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# **An Introduction to High Temperature Water Heating Plants**

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# An Introduction to High Temperature Water Heating Plants

*J. Paul Guyer, P.E., R.A., Fellow ASCE, Fellow AEI*

## CONTENTS

1. GENERAL REQUIREMENTS
2. DEFINITIONS
3. TYPES OF SYSTEMS
4. SYSTEM WATER VELOCITIES
5. TYPES OF DISTRIBUTION CIRCUITS
6. HOT WATER GENERATORS
7. PRESSURIZATION
8. EXPANSION VESSELS
9. PUMPS
10. CONTROLS

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## AN INTRODUCTION TO HIGH TEMPERATURE WATER HEATING PLANTS

### 1. GENERAL REQUIREMENTS

**1.1** One of the main advantages of High Temperature Water (HTW) compared to steam systems is the smaller pipe sizes and pumps required due to the greater thermal storage of water. Table 1 shows the influence of temperature differentials on pipe and pump size. The minimum temperature differential recommended is 100 degrees F (55.5 degrees C). The preferred temperature differential range is 120 to 150 degrees F (66.6 to 83.3 degrees C).

**1.2** Refer to Table 2, for information on types of equipment and their application.

### 2. DEFINITIONS

**2.1 HIGH TEMPERATURE HOT WATER (HTW) SYSTEMS.** HTW systems are designed to operate at export temperatures of 350 to 420 degrees F (177 to 215.5 degrees C). Generally 400 degrees F (204.5 degrees C) is considered as a maximum design temperature due to high pressures and the relative costs to achieve pressurization. The system pressure must be at least 25 psi (172 kPa) above the saturation pressure of the HTW maximum temperature to prevent pump cavitation and flashing of superheated water to steam. A system operating at a maximum temperature of 350 degrees F (177 degrees C) requires at least 160 psia (1104 kPa) pressure and a system operating at a maximum temperature of 400 degrees F (204.5 degrees C) requires a minimum pressure of 275 psia (1898 kPa). The maximum system temperature drop from export temperature to return temperature should be 100 to 150 degrees F (55.5 to 83.33 degrees C). High temperature differentials in the HTW system can reduce distribution piping sizes and distribution pumping costs by requiring less water flow for the heat required. However, as the temperature differential is increased the system heat storage capacity is reduced.

Influence of Temperature Differentials on Selection of Pumps and Pipe Sizes for HTW Systems						
Temperature Difference	°F	20	50	100	150	200
Discharge temperature	°F	270	300	350	400	450
Return temperature	°F	250	250	250	250	250
Mean temperature	°F	260	275	300	375	350
Flow rate per 20 million BTU/hr (MMBH)	Lb/hr	1,000,000	400,000	200,000	133,000	100,000
Density of returning water	Lbs/gal	7.86	7.86	7.86	7.86	7.86
Pump capacity	GPM	2125	850	425	283	212.5
Assumed pump head	Feet	100	100	100	100	100
Pump HP required	HP	84.0	33.6	16.8	11.2	8.4
Assumed pump efficiency	%	60	60	60	60	60
Pump size (assumed headloss 10'/100')	IPS (inches)	8	6	4	3-1/2	3

Table 1

**2.2 MEDIUM TEMPERATURE HOT WATER (MTHW) SYSTEMS.** MTHW systems are designed to operate at an export temperature between 250 and 350 degrees F (121 to 177 degrees C), with a maximum temperature drop of 75 to 100 degrees F (41.7 to 55.6 degrees C). The system pressure must be pressurized at least 25 psig (172.5 kPa) above the saturation pressure to prevent pump cavitation and flashing to steam.

**2.3 LOW TEMPERATURE HOT WATER (LTHW) SYSTEMS.** LTHW systems are designed to operate at an export temperature between 150 and 250 degrees F (65.6 and 121 degrees C). Systems above 180 degrees F (82.2 degrees C) must be pressurized to prevent pump cavitation.

### 3. TYPES OF SYSTEMS

#### 3.1 RECOMMENDED

**3.1.1 FORCED CIRCULATION HOT WATER GENERATORS, SEPARATE EXPANSION VESSEL, STEAM PRESSURIZATION, SINGLE PUMP.** See Figure 1.

Equipment Selection for HTW Systems		
Equipment	Type or Use	Pertinent Information
HTW Generators for new plants to 500 psig and to 470 °F	Field-erected steel watertube with no steam space	<p>Forced circulation HTW plants of small-to-large size. Generator design pressure 100 psi above that of expansion tank.</p> <p>Manufacturer must prove that method of controlling circulation in tube circuits is satisfactory.</p> <p>Do not permit extended surface in convection section.</p> <p>Consider space requirements of generators of several different manufacturers in plant layouts.</p> <p>Set safety valve 50 psig over expansion tank safety valve discharge setting.</p> <p>For oil or gas firing. Limit furnace size to flame clearance.</p>
Boiler furnace (maximum heat input per square foot of effective radiant heating surface).	125,000 Btu/hr	For oil or gas firing. Limit furnace size to flame clearance.
	95,000 Btu/hr	For coal of 2,200 deg F or less ash fusion temperature. Spreader stoker w/traveling grate over 25,000,000 Btu/hr output.
	105,000 Btu/hr	For coal over 2,200 deg F ash fusion temperature. Spreader stoker w/traveling grate over 25,000,000 Btu/hr output.
Coal fired HTW generator grate area		See stoker selection criteria. Furnace exit gas temperature not to exceed 2200 deg F or go 100 deg F below the ash fusion temperature.
Air heater	Tubular or regenerative	When economically justified. Check safe metal temperature for sulfur content of fuel.
Economizers	Not economically justified.	In counter-flow designs of forced circulation boilers, convection section of boiler acts as economizer.
Sootblowers	Compressed air	Coal or oil HTW generators. Not required for gas fuel.
Expansion tank		Design pressure to be at least 50 psig above operating pressure.
HTW pumps	350 deg F to 420 deg F maximum temperature and 1750 RPM or over	<p>Mechanical seals with heat exchanger for cooling the water to cool face temperature of the seals to 140 deg F max.</p> <p>Alloy steel impellers (min. of 11% chromium).</p> <p>Stainless steel shafts, sleeves and pump trim.</p> <p>Ball of roller bearings oil lubricated. Stuffing box seals water cooled.</p>

Table 2

Equipment Selection for HTW Systems		
Equipment	Type or Use	Pertinent Information
Makeup pumps, up to 15 gpm	Motor-driven reciprocating pumps.	Pump discharge pressure shall be sufficient to deliver water to the system at 3% over the highest safety valve setting according to ASME Boiler and Pressure Vessel Code. The safety valves are generally set at not more than 6% over the maximum pressure to which the system may be subjected.
Makeup pumps, over 15 gpm	Motor-driven centrifugal multistage or reciprocating pumps.	
Converters	<p>Tubes and sheets of copper nickel, admiralty metal or heavy gauge steel.</p> <p>Tube expanded and rolled into sheets, not welded.</p>	<p>For secondary hot water pumping system.</p> <p>Temperature difference between leaving HTW of primary system and leaving hot water of secondary system should be not less than 30 °F.</p> <p>Use fouling factor of 0.0005 on secondary side.</p>
Radiant panels or convectors	Heating of industrial type buildings.	Direct utilization of HTW.
Unit heaters and air handling coils	<p>Heating and ventilating industrial type buildings.</p> <p>Sufficient continuous flow of HTW through coil to prevent freezing, not less than 0.5 gpm.</p>	Select coils for circuiting, due to high water temp. drop and air stratification on air-leaving side.
Steam generators	Generation of steam for heating, atomizing oil burners, and process.	<p>Use fouling factor of 0.0001 on steam side.</p> <p>Temp. difference between leaving HTW and steam temp. should not be less than 30 deg F to 40 deg F.</p> <p>Vapor disengaging velocity under 3 ft/sec.</p>

Table 2 (continued).

**3.1.2 FORCED CIRCULATION HOT WATER GENERATORS, SEPARATE EXPANSION VESSEL, STEAM PRESSURIZATION, DOUBLE PUMP.** See Figure 2, at low loads, pressurization is greatly effected by increased temperatures.

**3.1.3 FORCED CIRCULATION HOT WATER GENERATORS, SEPARATE EXPANSION VESSEL, INERT GAS PRESSURIZATION, SINGLE PUMP.** See Figure 3.

**3.1.4 FORCED CIRCULATION HOT WATER GENERATORS, SEPARATE EXPANSION VESSEL, INERT GAS PRESSURIZATION, DOUBLE PUMP.** See Figure 4.

### **3.2 NOT RECOMMENDED**

- Steam boiler, separate expansion vessel, direct-contact heat exchange of steam and water in expansion vessel.
- Steam boiler, integral expansion vessel (boiler drum), water drawn from below water line of drum.

## **4. SYSTEM WATER VELOCITIES**

**4.1** Central heating distribution systems should be zoned.

**4.2** Irrespective of flow rates and velocities, each zone should be designed so that the total pressure drops in the zones do not vary more than 15 percent from each other.

**4.3** A minimum velocity of 2 ft/sec (0.61 m/s) in the distribution system should be maintained to prevent stratification.

**4.4** A reasonable average system water velocity is 5 ft/sec (1.52 m/s). Velocities should be based on the median temperature of the system, provided that operating temperatures are in excess of 350 degrees F (177 degrees C) and that the temperature drop through the heat exchange equipment is no less than 90 degrees F (50 degrees C) nor more than 130 degrees F (54.4 degrees C).

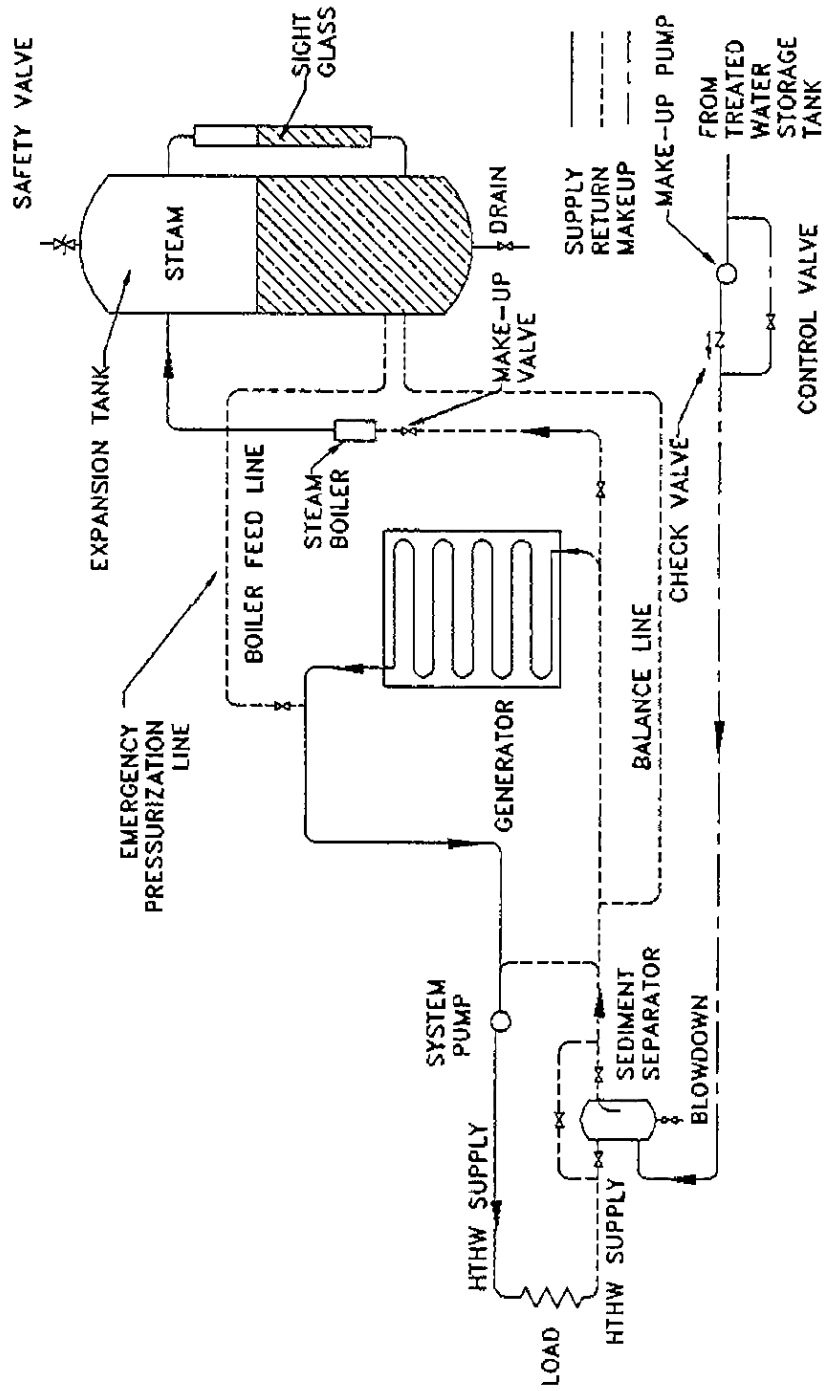


Figure 1

High Temperature Water System with Expansion Tank (one pump)



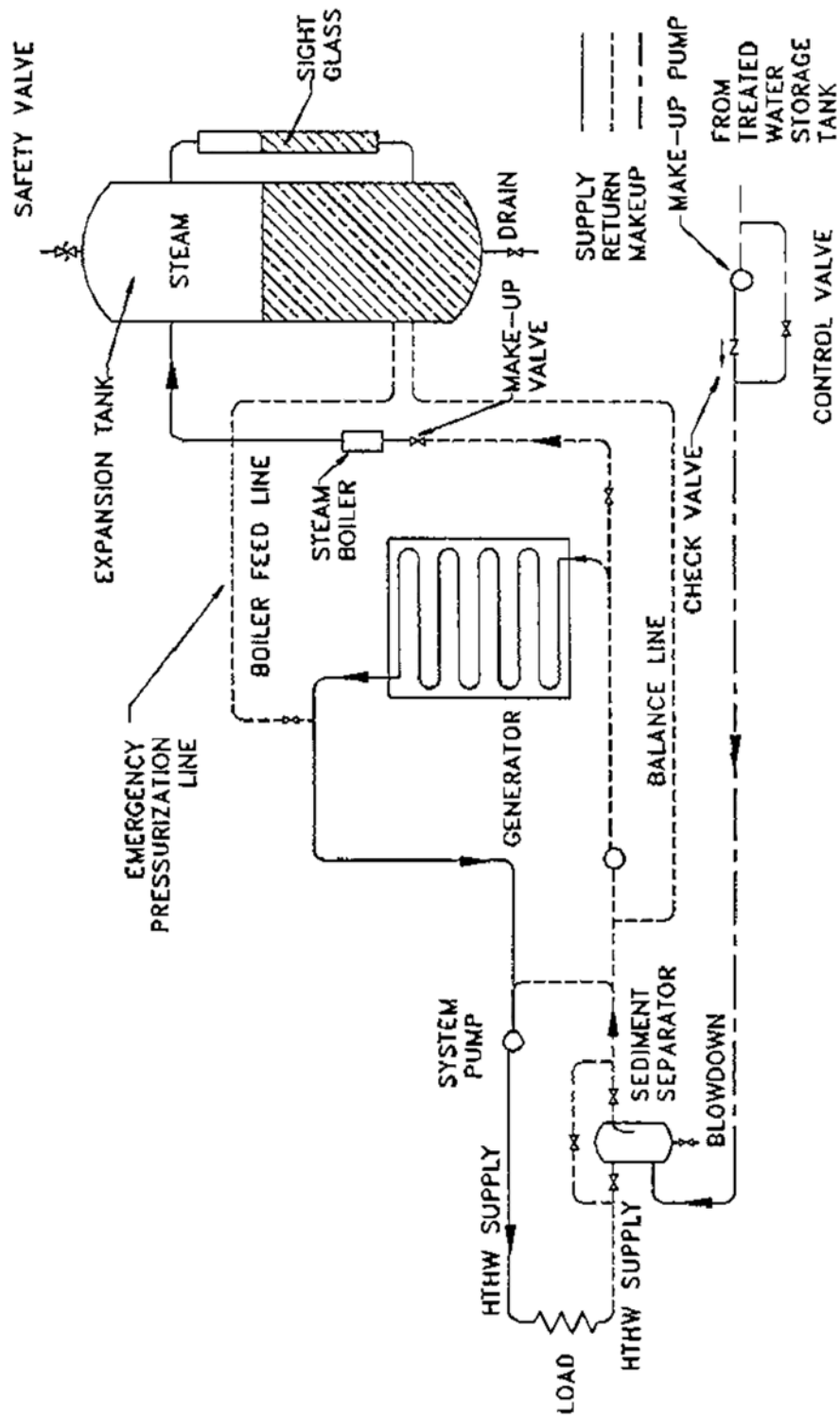


Figure 2

High Temperature Water System with Expansion Tank (two pumps)

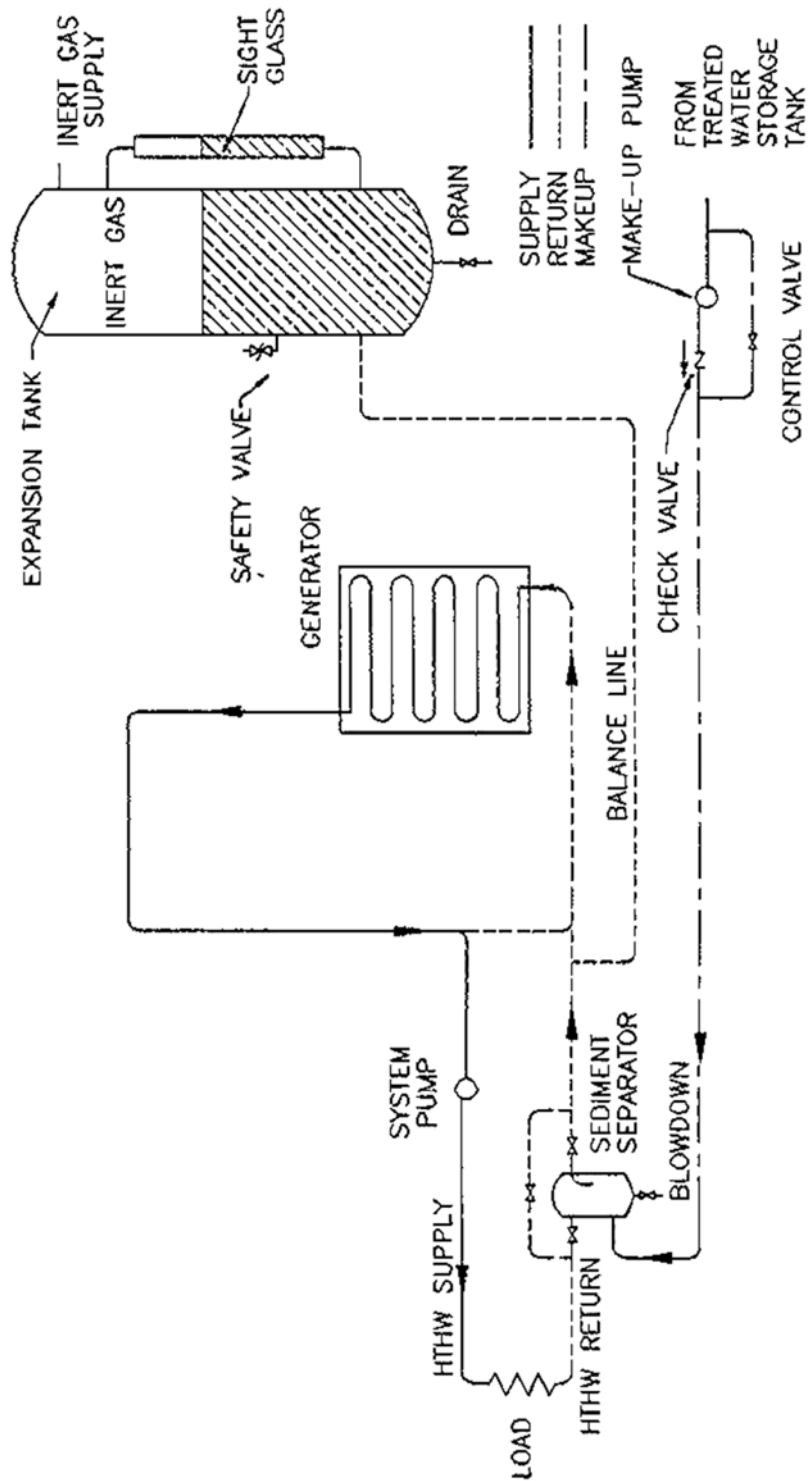


Figure 3

High Temperature Water System with Inert Gas Expansion (one pump)

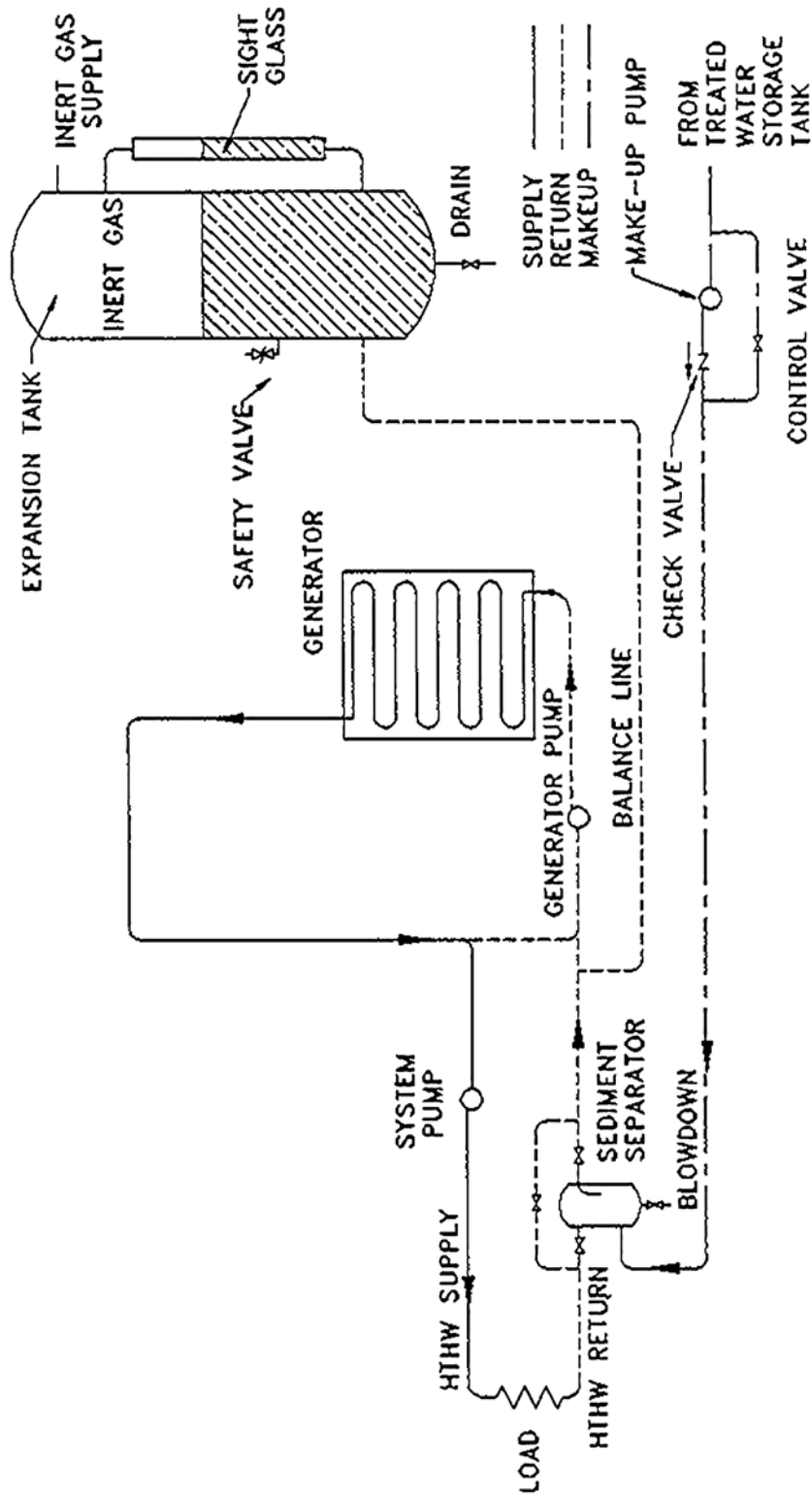


Figure 4

High Temperature Water System with Inert Gas Expansion (two pumps)

**5. TYPES OF DISTRIBUTION CIRCUITS.** There are many types of distribution circuits in general use. The selection of the best system for the particular terrain and situation is essential for satisfactory operation of a HTW plant. Extreme care must be exercised not to design a distribution system that is difficult to operate, balance, and control.

**5.1 DIRECT-SUPPLY, SINGLE-CIRCUIT.** HTW is fed from the central plant directly to the buildings to be served, passes through the heat exchange equipment, and returns to the generators through the return main. This is a simple system to design and is the most prevalent in use. It must be understood that the pressure at the entrance to each connected structure is different and the sizing of control valves to give balanced flow must be carefully analyzed. In a series circuit the decreasing supply-water temperature from structure to structure must be accounted for in heat exchanger design. See Figure 5.

**5.2 DIRECT-SUPPLY, RADIAL.** This system utilizes a number of individual distribution circuits. In such a design the length of runs tends to be shorter, and differences in pressure at the entrances of buildings served are less. Control-valve sizing is not as difficult as with the direct-supply single-circuit. See Figure 6.

**5.3 DIRECT-SUPPLY, REVERSE-RETURN.** As depicted in Figure 7, the return lines are reversed. HTW from the central plant is fed to the connected structures. The return mains are reversed so that the farthest buildings, which have the longest supplies, have the shortest returns. In this manner, the system is more easily balanced and pressure differentials at all connected structures are nearly equal.

**5.4 ONE-PIPE LOOP-MAIN.** A single distribution pipe is used to distribute HTW to the connected structures. Return water from the building is fed back into the loop main. The effect of lower temperatures at buildings farthest from the central plant must be considered. See Figure 8.

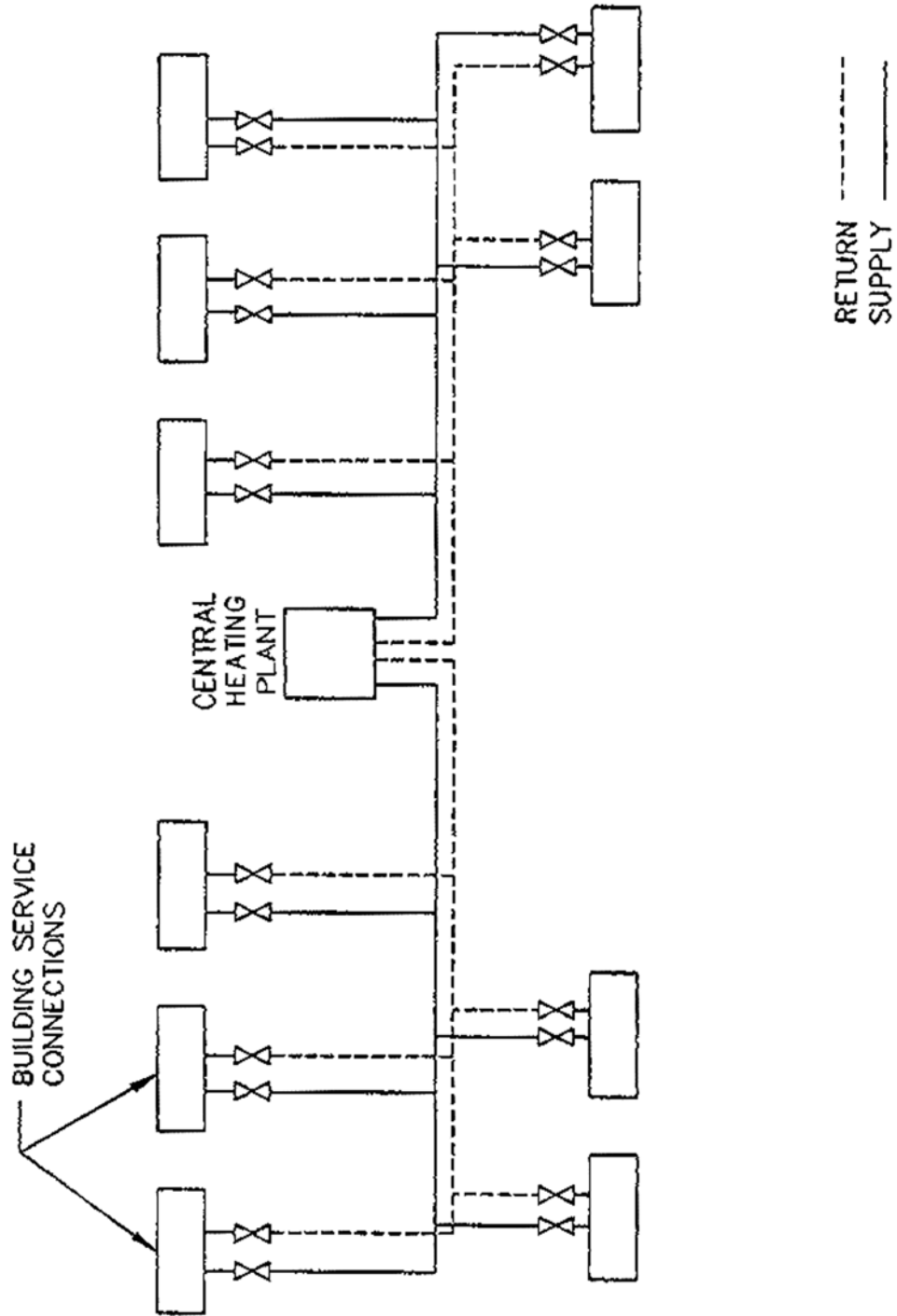


Figure 5  
Direct Supply, Single Circuit

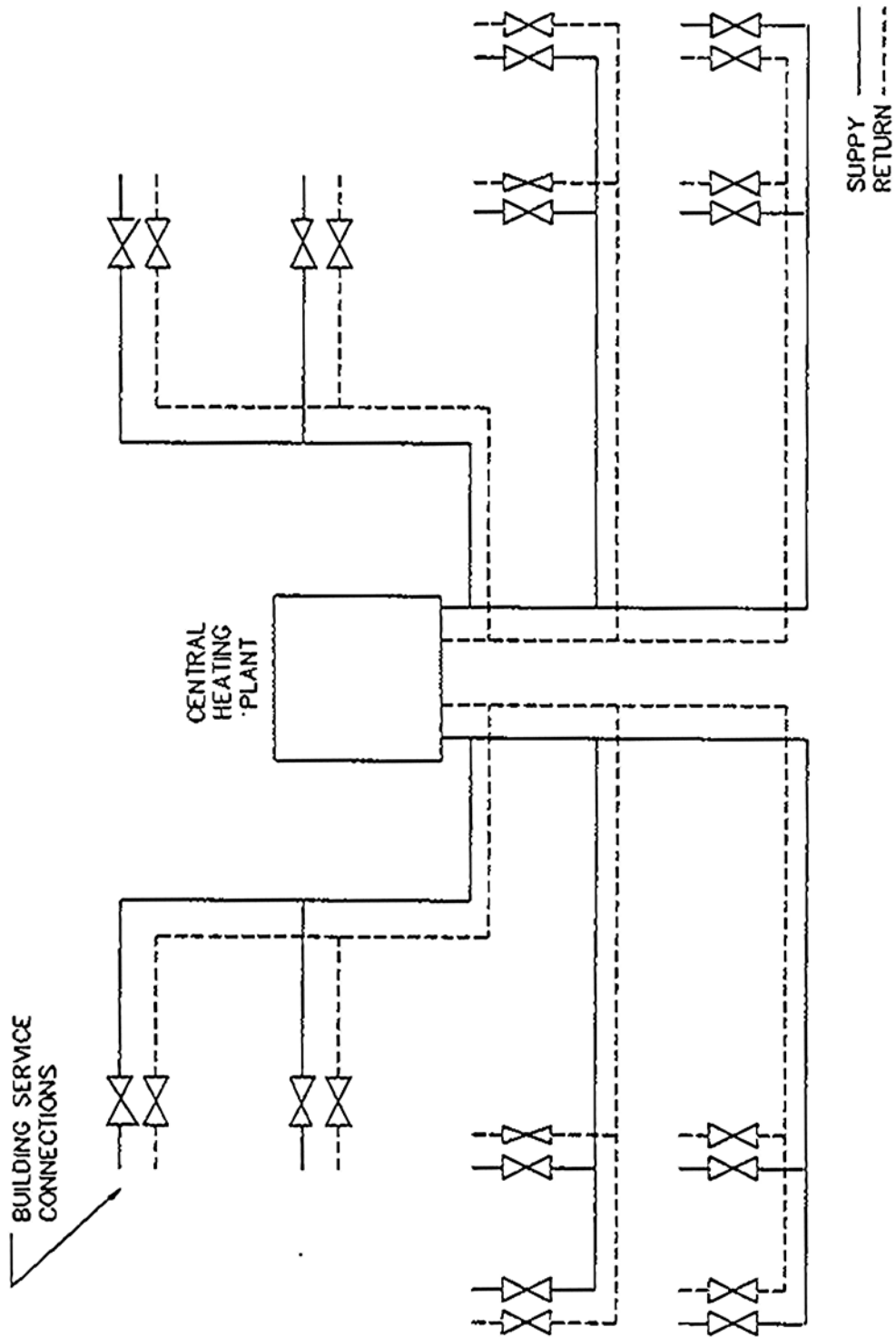


Figure 6  
Direct Supply, Radial

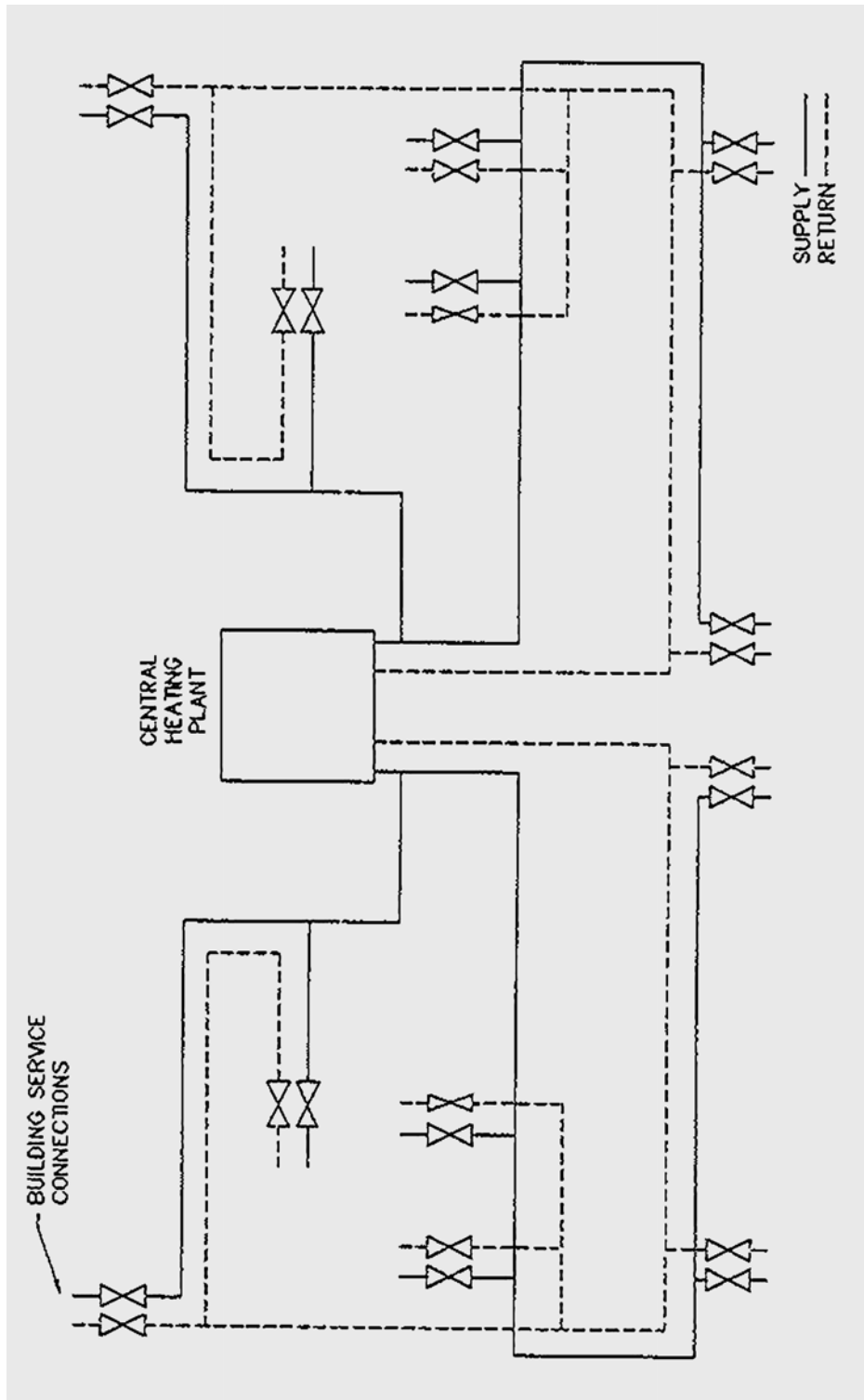


Figure 7  
Direct Supply, Reverse Return

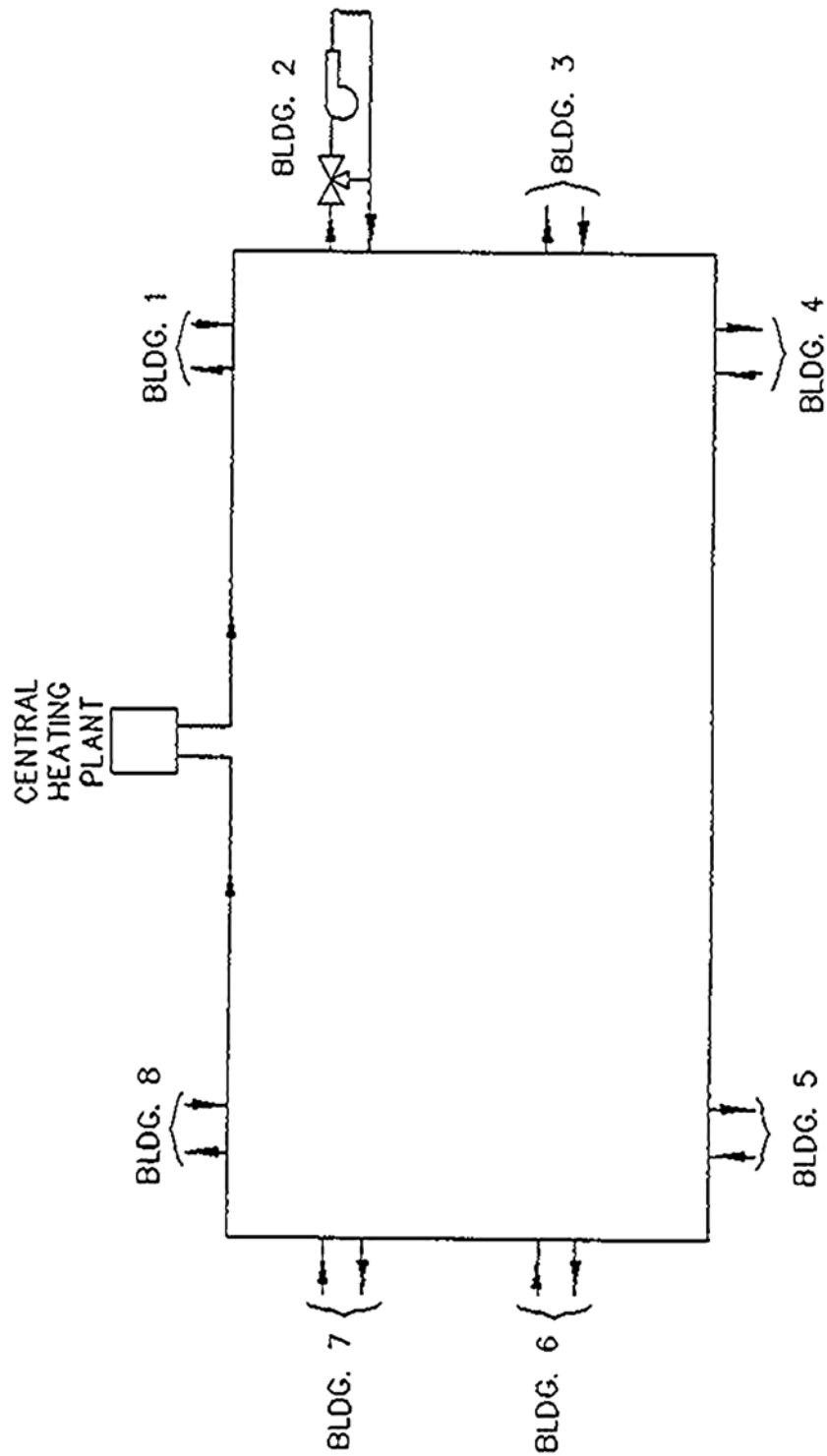


Figure 8  
One-Pipe, Loop-Main



5.5 Primary and Secondary Distribution Systems. This is actually not a separate system but a type of distribution that can be utilized by any of the previously described systems. HTW carries the water economically over long sections of pipe. At the connected structure, the HTW is converted through heat transfer devices into low temperature water. The designer can then use standard heat transfer devices for the buildings. See Figure 9.

## 6. HOT WATER GENERATORS

- Design the heating plant for not less than two generators totaling 135 to 150 percent of the heating load.
- Where practicable, the ultimate heating plant shall not require operation of more than three simultaneously fired generators.

### 6.1 TYPES

- HTW generators should be of the controlled forced circulation water tube type, specifically designed for HTW service.
- Fire-tube boilers and natural-circulation water-tube boilers are not recommended.

**6.2 DESIGN.** Generators should be designed and constructed to be suitable for the intended HTW service and should be certified as such by the manufacturer.

**6.2.1 MAXIMUM PRESSURE DROP THROUGH GENERATOR.** Hot water generators should be designed to have a maximum pressure drop through the generator of 15 psi (103.5 kPa). Keeping the pressure drop low, usually eliminates the need for a separate generator circulation pump, which reduces pump operating and investment costs.

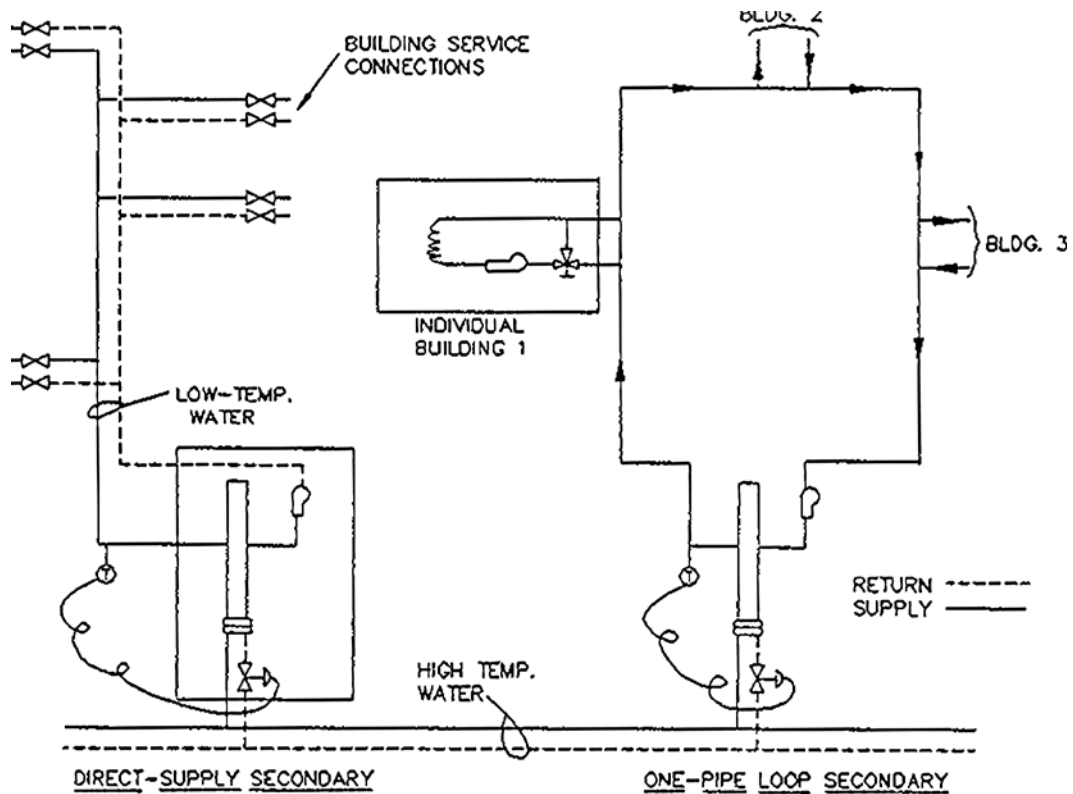


Figure 9

Primary and Secondary Systems

**6.2.2 STEAM SPACE.** A HTW generator should be designed to have no steam space. Inclusion of steam space of any kind within the generator can cause serious circulation problems in the internal tube circuits and possible tube failure.

**6.2.3 TUBE DESIGN.** All tubes in the heat transfer zones should be designed for upflow only. One of the inherent dangers in a HTW generator is the possibility of developing steam bubbles. Since steam occupies much greater space than water, steam bubble generation can cause interrupted flow in a tube or tube circuit with resultant tube failure. When all tubes can produce only upflow, it is possible for the steam to escape from the generator and for water flow equalization to be reestablished. Trapped steam spaces must be avoided. Design of economizers, which are similar in construction to hot water

generators, has shown that upflow is extremely important when the temperature of the water approaches that of saturation. Where a tube is designed for downflow of water, it should be removed from the heat transfer zones.

**6.2.4 EQUALIZATION OF FLOW THROUGH TUBE CIRCUITS.** Generator design must provide for equalization of flow through tube circuits. The water circuiting in the forced circulation generator is a major design consideration. The circuiting must effectively distribute the water in proportion to the heat input in any individual circuit. This is especially important in a steam pressurized system where the water approaches saturation temperature at the discharge of the generator. The flow of water must be proportioned to the heat input to prevent the formation of excessive amounts of steam.

**6.2.5 FURNACE DESIGN.** Furnace design and burner installation should be coordinated to ensure that there is no flame impingement on furnace tubes and walls. Flame clearance is the major criterion when designing oil and gas combustion chambers.

**6.2.6 BLOWDOWN.** Continuous blowdown of generators is a carryover from past steam practices of eliminating sludge from mud drums. Blowdown is not required since there is little, if any, sludge in HTW systems after the initial fill.

**7. PRESSURIZATION.** Pressurization is required in HTW systems in order to prevent the formation of steam in the flow lines. This can be accomplished by exerting a pressure on the water greater than the saturation pressure corresponding to the peak temperature of the system. Collapse of pressurization must be avoided when system is in operation. Sudden or complete collapse of pressurization will lead to flashing of steam, water hammer, and similar phenomena that will set up stresses and strains that the system is not designed to absorb. System should minimize fluctuations in system pressure and outgoing temperature of water from generator. If wide fluctuation in pressure is allowed, the entire system may be affected. Therefore, those systems that allow the system pressure or outgoing temperature to rise or fall significantly are not as

satisfactory. It is also possible that pressure variation will affect the flow rate of water through the generator, especially with one pump systems. Reduced flow rate may result in vapor locking and subsequent tube failure.

## **7.1 ACCEPTABLE PRESSURIZATION METHODS**

**7.1.1 SATURATED STEAM.** The expansion tank is located on the suction side of the system pump by means of an interconnecting balanced line. The steam cushion in the expansion tank is produced by flashing HTW supply and by the operation of the external steam boiler. The HTW heat energy source for flashing is provided by means of a small bleed line connected at the HTW supply leaving the generator. The HTW flows to the expansion tank to maintain the water in the tank at near generator discharge temperature. The bleed line also serves as a boiler feedwater source to the external steam boiler. The external steam boiler adds sufficient additional heat energy to the HTW bleed supply to produce steam at the desired pressure in the upper portion of the compression tank. Although the flashing water content in the lower part of the tank may alone produce a steam cushion at saturation pressure corresponding to HTW supply temperature, system characteristics require pressures higher than saturation. The external boiler provides a means for maintaining system pressures above saturation under all conditions of operation. A pressure of 25 psi (103.5 kPa) above HTW saturation pressure is considered to be a minimum differential. One difficulty experienced in many steam cushioned systems is that of steam flashing in generator tubes during a cold start-up. The reason for this flashing is that until steam has been produced, the system operates in an unpressurized condition. In this state, furnace heat produces steam bubbles in generator tubes in spite of maintained water circulation. As the steam bubbles form, they collect and reduce the mass of water circulated in the tube which further accelerates flashing and reduced heat transfer. This flashing has resulted in tube failure by overheating. The external boiler permits operating pressure to be established prior to firing the generators. This is accomplished by starting the external boiler and establishing the expansion tank pressure first. Once the system is at operating pressure there is little interchange of heat between the steam cushion and the

water in the expansion tank. Therefore, the energy requirements of the external boiler are essentially limited to the tank surface heat losses and the generation of steam to replace the loss of water volume experienced during the net contraction of system water. The small magnitude of heat exchange between the tank water and steam cushion can be better realized when one considers that the temperature of the steam and water at their point of contact is the same. Heat transfer, therefore, depends mainly on conduction between the upper and lower parts of the steam cushion and upper and lower parts of the water volume. Without mechanical turbulence, the water temperature levels will tend to stratify with the warmest (lowest density) on top and the coolest (highest density) on the bottom. Stratification, therefore, tends to limit heat exchange in a manner advantageous to the desired process.

**7.1.2 INERT GAS.** This cycle places the expansion tank on the suction side of the system pumps by means of an interconnecting balance line. No system water flows through the tank due to action of the pumps. The point of connection of the balance line to the system return water piping is known as "the point of no pressure change". This phrase is defined as indicating that the total pressure value within the piping at that point remains the same whether the pumps are running or stopped. The "point of no pressure change" is important to assure a condition that will prevent cavitation at the pump impeller. Such a condition requires that a pressure be maintained well above the boiling point of water at any temperatures likely to exist. The expansion tank is charged with nitrogen to provide the desired system static pressure level. The charge of gas is a fixed quantity and assuming no leakage or water absorption would remain without adding or subtracting amounts of any load condition. The pressure within the expansion tank, however, will not remain constant since the water level is constantly changing with heating load change. As the heating load decreases and the return water becomes hotter, the water expands and flows into the expansion tank raising its level. This rise in level will compress the nitrogen to a higher pressure. In addition to these thermal expansion pressure changes, loss in system water volume will also reduce tank level and subsequently the pressure. Nitrogen is automatically added to maintain the minimum system pressure. Any operating experience that shows steam formation is

taking place in the system requires a reevaluation of pressure settings. Because the system is designed to make pressure and temperature independent of each other, the pressure levels may be raised without affecting temperature control. Minimum pressure should be 25 psig (103.5 kPa) above saturation pressure corresponding to supply water temperature. It is important to note that the HTW generator burners should not be fired until the minimum system pressure has been established. Since the HTW generator will steam even with cold water at low pressure, tube failure is likely. When steam bubbles begin to form in the generator tubing, they insulate the tubes and further speed up tube burnout. Scaling of tubes is also accelerated with steam formation. Nitrogen should be added automatically to the expansion tank through a pressure reducing valve from the nitrogen storage tank. Do not use compressed air for pressurization because air will be absorbed by the HTW system and consequently cause oxygen corrosion in metal components.

## **7.2 UNACCEPTABLE PRESSURIZATION METHODS**

**7.2.1 ELEVATED TANK.** This is theoretically the simplest method of pressurization. The tank or pressurizing vessel is placed on a hillside or suitable elevation, sufficient to provide proper hydraulic pressurization. Pressure change with volume is automatic as it varies with the rise and fall of temperature. However, the practicability of this system depends on suitable terrain, which is rare.

**7.2.2 HYDRAULIC PUMP ARRANGEMENT.** As expansion occurs, an automatic valve releases water to a receiver. As the water contracts, a hydraulic pump is activated, pumping water from the receiver back into the system. This system is impracticable because small volume changes result in large pressure changes. Also, oxygen can be introduced into the system.

**7.2.3 WEIGHTED PLUNGER ARRANGEMENT.** This system utilizes a separate vertical expansion tank, a weighted plunger, and necessary seals. The plunger rises and falls as the volume of water changes and is independent of temperature and volume

changes, maintaining a constant pressure on the system. Seal problems, however, have been serious, and this system has not proved practicable for HTW.

**7.2.4 PRESSURIZATION OF THE BOILER DRUM.** Pressure is maintained in the boiler drum at the desired pressure level with expansion of the water taken up in the rising water line of the drum and any excess amount being relieved to a lightly pressurized vessel. A boiler tube failure would cause immediate pressure loss, with subsequent flashing and water hammer.

**7.2.5 COMBINATION INERT GAS AND STEAM PRESSURIZATION SYSTEM.** In this system a separate expansion vessel, inert-gas tank, external heat source, feed pumps, and necessary controls are used. As water expands, the inert gas pressurized tank allows water to enter an externally heated spill tank under its own pressurization. Pressure in the expansion vessel is kept constant by releasing and refeeding water into the system. This system is complex, costly, and difficult to maintain, and is therefore unacceptable.

**7.2.6 AIR PRESSURIZATION SYSTEM.** The use of air as a pressurization agent is unacceptable since corrosive oxygen is placed into the system.

**7.3 ADVANTAGES AND DISADVANTAGES OF STEAM AND INERT GAS SYSTEMS.** There is little advantage of one system over the other. The choice of pressurization is usually an economic choice rather than one of technical advantage.

#### **7.3.1 STEAM PRESSURIZATION ADVANTAGES**

Lower operating pressures due to pressure-temperature relationships.

- Constant system pressure in expansion vessel.
- Controls usually fewer and less complex.
- Large amount of thermal storage in expansion vessel which aids in peak load absorption.

### 7.3.2 STEAM PRESSURIZATION DISADVANTAGES

- Full flow of heated water through tank, which requires additional insulation.
- Inflexibility of expansion vessel location, which can require higher generator rooms.

### 7.3.3 INERT GAS PRESSURIZATION ADVANTAGES

- Relatively cool expansion vessel expansion tank which is located so that convection currents are restricted and system water flow will not enter the tank.
- Flexibility in locating expansion vessel.
- System pressure that can be designed for any value within recommended limits.

### 7.3.4 INERT GAS PRESSURIZATION DISADVANTAGES

- Higher system pressures. In order to ensure that system pressure will not drop below saturation pressure, a safety factor must be included in design considerations. This may necessitate the use of higher pressure rated fittings and valves.
- Inert gas costs.

**8. EXPANSION VESSELS.** All systems should have dual expansion tanks to allow for inspection and maintenance while the system is on-line.

**8.1 PURPOSE.** Expansion vessels absorb the expansion and contraction of system water due to load variation and ensure, at all times, a controlled system pressure above that corresponding to the saturation temperature. They may also act as a momentary source of water supply in case of a system malfunction.

**8.2 SIZING.** Under no circumstances where heating is the basic load should the expansion volume be based on cold water conditions. The expansion volume should be based on normal design supply and return line differentials.



In a steam-pressurized system the diameter of the expansion vessel should be 6 ft (1.83 m) or more with an aspect ratio of 3.5 to 1.

**8.3 EXPANSION VESSEL VOLUME FOR STEAM PRESSURIZED SYSTEMS.** See Figure 10.

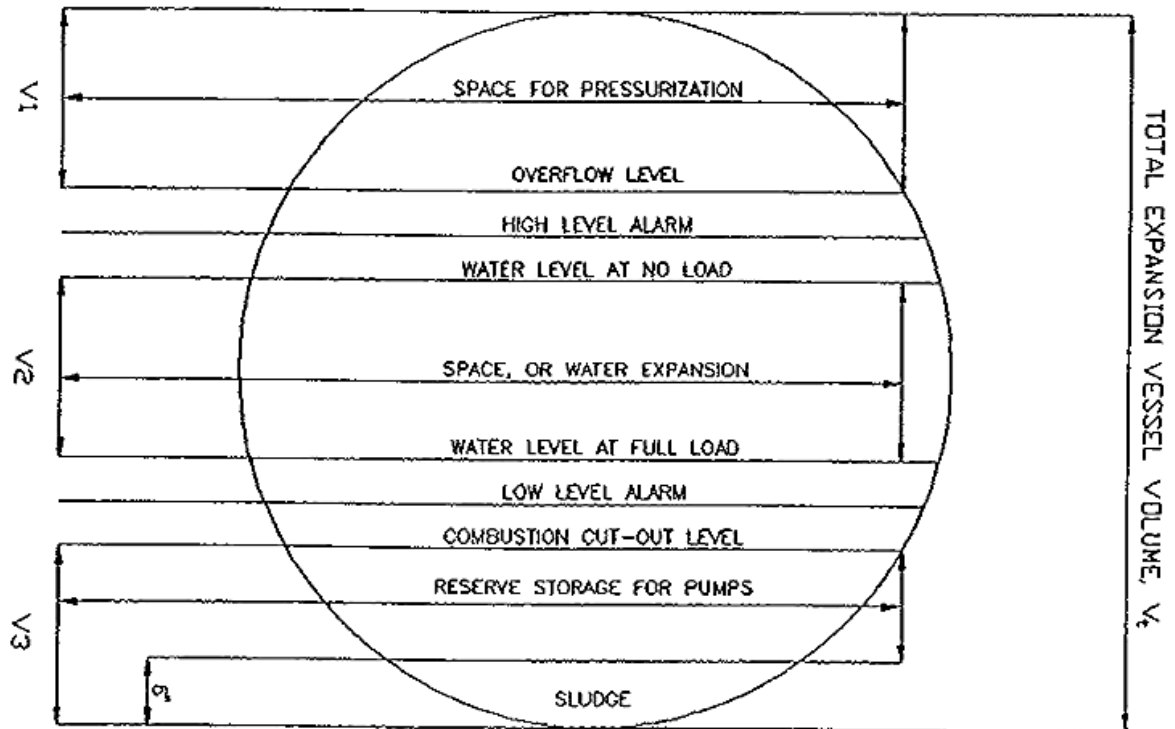


Figure 10

**Pressurized Expansion Tank Relationships**

EQUATION:  $V_T = V_1 + V_2 + V_3$

- Where:
- $V_T$  = Total expansion vessel volume
  - $V_1$  = Volume required for pressurization
  - $V_2$  = Volume required for expansion and contraction
  - $V_3$  = Volume required for sludge space, pump suction coverage, and reserve capacity

**8.3.1 VOLUME REQUIRED FOR PRESSURIZATION**

EQUATION:  $V_1 = 0.2 (V_2 + V_3)$

Where:  $V_1$  = Volume required for pressurization

$V_2$  = Volume required for expansion and contraction

$V_3$  = Volume of sludge space based on 6 inches of depth plus the greater of the following two volumes: (a) the volume of water sufficient to cover the top of the pump intake line in the expansion vessel by 6 inches or (b) the volume needed to provide a 30 second supply of water based on combined pump capacity.

### 8.3.2 VOLUME REQUIRED FOR EXPANSION AND CONTRACTION

These two equations show the development of this volume calculation.

EQUATION:  $V_2 = \text{Max Supply Water Expansion} + \text{Max Return Water Expansion}$

EQUATION:  $V_2 = ([LW_{\text{maxst}} / SD_{\text{maxst}}] - [LW_{\text{minst}} / SD_{\text{minst}}]) +$   
 $+ ([LW_{\text{maxrt}} / SD_{\text{maxrt}}] - [LW_{\text{minrt}} / SD_{\text{minrt}}])$

Where:  $LW_{\text{maxst}}$  = lb of water at maximum supply temperature  
 $LW_{\text{minst}}$  = lb of water at minimum supply temperature  
 $SD_{\text{maxst}}$  = specific density at maximum supply temperature  
 $SD_{\text{minst}}$  = specific density at minimum supply temperature  
 $LW_{\text{maxrt}}$  = lb of water at maximum return temperature  
 $LW_{\text{minrt}}$  = lb of water at minimum return temperature  
 $SD_{\text{maxrt}}$  = specific density at maximum return temperature  
 $SD_{\text{minrt}}$  = specific density at minimum return temperature

Supply water volume = the volume from the generator outlet, through the expansion vessel, pumps, supply distribution system and heat exchange equipment

Return water volume = the volume from the heat exchanger outlet, through the return distribution system to the inlet side of the generator

### 8.3 EXPANSION VESSEL VOLUME FOR GAS PRESSURIZATION SYSTEMS.

EQUATION:  $V_T = V_1 + V_2 + V_3$

Where:  $V_T$  = expansion vessel volume

$V_1$  = volume required for pressurization

$V_2$  = volume required for expansion and contraction

$V_3$  = volume required for sludge space, pump suction coverage, and reserve capacity

### 8.3.1 VOLUME REQUIRED FOR PRESSURIZATION

EQUATION:  $V_1 = (P_{\min}/V_{\max})/P_{\max}$

Where:  $V_1$  = minimum gas volume required for pressurization  
 $P_{\min}$  = minimum gas pressure (should be above saturation pressure-temperature relationships)  
 $V_{\max}$  = maximum gas volume ( $V_{\max} = V_2 + V_3$ )  
 $P_{\max}$  = maximum gas pressure (should be below pressure ratings of piping, valves and fittings)  
 $V_2$  = volume required for expansion and contraction  
 $V_3$  = volume of sludge space based on 6 inches of depth plus the greater of the following two volumes: (a) the volume based on sufficient water to cover the top of the pump intake line in the expansion vessel by 6 inches or (b) the volume needed for a 30-seconds supply of water based on combined pump capacity.

**8.3.2 VOLUME REQUIRED FOR EXPANSION AND CONTRACTION.** These two equations show the development of this volume calculation.

EQUATION:  $V_2 = \text{Max Supply Water Expansion} + \text{Max Return Water Expansion}$

EQUATION:  $V_2 = ([LW_{\maxst}/SD_{\maxst}] - [LW_{\minst}/SD_{\minst}]) + ([LW_{\maxrt}/SD_{\maxrt}] - [LW_{\minrt}/SD_{\minrt}])$

Where:  $LW_{\maxst}$  = lb of water at maximum supply temperature  
 $LW_{\minst}$  = lab of water at minimum supply temperature  
 $SD_{\maxst}$  = specific density at maximum supply temperature  
 $SD_{\minst}$  = specific density at minimum supply temperature  
 $LW_{\maxrt}$  = lb of water at maximum return temperature  
 $LW_{\minrt}$  = lb of water at minimum retrun temperature  
 $SD_{\maxrt}$  = specific density at maximum return temperature  
 $SD_{\minrt}$  = specific density at minimum retrun temperature

Supply water volume = the volume from the generator outlet, through the expansion vessel, pumps, supply distribution system and heat exchange equipment

Return water volume = the volume from the heat exchanger outlet, through the return distribution system to the inlet side of the generator

#### **8.4 DESIGN CRITERIA FOR STEAM PRESSURIZED SYSTEMS**

- The vertical height of the expansion vessel above the pump shall be such that the available net positive suction head (NPSH) is not less than 125 percent of the required NPSH of the pump.
- Provisions must be made for expansion and anchoring of the supply and return connections of the expansion vessel.
- The generator supply piping to the steam-pressurized vessel should slope upward to allow venting of free gases. Cut-off valves should be located at the beginning and end of the supply line. Each generator should have separate supply piping to the expansion vessel.
- Generator-supply piping entering a steam-pressurized vessel should be horizontal, with holes or slots to release water, thereby breaking up steam bubbles and avoiding shocks.
- In the expansion vessel, the pump intake line should be located to prevent short circuiting of the cooler return water, and a minimum of 6 inches (152 mm) below the water line of the expansion vessel.
- Provisions should be made to prevent vortexes from forming at the inlet of the pump intake line. This will aid in preventing cavitation in the pump.
- The expansion vessel must be located at a level above the generator outlet. An expansion vessel located below the boiler outlet can flood, causing the steam space to form outside the expansion vessel.

#### **8.5 DESIGN CRITERIA FOR GAS PRESSURIZED SYSTEMS**

- The pump suction line should extend a minimum of 6 inches (152 mm) above the expansion vessel bottom to prevent sludge from entering the pump.
- The line between the expansion vessel and return main should be the same size as the return main.

- The expansion vessel should be located on the inlet side of the generator and on the suction side of the pump.

**9. PUMPS.** The three primary considerations in pump selection are suitability for HTW services, leak-tightness and NPSH.

**9.1.1 PUMP TYPES.** Single stage centrifugal pumps are normally used to circulate HTW through the distribution system and through the generator. The pumps selected for this service must be designed especially for HTW in order to secure efficient, reliable operation with a minimum of maintenance. The head characteristic of the system circulating pumps should be flat in order to deliver nearly constant head throughout the range of operating capacities. Generator circulating pumps shall have steep head characteristics to accommodate the controlled circulation concept. At the same time it is necessary that the maximum head should occur at shutoff and should fall off gradually up to maximum capacity, suffering a decrease in pressure no more than 15 percent below the shutoff pressure at the maximum operating capacity. Circulating pumps are located in the return line of the system in order to maintain the highest possible positive suction head. To further improve and guarantee efficient operation of these pumps, a mixing connection is provided so that a portion of the system water mixes with the water from the generator, lowering its temperature to avoid the danger of flashing at the pump suction. The suction intake of HTW pumps must be carefully designed to avoid sudden changes in velocity or direction which might contribute to flashing and inefficient operation. Adequate water cooling must be provided for all pumps. Mechanical seals are recommended.

## **9.2 PUMP ACCEPTANCE TESTS**

- All pumps used for HTW should be tested at the factory in a range of temperatures and corresponding saturation pressures from 250 degrees F (121 degrees C) up to the design operating temperature of the system. The pump should be pressure tested at one and one-half times the maximum design

operating pressure of the system. The manufacturer must certify that these tests were performed.

- The pumps should be rated in terms of pounds per minute versus head requirements at the above mentioned pressures and temperatures.

### **9.3 CONSTANT VERSUS VARIABLE SPEED PUMPS**

- Variable speed pumps should be used for HTW systems when economically justifiable.
- Preferred procedure is to use three pumps, each sized for 50 percent of the load, with one pump for stand-by.
- Where summer loads are small, an additional pump sized at 25 percent or less may be used.

### **9.4 NET POSITIVE SUCTION HEAD**

- The required NPSH of the pump shall not exceed 80 percent of the available NPSH. The required NPSH is the head that the pump manufacturer must know for correct operation of the pump. The available NPSH is the head needed to provide this required head, in the form of either static or pressure head.
- If two or more pumps of differing head requirements are used, NPSH should be based on the pump having the greater head requirements.

### **9.5 ONE-PUMP VERSUS TWO-PUMP SYSTEMS**

- A one-pump system may have many pumps in the system, but they all serve the combined purpose of delivering water to the generators as well as the system.
- A two-pump system may have many pumps in the system, but one set of pumps delivers water to the generators, and another set of pumps delivers water to the system.
- Hot water generators are designed for a specific flow of water through the generator. A minimum quantity is needed to protect against tube failure and steam generation. In a one-pump installation, this flow is usually controlled by an automatic bypass valve which provides a uniform flow to the boiler regardless of

distribution system load variations. In a very large HTW system it may become necessary to use a two-pump system for control of water through the generator. The quantity of water circulated through each generator is kept more or less constant no matter at what rate the generator is fired. There need be no relationship during operation between the quantities of water circulated by the system pumps and the generator circulation pumps in this arrangement except that system flow must always be less than generator flow. With this double pump arrangement no instruments or other equipment are needed to control the flow through the generator because the circulation pumps have a constant capacity and are entirely independent of the system circulation.

- Where two or more generators are installed, the generator having the greatest pressure drop should be used in pump head calculations.

**9.6 SINGLE- VERSUS MULTIPLE-STAGE PUMPS.** Single-stage pumps should be used for HTW systems. Where the head requirements exceed the capabilities of a single-stage pump, the preferred procedure is to use single-stage booster pumps within the distribution system.

### **9.7 LOCATION**

- On steam-pressurized systems, pumps should be located in a central position with respect to the generator(s) and expansion vessel. The lines connecting the expansion vessel and pump should contain no unnecessary turns or restrictions, and the pump location should provide the maximum NPSH possible. The pump should be accessible for maintenance, and provisions should be made to prevent misalignment due to external piping at elevated temperatures. Usually the pump sucks from the hottest water in the system. On some systems, a blending mechanism is utilized to reduce the temperature to the pump to prevent flashing or cavitation.
- On gas-pressurized systems, the expansion vessel should be located on the inlet side of the generator and on the suction side of the pump. The pump shall be accessible for maintenance and provisions made to prevent misalignment at elevated temperatures.

## **9.8 MISCELLANEOUS**

- Where separate generator pumps are used, the pump characteristics should be in accordance with the recommendations of the generator manufacturer.
- In order to reduce the costs of meeting increased future head requirements of the system, all pumps and casings should be designed to take the next larger impeller size.
- The pump motor and accessories should be selected on the basis of the larger impeller size.

## **10. CONTROLS**

### **10.1 COMBUSTION CONTROLS FOR FORCED CIRCULATION GENERATORS WITH STEAM PRESSURIZED SYSTEMS**

- Provide for continuous modulating control of firing, since interruption of firing may cause a loss of pressurization in hot temperature water systems.
- For generator outputs up to 10,500,000 Btu per hour (3077 kW), use the water outlet temperature from each boiler to control the firing rate of the generator.
- For generator outputs under 30,000,000 Btu per hour (8790 kW), provide a water outlet temperature regulator on each generator to control the firing rate on that generator and a master pressure controller on the expansion drum to override the individual temperature regulators when necessary to average out the total load among the generators carrying the load.
- For generator outputs over 30,000,000 Btu per hour (8790 kW), regulate the firing rate of each generator by the temperature difference between outlet and inlet water temperatures. This difference must be measured directly in order to avoid compounding instrument errors. Provide a master pressure controller on the expansion drum to override the individual temperature regulators when necessary.
- As in steam boilers, draft controls shall be suited to the furnace draft arrangement, whether pressurized or balanced.



## **10.2 COMBUSTION CONTROLS FOR FORCED CIRCULATION GENERATORS**

**WITH INERT GAS-PRESSURIZED SYSTEMS.** Use the same controls as on a steam-pressurized system, except omit the master pressure regulator on the expansion tank.

## **10.3 WATER FLOW CONTROL FOR STEAM-PRESSURIZED HTW SYSTEMS WITH FORCED CIRCULATION GENERATORS**

### **10.3.1 PLANTS WITH COMBINATION SYSTEM AND GENERATOR CIRCULATING PUMPS**

- Measure water flow at each generator inlet so that all generator flows can be equalized.
- Place an automatic control valve (incorporating a manual three-valve bypass) in bypass piping between the pump discharge header and return line from the distribution system. Use generator flow measurements to regulate the automatic bypass control valve to assure constant design water flow through each generator, regardless of load conditions.
- Incorporate a pressure differential switch across the pump headers or provide a minimum flow switch in each flow meter to cut out combustion when there is insufficient flow through a generator.
- Interlock the pump starters with combustion control to prevent generator operation without pump operation.
- Variable speed control of pumps may be used if savings justify additional costs of wound rotor motors and speed control equipment or variable speed clutches.
- Control flow of blending water from return line to pump suction to maintain a constant supply water temperature to the distribution system and to prevent cavitation of pumps due to flashing. This should be done manually for plants with generators under 30,000,000 Btu per hour (8790 kW) and automatically for plants with larger generators.

### **10.3.2 PLANTS WITH SEPARATE GENERATOR CIRCULATING PUMPS IN USE WITH SYSTEM CIRCULATING PUMPS**

- Measure water flow at each generator and provide manual control of this flow so that all generator flows can be equalized.
- Incorporate a minimum flow switch in each generator flow meter to interrupt combustion when the flow drops below a safe value.
- Interlock the generator circulating pump starters with combustion controls of all generators to prevent any generator operating without a pump operating.
- Generator circulating pumps should always operate at constant speed. The system pumps may operate at variable speed only if the additional costs of variable-speed equipment can be economically justified.
- Control the flows of blending water from the return line to system pump suction by a manual valve for plants with generators under 30,000,000 Btu per hour (8790 kW) and by an automatic valve for plants with larger generators. Install a manual throttling valve in the return line to the suction side of the generators circulating pumps to create a pressure drop so that the control valve for the blending water will be effective and to stop steaming conditions.

### **10.3.3 MAKEUP WATER FLOW CONTROL**

- For small flow loss, use manual start and stop for normal makeup pumps when expected loads are steady. If loads fluctuate widely, provide for automatic start and stop of these pumps by float controls in the expansion tank.
- For large flow loss, use manual start and stop for emergency makeup pumps. If there is no emergency pump, provide an electrical interlock in the system circulating pump starters which would trip out these pumps when the low level alarm on an expansion tank is activated.

**10.3.4 AUTOMATIC ISOLATION VALVES.** Equip all systems with motor-operated valves to isolate the distribution system and assure flow through the generators in case of a distribution line break. The supply isolation valve should close in approximately 15 seconds with the pressure sensing element located on the downstream side of the

valve. The return line isolation valve should close as soon as possible without allowing excessive pressures to develop due to the change in velocity head into pressure head. The pressure sensing element should be on the upstream side of the return isolation valve. The controls shall provide for an interruption of combustion and stoppage of the secondary (distribution) system pump operation but allow continuation of primary (generating circulating) pump operation.

#### **10.4 WATER FLOW CONTROL FOR STEAM PRESSURIZED HTW SYSTEMS WITH NATURAL CIRCULATION GENERATORS**

- In plants with combustion system circulation and generator circulating pumps, part of the water discharged from combination pumps is fed to steam boilers through single element feedwater regulators. As with forced recirculation boilers, no other automatic bypass valves are required.
- Plants with separate system circulation and generator circulating pumps use the same type of system circulation pumps as for the forced-circulation boiler systems (see above). They also use the same type of feed pumps as for steam heating plants.
- Provide continuous operation makeup pumps which feed either the boilers or expansion tanks in response to level controls. In case of large water flow loss in a system, provide for manual start and stop of emergency makeup pumps.

**10.5 WATER FLOW CONTROL FOR INERT GAS PRESSURIZED SYSTEMS.** Use the same controls as for steam pressurized systems with forced circulation generators (see above), except, also use automatic level controls for expansion tank.

**10.6 OVERFLOW CONTROL ON STEAM PRESSURIZED EXPANSION TANKS.** Use pneumatic float valves for control of overflow levels.

### **11. PIPING**

- Pipe connections shall be welded. Screwed joint connections except for pressure or temperature sensing devices shall not be used. Connections to valves and equipment shall be flanged or welded. Use metallic or spiral wound gaskets.
- Pressure piping shall conform to the requirements of ANSI B31.1, Power Piping.
- Copper and bronze materials should be avoided for HTW piping.
- Expansion should be controlled by the use of expansion loops.

## 12. VALVES

- All valves should be constructed of cast-steel bodies, stainless steel trim, and packing such as Teflon.
- Bronze-trimmed valves should not be used in HTW systems.
- All valves should be capable of being repacked under operating pressures.
- Gate valves should be used only as generator isolation valves.
- Any valves other than control valves should have as low a pressure drop as possible in order to reduce frictional losses and pumping costs.

## 13. SPACE AND PROCESS HEATING EQUIPMENT

**13.1 DIRECT HEATING WITH HIGH TEMPERATURE WATER.** This type of heating may be achieved by:

- Unit heaters (usually high velocity type) used in buildings where the required height for mounting still gives suitable temperatures at the floor level.
- Radiant panel heating sometimes used in large spaces where the mounting height is greater than 10 ft from the floor level. The panels need to be spread apart so that the radiation is uniformly directed over the spaces to be heated. With high temperature radiant panel heating, comfort conditions can be obtained with lower space temperatures than those required for convection heating. This feature is especially desirable for heating areas with high ceilings such as a warehouse or hangar.

- Forced hot air heating systems distribute air throughout the spaces to be heated. These systems can be equipped with extended surface air heaters which use HTW as the heating medium.
- Hospitals, laundries, kitchens and similar facilities utilize steam. HTW can be used as the heating source provided that steam pressure beyond the saturation pressure of the HTW plant is not required. This eliminates separate steam-producing units, traps, and pressure-reducing valves in the primary circuit. A sudden demand for steam can be handled with the large heat storage available in the HTW system, but these heat exchangers will accumulate solids and must be periodically cleaned.

**13.2 INDIRECT HIGH TEMPERATURE.** Heat exchangers should be designed to effect maximum temperature drops consistent with the pressure or temperature of the medium produced. A reduction in primary operating temperatures may effectively nullify the operation of these heat exchangers unless they are specifically designed for varying inlet-temperature conditions. There are two basic types of indirect heat exchangers:

- Flash or instantaneous types. These are vessels which store a small amount of water with respect to the heating capabilities of the coil. Since no water is stored, the fly wheel effect of heavy demands is not available, and any demand in excess of the capabilities of the coil results in rapid temperature drops.
- Storage or inertial types. These are classified as vessels which store a large amount of water with respect to the heating ability of the coil. The large amount of stored water is able to meet unusually heavy demands without much difficulty. If load requirements are periodic, standby losses may be excessive.

#### **14. MAKEUP WATER AND WATER TREATMENT**

- Makeup water is required due to small leaks, leakage around packed joints of valves, relief valves, pump shafts, etc.
- Two makeup pumps are required, each sized for 0.5 percent of the total distribution system flow. In case of a coal-fired generator, an additional emergency pump rated at 5.0 percent of the distribution system flow is required.

- A treated water storage tank should be provided for emergency pumping requirements. This tank is usually sized for approximately 20 minutes makeup pump demand except, in coal-fired plants, the tank shall be sized for 40 minutes of emergency flow capacity.
- A qualified water consultant should be retained on every HTW installation to advise on water treatment for the primary and secondary water circuits.
- The initial filling of the HTW system or large water loss replacements should be through a water treatment source other than the plant system.
- Generally deaeration is not required. Oxygen is usually removed during the initial startup of the system.
- A demineralization unit is usually not required for a HTW system.
- A water softener sized to take care of make-up requirements for operating conditions is recommended.
- The permanent water softener may need to be supplemented for initial fill requirements
- Zero hardness (5 parts per million or less) and a PH of 9.3 to 9.9 with no free oxygen should be maintained in the system at all times.