load. This allows the natural circulation boilers to be removed from service during those periods—saving fuel and maintenance costs and increasing the service life of the boilers.
- **Short-duration load swings—**In those operations that experience load swings of relatively short duration, such as a hotel or prison that uses a portion of the steam for domestic hot water and has peak periods of shower use or laundry operation, the natural circulation boilers can be base-loaded for "normal" steam demand and the swings absorbed by the steam generator. Because the steam generator can be left cold until needed (5 min startup vs. heat up rates of as little as 20 F per hr in some boilers), fuel savings alone can often justify the cost.
- **Critical standby demands—**If the steam plant in a hotel or school goes down, it is inconvenient but not generally life threatening. Hospitals and health care facilities, however, can be a different story. They often depend on their boiler room for the steam for critical function—such as sterilization in addition to the usual heating, domestic hot water, laundry, and food service requirements—and they must have standby or backup steam capability. Often, there is no room left in the existing boiler. Room for another conventional boiler and new construction costs can be prohibitive. A compact, coil-type steam generator, located in the boiler room or even in the engine-generator shed, may be the solution.

units, basing it upon water content. It allows unlicensed operation of high-pressure boilers having a water content of no more than 75 gal (Imperial). This exempts the 600 bhp coil-type steam generator, which has an operating water capacity of 54 gal (Imperial), and all smaller sizes.

FEEDWATER CONSIDERATIONS

Many knowledgeable engineers, operators, and owners of steam plants believe that forced-circulation watertube steam generators must have feedwater that is treated to levels far exceeding those required for natural circulation boilers. The fact is, all boilers require proper water conditioning and are subject to premature failure if the feedwater is not properly treated for scale and corrosion prevention. Thermal shock also has to be avoided. These three feedwater considerations are now discussed in turn.

Scale

Because scale acts as an insulator, reducing the heat transfer efficiency and eventually resulting in burnout of the heat transfer surface (tube or coil), its prevention is important. However, its presence is easily detectable in a coil-type steam generator. Because scale formation inside the tube results in a decrease in the tube area, at any given flow rate, there will be a proportional increase in the pressure drop across the coil. Therefore, a pressure gauge on the inlet side of the coils, provided as standard trim on all steam generators of this type, will show an increase in pressure when scaling occurs. Coil-type steam generators also offer the option of additional protection with a stack-high temperature limit switch. However, high-stack temperature can also indicate sooting, which reduces heat transfer across the tube or coil, and is not a foolproof means of detecting scale formation.

Scale prevention begins with the selection of the proper treatment protocol. For most water, a sodium zeolite softener is usually effective in removing calcium and magnesium. In addition to removing hardness, the sodium zeolite also increases slightly the alkalinity of the feedwater, which helps reduce corrosion. The size of the water softener is a function of the hardness, the required flow rate, total flow (or time) desired between regeneration cycles, and the duty cycle of the steam generator. Most boiler manufacturers recommend that the services of a reputable water treatment firm be engaged prior to installation of the boiler, and coil-type steam generators are no different in that regard. Coil-type steam generators can be completely descaled by pumping an acid washout solution through the coils—an operation usually completed in just a few hours. The exception to this is when silicate, calcium sulfate, or iron scales are formed in which case a demineralizer and/or chemical treatment may be necessary.

Circle 341 on Card; see HPAC Info-dex, p. 129

Corrosion

Prevention of corrosion is more difficult—and more critical—than scale prevention, since the presence of corrosion cells are not readily detectable until tube or coil failure occurs. The dissolved oxygen and carbon dioxide in the feedwater must be eliminated to prevent oxygen and acidic (low pH) corrosion. As with any steam boiler, the best method of accomplishing this is with a properly designed deaerator. However, in many cases, the small capacity and relatively low cost of the coil-type steam generator makes a deaerator system economically impractical. A more common solution, especially in smaller installations, is the use of a heated feedwater tank.

A properly designed feedwater tank (Figure 4) must be capable of heating the water to a temperature range of 205 to 210 F and of venting to allow unrestricted escape of the gases to atmosphere. Although the solubility of oxygen in water decreases with increasing temperature (Figure 5), and theoretically it cannot stay in solution at saturation conditions, some oxygen will remain in solution even at 210 F. A deaerator, because it "works" the water by moving it over trays and/or through spray nozzles as it is heated—thus placing the oxygen molecules close to the surface to facilitate their escape—is much more effective than a heated feedwater tank. However, it too can leave some oxygen in solution.

To ensure complete oxygen removal, most feedwater treatment specialists recommend the use of a chemical oxygen scavenger to enhance the mechanical treatment. These scavengers may be either volatile or non-volatile, with the volatile chemicals also providing some corrosion-protection in the condensate system. And, any carbon dioxide still remaining can be treated with filming amines. A common oxygen scavenger in use includes sodium sulfite, which can only be used at operating pressures of less than 600 psig. Above that pressure, it breaks down to form sulfuric acid. Also, sodium sulfite contributes to total dissolved solids (TDS), thus promoting scale formation. Hydrazine, once a widely used volatile oxygen scavenger that was effective at higher pressures and did not add TDS to the feedwater, has been identified as a known carcinogen and is no longer recommended.

Acid corrosion can occur when the feedwater pH is low. A demineralizer can often produce slightly acid water, while sodium zeolite softeners slightly increase alkalinity. In either case, caustic soda or soda ash is often required to raise the feedwater pH. Table 1 shows "ideal" feedwater requirements; however, manufacturers of coil-type steam generators, like their firetube counterparts, recognize that these levels are not always achievable and design their equipment to be somewhat tolerant of temporary hardness at levels up to 5 ppm.

Circle 342 on Card; see HPAC Info-dex, p. 196

Water property	Preferred range
Total hardness ($CaCO_3$)	0.0 ppm
PH	9 to 9.5
Sulfate (as SO_4)	0 to 50 ppm
Total alkalinity ("M") ($CaCO_3$)	150 to 400 ppm
Carbon Dioxide (CO_2)	0 ppm
Oxygen (O_2)	0 ppm
F.W. Temp	Equal or greater than 180 F
Oxygen scavenger (as Sulfite, SO_3)	25 to 50 ppm (see special test)
Total dissolved solids	Less than 850 ppm
Silica (SiO_2)	0 to 5.5 ppm
Iron (dissolved)	0 to 1 ppm

Table 1. Ideal boiler feedwater requirements.

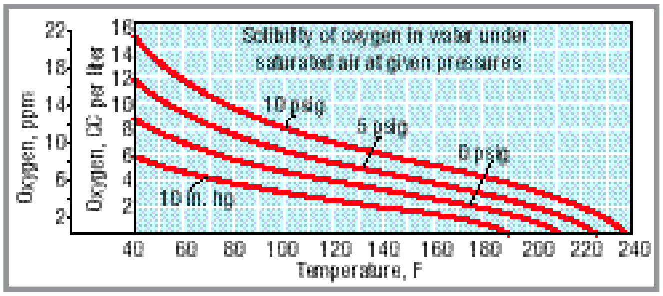

FIGURE 5. Oxygen solubility in water vs. temperature.

Thermal Shock

Coil-type steam generators are immune to thermal shock because they employ a wound coil that, when differing rates of expansion and contraction occur, tends to unwind like a clock spring without the stress associated with rigid tubes. The steam generators also have modulating feedwater controls that further reduce the possibility of thermal shock.

SO WHEN DO YOU SELECT A STEAM GENERATOR?

The following conditions or limitations should be present to justify selection of a steam generator:

- *Very high pressures required*—Certainly if operating pressures of more than 400 or 450 psig are required, the options are limited and the choice is easy.
- *Full modulation is required*—In case of rapidly fluctuating loads, where full modulation—of steam output, not just fuel—is desired. And, full range response time of the coil-type steam generator, measured at the header, is typically only 15 sec.
- *High-output turndown ratios are needed*—Coil-type steam generators generally offer turndown ratios starting at 8:1 and going as high as 13:1. So, if wide load swings are expected, this may be an important feature.
- *Rapid startup is desired*—If a boiler is to be base loaded and left at constant fire on a continuous basis, then quick steaming capability is not a tangible benefit. But for those applications where it is advantageous to go from cold start to full-steam output in typically 5 min, the coil-type steam generator is unsurpassed in performance.
- *Small size, low weight*—Perhaps the biggest advantage the coil-type steam generator has in steam-heating applications is its compact size. That, along with modular construction, permits substantial savings in construction and installation costs in both retrofits and new facilities. **HPAC**

REFERENCES

1) The National Board of Boiler and Pressure Vessel Inspectors, 1055 Crupper Ave., Columbus, OH 43229-1183.

2) Ohio Revised Code, Section 4739.04, State of Ohio.

3) Ordinance No. 706-G, Chapter 11-A, Sec. 2.3, City of Detroit, MI.

4) R.S.O. 1980, c. 363, s. 2; 1982, c. 42, s. 2, Province of Ontario, Canada.

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