
CHAPTER 11

FACILITY STEAM AND CONDENSATE SYSTEMS

This chapter describes systems concerned with the generation, distribution, installation, and sizing criteria for steam and steam condensate systems to be used for purposes other than comfort or space heating. The systems described here include those providing steam for kitchen and laundry facilities, water purification, humidification, and steam tracing, as well as steam systems for laboratory and sterilizing purposes. Steam for space and comfort heating, although briefly discussed, are outside the scope of this handbook. Heat tracing systems utilizing steam are described in Chap. 5.

SYSTEMS DESCRIPTION

The complete system is actually composed of two codependent, connected subsystems. The steam subsystem includes a source of steam, distribution piping to carry steam to the point of use, and controls to regulate steam flow at the required pressure or temperature. At some point after the steam has been used at the terminal equipment, the steam condenses into a liquid, called *condensate*. The condensate subsystem may be designed in such a way that the condensate is returned to the steam source, absorbed into the process and lost from the system, or simply wasted to a drain. If the condensate is to be recovered for reuse or is to be wasted, then additional components such as steam traps, flash tanks, condensate piping, heat rejection terminal units, and condensate pumps may be required.

CODES AND STANDARDS

The following standards are generally used to design the steam and condensate systems that are the subject of this handbook:

1. ASME Boiler and Pressure Vessel Code
2. ASTM B 31-9, Power Piping Code, Steam Properties

Local building codes and regulations should be carefully checked to ensure that the installation meets their requirements. Local conditions, such as atmospheric pressure, should be checked to ensure the usability of the details and design data.

FUNDAMENTALS

STEAM

Water exists in three states: solid, liquid, and gas. Steam vapor is a combination of liquid and gas. When liquid water is heated to a point where it can no longer exist as a liquid, it has reached the *saturation point*. From the saturation point, any further addition of heat (called the *heat of vaporization*) causes water to *boil*, that is, to rapidly and violently evaporate into vapor, or steam. When the term *steam* is used, it implies *dry steam*, without any suspended water droplets. Steam has all the characteristics of a gas and is normally invisible. It only appears as a mist when it cools and is partially condensed, causing droplets to form in the vapor stream.

Compared to water at any given temperature and pressure, steam occupies about 1600 times greater volume, which is its most useful property. This makes steam an economical heat transfer medium since relatively few pounds per hour of steam flow can transfer a great deal of heat as the steam condenses.

BOILER FEEDWATER

The term *boiler feedwater* is used to describe all water introduced into a boiler for the purpose of being converted into steam.

STEAM TEMPERATURE

Temperature of steam is the measurement of heat of the vapor at any given pressure.

STEAM QUALITY

Steam quality defines the amount of water present in the fluid stream that has not been evaporated into steam. It is calculated by the use of calorimeter tests. It is often defined by its dryness percentage, which is the proportion of completely dry steam present compared to the total amount of steam in the sample being measured. Steam quality, in percent, is measured to quantify flowmeter readings for billing purposes, check boiler practices, and to troubleshoot process operations.

Steam is classified as either wet or dry. Saturated steam has a steam quality of 100 percent.

Saturated Steam

The term *saturated steam* describes steam the moment it is generated in a common boiler where steam and liquid water are in direct contact.

Saturated steam is described as *dry* because all the moisture has been condensed into steam. A pound of wet steam may have the same temperature and pressure as a pound of dry steam, but it will contain less heat since some of the water is in liquid form and therefore contains no latent heat, only sensible heat. In practice, heat loss from the piping may condense a portion of the steam, so that a small amount of liquid may be carried along with the steam, producing a wet steam flow. Superheating the steam will minimize condensation of steam flowing in pipes.

Saturated steam pressure and saturation temperature are directly related. As the pressure of the steam rises, its temperature also rises. Some properties of saturated steam are listed in Table 11.1.

Dry Steam

Dry steam is steam that has been fully evaporated to a point where it contains no droplets of liquid water in suspension.

Wet Steam

Wet steam contains droplets of water in suspension. The droplets can be removed by means of separators and by adding heat.

HEAT

Heat is a form of energy and as such forms a part of the enthalpy of a liquid or gas.

Enthalpy (Sensible Heat)

Sensible heat is the heat energy added to boiler feedwater that raises the feedwater temperature. *Enthalpy*, or heat content, is the total internal and external energy of a fluid or vapor due to both its pressure and temperature. It is expressed in British thermal units (Btu). It's called "sensible heat" because the effect of the heat transfer can be sensed by observing a rise in the water temperature. Sensible heat is the number of British thermal units required to raise the temperature of a pound of melted ice from 32°F to the saturation temperature at a given pressure. The higher the initial temperature of the boiler feedwater, the less sensible heat is required to bring the water to the saturation point.

Latent Heat of Vaporization

Latent heat of vaporization is heat transferred to water that will change its state, at the saturation temperature for a given pressure, from liquid to steam. Also called *latent heat of evaporation* and *enthalpy of evaporation*, it is the number of British thermal units required to change a pound of boiling water into a pound of steam at a given pressure. The additional heat causes water molecules to break the bonds

TABLE 11.1 Properties of Saturated Steam

Pressure, psig	Temper- ature, °F	Heat, Btu/lb			Specific volume, ft ³ /lb
		Sensible	Latent	Total	
25*	134	102	1017	1119	142
20	162	129	1001	1130	73.9
15	179	147	990	1137	51.3
10	192	160	982	1142	39.4
5	203	171	976	1147	31.8
0	212	180	970	1150	26.8
1	215	183	968	1151	25.2
2	219	187	966	1153	23.5
3	222	190	964	1154	22.3
4	224	192	962	1154	21.4
5	227	195	960	1155	20.1
6	230	198	959	1157	19.4
7	232	200	957	1157	18.7
8	233	201	956	1157	18.4
9	237	205	954	1159	17.1
10	239	207	953	1160	16.5
12	244	212	949	1161	15.3
14	248	216	947	1163	14.3
16	252	220	944	1164	13.4
18	256	224	941	1165	12.6
20	259	227	939	1166	11.9
22	262	230	937	1167	11.3
24	265	233	934	1167	10.8
26	268	236	933	1169	10.3
28	271	239	930	1169	9.85
30	274	243	929	1172	9.46
32	277	246	927	1173	9.10
34	279	248	925	1173	8.75
36	282	251	923	1174	8.42
38	284	253	922	1175	8.08
40	286	256	920	1176	7.82
42	289	258	918	1176	7.57
44	291	260	917	1177	7.31
46	293	262	915	1177	7.14
48	295	264	914	1178	6.94
50	298	267	912	1179	6.68
55	300	271	909	1180	6.27
60	307	277	906	1183	5.84
65	312	282	901	1183	5.49
70	316	286	898	1184	5.18
75	320	290	895	1185	4.91
80	324	294	891	1185	4.67
85	328	298	889	1187	4.44
90	331	302	886	1188	4.24
95	335	305	883	1188	4.05

TABLE 11.1 Properties of Saturated Steam (*Continued*)

Pressure, psig	Temper- ature, °F	Heat, Btu/lb			Specific volume, ft ³ /lb
		Sensible	Latent	Total	
100	338	309	880	1189	3.89
105	341	312	878	1190	3.74
110	344	316	875	1191	3.59
115	347	319	873	1192	3.46
120	350	322	871	1193	3.34
125	353	325	868	1193	3.23
130	356	328	866	1194	3.12
140	361	333	861	1194	2.92
145	363	336	859	1195	2.84
150	366	339	857	1196	2.74
155	368	341	855	1196	2.68
160	371	344	853	1197	2.60
165	373	346	851	1197	2.54
170	375	348	849	1197	2.47
175	377	351	847	1198	2.41
180	380	353	845	1198	2.34
185	382	355	843	1198	2.29
190	384	358	841	1199	2.24
195	386	360	839	1199	2.19
200	388	362	837	1199	2.14
205	390	364	836	1200	2.09
210	392	366	834	1200	2.05
215	394	368	832	1200	2.00
220	396	370	830	1200	1.96
225	397	372	828	1200	1.92
230	399	374	827	1201	1.89
235	401	376	825	1201	1.85
240	403	378	823	1201	1.81
245	404	380	822	1202	1.78
250	406	382	820	1202	1.75
255	408	383	819	1202	1.72
260	409	385	817	1202	1.69
265	411	387	815	1202	1.66
270	413	389	814	1203	1.63
275	414	391	812	1203	1.60
280	416	392	811	1203	1.57
285	417	394	809	1203	1.55
290	418	395	808	1203	1.53
295	420	397	806	1203	1.49
300	421	398	805	1203	1.47
305	423	400	803	1203	1.45
310	425	402	802	1204	1.43
315	426	404	800	1204	1.41
320	427	405	799	1204	1.38

(Continued)

TABLE 11.1 Properties of Saturated Steam (*Continued*)

Pressure, psig	Temper- ature, °F	Heat, Btu/lb			Specific volume, ft ³ /lb
		Sensible	Latent	Total	
325	429	407	797	1204	1.36
330	430	408	796	1204	1.34
335	432	410	794	1204	1.33
340	433	411	793	1204	1.31
345	434	413	791	1204	1.29
350	435	414	790	1204	1.28
355	437	416	789	1205	1.26
360	438	417	788	1205	1.24
365	440	419	786	1205	1.22
370	441	420	785	1205	1.20
375	442	421	784	1205	1.19
380	443	422	783	1205	1.18
385	445	424	781	1205	1.16
390	446	425	780	1205	1.14
395	447	427	778	1205	1.13
400	448	428	777	1205	1.12
450	460	439	766	1205	1.00
500	470	453	751	1204	0.89
550	479	464	740	1204	0.82
600	489	475	728	1203	0.74

*Inches vacuum.

holding it to one another and allow each molecule to move freely into the gas phase. No change in temperature can be sensed because the steam forms at constant temperature, and the latent heat simply causes a change of state from liquid to gas. Latent heat from the steam is transferred to the end use device as steam condenses. The heat necessary to evaporate water into steam requires approximately 1000 Btu/lb of water.

Equivalent Direct Radiation (EDR)

The equivalent direct radiation (EDR) is an outmoded rating unit used for selecting boilers and other steam heating equipment like radiators and convectors. Many older steam pipe sizing tables used for designing steam distribution systems show pipe capacity in EDR. For a close, approximate conversion from EDR to pounds per hour flow, use the following formula:

$$\text{Pounds per hour steam flow} = \frac{\text{EDR}}{4} \quad (11.1)$$

A commonly used EDR value for low-pressure steam systems is 240 Btu/lb steam.

Superheated Steam

If saturated steam is further heated, it is called *superheated*. Superheated steam is dry steam in the sense that it does not carry any liquid water droplets. Superheated steam is generated in boilers that are specially equipped to expose saturated steam to additional heating, which increases its temperature above saturation temperature for that pressure. Superheating can also occur when steam is throttled from a higher pressure to a lower pressure, for example, in passing through a pressure regulator. Superheated steam requires 1 Btu of thermal energy to raise the temperature $\frac{1}{2}^{\circ}\text{F}$.

Boiler Output

The output of a steam generator is often expressed in pounds of steam per hour. Since the output will vary in temperature and pressure, the capacity is more completely indicated as the heat transferred, expressed in British thermal units per hour. An older method of expressing boiler capacity is *boiler horsepower*, which is the equivalent of 33,475 Btu/h at atmospheric conditions.

SPECIFIC VOLUME

The *specific volume* is a volume of unit mass and gives the volumetric space that 1 lb of steam will occupy. It is the reciprocal of density.

SYSTEM CLASSIFICATIONS

Steam Systems

Steam systems are classified in two ways:

1. Pressure rating
2. Piping arrangement

Condensate Systems

Condensate systems are classified by the method used to return condensate back to the boiler:

1. Gravity flow directly into a condensate tank and then into the boiler, with no condensate or vacuum pump. This system is rarely used.
2. Gravity flow to a condensate tank, with a condensate pump used to pump condensate to the boiler.
3. Gravity flow to a condensate tank, with a vacuum pump assisting condensate flow to the tank. A condensate pump is used to pump condensate to the boiler.
4. Condensate lift traps, used to raise condensate from one elevation to another. This system is rarely, if ever, used.

Steam Pressure

Steam pressure is an important factor when steam is to be used to heat another substance. The higher the steam pressure, the higher the temperature of the steam. The steam temperature must be high enough to provide a temperature differential between the steam and the substance being heated. A large differential will reduce the size, and usually the cost, of the heat transfer equipment. On the other hand, unnecessarily high pressure steam can be difficult to control in a temperature-sensitive process, and can actually result in higher operating costs through the waste of flash steam or add to the initial cost of the system by requiring the use of more expensive condensate handling equipment. Selection of the steam pressure to be used is fundamental to the system design. A good practice is to evaluate several alternative pressures and choose the lowest one that will minimize initial and operating costs.

Steam systems are classified by ASHRAE according to operating pressure range as follows:

High pressure: 16 psig (110.1 kPa) and above

Low pressure: 0 to 15 psig (0 to 103.4 kPa)

There is no general agreement as to the assigned limits of medium-pressure steam. Another often-used set of operating pressure ranges is:

Low pressure: 0 to 15 psig (0 to 103.4 kPa)

Medium pressure: 16 to 60 psig (110 to 413 kPa)

High pressure: All pressures above 60 psig

The pressure-heat relationship for steam is as follows:

1. When steam pressure increases:
 - a. The total heat increases slightly.
 - b. The sensible heat increases.
 - c. The latent heat decreases.
2. When steam pressure is reduced:
 - a. The total heat decreases slightly.
 - b. The sensible heat decreases.
 - c. The latent heat increases.

Low-pressure steam is usually associated with space heating, laboratory equipment service, direct laboratory use, and culinary uses, as well as other applications that do not require high-temperature heat transfer. Industrial applications that transfer heat at high temperatures must use higher-pressure steam. In many cases, the codes and standards that govern the design of pressure vessels and steam systems will categorize the system pressure.

STEAM SYSTEM VENTING

Proper venting of the steam piping is important to prevent air binding and to allow steam to fill the system rapidly. *Air binding* is the development of a mass of air

inside a piping system at a point from which it cannot escape. This forms a restriction or complete blockage depending on the quantity of air present. An air venting device installed at appropriate locations will minimize or eliminate this situation. The venting devices in steam systems are called *steam traps* or *vents*.

STEAM SUPPLY SYSTEMS

Water Hammer

Water hammer in an undrained or improperly drained steam supply pipe can be caused by the impact of a rapidly moving slug of water. Unless the condensate is removed from the steam mains, it gradually accumulates until the high-velocity steam forms ripples. As condensate builds up, it decreases the area available for steam flow, leading to even higher steam velocities. The slug of water accelerated by the steam can reach velocities in excess of 100 mi/h before it hits some obstruction such as an elbow or other fitting. The rapid change in speed can cause a loud noise or even severe damage to the system. The formation of this slug is illustrated in Fig. 11.1.

Water hammer in the condensate piping system could be caused by turbulent flow creating pockets of lower pressure that cause some of the condensate to flash

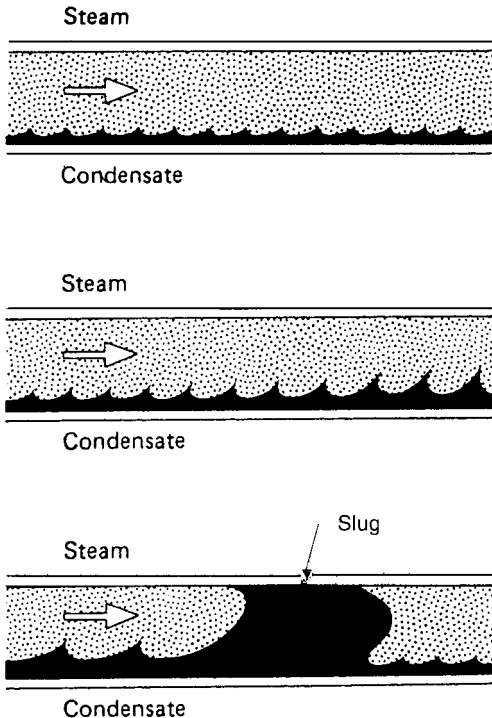


FIGURE 11.1 Formation of condensate water slug in steam piping.

into steam. Improperly operating steam traps may also leak steam into the condensate piping, mg, causing additional condensate to flash into steam. Flashing in this manner can cause a loud noise and increase system pressure to a point where damage is possible.

One-Pipe Steam Distribution

A one-pipe system uses a single pipe through which the steam is distributed and the condensate is returned to the boiler from the terminal unit. Designed to operate at low steam pressures, these systems usually have a gravity condensate return. A condensate pump may be required where gravity return directly to the boiler is not possible. Condensate could be returned to the boiler by either the counterflow or parallel flow method.

The one-pipe system does not have steam traps at the terminal units. Air vents are provided to vent the air, enabling the system to fill with steam. Self-contained thermostatic valves are available to help achieve some degree of terminal unit control. Proper venting is very important to prevent air binding and to allow steam to fill the pipes rapidly. Temperature is controlled by cycling the steam on and off.

An obsolete *vapor system* is a one-pipe steam distribution arrangement that depends on the slow condensation of steam to lower the pressure within the condensate piping into the vacuum range during the time of no or partial load. This system is no longer used because modern boilers do not allow the slow development of system vacuum.

The one-pipe system is used almost exclusively in small warehouses and residential and commercial applications for space heating and finds very limited use in any other type of facility.

Counterflow Condensate Return

This type of return has the steam main pitched back to the boiler opposite the flow of steam, requiring the condensate to also drain in a direction opposite to the flow of steam. The advantage is lower initial cost. Disadvantages include large pipe size (necessary to carry both steam and condensate in one pipe), noise in the system, and difficult installation.

Parallel Flow Condensate Return

In this type of return system, the steam main is pitched in the same direction as the flow of the steam, and the condensate flows in the same direction as the steam. The disadvantage is the higher cost involved with more piping. The advantages include smaller pipe size, quieter operation, and the less pitch required. This arrangement is the most often used.

Two-Pipe Steam Distribution

The two-pipe arrangement uses separate piping systems to deliver the steam to the terminal device and to return the condensate to the boiler, either by gravity or mechanical return. Gravity return is restricted to use in small systems.

A steam trap removes condensate from the steam piping network by allowing condensate to flow from the pipe or terminal unit into the condensate piping system. It also prevents steam from flowing back into the condensate system. It is installed at intervals along the supply pipe distribution system and at the discharge side of all terminal devices. The steam trap is the boundary between the steam supply and the condensate return at each terminal device. A schematic diagram of a two-pipe system is illustrated in Fig. 11.2.

CONDENSATE RETURN SYSTEMS

There are two general categories of condensate return systems: gravity and vacuum. For larger systems with long condensate return distribution piping runs, intermediate condensate or vacuum tank and pump sets may be required to return condensate to the boiler from various points in the system.

Gravity Flow

The gravity return system may be of a nonmechanical type of condensate return that depends on the pitch of the condensate return pipe back to the boiler for the

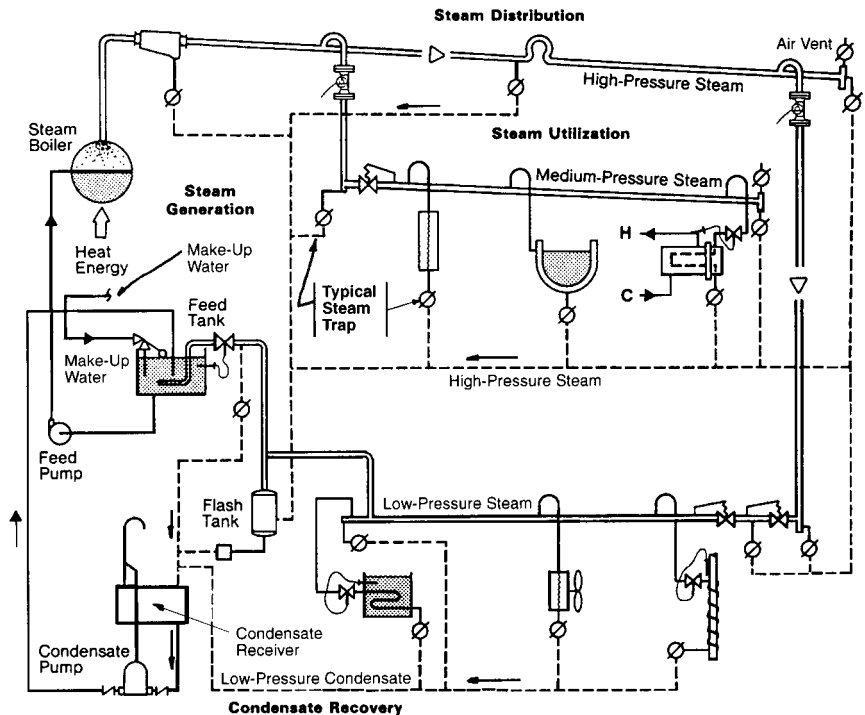


FIGURE 11.2 Schematic diagram of a typical two-pipe steam distribution system.

return of condensate. This system is generally suitable only for small, uncomplicated facilities.

In most gravity return systems, the condensate flows into a condensate storage tank, which is vented to the atmosphere. A condensate pump then transfers the stored condensate to the boiler as required.

Vacuum System

The vacuum condensate return system is similar to the gravity flow system except that a vacuum pump is placed at the condensate storage tank in lieu of the atmospheric vent. The vacuum pump removes air from the condensate return piping system. This allows the condensate to flow more rapidly, thereby reducing corrosion, and allows the use of smaller condensate return pipe sizes.

The vacuum system produces more effective air venting and provides a faster and more even steam distribution. It is often used on larger systems, permitting the steam pressure to be lower than the gravity system and enables quicker filling of the steam pipes with steam.

Special Systems

Clean Steam. A clean steam system provides particulate- and gas-free steam. It is usually produced from high-quality feedwater that is additive free or uncondensed water-for-injection (WFI) steam.

Pure Steam. A pure steam system provides clean steam that is pyrogen free.

STEAM

GENERAL

The steam distribution system consists of components and the piping network from the source of the steam up to and including the inlet of the steam trap at terminal equipment. The condensate return system starts beyond the inlet of the steam trap.

COMPONENT DESCRIPTION

Steam Sources

Steam can be obtained by purchasing it from an outside source such as a utility (if available), from a central internal steam system generator within a facility, or from a dedicated boiler, or generator, within a facility.

Boilers. A boiler is a closed vessel with associated equipment, piping, and controls that uses heat energy from an outside source to generate steam. Boilers that provide facility steam are available using coal, fuel gas, oil, or electricity as the source of heat. In addition, some are designed to use locally available fuel, such as wood shavings or other combustible products.

In general, boilers are designed to provide enough steam for the following:

1. To allow all the steam-condensing devices in the system to operate at their design heat transfer rate
2. To provide for piping and system thermal losses such as raising the mass of metal in the piping system up to operating temperature from some assumed initial ambient temperature
3. To provide for boiler start-stop cycling losses
4. To make up for losses of heat to the ambient air from the piping after it has reached the operating temperature

A small system boiler may be oversized by as much as 133 percent of the connected radiation steam requirement in order to account for these extra “pickup” and heat loss loads because the boiler will probably cycle on and off in response to an interior or outside temperature controller. If the boiler in a facility application is intended to be operated continuously, then oversizing capacity may be reduced. All piping should be well insulated to minimize the heat loss from the piping, especially if the piping is routed through nonheated areas and the condensate is to be returned to the boiler for conversion back to steam.

Boilers must be properly installed with headers and risers sized to allow adequate steam flow from the boiler. Failure to follow the manufacturer’s instructions in this “near boiler” piping can lead to reduced output characteristics and *carryover*; that is, liquid droplets and solids from the boiler being suspended in the flow of steam. In any system, carryover should be avoided since it reduces the heat-carrying capacity per pound of fluid, leads to noisy and possibly damaging water hammer in the steam piping, and can cause traps and regulators to foul and clog.

All steam generators require controls to regulate pressure and water level and to prevent unsafe operation.

Electric Steam Generators. Electric boilers have unique advantages for small-facility steam applications:

1. They do not require fuel piping.
2. They have no burner systems or draft blowers.
3. They don't require flues to carry off the exhaust gas.
4. They are smaller and easier to install.

These boilers must be properly operated and maintained to prevent hot-spots and buildup of solids, which may cause early failure of the boiler.

Clean Steam Generators. In many facility applications, carryover of boiler treatment chemicals and boiler water is especially prohibited, for example, if steam is to be injected directly into the process or if boiler solids would contaminate the airstream in humidification. For these applications, a "clean steam" generator is appropriate.

Boiler steam or hot water is introduced on one side of a suitable heat exchanger. Clean water on the other side of the heat exchanger is evaporated and sent off to the application as "clean steam." A schematic diagram of a steam-fired clean steam generator is illustrated in Fig. 11.3.

Steam Obtained from a Facility or Outside Source. In a plant served by a large steam boiler, facility steam could be provided from this source. Because the facility central steam boiler pressure is usually high, a reduced pressure for utility steam is usually required. Reduced steam pressure is obtained by the use of a *pressure-regulating (reducing) valve (PRV)*. A PRV is part of a larger assembly that is usually called a *steam pressure-reducing station*. A typical PRV station is illustrated in Fig. 11.4.

Flash Steam from a Higher-Pressure Process. Condensate that is formed at high pressure contains a significant amount of sensible heat. If pressure on that condensate is suddenly reduced in a flash tank, part of the condensate will reevaporate to form "flash steam," which could be used in a facility application. It is a common practice to use flash tanks in a high-pressure system to allow high-pressure condensate to flash down to some lower pressure and temperature so that it can be handled by lower temperature-rated equipment. Plant-operating costs are increased if the flash steam is simply allowed to escape from the system since it will carry away with it heat and water. Using flash steam as a facility supply will contribute to energy recovery efforts. If a flash tank is to be the source of facility steam, several issues must be considered, including the maximum pressure available in the flash tank, the amount of flash steam available, and the time that the flash steam will be available. A typical flash tank assembly is illustrated in Fig. 11.5.

Many flash tanks are designed to operate at or slightly above atmospheric pressure. If this is not satisfactory, the flash tank pressure might be raised, assuming that the flash tank is constructed to operate as a pressure vessel. The tank will also require back pressure controls to limit operating pressure and a safety valve, in case the operating controls fail.

It is common practice to provide a PRV to augment or replace the flash steam if the source of high-pressure condensate fails to generate enough flash steam to

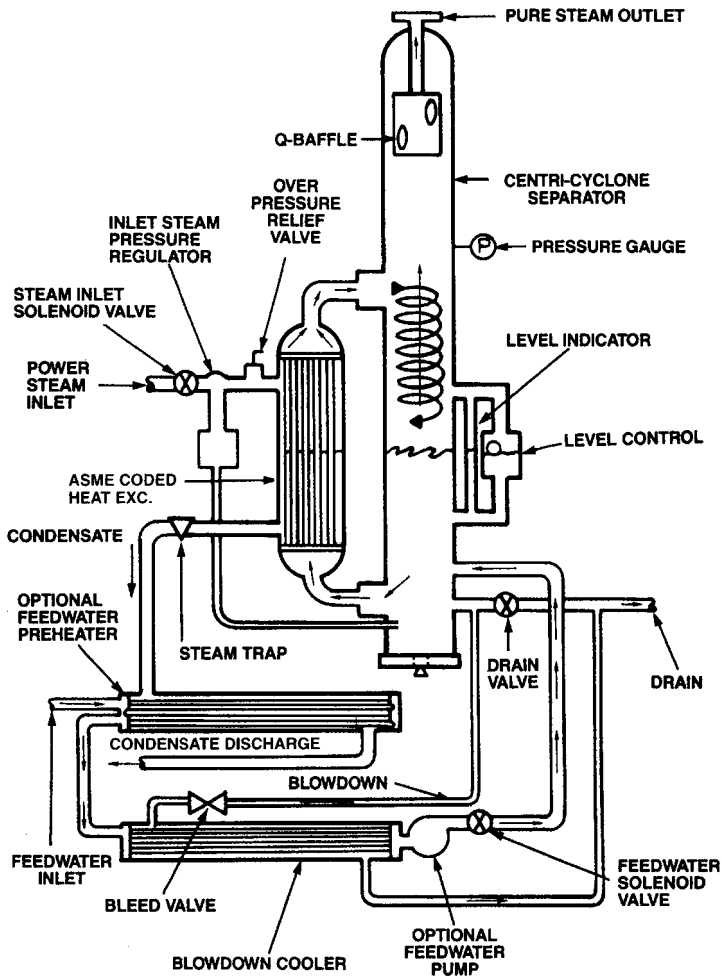


FIGURE 11.3 Schematic diagram of a steam-fired, clean steam generator. (Courtesy of Mueller/Barnstead.)

meet the facility demand for low-pressure steam or if it cannot be guaranteed that flash steam will be available. Additional details on flash tank design can be found in “Flash Tanks for Steam and Boiler Systems,” published by ASHRAE (1991). The amount of flash steam, in pounds, released from 100 lb of condensate can be found from Table 11.2.

Main Pressure-Regulating Valves

The purpose of the main pressure-regulating valve is to reduce a high inlet steam pressure to a lower pressure under variable flow conditions. Pressure regulators come in a variety of designs. All of them have a valve body to actually contain

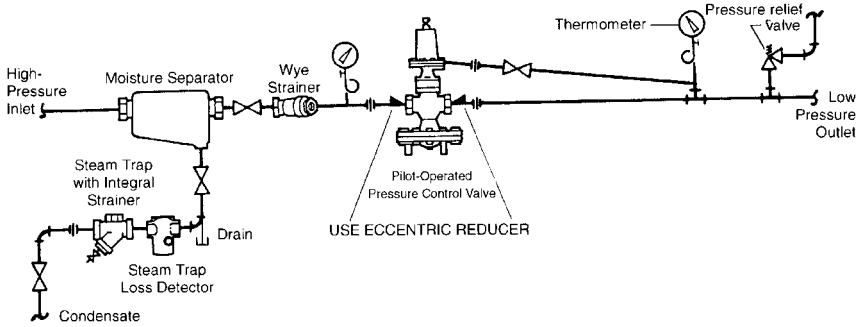


FIGURE 11.4 Pressure-reducing valve station.

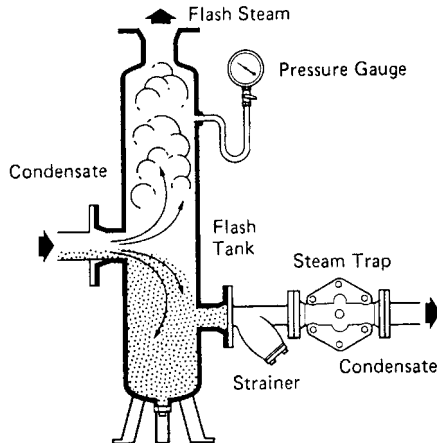


FIGURE 11.5 Typical flash tank assembly.

and control the flow of steam, an actuator that positions the valve stem to allow the proper flow, and a feedback system to determine if the desired downstream pressure is being maintained. The type of actuator and the location of the feedback pressure signal are often used in describing the pressure regulator. There are two types: direct acting and pilot operated.

Direct-Acting Valves. The direct-acting valve, illustrated in Fig. 11.6, is the simplest and least costly design. A reduction in pressure at the inlet acts on the underside of the diaphragm, which in turn, opposes the pressure exerted by the main spring, allowing the closure member to open, thereby increasing pressure. This type of valve is suitable where accurate control is not essential and where the steam flow rate is small and reasonably constant. It has some fluctuation of steam pressure and a relatively low capacity for its size.

Pilot-Operated Valves. The pilot-operated valve is illustrated in Fig. 11.7. A reduction in pressure acts on the underside of the pilot diaphragm either through a pressure control pipe or the drilling. The pilot diaphragm in turn operates the main

TABLE 11.2 Pounds of Flash Steam Released from 100 lb of Condensate

Inlet steam pressure, psig	Dis-charge, psig	Flash tank pressure, psig																		
		0	2	5	10	15	20	30	40	60	80	100								
5	1.7	1.0	0																	
10	2.9	2.2	1.4	0																
15	4.0	3.2	2.4	1.1	0															
20	4.9	4.2	3.4	2.1	1.1	0														
30	6.5	5.8	5.0	3.8	2.6	1.7	0													
40	7.8	7.1	6.4	5.1	4.0	3.1	1.3	0												
60	10.0	9.3	8.6	7.3	6.3	5.4	3.6	2.2	0											
80	11.7	11.1	10.3	9.0	8.1	7.1	5.5	4.0	1.9	0										
100	13.3	12.6	11.8	10.6	9.7	8.8	7.0	5.7	3.5	1.7	0									
125	14.8	14.2	13.4	12.2	11.3	10.3	8.6	7.4	5.2	3.4	1.8									
160	16.8	16.2	15.4	14.1	13.2	12.4	10.6	9.5	7.4	5.6	4.0									
200	18.6	18.0	17.3	16.1	15.2	14.3	12.8	11.5	9.3	7.5	5.9									
250	20.6	20.0	19.3	18.1	17.2	16.3	14.7	13.6	11.2	9.8	8.2									
300	22.7	21.8	21.1	19.9	19.0	18.2	16.7	15.4	13.4	11.8	10.1									
350	24.0	23.3	22.6	21.6	20.5	19.8	18.3	17.2	15.1	13.5	11.9									
400	25.3	24.7	24.0	22.9	22.0	21.1	19.7	18.5	16.5	15.0	13.4									

Source: Courtesy of SARCO.

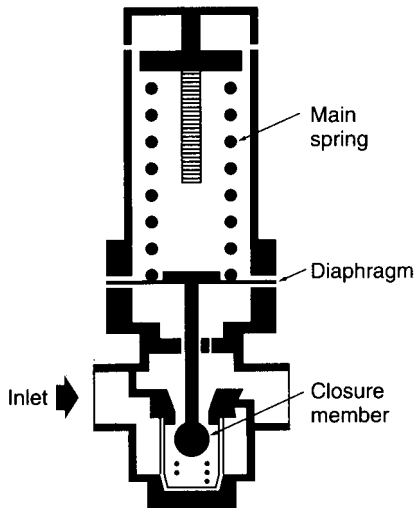


FIGURE 11.6 Direct-acting pressure-reducing valve.

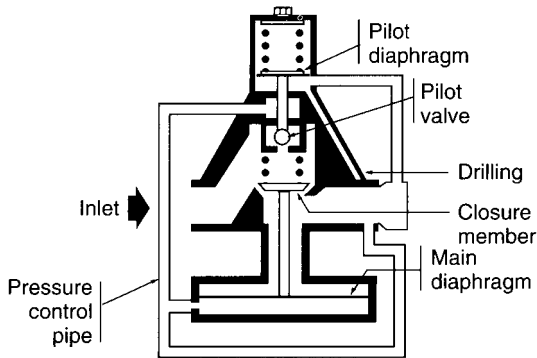


FIGURE 11.7 Pilot-operated pressure-reducing valve.

diaphragm, allowing the closure member to open, thereby increasing pressure. This type of valve is capable of accurate control downstream of the valve and has a relatively high capacity for its size.

Boiler Feed Pump System

A boiler feed pump assembly maintains the water level in the boiler within acceptable limits. The assembly consists of a feedwater receiver, feedwater pump(s), a method to add water to the system, and a level control in the boiler to turn the pump on and off.

Steam Separators

A steam separator is a device used to remove droplets of water from steam in piping and thereby provide equipment with good-quality dry steam. A secondary function is to remove carryover immediately after a boiler outlet. Two types of separators are used: impingement and centrifugal. A typical impingement separator is illustrated in Fig. 11.8*a*. A typical centrifugal separator is illustrated in Fig. 11.8*b*.

Steam Meters

It is often required that steam be metered to determine energy efficiency, process control, usage, and equipment efficiency as well as for measurement of the amount of steam used within a facility for utility company billing purposes.

A steam meter must compensate for steam quality as well as pressure and temperature. Performance of different types of meters will vary. Most meters depend on volume measurement, which is dependent on pressure. Measurement must be taken at the appropriate pressure; otherwise corrections have to be applied to the reading. Metering should be done downstream of a properly designed pressure-reducing valve station. A typical steam meter assembly is illustrated in Fig. 11.9.

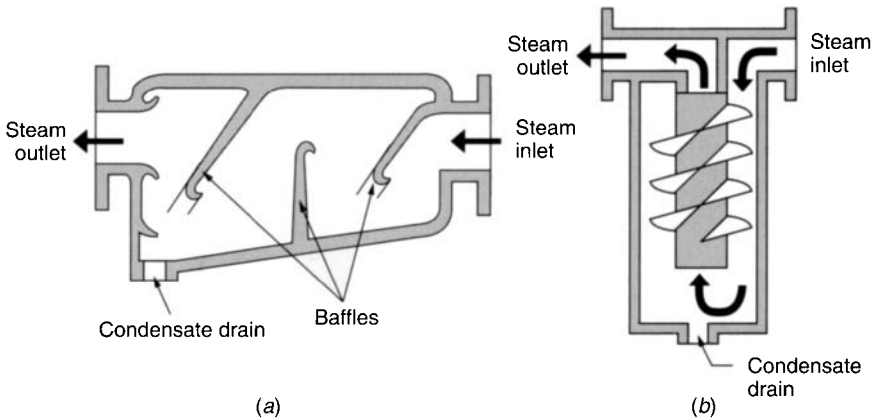


FIGURE 11.8 Steam separators. (a) Impingement separator and (b) centrifugal separator.

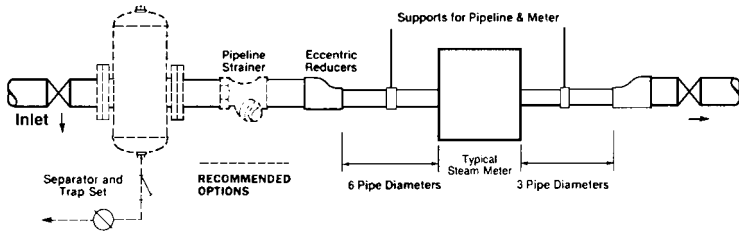


FIGURE 11.9 Steam meter assembly.

Steam Traps

A steam trap removes condensate, noncondensable gases and air from a steam piping network. No single type of trap is suitable for all applications, and most systems require more than one type.

Noncondensable gases, such as carbon dioxide and air, must be removed because they dilute the steam and lower the condensation temperature, as well as reducing efficient heat transfer. Removal is accomplished by either installing vents on top of terminal equipment or through a thermostatic sensor in a steam trap. Thermostatic traps are the most commonly used. The element operates by measuring the steam temperature and determining if it is below the saturation temperature for a given pressure. If it is, then noncondensable gases are present, which must be vented. The trap opens, venting the gas.

Proper condensate removal is essential for efficient plant and process operation. All steam traps shall be able to:

1. Vent air and other gases from piping and equipment
2. Prevent the flow of steam into the condensate piping
3. Allow only condensate into the condensate piping network

Condensate removal can be accomplished either manually or automatically. The manual removal of condensate will require that a valve placed in the network be constantly opened and closed by operating personnel. This method is inefficient and wasteful.

An automatic steam trap is a valve that opens in the presence of condensate or noncondensable gases and closes in the presence of steam in order to remove condensate from the steam piping network and prevent steam from entering the condensate piping network.

There are three main groups of automatic steam traps, grouped together by their mode of operation: mechanical, thermostatic, and thermodynamic.

Mechanical Traps. Mechanical traps are buoyancy operated and sense the density difference between steam and condensate through the use of a float or bucket as the operating member. Mechanical traps are usually preferred in applications that do not require much air venting, such as high-pressure steam mains and other noncycling systems. Condensate subcooling is not required, and the trap cycles either wide open or dead shut. Mechanical traps are preferred where immediate removal of the condensate is required or where a cooling leg upstream of the trap could interfere with operation of the equipment. This is the typical situation in industrial traps draining condensate from high-pressure steam mains or heat exchangers that can be damaged by flooding.

One disadvantage of all mechanical traps is that the size of the discharge orifice is controlled by the buoyancy power of the float, which is constant. As the pressure of the steam system increases, the size of the orifice should decrease. This requires that the size of the valve seat be different for various pressures.

Loose Float Trap. The loose float trap, illustrated in Fig. 11.10, is the simplest of traps. When condensate enters the chamber, the float B is lifted off its seat A and allows condensate to discharge. It has no moving parts except for the float and is very inexpensive. Disadvantages are that it cannot vent air, and it is difficult to obtain good seating. A hand cock C has been added to vent air. This type of trap is no longer used but may be found in older facilities.

Float and Lever Trap. The float and lever trap, illustrated in Fig. 11.11, overcomes some of the problems of the loose float by providing a float arm C connected to an outlet valve D for more effective seating. This type of trap is no longer used in modern systems but may be found in older facilities.

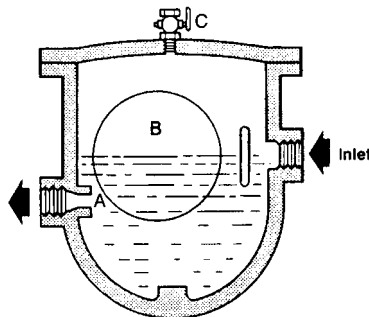


FIGURE 11.10 Loose float steam trap.

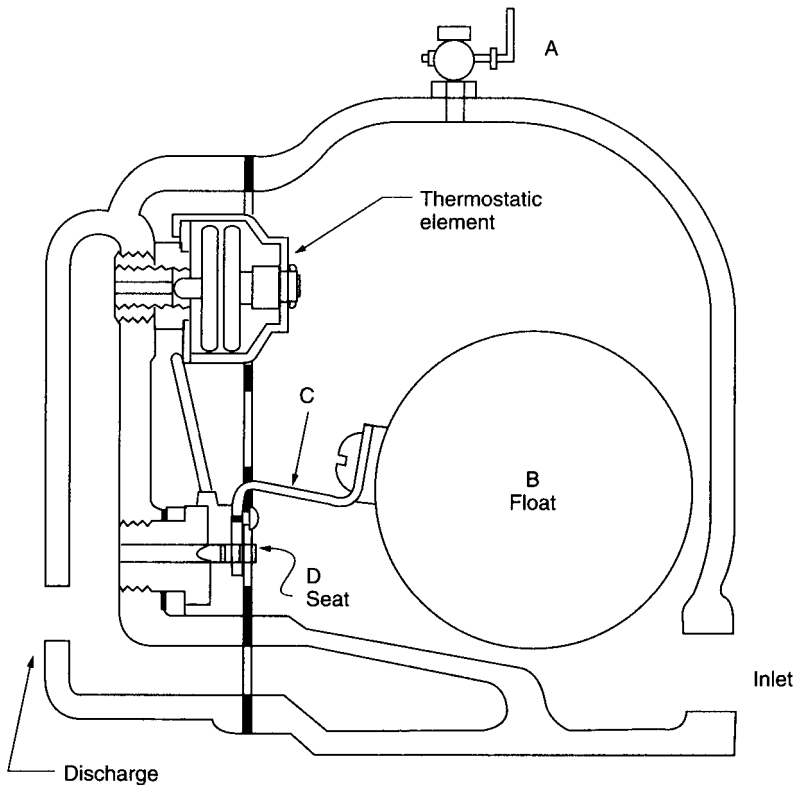


FIGURE 11.11 Float and lever steam trap.

Float and Thermostatic Trap. The float and thermostatic element trap is illustrated in Fig. 11.12. When condensate enters the trap, the float rises and allows condensate to discharge. A thermostatic element is provided to automatically vent air out of the chamber. This element is open only when air is present to cool the element, thereby allowing air to vent. As the temperature of the chamber rises when no air is present, the element is closed.

Open Bucket Trap. The open bucket trap, illustrated in Fig. 11.13, uses a bucket instead of a float. The bucket floats when condensate is present and falls when empty. When condensate enters the trap, it first fills the body outside the bucket. The floating bucket holds the seat closed. After the body is full, condensate spills over to fill the bucket causing it to sink drawing the seat open and allowing condensate to discharge.

These traps are mechanically simple and strong, and they are capable of withstanding shock and corrosive condensate. Disadvantages are reduced air-venting capability, heavy weight in relation to their discharge capacity, and susceptibility to damage by freezing.

Inverted Bucket Trap. The inverted, bucket trap, illustrated in Fig. 11.14, uses an inverted bucket instead of a float. The bucket is normally at the bottom, causing the seat to be open. When condensate enters and fills the chamber, it is able to

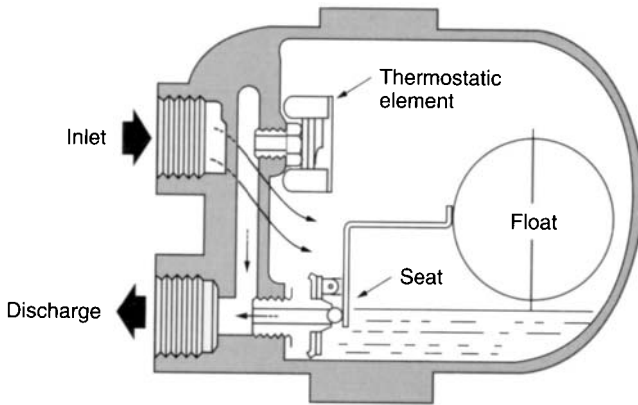


FIGURE 11.12 Float and thermostatic element steam trap.

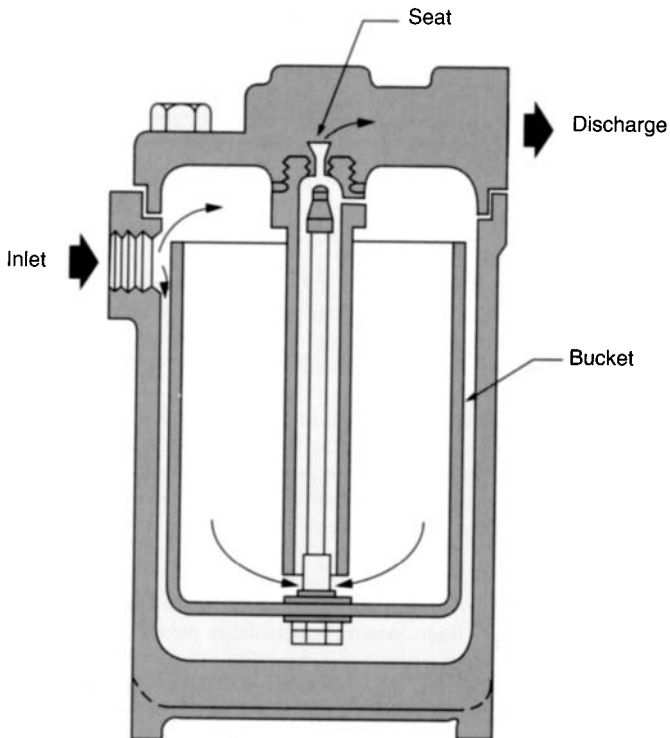


FIGURE 11.13 Bucket steam trap.

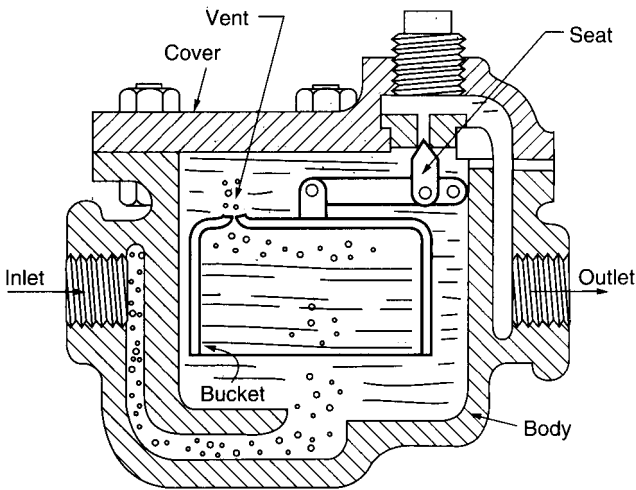


FIGURE 11.14 Inverted bucket steam trap.

discharge through the open seat. When a small amount of steam enters the trap, it escapes through the vent. More steam entering causes the bucket to rise, closing the seat. As the steam escapes through the vent, the bucket will again drop to the bottom, opening the seat.

These traps are mechanically simple and strong, capable of withstanding shock, corrosive condensate, and superheated steam. Disadvantages are the low air-venting capacity and the need to have a steady pressure. Air vent capacity can be increased by oversizing the condensate discharge piping.

Thermostatic Traps. In this type of trap, a bimetallic or fluid-filled element operates a valve that opens in the presence of condensate and closes in the presence of steam. There are a large number of variations for this type of valve.

The working pressure of the steam does not affect the operation of the trap. Instead, it is the difference in temperature between the steam and the condensate which sets up the difference between the pressure inside and outside the element, that opens and closes the seat.

Thermostatic traps are intended for relatively low condensate removal capacities and typically used in low-pressure steam heating equipment, in equipment that can tolerate condensate collection upstream of the trap in a "cooling leg" where it can reach the subcooled temperature that opens the trap. While the condensate is subcooling, some sensible heat is made available. Sometimes this sensible heat can be useful, for example, in tracing temperature-sensitive components.

Bellows Trap. Often referred to as a *balanced-pressure trap*, the bellows type is illustrated in Fig. 11.15. The principle of operation is the expansion and contraction of a bellows filled with a liquid that has a lower boiling point than water. The valve seat is open when cold, allowing air to vent and condensate to discharge. As condensate enters and before it reaches the boiling point, the element closes. As the condensate cools, the element opens, discharging the condensate.

Bimetallic Trap. The bimetallic trap operates by the action of a composite strip of metal that bends when the temperature changes. The principle of operation is illustrated in Fig. 11.16. The seat is open when cold, allowing the free passage of

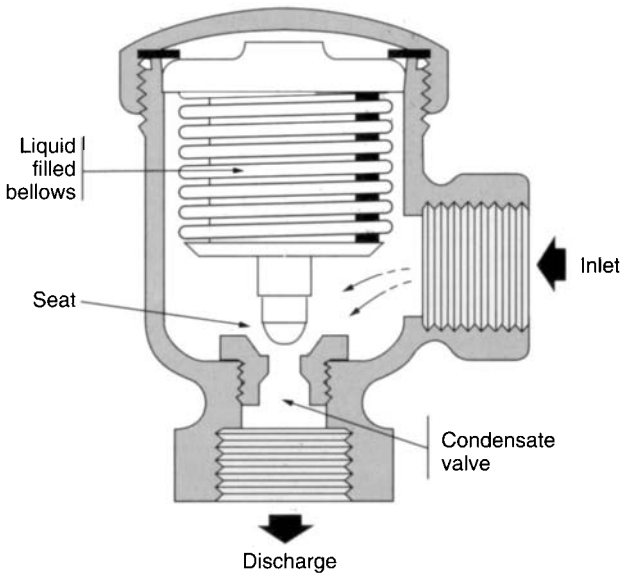


FIGURE 11.15 Bellows steam trap.

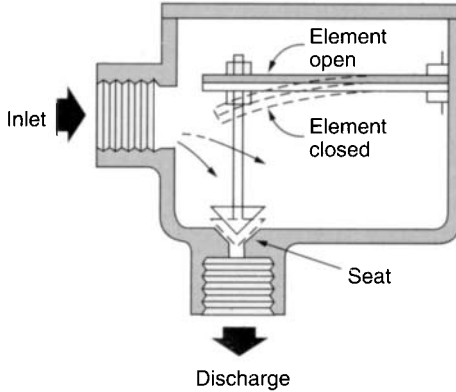


FIGURE 11.16 Bimetallic thermostatic steam trap.

air and condensate. When steam temperature is approached, the element bends and closes the seat.

Liquid Expansion Trap. Another type of thermostatic trap is the liquid expansion type, illustrated in Fig. 11.17.

Kinetic Traps. These types of traps operate on the difference between the flow characteristics of steam and condensate and on the fact that condensate discharging to a lower pressure contains more heat than required to keep it in the liquid phase. The excess heat will cause the condensate to flash into steam at the lower pressure.

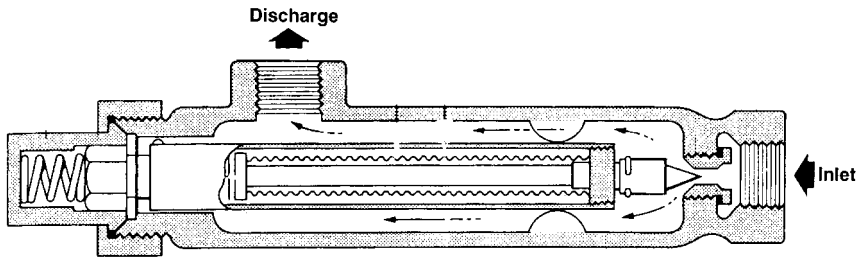


FIGURE 11.17 Liquid expansion steam trap.

Thermodynamic Trap. The thermodynamic trap, often referred to as a disk trap, is illustrated in Fig. 11.18. This device has only one moving part—the disk. When air or cold condensate enters the trap, it lifts the disk off its seat and is discharged. When steam or hot condensate enters the trap, some of it flashes into steam upon exposure to a lower pressure. The increased velocity of this vapor flow decreases the pressure on the underside of the disk causing it to close.

Piston Trap. A piston trap, also called an *impulse trap*, is illustrated in Fig. 11.19. As cooler condensate enters the body, pressure raises the piston to open the trap, allowing air and condensate to discharge. As the condensate nears steam temperature, some flashes into steam, which passes through the gap. The flash steam with the greater pressure forces the cylinder closed, stopping flow.

Labyrinth Trap. Another type of kinetic trap is the labyrinth, illustrated in Fig. 11.20.

Terminal Equipment Temperature Control

Temperature controls are used to modulate either the amount of heat or temperature at the terminal equipment. This control will vary either the steam pressure to control

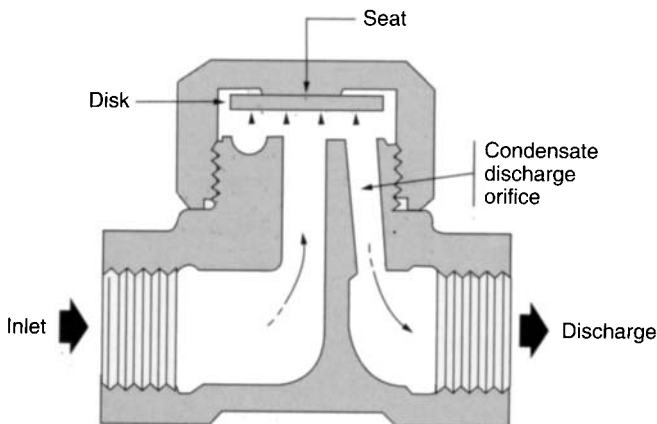


FIGURE 11.18 Thermodynamic steam trap.

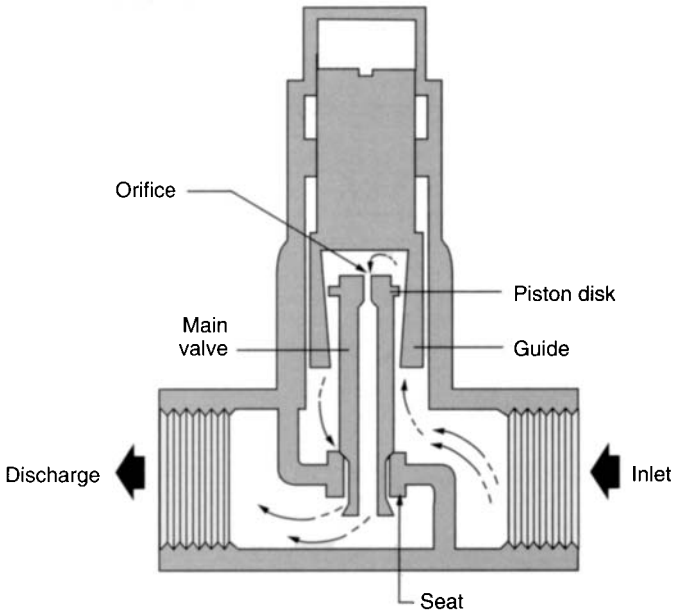


FIGURE 11.19 Piston steam trap.

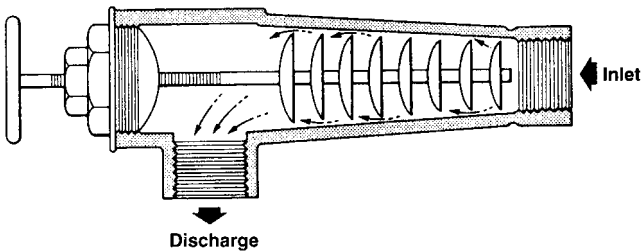


FIGURE 11.20 Labyrinth steam trap.

the steam temperature or the flow rate of steam to control the amount of heat provided.

To vary the pressure, the controlling device will be a pilot or thermostatically operated pressure-regulating valve activated by a temperature sensor in the discharge steam line. This type of valve is different from that of a master type PRV used to provide reduced pressure facility steam from a central source. The principle of operation is illustrated in Fig. 11.21. To modulate the flow rate of steam, a self-acting control valve is needed to activate a temperature sensor (bulb) in the fluid whose temperature is being controlled. The principle of operation is illustrated in Fig. 11.22.

An important consideration in the selection of a temperature control device is the proportional band of the valve, which is the range of accurate temperature regulation. This is obtained from the individual manufacturer.

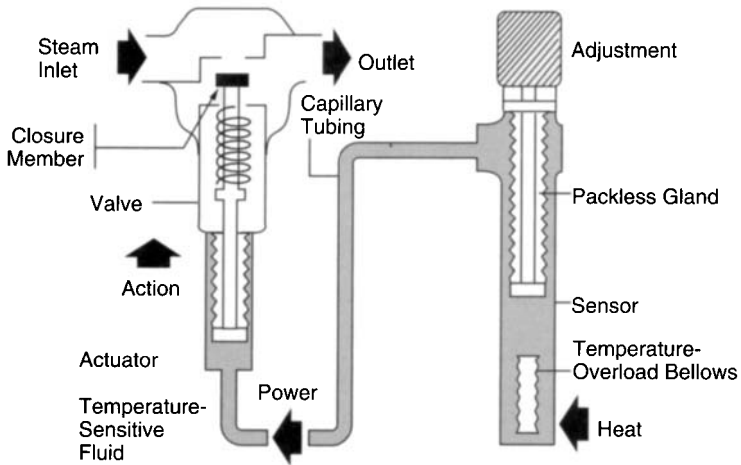


FIGURE 11.21 Self-acting temperature control valve.

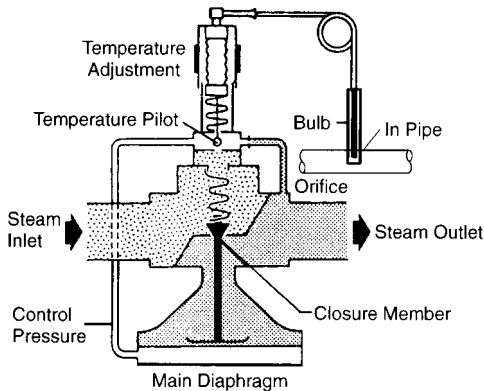


FIGURE 11.22 Pilot-operated temperature control valve.

The type of temperature control may have an effect on the selection of the steam trap necessary to drain condensate from the steam space of the terminal equipment depending on whether the steam flow is constant, variable, or batch.

Other Devices That Use Steam

Nozzles. Nozzles reduce the high pressure available in the steam to accelerate the steam flow for a number of related applications. The accelerated flow creates a low pressure region in the throat of the nozzle that can be used to pick up a detergent solution, which then mixes with the steam to form a high-velocity jet useful in equipment cleaning. This same principle can be applied as a “jet pump” or air ejector to establish a vacuum.

Direct Steam Injection. Mixing tees and sparging tubes can be used to provide instant heating without the use of a heat exchanger. Of course, the use of mixing tees and sparging tubes implies that the steam will condense in the process fluid and be lost from the steam system. This arrangement is often used for heating water for wash-down purposes in small hose stations.

Steam Tracers. Tracers are small-diameter steam pipes installed parallel to a process pipeline or around some other component that must be kept warm. Special compounds are often applied in order to enhance the heat transfer between the tracer and the item to be traced, and insulation generally covers both the tracer and the item. As steam condenses in the tracer, heat is released to keep fluids from freezing or to maintain a desired temperature in the process fluid. Steam tracing is discussed in Chap. 5.

STEAM SYSTEM COMPONENT SIZING

Steam Pipe Sizing

Steam system piping differs from other piping because it can carry two different fluids: steam and liquid water. The proportions of steam and liquid expected in a given steam system pipe depends upon the type of system and the method of operation.

Pipe Sizing Criteria. The size of steam piping is based on the flow rate and either maximum velocity of the steam or pressure drop, whichever is the greater consideration.

Flow Rate. The flow rate required depends upon the specific piece of equipment and application. If steam is being used as a heat transfer medium, then the flow rate is determined by the ratio of the heat transfer requirement in British thermal units per hour to the enthalpy of evaporation from the steam tables at the desired steam pressure in British thermal units per pound. For humidification applications, the required steam flow is determined from a psychometric chart for the given and desired conditions. For a given flow rate of dry saturated steam, the pipe size required depends upon the initial pressure of the steam and the pressure drop or velocity of flow.

Velocity. The velocity of steam is limited to prevent flow noise and pipe erosion. Industrial and facility steam systems generally use velocity as the limiting criteria in the selection of pipe sizes. Most systems are sized using a velocity of between 6000 and 8000 fpm (1800 and 2400 mpm), with a maximum of 10,000 fpm (3000 mpm) in industrial applications where noise is not a consideration.

Steam Pressure. A pound of high-pressure steam occupies a smaller volume than low-pressure steam. This has a significant effect on steam pipe sizing since higher-pressure systems can use smaller pipes than low-pressure systems for the same steam flow.

Pressure Loss. Often, low-pressure steam systems will be sized on pressure drop criteria. A range of between $\frac{1}{8}$ and $\frac{1}{4}$ psi drop for 100 ft is recommended. The minimum operating pressure for any equipment shall be obtained from the manufacturer, which relates to the temperature required for the process to proceed efficiently. Under these circumstances the lowest possible pressure of the steam system is desirable. Considerations are:

1. The longest equivalent run of pipe
2. Pressure of the steam required at the terminal equipment and that available at the source
3. Flow rate
4. Velocity of the steam
5. Selection of economical pipe size based on an acceptable range of pressure loss while keeping below the maximum selected velocity

Pressure drop figures in common use are given in Table 11.3.

Pipe-Sizing Method

1. Calculate or obtain the steam flow rate, in pounds per hour.
2. Establish the minimum system steam pressure required to service all connected equipment.
3. Establish the maximum steam velocity for the system.
4. Calculate the allowable friction loss permissible in each branch or main under design.

With all of the above information available, use Fig. 11.23, a basic sizing chart, to size the pipe as follows:

1. The chart is divided into two halves, top and bottom. Using the bottom half, enter with the flow rate and rise vertically until the required steam pressure figure is intersected. From the point where these values intersect on the chart, draw a line parallel to the skewed lines up to the 0 line separating the top half from the bottom half.

TABLE 11.3 Steam Pressure Drops in Common Use for Sizing Steam Pipe*

For corresponding steam pressures

Initial steam pressure, psig	Pressure drop per 100 ft	Total pressure drop in steam supply piping
Vacuum return	2–4 oz/in ²	1–2 psi
0	0.5 oz/in ²	1 oz/in ²
1	2 oz/in ²	1–4 oz/in ²
2	2 oz/in ²	8 oz/in ²
5	4 oz/in ²	1.5 psi
10	8 oz/in ²	3 psi
15	1 psi	4 psi
30	2 psi	5–10 psi
50	2–5 psi	10–15 psi
100	2–5 psi	15–25 psi
150	2–10 psi	25–30 psi

*Equipment, control valves, and so forth must be selected based on delivered pressures.

For older systems using EDR as the reference, refer to Table 11.4 using the pipe pitch and EDR at the point of design to determine the pipe size.

BOILER FEED PUMPS

A boiler feed unit maintains boiler water level within acceptable limits. Condensate should enter the boiler from only one source in order to maintain the pressure and flow integrity of the system.

If condensate cannot flow directly into a boiler feedwater tank, condensate receivers may be required to transfer condensate to the boiler feedwater tank. Larger commercial or industrial steam systems are likely to have a boiler feed pump in addition to a condensate transfer pump.

A boiler feed pump unit differs from a condensate receiver set in three major respects:

1. The boiler feed pump is controlled by a level-sensing control mounted on the boiler.
2. The boiler feed receiver must be large enough to act as a reservoir of feedwater immediately available in order to maintain the desired level in the boiler. The generally used figure is up to a 1-h supply.
3. The boiler feed receiver has a makeup water supply to add water to the system due to system losses.

Receivers should be manufactured of a corrosion-resistant material since condensate is often highly corrosive. Thick cast iron receivers are common in the industry, though thinner-wall steel receivers are also available. These receivers are usually not rated to handle internal pressure, so they are installed with a vent to the atmosphere.

The most common control used in condensate receiver sets and boiler feed pumps is the float switch, but any level-sensing control compatible with condensate and capable of starting the pump would be satisfactory. Small single-phase pumps may be started directly through the level control, but three-phase pump motors and single-phase motors that draw a large starting current must be started through a motor starter. It is accepted practice to use prepped and engineered units ready for operation after installation.

The most common pump found in these applications is a centrifugal volute pump. It shall be selected for a discharge head adequate to deliver condensate to the boiler.

This equipment is often supplied with two pumps as a duplex unit so that a second pump is available if one pump fails. A lead-lag control of some type is usually provided to alternate pump operation, providing equal usage, thereby increasing life expectancy. In the event that an unusually heavy condensate load is encountered, the alternator is electrically wired so that both pumps can be operated simultaneously under peak load conditions. Piping and valve arrangements for multiple-pump installations shall be in accordance with recommendations of the specific manufacturer of the installed equipment.

TABLE 11.4 Pipe Sizes Using EDR As Criteria

Pipe size, in	Pitch of pipe, in/10 ft; velocity, ft/s; capacity, ft ² , EDR															
	1/4 in		1/2 in		1 in		1 1/2 in		2 in		3 in		4 in		5 in	
	Capac- ity	Max. vel.	Capac- ity	Max. vel.	Capac- ity	Max. vel.	Capac- ity	Max. vel.	Capac- ity	Max. vel.	Capac- ity	Max. vel.	Capac- ity	Max. vel.	Capac- ity	Max. vel.
3/4	12.8	8	16.4	11	22.8	13	25.6	14	28.4	16	33.2	17	38.6	22	42.0	22
1	27.2	9	36.0	12	46.8	15	51.2	17	59.2	19	69.2	22	76.8	24	82.0	25
1 1/4	47.2	11	63.6	14	79.6	17	98.4	20	108.0	22	125.2	25	133.6	26	152.4	31
1 1/2	79.2	12	103.6	16	132.0	19	149.6	22	168.0	24	187.2	26	203.2	28	236.8	33
2	171.6	15	216.0	18	275.2	24	333.2	27	371.6	30	398.4	32	409.6	32	460.0	33

Source: From research sponsored by ASHRAE.

STEAM CONDENSATE

At some point after the steam has entered the terminal equipment, the steam condenses into a liquid, called *condensate*. This condensate must be drained away from the point where it is created and removed from the terminal equipment to assure proper equipment operation. There are three elimination alternatives available:

1. The condensate may be absorbed into the process and lost from the steam system.
2. The condensate may be simply wasted to a drain in an approved manner.
3. The condensate may be recovered resulting from the action of the steam and sent back to the boiler as feedwater.

Many systems do not recover condensate at all. Low condensate flow rates, the length of condensate piping required, or the inherent nature of the operation may make it impossible or economically unwise to install condensate return piping. If condensate becomes contaminated with heavy metals, phosphates, oil, dirt, or other chemicals, or if the cost of collecting and returning the condensate is considered to be too high, then it may be wasted to a drain. There are limitations imposed by environmental regulations that should be considered before this is done. Local codes must be consulted to ensure that proper treatment of this waste is accomplished. If clean condensate is to be wasted, additional components, such as condensate coolers, will be necessary to reduce the temperature of the condensate below a level acceptable to code requirements, enabling it to be discharged into a sanitary drainage system. This temperature is generally 140°F (60°C).

If the condensate is to be recovered, then additional components, such as steam traps, flash tanks, contaminant piping, condensate piping, and condensate pumps may be required to return the condensate back to the steam source. The steam trap, which is part of the condensate drainage system, is generally considered the boundary between the steam supply subsystem and the condensate recovery subsystem.

CONDENSATE RECOVERY SYSTEM DESCRIPTION

Condensate shall be drained and recovered from the following directly interconnected portions of the steam supply and condensate drainage system (a diagram of typical condensate drainage system components is illustrated in Fig. 11.24):

1. Collection legs receiving condensate produced in steam mains resulting from cooling of the steam
2. Drain pipes leading to steam traps, often called *drain lines*
3. Steam traps
4. Steam trap discharge pipes
5. The main condensate return pipe

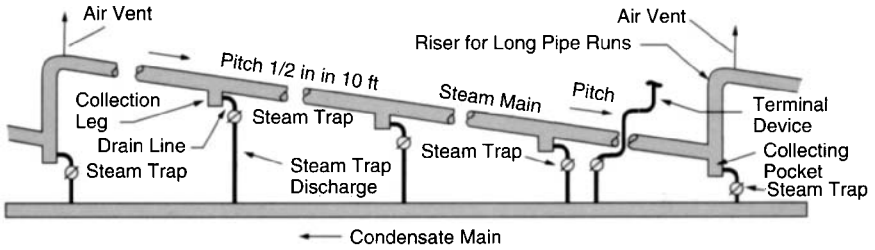


FIGURE 11.24 Components of a condensate drainage system.

COMPONENT DESCRIPTION

Collection Leg

A reservoir, or *collecting leg*, is a fitting or portion of a pipe that collects all the condensate produced from inside a main. One must be provided if the steam trap is to be effective since a steam trap can discharge only the condensate that is brought into it. Collecting legs should be provided at all low points in the system and wherever the condensate can collect such as at the ends of the mains, the bottom of risers, and ahead of expansion joints, separators, pressure-reducing valves, and temperature regulators.

Drain Pipes

The drain pipe conveys condensate from the collection leg to the steam trap. It carries pressurized, high-temperature water.

Steam Trap

The steam trap separates steam from the condensate and discharges condensate only. Steam traps have been previously described.

Steam Trap Discharge Pipe

The steam trap discharge line conveys condensate from the steam trap to the main condensate collecting line. This line must be capable of carrying condensate, flash steam, and noncondensed gases.

Main Condensate Collecting Line

This is the main condensate pipe that collects and returns condensate back to the condensate storage tank.

Condensate Cooler

A condensate cooler is a heat exchanger that lowers the temperature of waste condensate before it can be discharged to a sewer. This can be accomplished by the use of a tempering tank or heat exchanger. The heat exchanger often is used to preheat domestic water prior to heating or to heat water for other purposes. If the water is too hot, a tempering tank, illustrated in Fig. 11.25, mixes cold water with the condensate based on the temperature of the discharge. To determine the quantity of cold water needed, refer to Fig. 9.30 or 9.31.

Condensate Transfer Pump Assembly

The condensate transfer pump assembly collects the condensate and pumps it back to the boiler as quickly as possible in order to minimize heat loss. Higher condensate temperatures at the boiler relate directly to higher system efficiency since the sensible heat of the condensate represents a reduction in fuel required. The assembly usually consists of a vented receiver, a condensate pump, and a level switch to turn the pump on and off. In small systems, condensate receiver sets may be used in place of more complex boiler feed pump systems.

The condensate receiver is relatively small to minimize heat loss as the receiver fills between pumping cycles. The pump is controlled by a float switch mounted in the condensate receiver.

The volume of a condensate transfer receiver should be small compared to the rate of condensate return so that it will fill quickly and start the pump so that the condensate will not cool off excessively. A generally used figure is approximately a 1- to 2-mm supply.

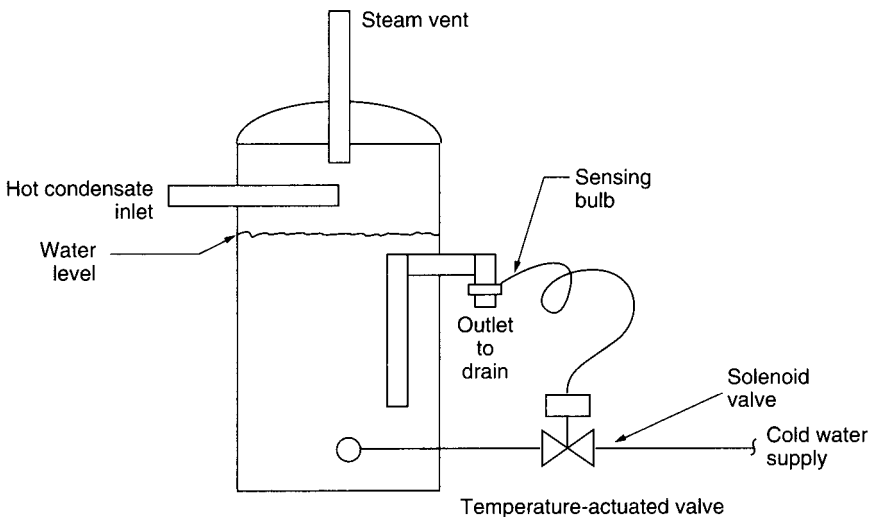


FIGURE 11.25 Detail of condensate cooler.

Flash Tanks

A flash tank is a pressure vessel, often vented to atmosphere, that contains steam produced from hot condensate under pressure that enters the tank. Flash tanks play an important role in condensate return systems. Its name is derived from the sudden evaporation, or “flashing,” that occurs when condensate at higher pressure is suddenly released to a lower pressure. When hot condensate under pressure is discharged to a lower pressure, the condensate contains more heat than necessary to maintain itself as a liquid. This excess heat causes some of the liquid to vaporize instantly, or flash, into steam at the lower pressure.

A flash tank may be required to cool condensate before it flows into the condensate receiver tank if large quantities of high-pressure condensate could flow into a relatively small tank.

COMPONENT SELECTION AND SIZING CRITERIA

Steam Trap Ancillary Component Sizing

Collecting Legs Draining Steam Mains. Properly drained mains and care taken in starting up a cold system not only prevent water hammer damage but also improve the quality of the steam and reduce the maintenance required on pressure-reducing valves, temperature controls, and other components.

On long horizontal runs, drain points should be located at intervals of 150 to 400 ft (45 to 120 m). For reverse draining of condensate, intervals of 50 ft (15 m) are recommended. Drain points should also be located at any natural collection point. In general, automatic start-up systems and high-pressure systems will have collection legs located closer together. The diameter of the collecting leg pipe should be 1.5 times the size of the steam main and extend a minimum of 6 to 12 in (18 to 30 cm).

Drain Lines. Drain pipes discharge by gravity, with an average minimum pitch of approximately 1 in per 10 ft (25 mm per 3 m). The size is generally based on twice the full running flow expected. The heaviest condensate load in a steam main occurs during the warm-up period. Table 11.5 shows the amount of steam used to warm up a given length of different size mains. Once the steam main has been raised to the operating pressure, further condensation is the result of heat loss through the insulation and the separation of moisture from wet steam as described in Table 11.6. Condensate mains are drained by means of collecting legs, similar to a tee facing down, that drain the condensate from the bottom of the main into a 6- to 12-in-long (18- to 30-cm) capped nipple.

Collection Legs. The diameter of the collecting leg should be the same as that of the steam main if possible, but not more than one pipe size smaller. The collecting legs for systems using the automatic heat-up method should have a pipe diameter equal to that of the main. The collecting legs for supervised heat-up need not be as long as for automatic heat-up since the warm-up condensate is being eliminated through manually operated drain valves. The length should be about 1.5 times the leg diameter and not less than 8 in.

TABLE 11.5 Condensate Load in Main during Warm-Up*Warm-up load, in pounds of steam per 100 ft of steam main, ambient temperature 70°F**

Steam pressure, psig	Main size, in														0°F correction factor†
	2	2½	3	4	5	6	8	10	12	14	16	18	20	24	
0	6.2	9.7	12.8	18.2	24.6	31.9	48	68	90	107	140	176	207	208	1.50
5	6.9	11.0	14.4	20.4	27.7	35.9	48	77	101	120	157	198	233	324	1.44
10	7.5	11.8	15.5	22.0	29.9	38.8	58	83	109	130	169	213	251	350	1.41
20	8.4	13.4	17.5	24.9	33.8	43.9	66	93	124	146	191	241	284	396	1.37
40	9.9	15.8	20.6	29.3	39.7	51.6	78	110	145	172	225	284	334	465	1.32
60	11.0	17.5	22.9	32.6	44.2	57.3	86	122	162	192	250	316	372	518	1.29
80	12.0	19.0	24.9	35.3	47.9	62.1	93	132	175	208	271	342	403	561	1.27
100	12.8	20.3	26.6	37.8	51.2	66.5	100	142	188	222	290	366	431	600	1.26
125	13.7	21.7	28.4	40.4	54.8	71.1	107	152	200	238	310	391	461	642	1.25
150	14.5	23.0	30.0	42.8	58.0	75.2	113	160	212	251	328	414	487	679	1.24
175	15.3	24.2	31.7	45.1	61.2	79.4	119	169	224	265	347	437	514	716	1.23
200	16.0	25.3	33.1	47.1	63.8	82.8	125	177	234	277	362	456	537	748	1.22
250	17.2	27.3	35.8	50.8	68.9	89.4	134	191	252	299	390	492	579	807	1.21
300	25.0	38.3	51.3	74.8	104.0	142.7	217	322	443	531	682	854	1045	1182	1.20
400	27.8	42.6	57.1	83.2	115.7	158.7	241	358	492	590	759	971	1163	1650	1.18
500	30.2	46.3	62.1	90.5	125.7	172.6	262	389	535	642	825	1033	1263	1793	1.17
600	32.7	50.1	67.1	97.9	136.0	186.6	284	421	579	694	893	1118	1367	1939	1.16

*Loads based on Schedule 40 pipe for pressures up to and including 250 psig and on Schedule 80 pipe for pressures above 250 psig.

†For outdoor temperature of 0°F, multiply the load value in the table for each main size by the correction factor corresponding to steam pressure.

TABLE 11.6 Condensate Load in Main during Running

Condensation load, in pounds per hour per 100 ft of insulated steam main, * ambient temperature 70°F, insulation 80 percent efficient

Steam pressure, psig	Main size, in														0°F correction factor†
	2	2½	3	4	5	6	8	10	12	14	16	18	20	24	
10	6	7	9	11	13	16	20	24	29	32	36	39	44	53	1.58
30	8	9	11	14	17	20	26	32	38	42	48	51	57	68	1.50
60	10	12	14	18	24	27	33	41	49	54	62	67	74	89	1.45
100	12	15	18	22	28	33	41	51	61	67	77	83	93	111	1.41
125	13	16	20	24	30	36	45	56	66	73	84	90	101	121	1.39
175	16	19	23	26	33	38	53	66	78	86	98	107	119	142	1.38
250	18	22	27	34	42	50	62	77	92	101	116	126	140	168	1.36
300	20	25	30	37	46	54	68	85	101	111	126	138	154	184	1.35
400	23	28	34	43	53	63	80	99	118	130	148	162	180	216	1.33
500	27	33	39	49	61	73	91	114	135	148	170	185	206	246	1.32
600	30	37	44	55	68	82	103	128	152	167	191	208	232	277	1.31

*Chart loads represent losses due to radiation and convection for saturated steam.

†For outdoor temperature of °F, multiply the load value in the table for each main size by the correction factor corresponding to the steam pressure.

STEAM TRAP SELECTION AND SIZING

Selecting and Sizing the Steam Trap

General. Each trap design has specific characteristics. Because there is such a variety of trap designs, one of the key decisions in condensate drainage design is the choice of the right type of trap. Often, this choice is easy; for example, low-pressure heating system radiators are almost always equipped with a thermostatic trap because the characteristics of that type of trap match the condensate drainage and air venting requirements of low-pressure heating equipment. Sometimes, either of two different types of traps could equally well be applied to a given condensate drainage situation because either set of trap characteristics meets the drainage and venting requirements. There are some advantages and disadvantages to both, but either one could do the job. For example, a high-pressure steam main could be equipped with either a thermostatic or an inverted bucket trap. The choice between them then becomes a nontechnical matter, for example, cost, personal preference. In some cases, a given kind of trap simply would not be able to do the job; for example, a thermostatic trap requires a significant pressure drop between the steam-condensing device and the condensate pipe. Such a trap installed in a low-pressure heating system would not have a great enough pressure differential to operate. General selection criteria are given in Table 11.7. General characteristics are given in Table 11.8.

Liberal and oversized steam traps do not always provide an efficient and safe steam main drain installation. The following points should also be considered by the design professional:

1. Method of heat-up to be employed
2. Providing suitable reservoirs, or collecting legs, for condensate
3. Ensuring adequate pressure differential across the steam trap
4. Steam trap load safety factor
5. Flow of condensate from the selected trap

TABLE 11.7 General Steam Trap Selection Criteria

Application or condition	Recommended traps
Steam distribution lines	Thermostatic, balanced pressure
Heat exchangers that cannot tolerate back-up	Mechanical float or inverted bucket
Water hammer	Bimetallic, inverted bucket, or thermostatic
Batch processes with frequent start-ups	Balanced-pressure or bimetallic thermostatic
Heat exchangers with varying loads and pressures	Mechanical float or inverted bucket
Systems that shut off abruptly	All except inverted bucket traps, which can lose their seals
Freezing	Thermostatic, balanced pressure, bimetallic, or thermostatic

TABLE 11.8 General Steam Trap Characteristics*

Type of steam trap	Key advantages	Significant disadvantages	Frequently recommended services
Float and thermostatic (F&T)	Continuous condensate discharge	Float can be damaged by water hammer.	Heat exchangers with high and variable heat-transfer rates
	Handles rapid pressure changes	Level of condensate in chamber can freeze, damaging float and body.	When a condensate pump is required
	High noncondensable capacity	Some thermostatic air vent designs are susceptible to corrosion.	Batch processes that require frequent start-up of an air-filled system
Inverted bucket (IB)	Rugged	Discharges noncondensables slowly (additional air vent often required).	Continuous operation where noncondensable venting is not critical and rugged construction is important.
Wax or liquid expansion thermostatic (TS)	Tolerates water hammer without damage	Level of condensate can freeze, damaging the trap body (some models can handle some freezing).	
		Must have water seal to operate. Subject to losing prime. Pressure fluctuations and superheated steam can cause loss of water seal (can be prevented with a check valve).	
	Utilizes sensible heat of condensate	Element subject to corrosion damage.	Ideal for tracing used for freeze protection
	Allows discharge of noncondensables at start-up to the set point temperature	Condensate backs up into the drain line and/or process.	Freeze-protection, water and condensate lines and traps
	Not affected by superheated steam, water hammer, or vibration		Noncritical temperature control of heated tanks
	Resists freezing		

TABLE 11.8 General Steam Trap Characteristics* (*Continued*)

Type of steam trap	Key advantages	Significant disadvantages	Frequently recommended services
Balanced-pressure thermostatic (BP)	Small and light-weight Maximum discharge of noncondensables at start-up Unlikely to freeze	Some types damaged by water hammer, corrosion, and superheated steam. Condensate backs up into the drain line and/or process.	Batch processes requiring rapid discharge of noncondensables at start-up (when used for air vent) Drip-legs on steam mains and tracing Installations subject to ambient conditions below freezing
Bimetal thermostatic (BM)	Small and light-weight Maximum discharge of condensables at start-up Unlikely to freeze; unlikely to be damaged if it does freeze Rugged. Withstands corrosion, water hammer, high pressure, and superheated steam	Responds slowly to load and pressure changes. More condensate back-up than BP trap. Back-pressure changes operating characteristics.	Drip legs on constant-pressure steam mains Installations subject to ambient conditions below freezing
Thermodynamic (TD)	Rugged. Withstands corrosion, water hammer, high pressure, and superheated steam Handles wide pressure range Compact and simple Audible operation warns when repair is needed	Poor operation with very low pressure steam or high back-pressure. Requires slow pressure build-up to remove air at start-up to prevent air binding. Noisy operation.	Steam main drips, tracers Constant-pressure, constant-load applications Installations subject to ambient conditions below freezing

*This table is intended to serve as a general guide only. Trap design options, materials of construction, and techniques for using the trap in conjunction with other devices (for example, an air vent) can modify some of a trap's inherent characteristics.

Heat-Up Method. The type, size, and installation of the steam trap used to drain steam mains depends upon the method used in bringing the system up to normal operating pressure and temperature. The two methods of system heat-up commonly used are the supervised heat-up and the automatic heat-up.

Supervised Heat-Up. In the supervised heat-up method, manual drain valves are installed at all drainage points in the steam main system. The valves are fully opened to the condensate return before steam is admitted to the system. After most of the heat-up condensate has been discharged, the drain valves are closed, allowing the steam traps to drain the normal operating load. Therefore, the steam traps are sized to handle only the condensate formed due to radiation losses at the system's operating pressure. This heat-up method is generally used for large installations, having steam mains of appreciable size and length, and where the heat-up generally occurs only once a year, such as in large systems where the system pressure is maintained at a constant level after the start-up and is not shut down except in emergencies. A typical installation detail is illustrated in Fig. 11.26.

Automatic Heat-Up. In the automatic heat-up method, the steam boiler brings the system up to full steam pressure and temperature without supervision or manual drainage. This method relies on the traps to automatically drain the warm-up load of condensate as soon as it forms. This heat-up method is generally used in small- and medium-sized installations that are shut down and started up at regular intervals, as in heating systems or in dry cleaning plants, where the boiler is usually shut down at night and started up again the following morning. A typical installation detail is illustrated in Fig. 11.27.

Adequate Pressure Differential across the Trap. The trap cannot discharge condensate unless a pressure differential exists across it, that is, a higher pressure at the inlet compared to a lower pressure in the condensate line. The collecting leg should be of sufficient length to provide a hydrostatic head at the trap inlet so that the condensate can be discharged during warm-up, before a positive steam pressure develops in the steam main. For mechanical traps, not only the minimum differential, but also the maximum allowable differential—that is, the trap “seat pressure rating”—must be considered. In draining devices like heat exchangers controlled by temperature-regulating valves that could possibly operate in a vacuum at part

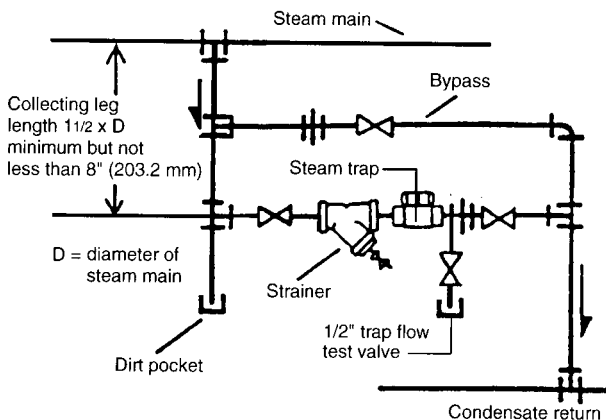


FIGURE 11.26 Steam trap installation for supervised heat-up.

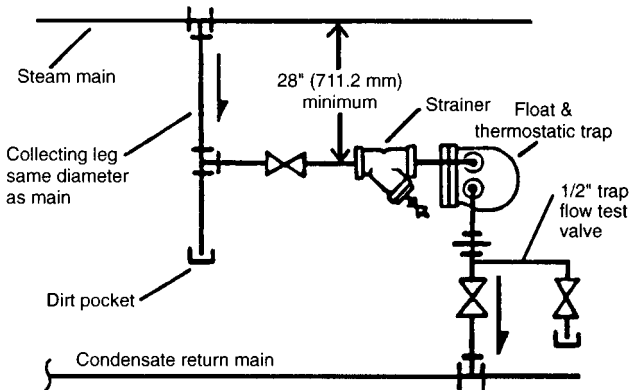


FIGURE 11.27 Steam trap installation for automatic heat-up.

load, install a vacuum breaker to ensure that pressure upstream of the trap cannot fall below atmospheric, and ensure that adequate hydrostatic head is available.

Steam Trap Load Safety Factor. After determining the actual amount of condensate expected to enter a trap, it is accepted practice to assign a safety factor to increase the amount of condensate. This safety factor is obtained from the manufacturer of the trap. As a guide, Table 11.9 provides recommended safety factors.

Sizing Condensate Pipes to Carry Flashing Condensate

1. Determine the pounds of flash steam from Table 11.2.
2. Multiply total high-pressure condensate flow by the pounds of flash steam to determine the flash steam flow rate.
3. Using Fig. 11.23, size the condensate pipe as if it were a steam pipe carrying nothing but the flash steam flow.

This procedure will oversize the condensate pipe to accommodate the flash steam without generating excess return line pressures. For example, determine the trap requirements for 1000 ft of 10-in horizontal main with a maximum operating pressure of 250 psig. Assume that the supervised heat-up method will be used.

TABLE 11.9 Steam Trap Safety Factors

Type of trap	Safety factor*
Thermostatic	2–4
Float and thermostatic	1.5–2.5
Inverted bucket	2–4
Thermodynamic	1.0–1.2

*Note: The safety factor to be applied depends upon the accuracy of the estimates of condensate load and differential pressure, as well as the possibility of any unusual conditions.

PROJECT DESIGN EXAMPLES

EXAMPLE 1 For 1000 ft of 10-in steam pipe at 5 psig, find the condensate load due to heat loss. The calculation consists of the following general steps:

1. Use Table 11.5, entering with 10-in pipe and S psig steam, find the figure of 77 lb/h per 100 ft of pipe length.
2. For 1000 ft, the condensate load is: $(77)(1000)I(100) = 770$ lb/h.
3. To drain 1000 ft of horizontal main, assume that a minimum of two traps should be used at approximately 500-ft intervals. The capacity required for each trap at 5 psig steam pressure is: $770/2 = 385$ lb/h each. If additional traps are desired, use the proposed number of traps.
4. The proposed type of trap is inverted bucket.
 - a. From Table 11.3, the recommended safety factor is 2 to 4.
 - b. Select a trap with a minimum capacity of $(385)(3) = 770$ lb/h at S psig.
5. The length of the collecting leg would be:
 - a. Diameter: 10 in.
 - b. Length: $(1.5)(10) = 15$ in.

EXAMPLE 2 Determine the size of the trap and the collecting leg size using the automatic heat-up method for 75 ft of 4-in main, maximum steam pressure 15 psig, ambient temperature of 75°F, and heat-up time of 15 mm.

1. Using Table 11.4, entering with 4-in pipe and 15 psig, interpolate to find 23.5 lb/h for 100 ft of pipe.
2. Calculate the actual condensation load for 75 ft of pipe:

$$75 \times \frac{23.5}{100} = 17.6 \text{ lb/h}$$

3. Calculate the average condensate formation rate during the heat-up period:

$$17.6 \times \frac{60}{15} = 70.4 \text{ lb/h}$$

4. The collecting leg size would be:
 - a. Diameter: 4 in.
 - b. Length: Minimum 28 in to provide a minimum 1 psig hydrostatic head at the inlet of the trap during warm-up.
5. The type and size of the trap might be:
 - a. Float and thermostatic.
 - b. Capacity: 70.4 lb/h at 1 psig pressure differential.
 - c. Maximum operating pressure: The trap must be able to open against differential pressures of at least 15 psig.
 - d. Maximum safety factor recommended from Table 11.3 is 1.5.
 - e. Trap capacity is $70.4 \times 1.5 = 105.6$ lb/h.

In determining the heat-up time, safety is the main consideration. Liberal time for heat-up should be allowed to limit the stresses in the piping system caused by thermal expansion, allow drainage in order to minimize the possibility of water hammer, and reduce the size of the trap required. Small bypass valves installed around the large main valves [generally 6 in (15 mm) and larger] are often used to warm up the main slowly.

Maximum Condensate Flow Rate

Maximum Flow Rate from Any Individual Trap. When the trap is installed at a piece of terminal equipment, the PPH steam use of the equipment will discharge the same PPH of condensate. Therefore, 100 PPH of steam will produce 100 PPH of condensate discharged from the trap. The maximum flow rate actually discharged will be determined from published literature for the specific trap selected. For traps placed in steam mains to drain system condensate, the maximum flow rate depends on several variables. Refer to sizing the steam trap as previously discussed.

Diversity Factor. When several traps discharge into a common line, it is not good practice to design a system in the belief that they will all discharge at the same time. Therefore, some diversity factor must be assigned. If the traps are operating on a light loading, a maximum factor of 20 percent should be used. For a medium loading, a 35 to 40 percent factor should be used, and for heavy loads, a 70 percent factor is recommended. Only when using a modulating trap, such as a float and thermostatic trap, can the drainage flow rate be the same as the calculated condensate load.

Condensate Main Pipe Sizing

The following information is required to size the condensate drainage system:

1. All condensate must drain by gravity or be pumped to an elevation from which it can flow by gravity to the final storage point. Determine if the system is to be atmospheric or vacuum assisted.
2. To determine the optimal pitch of the condensate pipe, refer to Table 11.10 for equivalency between sloped and horizontal flows.

TABLE 11.10 Equivalency between Sloped and Horizontal Flows

Pipe slope in 10 ft	Pressure loss, psi/100 ft
½ in	0.180
1 in	0.361
1½ in	0.540
2 in	0.722
3 in	1.084
4 in	1.440
5 in	1.805

3. The actual flow rate at the point of design, including the diversity factor, must be known.

The system design, whether atmospheric or vacuum assisted, is determined at the start of the project. The pitch of the pipe is determined by space and project conditions.

To size a condensate main for low-pressure steam, use Table 11.11. To size a condensate main for various steam pressures in a dry, closed system, use Table 11.12.

Condensate Cooler

The condensate cooler size is based on the total maximum expected flow rate in gallons per minute. This information is obtained from the condensate load plus the secondary side fluid requirements to which heat will be transferred. The outlet should be sized to flow half full using Table 9.5. The vessel volume receiving both the condensate and cooling water shall be sized 1.5 times the maximum gallons per minute rate capable of being drained.

Condensate Transfer Pumps

The condensate pump assembly collects the condensate and pumps it back to the boiler as quickly as possible in order to minimize heat loss. Condensate transfer pump assembly should be designed with input from the proposed manufacturer of the equipment. The role of remote condensate transfer pumps is to collect and return the condensate to the boiler as soon as possible.

In higher-pressure steam systems, special pumping equipment might be used to handle higher-temperature condensate (such as from absorption refrigeration machines) without cavitation or other damage. Pressure powered pumps that use compressed air or steam to pump the condensate are also available.

In a two-pipe system the traps vent air and other noncondensable gases into the condensate piping. This piping must be sized to consider the movement of air to the receiver vent in order to actually remove it from the system.

Flash Tanks

A flash tank may be required to cool the condensate before it flows into the receiver. Materials in the condensate pump may not be rated to handle temperatures of the high-temperature condensate, or the pump may cavitate in pumping high-temperature condensate. A flash tank vented to the atmosphere will immediately reduce condensate temperatures to 212°F. A liquid-to-liquid heat exchanger may also be required to further reduce condensate temperatures below 200°F so that the pump will be able to operate without cavitation or other damage.

Cooling condensate so that it can be pumped by low-temperature-rated equipment can add to plant operating costs as much as one-way system operation does, by increasing the use of water and sewage, by adding to energy costs through waste of heat, and by adding to the costs of chemical treatment required at the higher make-up feedwater rates. For these reasons, special low NPSH pumps have been developed to minimize or eliminate the need for condensate cooling when the heat is not needed. A typical low NPSH pump is illustrated in Fig. 11.28.

TABLE 11.11 Condensate Main Size, Low-Pressure Systems

Pipe size, in	$\frac{1}{32}$ psi or $\frac{1}{2}$ oz drop per 100 ft			$\frac{1}{24}$ psi or $\frac{2}{3}$ oz drop per 100 ft			$\frac{1}{16}$ psi or 1 oz drop per 100 ft			$\frac{1}{8}$ psi or 2 oz drop per 100 ft			$\frac{1}{4}$ psi or 4 oz drop per 100 ft			$\frac{1}{2}$ psi or 8 oz drop per 100 ft		
	Wet	Dry	Vac.	Wet	Dry	Vac.	Wet	Dry	Vac.	Wet	Dry	Vac.	Wet	Dry	Vac.	Wet	Dry	Vac.
G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
Return Main																		
$\frac{3}{4}$	—	—	—	—	—	42	—	—	100	—	—	142	—	—	200	—	—	283
1	125	62	—	145	71	143	175	80	175	250	103	249	350	115	350	—	—	494
$1\frac{1}{4}$	213	130	—	248	149	244	300	168	300	425	217	426	600	241	600	—	—	848
$1\frac{1}{2}$	338	206	—	393	236	388	475	265	475	675	340	674	950	378	950	—	—	1,340
2	700	470	—	810	535	815	1,000	575	1,000	1,400	740	1,420	2,000	825	2,000	—	—	2,830
$2\frac{1}{2}$	1,180	760	—	1,580	868	1,360	1,680	950	1,680	2,350	1,230	2,380	3,350	1,360	3,350	—	—	4,730
3	1,880	1,460	—	2,130	1,560	2,180	2,680	1,750	2,680	3,750	2,250	3,800	5,350	2,500	5,350	—	—	7,560
$3\frac{1}{2}$	2,750	1,970	—	3,300	2,200	3,250	4,000	2,500	4,000	5,500	3,230	5,680	8,000	3,580	8,000	—	—	11,300
4	3,880	2,930	—	4,580	3,350	4,500	5,500	3,750	5,500	7,750	4,830	7,810	11,000	5,380	11,000	—	—	15,500
5	—	—	—	—	—	7,880	—	—	9,680	—	—	13,700	—	—	19,400	—	—	27,300
6	—	—	—	—	—	126	—	—	15,500	—	—	22,000	—	—	31,000	—	—	43,800
Riser																		
$\frac{3}{4}$	—	48	—	—	48	143	—	48	175	—	48	249	—	48	350	—	—	494
1	—	113	—	—	113	244	—	113	300	—	113	426	—	113	600	—	—	848
$1\frac{1}{4}$	—	248	—	—	248	388	—	248	475	—	248	674	—	248	950	—	—	1,340
$1\frac{1}{2}$	—	375	—	—	375	815	—	375	1,000	—	375	1,420	—	375	2,000	—	—	2,830
2	—	750	—	—	750	1,360	—	750	1,680	—	750	2,380	—	750	3,350	—	—	4,730
$2\frac{1}{2}$	—	—	—	—	—	2,180	—	—	2,680	—	—	3,800	—	—	5,350	—	—	7,560
3	—	—	—	—	—	3,250	—	—	4,000	—	—	5,680	—	—	8,000	—	—	11,300
$3\frac{1}{2}$	—	—	—	—	—	4,480	—	—	5,500	—	—	7,810	—	—	11,000	—	—	15,500
4	—	—	—	—	—	7,880	—	—	9,680	—	—	13,700	—	—	19,400	—	—	27,300
5	—	—	—	—	—	12,600	—	—	15,500	—	—	22,000	—	—	31,000	—	—	43,800

TABLE 11.12 Dry, Closed System Condensate, Main Size*Flow rate (lb/h) for dry-closed returns*

D, in	Supply pressure = 5 psig Return pressure = 0 psig			Supply pressure = 15 psig Return pressure = 0 psig			Supply pressure = 30 psig Return pressure = 0 psig			Supply pressure = 50 psig Return pressure = 0 psig		
	$\Delta p/L$, psi/100 ft											
	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1
1/2	240	520	1,100	95	210	450	60	130	274	42	92	200
3/4	510	1,120	2,400	210	450	950	130	280	590	91	200	420
1	1,000	2,150	4,540	400	860	1,820	250	530	1,120	180	380	800
1 1/4	2,100	4,500	9,500	840	1,800	3,800	520	1,110	2,340	370	800	1,680
1 1/2	3,170	6,780	14,200	1,270	2,720	5,700	780	1,670	3,510	560	1,200	2,520
2	6,240	13,300	*	2,500	5,320	*	1,540	3,270	*	1,110	2,350	*
2 1/2	10,000	21,300	*	4,030	8,520	*	2,480	5,250	*	1,780	3,780	*
3	18,000	38,000	*	7,200	15,200	*	4,440	9,360	*	3,190	6,730	*
4	37,200	78,000	*	14,900	31,300	*	9,180	19,200	*	6,660	13,800	*
6	110,500	*	*	44,300	*	*	27,300	*	*	19,600	*	*
8	228,600	*	*	91,700	*	*	56,400	*	*	40,500	*	*
D, in	Supply pressure = 100 psig Return pressure = 0 psig			Supply pressure = 150 psig Return pressure = 0 psig			Supply pressure = 100 psig Return pressure = 15 psig			Supply pressure = 150 psig Return pressure = 15 psig		
	$\Delta p/L$, psi/100 ft											
	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1	1/16	1/4	1
1/2	28	62	133	23	51	109	56	120	260	43	93	200
3/4	62	134	290	50	110	230	120	260	560	93	200	420
1	120	260	544	100	210	450	240	500	1,060	180	390	800
1 1/4	250	540	1,130	200	440	930	500	1,060	2,200	380	800	1,680
1 1/2	380	810	1,700	310	660	1,400	750	1,600	3,320	570	1,210	2,500
2	750	1,590	*	610	1,300	*	1,470	3,100	6,450	1,120	2,350	4,900
2 1/2	1,200	2,550	*	980	2,100	*	2,370	5,000	10,300	1,800	3,780	7,800
3	2,160	4,550	*	1,760	3,710	*	4,230	8,860	*	3,200	6,710	*
4	4,460	9,340	*	3,640	7,630	*	8,730	18,200	*	6,620	13,800	*
6	13,200	*	*	10,800	*	*	25,900	53,600	*	19,600	40,600	*
8	27,400	*	*	22,400	*	*	53,400	110,300	*	40,500	83,600	*

*For these sizes and pressure losses, the velocity is above 7000 fpm. Select another combination of size and pressure loss.

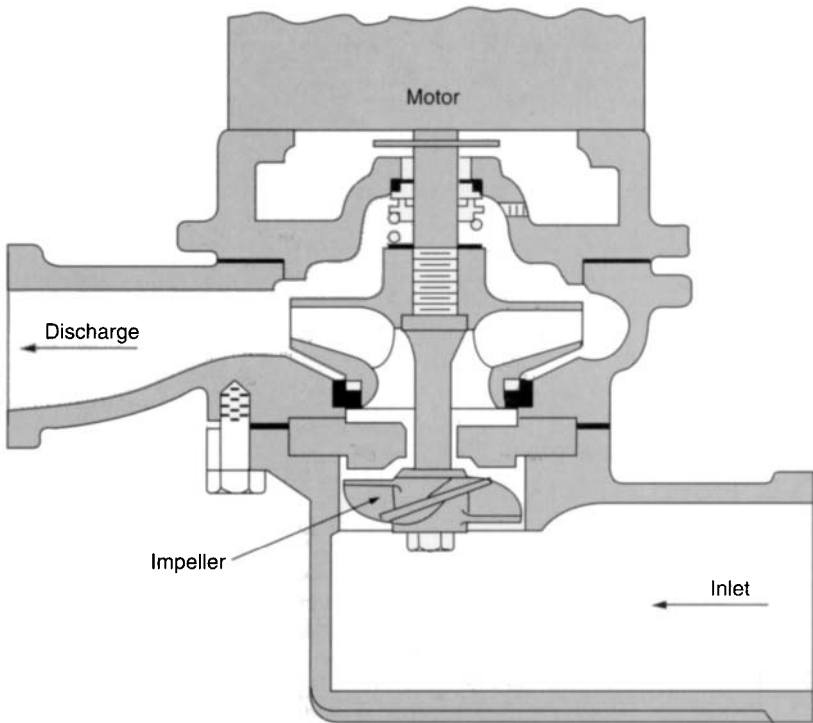


FIGURE 11.28 Typical low NPSH transfer pump.

SYSTEM DESIGN CONSIDERATIONS

Steam Trap Installation

The following recommendations should be observed:

1. The steam trap should be installed as close as possible to the collecting leg.
2. Lifting the condensate or piping condensate directly to a return line under pressure should be avoided. If the condensate must be lifted or discharged into a return system under pressure, the condensate should be collected in a vented flash tank and pumped to the elevated return or return system under pressure. If the trap must discharge to a return line that may be under pressure, then the differential pressure across the trap and the trap capacity will be reduced. A check valve on the discharge side of the trap is always required if the trap discharges into an elevated or pressurized return. A typical detail of discharging to an elevated return line is illustrated in Fig. 11.29.
3. Pipe connections to and from the steam trap should be at least equal to the pipe size of the trap connection, and full-size isolation valves should be installed on each side of the trap to allow service.
4. A strainer equipped with a blowdown valve should be installed before the steam trap.

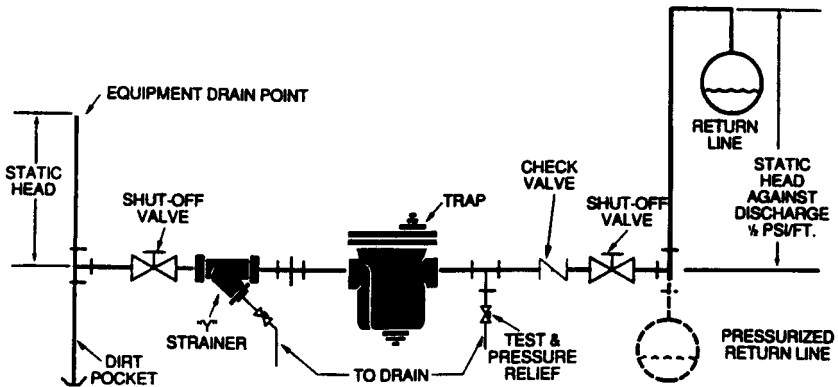


FIGURE 11.29 Steam trap discharging to an overhead return.

5. A test and pressure relief fitting is recommended downstream of the trap to ensure that the service valves are holding before the trap is serviced. It can also provide for quick testing of the trap.
6. All low points of the steam main and wherever condensate can collect, such as ahead of pressure-reducing valves and temperature regulators, should be drained.

High-Pressure System Condensate

Special procedures may be required to size the condensate pipes in high-pressure systems since they can carry a mixture of flash steam and condensate. The production of flash steam is influenced by other components in the system too. For example, thermostatic steam traps open only after the condensate has subcooled below saturation temperature for the given pressure. This subcooled condensate contains less energy than condensate at saturation temperature, so the amount of flash steam for a given drop in pressure will be reduced. Table 11.2 shows the amount of reevaporation, or the percentage of flash steam that will occur for different conditions of initial pressure and pressure drop. In sizing condensate returns for high-pressure systems, the pipe sizing tables shall consider this flash steam since it will provide a great deal more friction loss than would be the case if the flashing had not occurred and the pipes were carrying only liquid.

Pitching of Steam Piping

In the past some steam systems had “counterflow” steam mains, meaning that the pipe was pitched toward the boiler to return the condensate formed in the system. Counterflow piping designs have some shortcomings. Pipes must be generously sized since steam and water are moving opposite to one another at the same time. Small bubbles of condensate are likely to be surrounded by the steam, rapidly condensing the steam and causing noise in the pipe that sounds like gravel rattling. In addition to the noise, the highly pitched counterflow piping is difficult to install and must be large enough to:

1. Allow for the increase in friction between the fluids traveling in opposite directions
2. Limit the velocity of steam flow to prevent water hammer

For these reasons, it is preferable to pitch the steam mains in the direction of steam flow so that the steam and condensate will flow in the same direction. Short runouts of 3 to 4 ft (0.9 to 1.2 m) may be pitched for counterflow to eliminate the need for traps. These “parallel flow” mains are likely to be quieter and require less pitch and smaller pipe sizes for a given steam flow rate. Modern steam pipe sizing charts usually assume that parallel flow will be maintained to minimize interference between the steam and condensate.

All of these advantages are at least partly offset by the fact that the parallel flow system needs more pipes because *returns* must be installed at the end of the system to bring the condensate back to the boiler. A *dry return* is located above the water line of the boiler, and therefore can carry steam and air in addition to condensate. A *wet return* is located below the boiler water line; it is therefore flooded and doesn't need to be pitched. It does require some hydrostatic head in the form of a column of water to return condensate to the boiler.

Steam-condensing units have separate connections for the steam supply and the condensate return. A steam trap is installed at the condensate connection from each unit and at intervals along the steam main to eliminate any interference between the steam and liquid flow. This trap is the boundary between the steam and the condensate piping.

Costs of Wasting Condensate

There are costs associated with nonrecovery of condensate. Water lost from the steam system must eventually be made up, as well as any water used to lower the condensate temperature before discharge into a sewer. Even in areas that have abundant supplies of fresh water, these costs are rising. In areas that do not have abundant supplies, there may be limits on the amount of water that can be used in such a process.

The loss of condensate will always increase the rate of makeup feedwater introduced to the system. Since it's likely that the makeup feed is colder than the condensate, each pound of makeup water requires significantly more heat to bring it to the boiling temperature. The energy loss of wasted condensate increases with increasing system pressure. In tempering condensate and discharging it, the sensible heat is lost, adding to the energy costs of the process. That's why heat from steam condensate should be used whenever possible to preheat domestic hot water or ventilation air before discharging it.

Problems Resulting from Poor Condensate Drainage

A loss of heat transfer performance will result unless condensate is drained from the steam heating unit. Since heat transfer in a steam system is based upon the large amount of latent heat that becomes available as the steam condenses, it follows that if the heating unit is flooded, only the sensible heat from the condensate will become available as it cools. Table 11.1 shows that the sensible heat is only a small fraction of the latent heat available in a pound of steam at any given pressure. The

latent heat is transferred at constant steam temperature as the steam condenses, while the condensate would have to cool down to 32°F (0°C) in order to make all the sensible heat available.

Corrosion

Corrosion generally occurs in steam heating units and condensate piping that are not properly drained. Several corrosion processes have been defined including:

1. Generalized corrosion
2. Oxygen pitting
3. Condensate grooving, which etches away the metal along the path followed by condensate that has become acidic due to dissolved carbon dioxide
4. Fouling or scaling on heat transfer surfaces, which is increased by inadequate condensate drainage and venting

Corrosion is accelerated by the presence of carbon dioxide which can form in the boiler as chemical components like carbonates and bicarbonates decompose. Oxygen introduced by vacuum breakers or from makeup feedwater also increases the corrosion rate. Properly installed steam traps, condensate return piping, and pumping equipment can minimize these problems by draining the condensate and venting noncondensable gases from steam piping and heat exchangers.

Parallel Trapping

For the automatic heat-up method, the largest load that the steam trap must deal with is the warming-up load; consequently, the steam trap must be sized on the warm-up load. Depending on the size of the installation, this condition can result

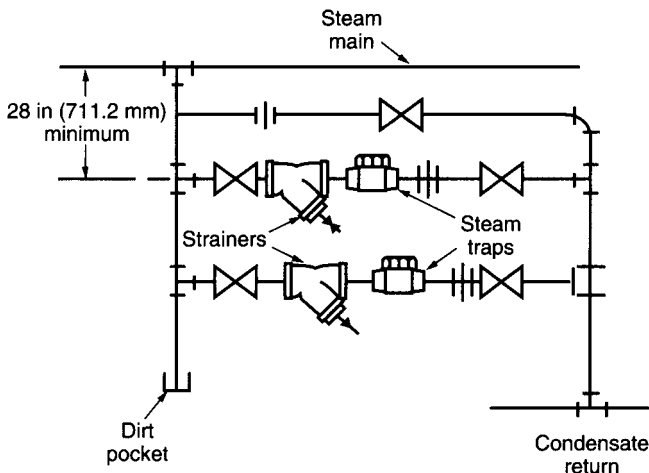


FIGURE 11.30 Parallel steam trapping.

in a considerably oversized steam trap, after the system is up to normal operating pressure. Oversized steam traps can create problems, particularly in high-pressure installations. For example, inverted bucket traps can lose their condensate level and pass live steam. All steam traps wear more rapidly on light loads than on heavy loads. Frequent release of small quantities of condensate at full discharge rate of the steam trap can create undesirable pressures in the condensate return piping system.

These problems can be reduced by installing smaller steam traps in parallel with the same aggregate capacity. Figure 11.30 shows a typical installation. It is recommended that parallel trapping be considered in any situation in which a single large steam trap would otherwise be required. In addition to the economies inherent in a parallel piping hookup, it provides emergency protection in the event that one steam trap becomes clogged or fails closed.

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