Sizing: The vessel pressurized by steam should be sized for a total volume V_T which is the sum of the volume V_1 required for the steam space, the volume V_2 required for water expansion, and the volume V_3 required for internal headers or piping, sludge and reserve. An allowance of 20 percent of the sum of V_2 and V_3 is reasonable for the volume V_1, required for the steam space.

The volume V_2 required for water expansion is determined from the change in water volume from the minimum operating temperatures to the maximum operating temperatures of the complete cycle. It is not necessary to allow for expansion of the total water volume in the system from a cold initial start. It will be necessary during a start-up period to bleed off the volume of water due to expansion from the initial starting temperature to the lowest average operating temperature.

The volume V_3 for internals, sludge, and reserve varies greatly depending upon size of system, design of internals and desirable allowance for sludge and reserve. For smaller systems with minimum internals an allowance of 40 percent of the volume V_2 required for water expansion is reasonable. For larger systems with horizontal tanks and complete internal distribution piping arrangements the allowance goes as high as 80 percent of V_2.

4. The simplest type of gas pressurization system uses a *fixed quantity* of gas in a separate expansion vessel which accommodates the change in water volume. In this case, the pressure within the gas space varies with changes in water level in the expansion vessel. As the average system water temperature increases on partial load operation, the expansion of the system water into the vessel compresses the inert gas, raising the system pressure. The reverse condition takes place on a drop in average system water temperature. The pressure is permitted to vary from a minimum point above saturation to a maximum determined by the materials used in the system.[4]

Sizing: The vessel should be sized for a total volume V_T which is the sum of the volume V_1 required for pressurization, the volume V_2 required for water expansion, and the volume V_3 required for sludge and reserve.

Reasonably accurate calculations may be made on the basis of pressure-volume variations following Boyle's Law, assuming that the tank operates at a relatively constant temperature. The minimum gas volume can be determined when the expansion volume V_2, the minimum tank pressure P_1, and the maximum tank pressure P_2, are known. The gas volume varies from the minimum (V_1) to a maximum which *includes* the water expansion volume V_2.

The minimum gas volume V_1 can be obtained from the following equation:

$$V_1 = P_1V_2/(P_2 - P_1)$$

where the units of P_1 and P_2 are psia.

An allowance of 10 percent of the sum of V_1 and V_2 is reasonable for the sludge and reserve capacity, V_3. The volume V_2 required for water expansion should be limited to the actual expansion which occurs during system operation through its minimum to maximum operating temperatures. It would be necessary to bleed off water during a start-up cycle from a cold start. It is generally practicable on small systems, such as under 1,000,000 to 10,000,000 Btuh, to size the expansion vessel for the total water expansion from the initial fill temperature.

The ratings of fittings, valves, piping and equipment is a consideration in determining the maximum system pressure. The greater the maximum system pressure the smaller the size of the expansion vessel. The savings in the cost of the vessel, however, may be more than offset by the increase in cost of the other elements of the system. It is suggested that a minimum pressure be selected which is about 25 to 50 psi over the maximum saturation pressure. In checking the ratings of valves, pipe and fittings, it will be necessary to determine the specific rating rating point for the given application. For example, standard 300 psi steel fittings and valves are rated at a temperature of 850 F. The *pressure* rating for a standard 300 psi steel valve when operating at 400 F is 665 psi. Therefore, it is generally not necessary to use steel valves and fittings over 300 psi ratings in HTW systems. Similarly, standard 150 psi steel fittings and valves can usually be used in systems operating as high as 325 F.

The expansion vessel is connected to the suction side of the HTW pump, preferably as close as possible, by means of a balance line. The inert gas used for pressurization is fed into the top of the cylinder, preferably through a manual fill connection using a reducing station connected to an inert gas cylinder.

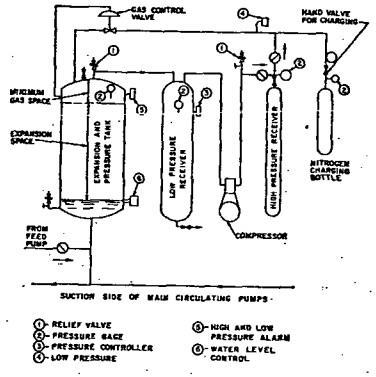


Fig. 5 .... Inert Gas Pressurization Using Variable Gas Quantity

The basic HTW pumping arrangements may either be the single-pump type, where one pump handles both the generator and system loads; or two-pump type, where one pump circulates HTW water through the generator and a second pump circulates HTW water through the system.

The use of air as the gas for pressurization is not recommended. Nitrogen is the most commonly used inert gas, as it is readily available at a reasonable cost. This method of pressurization has the greatest advantage in its relative simplicity, ease of control, and flexibility. There is no flow in the expansion vessel, which generally remains cool and need not be insulated.

Also used as a method of inert gas pressurization is a system which employs a variable gas quantity (see Fig. 5).[3] In this system the inert gas is relieved from the expansion vessel on a rise in water level into a low pressure gas receiver. A gas compressor pumps from this low pressure into a high pressure receiver for storage. When the water level drops in the expansion vessel, the control cycle adds inert gas from the high pressure receiver to the expansion vessel to maintain the required pressure. This system is somewhat more complicated and should be analyzed on the basis of the economics involved for each application. Generally it is more applicable to large central systems.

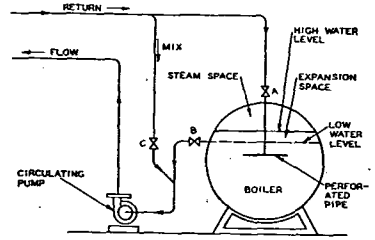


Fig. 6 .... Arrangement of Boiler Piping

Arrangement of Direct-Fired Generators

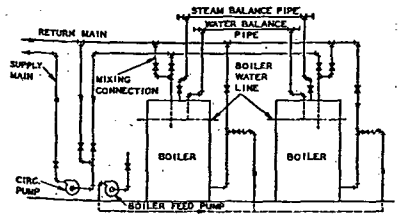
The method of integrating the high-temperature water generator into the high-temperature water heating circuit depends on the type of generator and the method of pressurization.

Where the generator is a steam boiler with an integral steam drum used to absorb the expansion of the water level and for pressurization, a dip pipe is generally employed to take the water out from below the water line (see Fig. 6).[5] This dip pipe should be so installed that it picks up water at or near the saturation temperature, but without too many steam bubbles in it, and that in the event of a pipe break somewhere in the system the boiler is not emptied to a point where heating surfaces are bared and the danger of a boiler explosion results. Equal precautions must be taken with the return pipe. If the return pipe is connected in the lower part of the boiler, a check valve should be placed in the line connecting to the boiler to preclude the danger of emptying the boiler.

When two or more such boilers are used to supply a common system, means must be provided to maintain the same steam pressure and water level in each. Water and steam balance pipes are usually installed between the drums (see Fig. 7). These should be liberal in size. Recommended sizes are shown in the following table.

Boiler Rating Millions Btuh	Balance Pipe Dia, Inches
2.5	3
5	3½
10	4
15	5
20	6
30	8

It should be noted that a difference of only ¼ psi in the system pressure between two boilers operated at 100 psig would cause a difference of 9 in. in the water level. The situation is further aggravated by the fact that an upset is not self balancing. Rather, when too high a heat release in one of the boilers has caused the pressure to rise and the water level to fall in this boiler, the decrease in the flow of colder return water into this boiler will cause a further pressure rise, and the opposite will happen in the other boiler. It is therefore of primary importance that the firing rates match the flow through each boiler at all times.



Note: Boiler water lines must be kept at a common level.

Fig. 7 .... Piping Connections for Two or More Boilers in High-Temperature Water Systems Pressurized by Steam

Although some existing high-temperature water plants have up to 12 boilers operating in parallel, the trend is away from connecting more than two boilers in this manner. Modern practice is to employ either flooded high-temperature water heaters with one external steam drum common to all the generators, or the combination of steam boilers and direct contact heaters.

The matching of firing and flow rates is less critical in flooded boilers operated in parallel. These boilers may carry some steam provided there is no restriction which prevents the steam that is generated from finding its way to the steam space of the drum. In systems pressurized by gas, the imposed additional pressure-head above the vapor pressure of the water is normally sufficient to prevent any steaming. This system therefore requires no means of separating the steam from the water. The expansion tank is usually placed on the boiler house floor.

Relief valves, drain valves, gages, thermometers, and fill connections for HTW generators should be selected with special attention to the fact that they are for HTW service. The basic HTW system operates at a relatively constant pressure with a wide variation in temperature, whereas the ordinary steam cycle operates at varying pressures and temperatures which generally rise and fall together. Trim items designed for steam may not be satisfactory when used on a HTW application.

Expansion tanks used for inert gas pressurization cycles can be a simple vessel built to conform to the ASME *Unfired Pressure Vessel Code*, as required by the system characteristics. Locating the relief valve below the minimum water line is an advantage since it is easier to keep the relief valve tightly sealed with water on the pressure side than if it is located above the water line and is exposed to the inert gas of the system. Vertical tanks may be used to advantage since the space problem and mounting and support problem is simplified.

Expansion tanks for steam-pressurized cycles require careful design. They need to be mounted as high as practicable to give the maximum NPSH to the HTW pumps. The HTW supply from the generators should be introduced through relatively small holes by means of a perforated internal distributing pipe. The pump intake line should be located as far as possible from the return water connection and at least 6 in. below the normal water line. This pump intake line should have a serrated entrance connection or similar construction to break up vortex formations at this point. The tank is normally mounted horizontally and an aspect ratio of 3.5 to 1 is generally used to accommodate the internal piping described. This tank is normally insulated. Present practice indicates that a minimum vessel diameter of approximately 6 ft is required to accommodate the internal piping and achieve stable operation.

Direct Contact Heaters

High-temperature water may be obtained from direct contact heaters in which steam from turbine exhaust or extraction or from steam boilers is mixed with return water from the system. (See Fig. 8.) The mixing takes place in the upper part of the heater where the water cascading from horizontal baffles comes in direct contact with steam.[6]

The steam space in the upper part of the heaters serves as the steam cushion for pressurizing the system. The lower part of the heater serves as the expansion tank for the system.

Where the water heater and the boiler operate under the same pressure, the surplus water is usually returned directly