

CHAPTER 15. MEDIUM- AND HIGH-TEMPERATURE WATER HEATING

MEDIUM-TEMPERATURE water (MTW) systems have operating temperatures ranging from 250°F to 350°F and are designed to a pressure rating of 125 to 150 psig. High-temperature water (HTW) systems are classified as those operating with supply water temperatures above 350°F and designed to a pressure rating of 300 psig. The usual practical temperature limit is about 450°F because of pressure limitations on pipe fittings, equipment, and accessories. The rapid pressure rise that occurs as the temperature rises above 450°F increases cost because components rated for higher pressures are required (see [Figure 1](#)). The design principles for both medium- and high-temperature systems are basically the same.

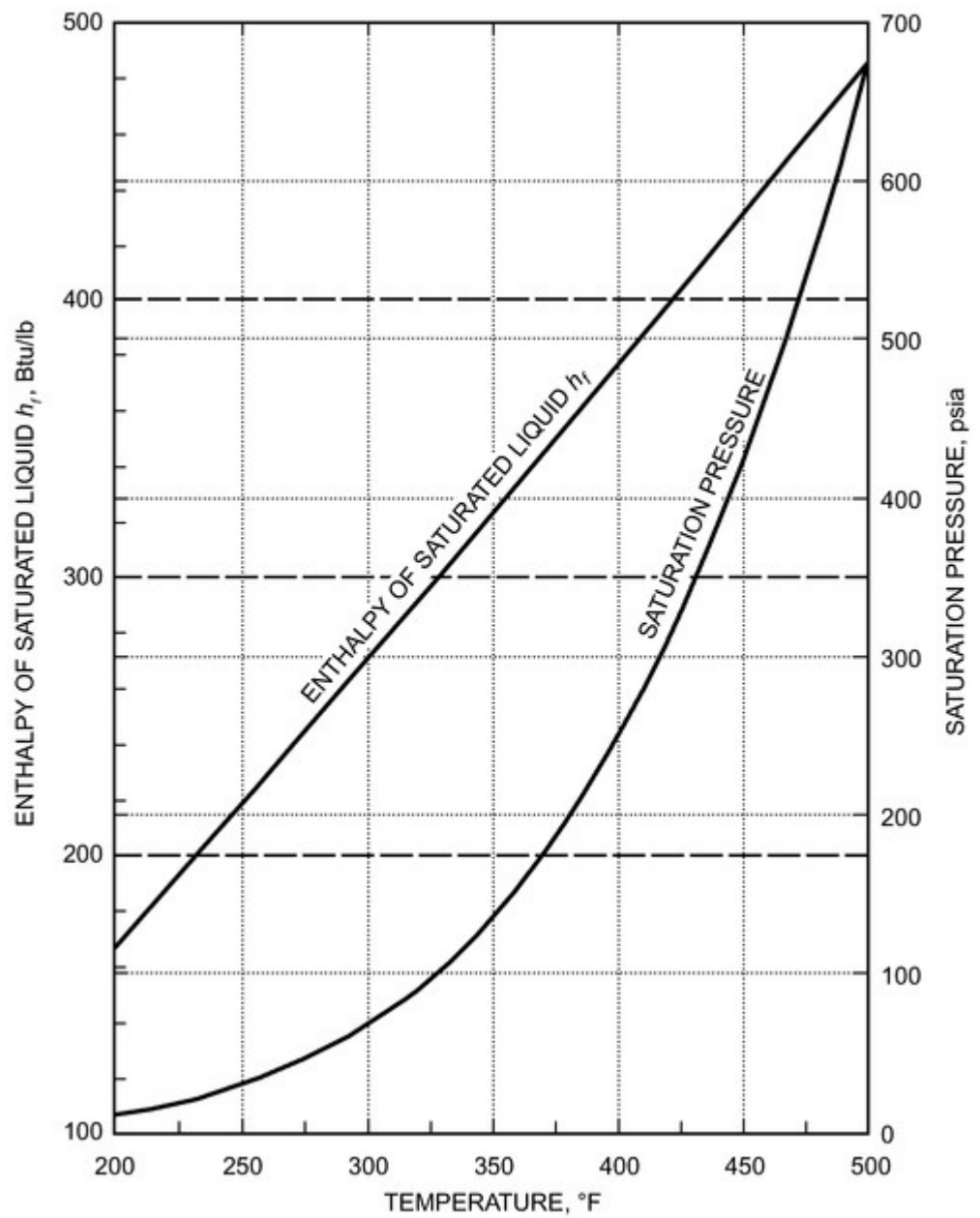


Figure 1. Relation of Saturation Pressure and Enthalpy to Water Temperature

This chapter presents the general principles and practices that apply to MTW/HTW systems and distinguishes them from low-temperature water systems operating below 250°F. See [Chapter 13](#) for basic design considerations applicable to all hot-water systems.

1. SYSTEM CHARACTERISTICS

The following characteristics distinguish HTW systems from steam distribution or low-temperature water systems:

- The system is a completely closed circuit with supply and return mains maintained under pressure. There are no heat losses from flashing from steam condensate, and heat that is not used in the terminal heat transfer equipment is returned to the MTW or HTW generator. Tight systems have minimal corrosion.
- Mechanical equipment that does not control performance of individual terminal units is concentrated at the central station.
- Piping can slope up or down or run at a variety of elevations to suit the terrain and the architectural and structural requirements without provision for trapping at each low point. This may reduce the amount of excavation required and eliminate drip points, access ports, and return pumps required with steam. Manual air vents must be provided at all high points in the system.
- Greater temperature drops are used and less water is circulated than in low-temperature water systems.
- The pressure in any part of the system must always be above the pressure corresponding to the temperature at saturation in the system to prevent the water flashing into steam. Pressure at the expansion/compression tank is customarily 30 psig above the saturation pressure.
- Terminal units requiring different water temperatures can be served at their required temperatures by regulating the flow of water, modulating water supply temperature, placing some units in series, and using heat exchangers or other methods.
- The high heat content of the water in the HTW circuit acts as a thermal flywheel, evening out fluctuations in the load. The heat storage capacity can be further increased by adding heat storage tanks or by increasing the temperature in the return mains during periods of light load.
- The high heat content of the heat carrier makes MTW/HTW unsuitable for two-pipe dual-temperature (hot and chilled water) applications and for intermittent operation if rapid start-up and shutdown are desired, unless the system is designed for minimum water volume and is operated with rapid response controls.
- Basic engineering skills are required to design a HTW system that is simple, yet safer and more convenient to operate than a comparable steam system.
- HTW system design requires careful attention to basic laws of chemistry, thermodynamics, and physics because these systems are less forgiving than standard hydronic systems.

2. BASIC SYSTEM

MTW/HTW systems are similar to conventional forced hot-water heating systems. They require a heat source (which can be a direct-fired HTW generator, a steam boiler, or an open or closed heat exchanger) to heat the water. The expansion of the heated water is usually taken up in an expansion vessel, which simultaneously pressurizes the system. Heat transport depends on circulating pumps. The distribution system is closed, comprising supply and return pipes under the same basic pressure. Heat emission at the terminal unit is indirect by heat transfer through heat transfer surfaces in devices such as converters (heat exchangers) or steam generators. The basic system is shown in [Figure 2](#).

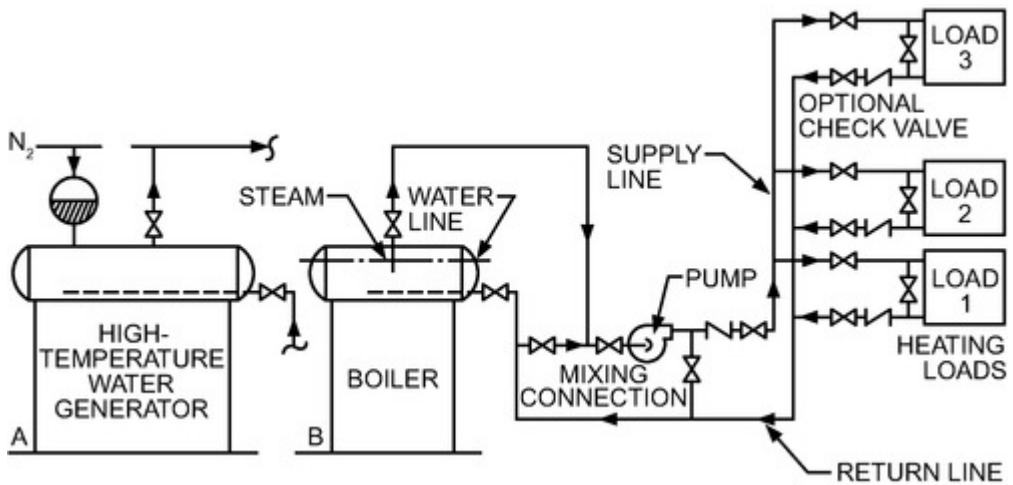


Figure 2. Elements of High-Temperature Water System

The main differences of MTW/HTW systems from low-temperature water systems are the higher pressure, heavier equipment, generally smaller pipe sizes, and manner in which water pressure is maintained. Most systems use inert gas or a pump-pressurized system, in which the pressure is imposed externally. HTW generators and all auxiliaries (such as water makeup and feed equipment, pressure tanks, and circulating pumps) are usually located in a central station. Cascade MTW/HTW converters use an existing steam distribution system and are installed remote from the central plant.

3. DESIGN CONSIDERATIONS

Selection of the system pressure, supply temperature, temperature drop, type of HTW generator, and pressurization method are the most important initial design considerations. The following are some of the determining factors:

- Type of load (space heating and/or process); load fluctuations during a 24 h period and a 1 year period. Process loads might require water at a given minimum supply temperature continuously, whereas space heating can allow temperature modulation as a function of outdoor temperature or other climatic influences.
- Terminal unit temperature requirements or steam pressures required in process systems.
- Distance between heating plant and space or process requiring heat.
- Quantity and pressure of steam used for power equipment in the central plant.
- Elevation variations within the system and the effect of basic pressure distribution.

Usually, distribution piping is the major investment in an HTW system. A distribution system with the widest temperature spread Δt between supply and return will have the lowest initial and operating costs. Economical designs have a Δt of 150°F or higher. The requirements of terminal equipment or user systems determine the system selected. For example, if the users are 10 psig steam generators, the return temperatures would be 250°F. A 300 psig rated system operated at 400°F would be selected to serve the load. In another example, where the primary system serves predominantly 140 to 180°F hot-water heating systems, an HTW system that operates at 325°F could be selected. The supply temperature is reduced by blending with 140°F return water to the desired 180°F supply temperature in a direct-connected hot-water secondary system. This highly economical design has a 140°F return temperature in the primary water system and a Δt of 185°F. However, water-to-water converters are often used to limit pressures in occupied spaces, and the MTW return temperature will be 175°F or the Δt 150°F. Because the danger of water hammer is always present when the pressure drops to the point at which pressurized hot water flashes to steam, the primary HTW system should be designed with steel valves and fittings of 150 psi. The secondary water, which operates below 212°F and is not subject to flashing and water hammer, can be designed for 125 psi and standard HVAC equipment. Theoretically, water temperatures up to about 350°F can be provided using equipment suitable for 125 psi. In practice, however, maximum water temperatures are limited by the system design, pump pressures, and elevation characteristics to values between 300 and 325°F. Most systems are designed for inert-gas pressurization. The pressurizing tank is connected to the system by a single balance line on the suction side of the circulating pump. This establishes the point in the system at which the pressure does not change during operation and is significant in controlling system pressures and ingestion of air into the system. The circulating pump is located at the inlet side of the HTW generator. There is no flow through the pressurizing tank, and a reduced temperature will normally establish itself inside. A special characteristic of a gas-pressurized system is the apparatus that creates and maintains gas pressure inside the tank. In designing and operating an MTW/HTW system, it is important to maintain a pressure that always exceeds the vapor pressure of the water, even if the system is not operating. This may require limiting the water temperature and thereby the vapor pressure, or increasing the imposed pressure. Elevation and the pressures required to prevent water from flashing into steam in the supply system can also limit the maximum water temperature that may be used and must therefore be studied in evaluating the temperature-pressure relationships and method of pressurizing the system. The properties of water that govern design are as follows:

- Temperature versus pressure at saturation ([Figure 1](#))
- Density or specific volume versus temperature
- Enthalpy or sensible heat versus temperature
- Viscosity versus temperature
- Type and amount of pressurization

The relationships among temperature, pressure, specific volume, and enthalpy are all available in steam tables. Some properties of water are summarized in [Table 1](#) and [Figure 3](#).

Direct-Fired High-Temperature Water Generators

In direct-fired HTW generators, the central stations are comparable to steam boiler plants operating within the same pressure range. The generators should be selected for size and type in keeping with the load and design pressures, as well as the circulation requirements peculiar to high-temperature water. In some systems, both steam for power or processing and high-temperature water are supplied from the same boiler; in others, steam is produced in the boilers and used for generating high-temperature water; in contemporary systems, the burning fuel directly heats the water. HTW generators are predominantly water-tube, and can be equipped with any conventional fuel-firing apparatus. Water-tube generators can have either forced circulation, gravity circulation, or a combination of both. The recirculating pumps of forced-circulation generators must operate continuously while the generator is being fired. Forced-circulation HTW generators are usually the once-through type and rely solely on pumps to achieve circulation. Depending on the design, internal orifices in the various circuits may be required to regulate the water flow rates in proportion to the heat absorption rates. Circulation must be maintained at all times while the generator is being fired, and the flow rate must never drop below the minimum indicated by the manufacturer. Fire-tube boilers designed for MTW/HTW service may be used, but thermal shock, which damages tubes and tube sheets, caused by sudden drops in the return temperature (sudden load increases), is difficult to avoid. Therefore, fire-tube generators should be avoided, used in small systems, or at least used with caution.

Table 1. Properties of Water, 212 to 400°F

Temperature, °F	Absolute Pressure, psia ²	Density, lb/ft ³	Specific Heat, Btu/lb · °F	Total Heat above 32°F		Dynamic Viscosity, Centipoise
				Btu/lb ²	Btu/ft ³	
212	14.70	59.81	1.007	180.07	10,770	0.3838
220	17.19	59.63	1.009	188.13	11,216	0.2712
230	20.78	59.38	1.010	196.23	11,770	0.2567
240	24.97	59.10	1.012	206.34	12,313	0.2436
250	29.83	58.82	1.015	218.48	12,851	0.2317
260	35.43	58.51	1.017	228.64	13,378	0.2207
270	41.86	58.24	1.020	238.84	13,910	0.2107
280	49.20	57.94	1.022	249.06	14,430	0.2015
290	57.56	57.64	1.025	259.31	14,947	0.1930
300	67.01	57.31	1.032	269.59	15,450	0.1852
320	89.66	56.66	1.040	290.28	16,437	0.1712
330	103.06	56.31	1.042	300.68	16,931	0.1649
340	118.01	55.96	1.047	311.13	17,409	0.1591
350	134.63	55.59	1.052	321.63	17,879	0.1536
360	153.04	55.22	1.057	332.18	18,343	0.1484
370	173.37	54.85	1.062	342.79	18,802	0.1436
380	195.77	54.47	1.070	353.45	19,252	0.1391
390	220.37	54.05	1.077	364.17	19,681	0.1349
400	247.31	53.65	1.085	374.97	20,117	0.1308

² Source: *Thermodynamic Properties of Steam*, J.H. Keenan and F.G. Keyes, John Wiley & Sons, 1936 edition.

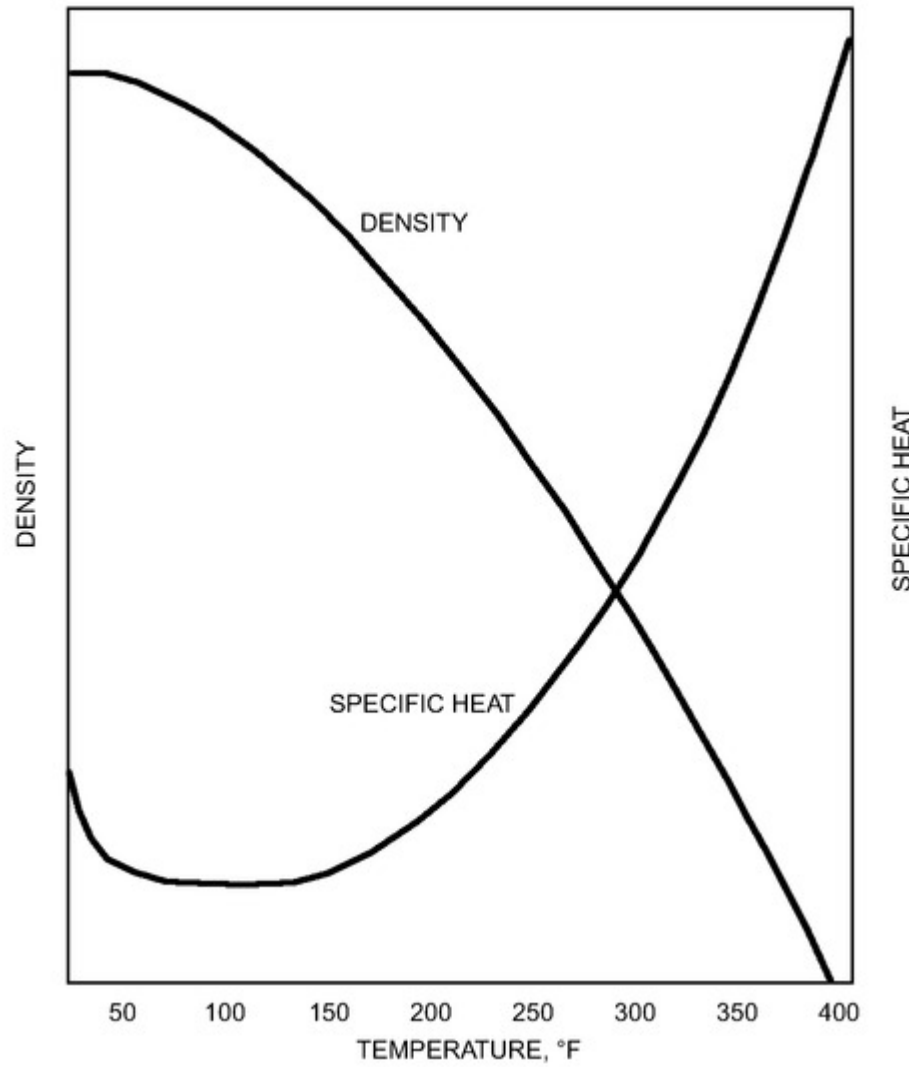


Figure 3. Density and Specific Heat of Water

A separate vessel is always used when the system is cushioned by an inert gas. Proper internal circulation is essential in all types of generators to prevent tube failures caused by overheating or unequal expansion.

Expansion and Pressurization

In addition to the information in [Chapter 13](#), the following factors should be considered:

- The connection point of the expansion tank used for pressurization greatly affects the pressure distribution throughout the system and the avoidance of HTW flashing. For stable pressure control, the expansion tank balance line should be attached to the inlet side of the MTW/HTW generator. It is the only point of no pressure change in the system.
- Proper safety devices for high and low water levels and excessive pressures should be incorporated in the expansion tank and interlocked with combustion safety and water flow rate controls.

The following four fundamental methods, in which pressure in a given hydraulic system can be kept at a desired level, amplify the discussion in [Chapter 13](#) (Blossom and Ziel 1959; National Academy of Sciences 1959).

Elevating the Storage Tank. This is a simple pressurization method, but because of the great heights required for the pressure encountered, it is generally impractical.

Steam Pressurization. This method requires the use of an expansion vessel separate from the HTW generator. Steam pressurization systems are seldom used in contemporary systems. Detailed discussion of this method of pressurization may be found in previous editions of this chapter or noted in references therein.

The expansion vessel must be equipped with steam safety valves capable of relieving the steam generated by all the generators. The generators themselves are usually designed for a substantially higher working pressure than the expansion drum, and their safety relief valves are set for the higher pressure to minimize their lift requirement.

The basic HTW pumping arrangements can be either single-pump, in which one pump handles both the generator and system loads, or two-pump, in which one pump circulates high-temperature water through the generator and a second pump circulates high-temperature water through the system. The circulating pump moves the water from the expansion vessel to the system and back to the generator. The vessel must be elevated to increase the net positive suction pressure to prevent cavitation or flashing in the pump suction. This arrangement is critical. A bypass from the HTW system return line to the pump suction helps prevent flashing. Cooler return water is then mixed with hotter water from the expansion vessel to give a resulting temperature below the corresponding saturation point in the vessel.

Inert-Gas Pressurization. Nitrogen is the most commonly used inert gas for pressurization. Air is not recommended, because the oxygen in air contributes to corrosion in the system.

The expansion vessel is connected as close as possible to the suction side of the HTW pump by 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. Locating the relief valve below the minimum water line is advantageous, because it is easier to keep it tightly sealed with water on the pressure side. If the valve is located above the water line, it is exposed to the inert gas of the system.

To reduce the area of contact between gas and water and the resulting absorption of gas into the water, the tank should be installed vertically. It should be located in the most suitable place in the central station. Similar to the steam-pressurized system, the pumping arrangements can be either one- or two-pump (see [Figures 4](#) and [5](#)).

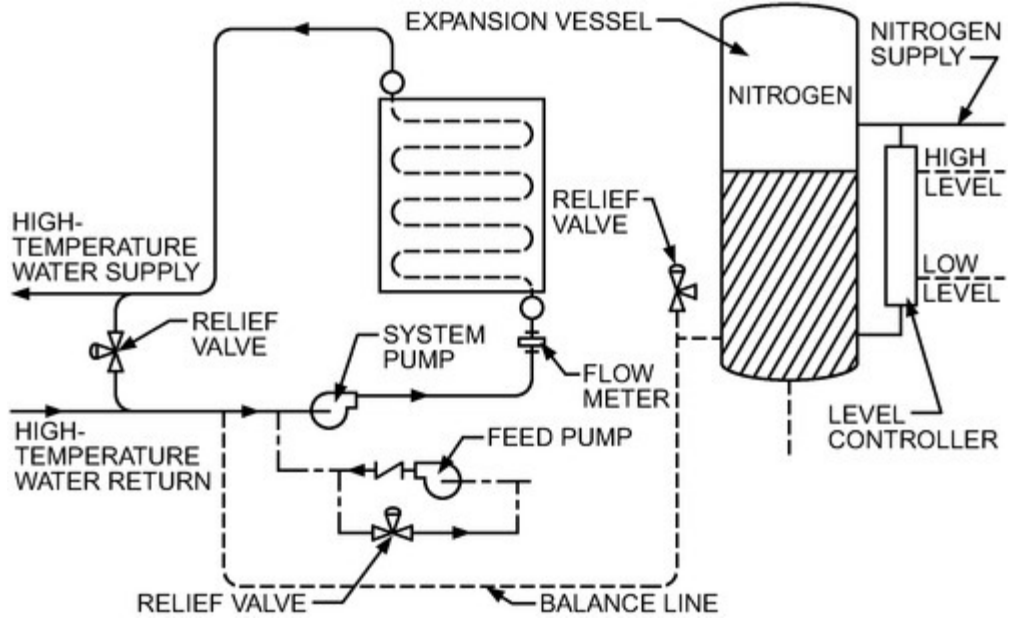


Figure 4. Inert-Gas Pressurization for One-Pump System

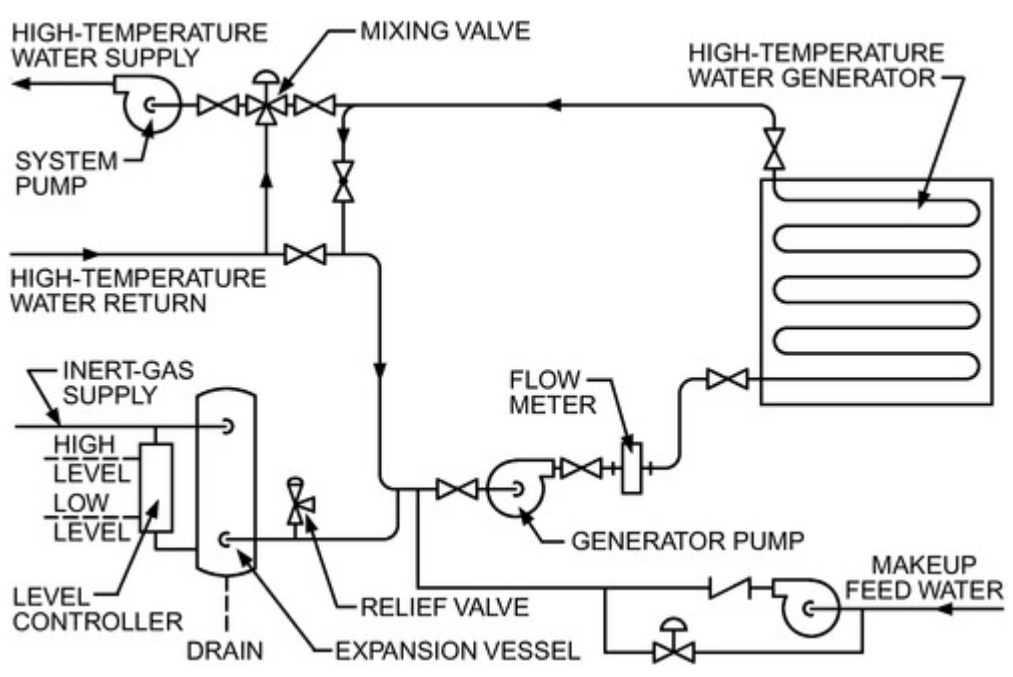


Figure 5. Inert-Gas Pressurization for Two-Pump System

The ratings of fittings, valves, piping, and equipment are considered in determining the maximum system pressure. A minimum pressure of about 25 to 50 psi over the maximum saturation pressure can be used. The imposed additional pressure above the vapor pressure must be large enough to prevent steaming in the HTW generators at all times, even under conditions when flow and firing rates in generators operated in parallel, or flow and heat absorption in parallel circuits within a generator, are not evenly matched. This is critical, because gas-pressurized systems do not have steam separating means and safety valves to evacuate the steam generated.

The simplest type of gas-pressurization system uses a variable gas quantity with or without gas recovery (Figure 6) (National Academy of Sciences 1959). When the water rises, the inert gas is relieved from the expansion vessel and is wasted or recovered in a low-pressure gas receiver from which the gas compressor pumps it into a high-pressure receiver for storage. When the water level drops in the expansion vessel, the control cycle adds inert gas from bottles or from the high-pressure receiver to the expansion vessel to maintain the required pressure.

Gas wastage can significantly affect the operating cost. The gas recovery system should be analyzed based on the economics of each application. Gas recovery is generally more applicable to larger systems.

Sizing: The vessel should be sized for a total volume V_1 , which is the sum of the volume V_2 required for pressurization, the volume V_3 required for water expansion, and the volume V_4 required for sludge and reserve.

Calculations made on the basis of pressure-volume variations following Boyle's Law are reasonably accurate, assuming that the tank operates at a relatively constant temperature. The minimum gas volume can be determined from the expansion volume V_2 and from the control range between the minimum tank pressure P_1 and the maximum tank pressure P_2 . 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

$$V_1 = P_1 V_2 / (P_2 - P_1)$$

where P_1 and P_2 are units of absolute pressure.

An allowance of 10% of the sum of V_1 and V_2 is a reasonable estimate of the sludge and reserve capacity V_3 . The volume V_2 required for water expansion should be limited to the actual expansion that occurs during operation through its minimum to maximum operating temperatures. It is necessary to bleed off water during a start-up cycle from a cold start. It is practicable on small systems (e.g., under 1,000,000 to 10,000,000 Btu/h) to size the expansion vessel for the total water expansion from the initial fill temperature.

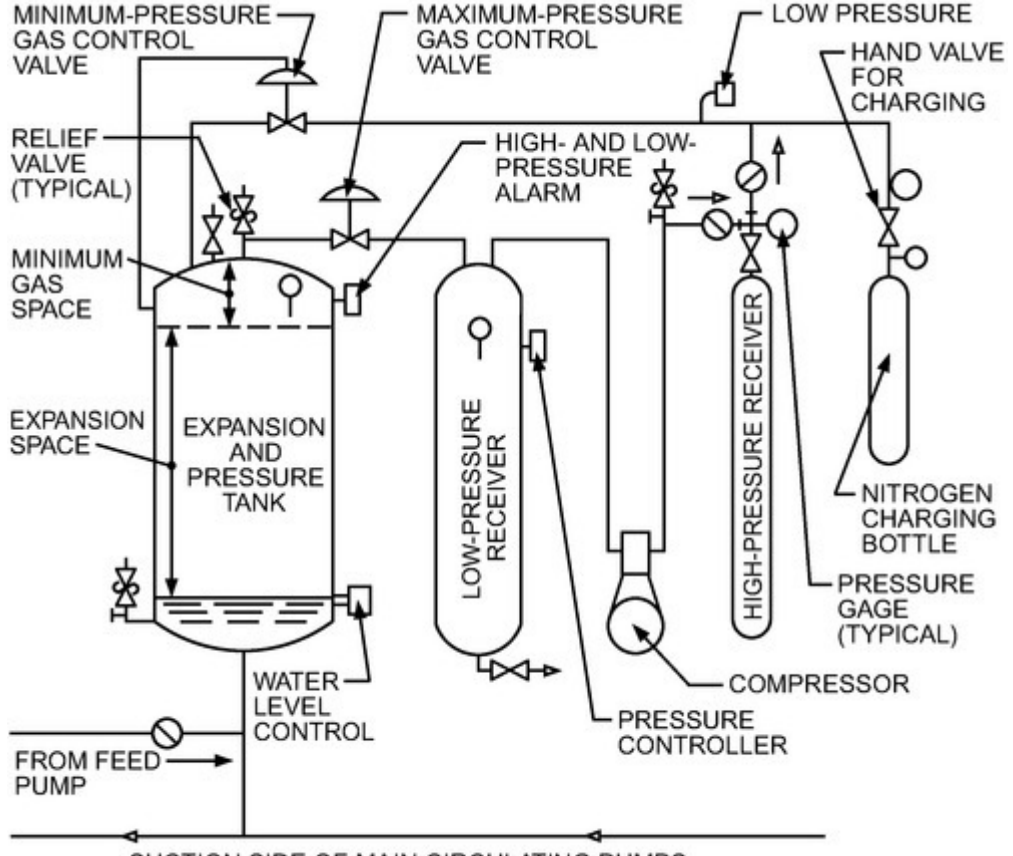


Figure 6. Inert-Gas Pressurization Using Variable Gas Quantity with Gas Recovery

Pump Pressurization. In its simplest form, this method requires a feed pump and a regulator valve. The pump operates continuously, introducing water from the makeup tank into the system. The pressure regulator valve bleeds continuously back into the makeup tank. This method is usually restricted to small process heating systems. However, it can be used to temporarily pressurize a larger system to avoid shutdown during inspection of the expansion tank.

In larger central HTW systems, pump pressurization is combined with a fixed-quantity gas compression tank that acts as a buffer. When the pressure rises above a preset value in the buffer tank, a control valve opens to relieve water from the balance line into the makeup storage tank. When the pressure falls below a preset second value, the feed pump is started automatically to pump water from the makeup tank back into the system. The buffer tank is designed to absorb only the limited expansion volume that is required for the pressure control system to function properly; it is usually small.

To prevent corrosion-causing elements, principally oxygen, from entering the HTW system, the makeup storage tank is usually closed and a low-pressure nitrogen cushion of 1 to 5 psig is maintained. The gas cushion is usually the variable gas quantity type with release to the atmosphere.

Direct-Contact Heaters (Cascades)

High-temperature water can be obtained from direct-contact heaters in which steam from turbine exhaust, extraction, or steam boilers is mixed with return water from the system. The mixing takes place in the upper part of the heater where the water cascading from horizontal baffles comes in direct contact with steam (Hansen 1966). The basic systems are shown in Figures 7 and 8.

The steam space in the upper part of the heater serves as the steam cushion for pressurizing the system. The lower part of the heater serves as the system's expansion tank. Where the water heater and the boiler operate under the same pressure, the surplus water is usually returned directly into the boiler through a pipe connecting the outlet of the high-temperature water-circulating pump to the boiler. The cascade system is also applicable where both steam and HTW services are required (Hansen and Liddy 1958). Where heat and power production are combined, the direct-contact heater becomes the mixing condenser (Hansen and Pernsall 1960).

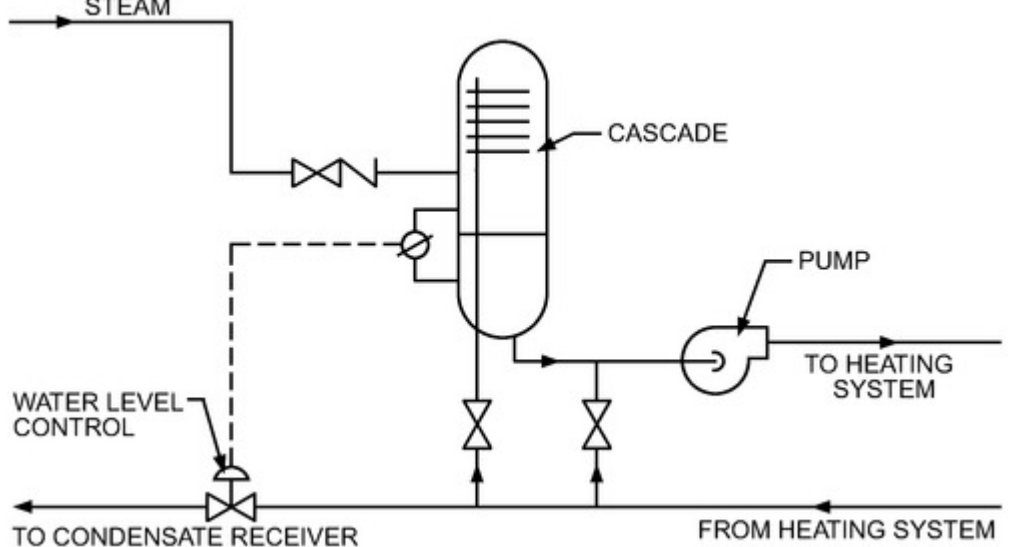


Figure 7. Cascade HTW System

System Circulating Pumps

Forced-circulation MTW/HTW generator systems can be either one-pump or two-pump. These terms do not refer to the number of pumps but to the number of groups of pumps installed. In the one-pump system (see Figure 4), a single group of pumps assures both generator and distribution system circulation. In this system, both the distribution system and the generators are in series (Blossom and Ziel 1959). However, to ensure the minimum flow through the generator at all times, a bypass around the distribution system must be provided. The one-pump method usually applies only to systems in which the total friction pressure is relatively low, because the energy loss of available circulating pressure from throttling in the bypass at times of reduced flow requirements in the district can substantially increase the operating cost.

In the two-pump system (see Figure 5), an additional group of recirculating pumps is installed solely to provide circulation for the generators (Blossom and Ziel 1959). One pump is often used for the system return and to pump it through the generator into the system. The system circulating pumps draw water from the generator outlet header and circulate it through the distribution system only. The supply temperature to the distribution system can be varied by mixing water from the return into the pump suction side. Where zoning is required, several groups of pumps can be used with a different pressure and temperature in each zone. The flow rate can also be varied without affecting the generator circulation and without using a system bypass.

It is common practice to install a mixing connection from the return to the pump suction that bypasses the HTW generator. This connection is used for start-up and for modulating the supply temperature; it should not be relied on for increasing the pressure at the pump inlet. Where it is impossible to provide the required submergence by proper design, a separate small-bore premixing line should be provided.

Hansen (1966) describes push-pull pumping, which divides the circulating pressure equally between two pumps in series. One is placed in the supply and is sized to overcome frictional resistance in the supply line of the heat distribution system. The second pump is placed in the return and is sized to overcome frictional resistance in the return. The expansion tank pressure is impressed on the system between the pumps. The HTW generator is either between the pumps or in the supply line from the pumps to the distribution system. More detailed information about push-pull pumping system design is provided in previous editions of this chapter.

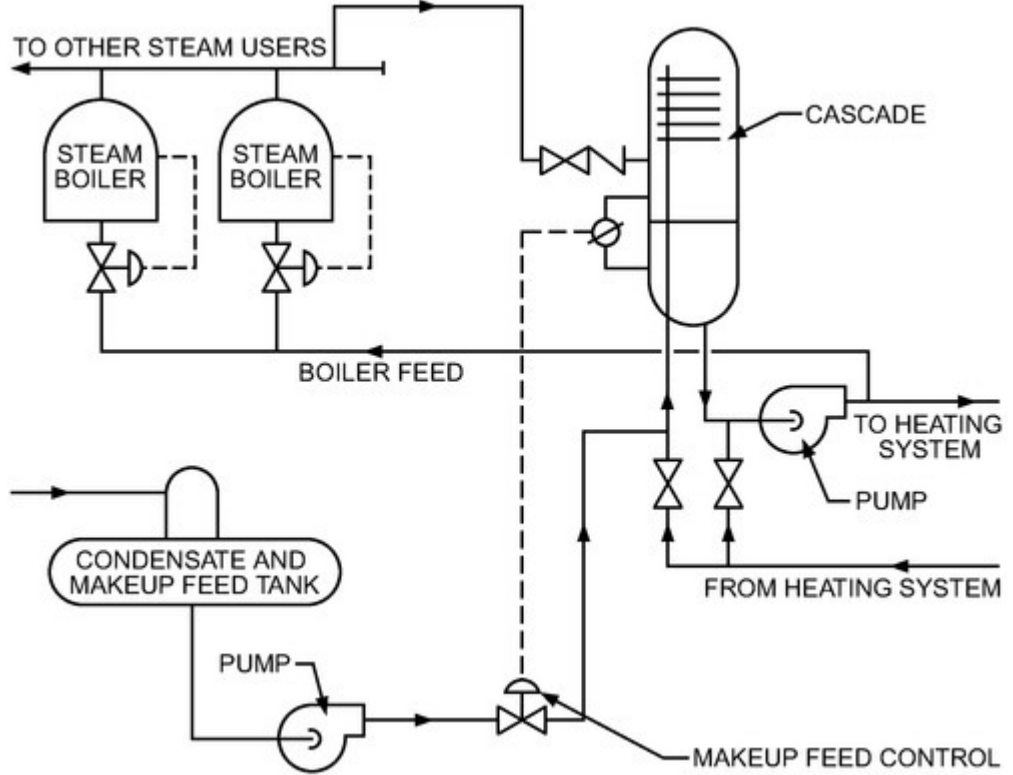


Figure 8. Cascade HTW System Combined with Boiler Feedwater Preheating

Pumps for MTW/HTW service must be provided with air or water cooling systems to provide cooling for mechanical seals. This is most important in HTW systems. System water is run through high-efficiency filters and cooled by compact air- or potable-water-cooled heat exchangers to cool and flush the seal surfaces. Such pumps are also found in chemical processing systems.

4. DISTRIBUTION PIPING DESIGN

Data for pipe friction are presented in Chapter 22 of the 2013 ASHRAE Handbook—Fundamentals. These pipe friction and fitting loss tables are for a 60°F water temperature. When applied to HTW systems, the values obtained are excessively high. The data should be used for preliminary pipe sizing only. Final pressure drop calculations should be made using the fundamental Darcy-Weisbach equation (Equation (1) in Chapter 22 of the 2013 ASHRAE Handbook—Fundamentals) in conjunction with friction factors, pipe roughness, and fitting loss coefficients presented in the section on Flow Analysis in Chapter 3 of the 2013 ASHRAE Handbook—Fundamentals.

The conventional conduit or tunnel distribution systems are used with similar techniques for installation (see Chapter 12). A small valved bypass connection between the supply and the return pipe should be installed at the end of long runs to maintain a slight circulation in the mains during periods of minimum or no demand.

All pipe, valves, and fittings used in HTW systems should comply with the requirements of ASME Standard B-31.1 and the National Fuel Gas Code (NFPA 54/ANSI Z223.1). These codes state that hot water systems should be designed for the highest pressure and temperature actually existing in the piping under normal operation. This pressure equals cushion pressure plus pump pressure plus static pressure. Schedule 40 steel pipe is applicable to most HTW systems with welded steel fittings and steel valves. The number of joints should be minimized. In many installations, all valves in the piping system are welded or brazed. Flange connections used at major equipment can be serrated, raised flange facing, or ring joint. It is desirable to have back-seating valves with special packing suitable for this service.

Valve quality, especially at headers, end-use equipment, and similar points requiring positive shutoff over time for maintenance, is very important. Valve selection must consider both initial and long-term capability to provide tight shutoff. New technologies, such as triple-offset steel butterfly valves, provide these characteristics and should be considered for use in MTW/HTW systems at critical points. Life-cycle costs favor valves that ensure tight shutoff no matter how long they are in service.

The ratings of valves, pipes, and fittings must be checked to determine the specific rating point for the given application. The pressure rating for a standard 300 psi steel valve operating at 400°F is 665 psi. Therefore, it is generally not necessary in MTW/HTW systems to use steel valves and fittings with ratings greater than 300 psi.

Because high-temperature water is more penetrating than low-temperature water, leakage caused partly by capillary action should not be ignored, because even a small amount of leakage vaporizes immediately. This slight leakage becomes noticeable only on the outside of the gland and stem of the valve where thin deposits of salt are left after evaporation. Avoid screwed joints and fittings in HTW systems. Pipe unions should not be used in place of flange connections, even for small-bore piping and equipment.

Individual heating equipment units should be installed with separate valves for shutoff. These should be readily accessible. If the unit is to be isolated for service, valves are needed in both the supply and return piping to the unit. Valve trim should be stainless steel or a similar alloy. Do not use brass and bronze.

High points in piping should have air vents for collecting and removing air, and low points should have provision for drainage. Loop-type expansion joints, in which the expansion is absorbed by deflection of the pipe loop, are preferable to the mechanical type. Mechanical expansion joints must be properly guided and anchored.

5. HEAT EXCHANGERS

Heat exchangers or converters commonly use steel shells with stainless steel, admiralty metal, or cupronickel tubes. Copper should not be used in HTW systems above 250°F. Material must be chosen carefully, considering the pressure-temperature characteristics of the particular system. All connections should be flanged or welded. On larger exchangers, water box-type construction is desirable to remove the tube bundle without breaking piping connections. Normally, HTW is circulated through the tubes, and because the heated water contains dissolved air, the baffles in the shell should be constructed of the same material as the tubes to control corrosion.

6. AIR-HEATING COILS

In HTW systems over 400°F, coils should be cupronickel or all-steel construction. Below this point, other materials (e.g., red brass) can be used after determining their suitability for the temperatures involved. Coils in outdoor air connections need freeze protection by damper closure or fan shutdown controlled by a thermostat. It is also possible to set the control valve on the preheat coil to a minimum position. This protects against freezing, as long as there is no unbalance in the tube circuits where parallel paths of HTW flow exist. A better method is to provide constant flow through the coil and to control heat output with face and bypass dampers or by modulating the water temperature with a mixing pump.

7. SPACE-HEATING EQUIPMENT

In industrial areas, space-heating equipment can be operated with the available high-temperature water. Convectors and radiators may require water temperatures in the low- and medium-temperature range 120 to 180°F or 200 to 250°F, depending on their design pressure and proximity to the occupants. The water velocity through the heating equipment affects its capacity. This must be considered in selecting the equipment because, if a large water temperature drop is used, the circulation rate is reduced and, consequently, the flow velocity may be reduced enough to appreciably lower the heat transfer rate.

Convectors, specially designed to provide low surface temperatures, are now available to operate with water temperatures from 300 to 400°F.

These high temperatures are suitable for direct use in radiant panel surfaces. Because radiant output is a fourth-power function of the surface temperature, the surface area requirements are reduced over low-temperature water systems. The surfaces can be flat panels consisting of a steel tube, usually 0.38 or 0.5 in., welded to sheet steel turned up at the edges for stiffening. Several variations are available. Steel pipe can also be used with an aluminum or similar reflector to reflect the heat downward and to prevent smudging the surfaces above the pipe.

8. INSTRUMENTATION AND CONTROLS

Pressure gages should be installed in the pump discharge and suction and at locations where pressure readings will assist operation and maintenance. Thermometers (preferably dial-type) or thermometer wells should be installed in the flow and return pipes, the pump discharge, and at any other points of major temperature change or where temperatures are important in operating the system. It is desirable to have thermometers and gages in the piping at the entrance to each building converter.

Inert-gas-pressurized systems should be controlled from the generator discharge temperature. Combustion controls are discussed in detail in Chapter 31.

In the water-tube generators most commonly used for HTW applications, the flow of water passes through the generator in seconds. The temperature controller must have a rapid response to maintain a reasonably uniform leaving water temperature.

Keep the controls simple. The rapid response through the generator makes it necessary to modulate the combustion rate on all systems with a capacity of over a few million Btu/h. In the smaller size range, this can be done by high/low firing. In large systems, particularly those used for central heating applications, full modulation of the combustion rate is desirable through at least 20% of full capacity. On/off burner control is generally not used in steam-pressurized cycles because the system loses pressurization during the off cycle, which can cause flashing and cavitation at the HTW pumps.

All generators should have separate safety controls to shut down the combustion apparatus when the system pressure or water temperature is high. HTW generators require a minimum water flow at all times to prevent tube failure. Means should be provided to measure the flow and to stop combustion if the flow falls below the minimum value recommended by the generator manufacturer. For inert-gas-pressurized cycles, a low-pressure safety control should be included to shut down the combustion system if pressurization is lost. Figure 9 shows the basic schematic control diagram for an HTW generator.

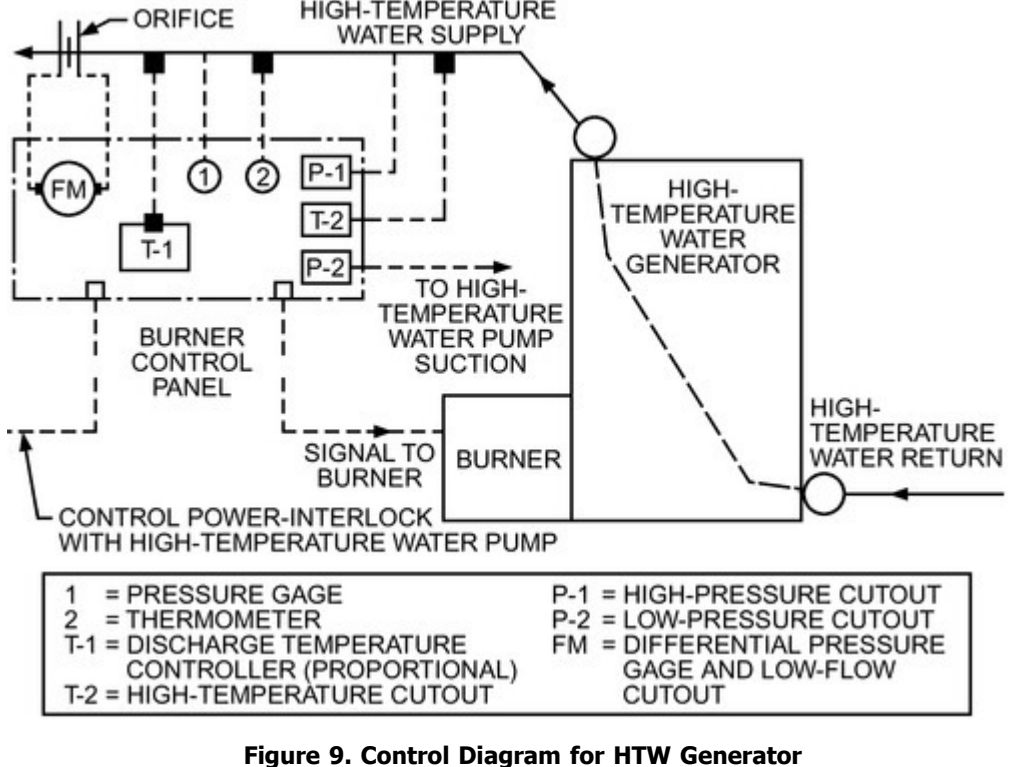


Figure 9. Control Diagram for HTW Generator

Valve selection and sizing are important because of relatively high temperature drops and smaller flows in HTW systems. The valve must be sized so that it is effective over its full range of travel. The valve and equipment must be sized to absorb, in the control valve at full flow, not less than half the available pressure difference between supply and return mains where the equipment is served. A valve with equal percentage flow characteristics is needed. Sometimes, two small valves provide better control than one large valve. Stainless steel trim is recommended, and all valve body materials and packing should be suitable for high temperatures and pressures. The valve should have a close-off rating at least equal to the maximum pressure produced by the circulating pump. Generally, two-way valves are more desirable than three-way valves because of equal percentage flow characteristics and the smaller capacities available in two-way valves. Single-seated valves are preferable to double-seated valves because the latter do not close tightly.

Control valves are commonly located in the return lines from heat transfer units to reduce the valve operating temperature and to prevent plug erosion caused by high-temperature water flashing to steam at lower discharge pressure. A typical application is for controlling the temperature of water being heated in a heat exchanger where the heating medium is high-temperature water. The temperature-measuring element of the controller is installed on the secondary side and should be located where it can best detect changes to prevent overheating of outlet water. When the measuring element is located in the outlet pipe, there must be a continuous flow through the exchanger and past the element. The controller regulates the HTW supply to the primary side by means of the control valve in the HTW return. If the water leaving the exchanger is used for space heating, the set point of the thermostat in this water can be readjusted according to outdoor temperature.

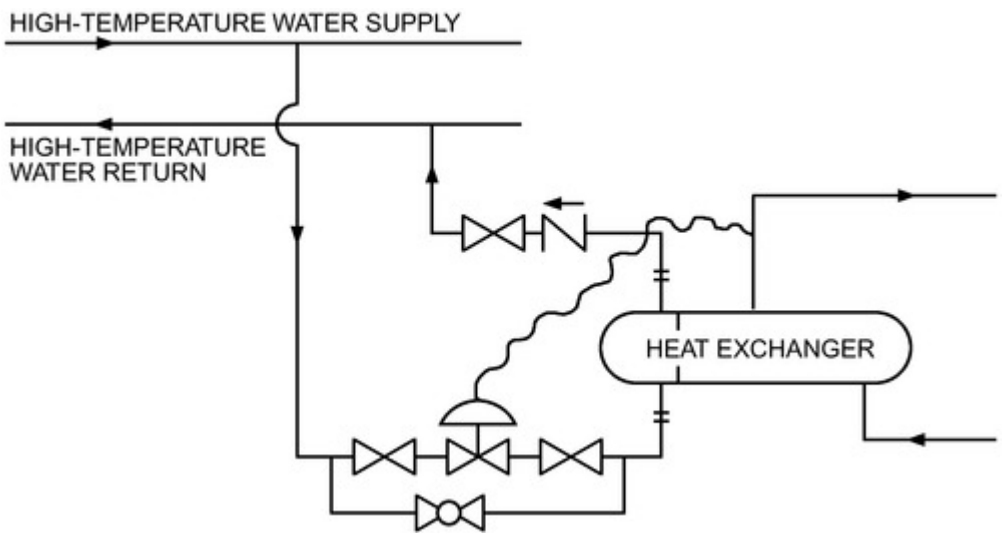


Figure 10. Heat Exchanger Connections

Another typical application is to control a low- or medium-pressure steam generator, usually less than 50 psig, using high-temperature water as the heat source. In this application, a proportional pressure controller measures the steam pressure on the secondary side and positions the HTW control valve on the primary side to maintain the desired steam pressure. For general information on automatic controls, refer to [Chapter 47 of the 2015 ASHRAE Handbook—HVAC Applications](#). Where submergence is sufficient to prevent flashing in the **vena contracta**, control valves can be in the HTW supply instead of in the return to water heaters and steam generators ([Figure 10](#)). When used in conjunction with a check valve in the return, this arrangement shuts off the high-temperature water supply to the heat exchangers if a tube bundle leaks or ruptures.

9. WATER TREATMENT

Water treatment for HTW systems should be referred to a specialist. However, the design engineer should be conversant with the technology to ensure that systems are not overtreated. MTW/HTW systems designed to minimize water loss in the system require minimal chemical additions. Experience shows that, in a well-designed, tight system, the pressure drop in the piping decreases over time as mill scale is removed from the interior of the pipe. Pretreatment of makeup water, based on local water characteristics, is important. Such pretreatment systems are relatively small because of the limited amount of water loss that occurs at valve packings. The presence of stalagmites of chemical crystals is a good indicator that a system is being overtreated. Oxygen introduced in makeup water immediately oxidizes steel at these temperatures, and over a period of time the corrosion can be substantial if air ingestion is not a primary design consideration. Other impurities can also harm generator tubes. Solids in impure water left by invisible vapor escaping at packings increase maintenance requirements. The condition of the water and the steel surfaces should be checked periodically in systems operating at these temperatures. For further information, see [Chapter 49 of the 2015 ASHRAE Handbook—HVAC Applications](#), especially the section on Water-Heating Systems under Selection of Water Treatment.

10. HEAT STORAGE

The high heat storage capacity of water produces a flywheel effect in most HTW systems that evens out load fluctuations. Systems with normal peaks can obtain as much as 15% added capacity through such heat storage. Excessive peak and low loads of a cyclic nature can be eliminated by an HTW accumulator, based on the principle of stratification. Heat storage in an extensive system can sometimes be increased by bypassing water from the supply into the return at the end of the mains, or by raising the temperature of the returns during periods of low load.

11. SAFETY CONSIDERATIONS

A properly engineered and operated HTW system is safe and dependable. Careful selection and arrangement of components and materials are important. Piping must be designed and installed to prevent undue stress. When high-temperature water is released to atmospheric pressure, flashing takes place, which absorbs a large portion of the energy. Turbulent mixing of the liquid and vapor with room air reduces the temperature well below 212°F. With low mass flow rates, the temperature of the escaping mixture can fall to 125 to 140°F within a short distance, compared with the temperature of the discharge of a low-temperature water system, which remains essentially the same as the temperature of the working fluid (Armstrong and Harris 1966; Hansen 1959). If large mass flow rates of HTW are released to atmospheric pressure in a confined space (e.g., rupture of a large pipe or vessel) a hazardous condition could exist, similar to that occurring with the rupture of a large steam main. Failures of this nature are rare if good engineering practice is followed in system design.

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