

Steam is an invisible gas generated by adding heat energy to water in a boiler. Enough energy must be added to raise the temperature of the water to the boiling point. Then additional energy—without any further increase in temperature—changes the water to steam.

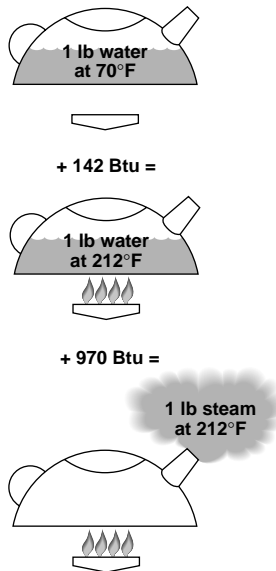
Steam is a very efficient and easily controlled heat transfer medium. It is most often used for transporting energy from a central location (the boiler) to any number of locations in the plant where it is used to heat air, water or process applications.

As noted, additional Btu are required to make boiling water change to steam. These Btu are not lost but stored in the steam ready to be released to heat air, cook tomatoes, press pants or dry a roll of paper.

The heat required to change boiling water into steam is called the heat of vaporization or latent heat. The quantity is different for every pressure/temperature combination, as shown in the steam tables.

### Steam at Work... How the Heat of Steam Is Utilized

Heat flows from a higher temperature level to a lower temperature level in a process known as heat transfer. Starting in the combustion chamber of the boiler, heat flows through the boiler tubes to the water. When the higher pressure in the boiler pushes steam out, it heats the pipes of the distribution system. Heat flows from the steam through the walls of the pipes into the cooler surrounding air. This heat transfer changes some of the steam back into water. That's why distribution lines are usually insulated to minimize this wasteful and undesirable heat transfer.



**Figure CG-1.** These drawings show how much heat is required to generate one pound of steam at atmospheric pressure. Note that it takes 1 Btu for every 1° increase in temperature up to the boiling point, but that it takes more Btu to change water at 212°F to steam at 212°F.

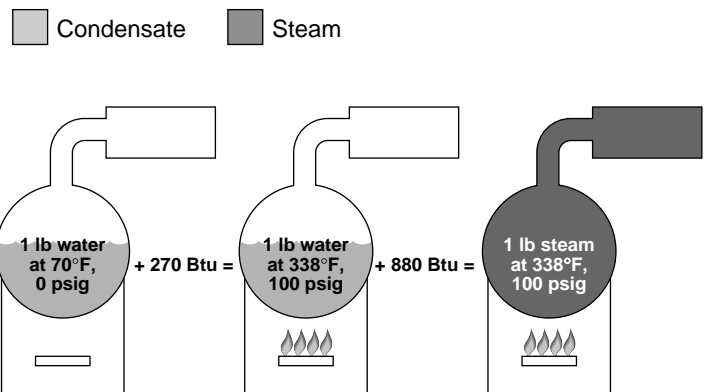
When steam reaches the heat exchangers in the system, the story is different. Here the transfer of heat from the steam is desirable. Heat flows to the air in an air heater, to the water in a water heater or to food in a cooking kettle. Nothing should interfere with this heat transfer.

### Condensate Drainage... Why It's Necessary

Condensate is the by-product of heat transfer in a steam system. It forms in the distribution system due to unavoidable radiation. It also forms in heating and process equipment as a result of desirable heat transfer from the steam to the substance heated. Once the steam has condensed and given up its valuable latent heat, the hot condensate must be removed immediately. Although the available heat in a pound of condensate is negligible as compared to a pound of steam, condensate is still valuable hot water and should be returned to the boiler.

### Definitions

- **The Btu.** A Btu—British thermal unit—is the amount of heat energy required to raise the temperature of one pound of cold water by 1°F. Or, a Btu is the amount of heat energy given off by one pound of water in cooling, say, from 70°F to 69°F.
- **Temperature.** The degree of hotness with no implication of the amount of heat energy available.
- **Heat.** A measure of energy available with no implication of temperature. To illustrate, the one Btu that raises one pound of water from 39°F to 40°F could come from the surrounding air at a temperature of 70°F or from a flame at a temperature of 1,000°F.

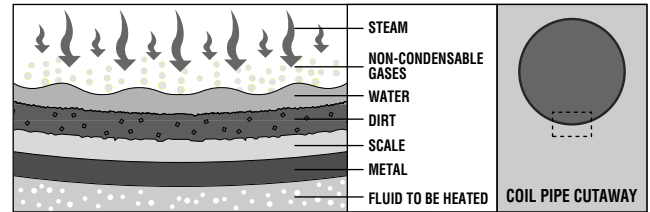


**Figure CG-2.** These drawings show how much heat is required to generate one pound of steam at 100 pounds per square inch pressure. Note the extra heat and higher temperature required to make water boil at 100 pounds pressure than at atmospheric pressure. Note, too, the lesser amount of heat required to change water to steam at the higher temperature.

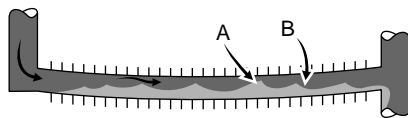
**The need to drain the distribution system.** Condensate lying in the bottom of steam lines can be the cause of one kind of water hammer. Steam traveling at up to 100 miles per hour makes “waves” as it passes over this condensate Fig. CG-4). If enough condensate forms, high-speed steam pushes it along, creating a dangerous slug that grows larger and larger as it picks up liquid in front of it. Anything that changes the direction—pipe fittings, regulating valves, tees, elbows, blind flanges—can be destroyed. In addition to damage from this “battering ram,” high-velocity water may erode fittings by chipping away at metal surfaces.

**The need to drain the heat transfer unit.** When steam comes in contact with condensate cooled below the temperature of steam, it can produce another kind of water hammer known as *thermal shock*. Steam occupies a much greater volume than condensate, and when it collapses suddenly, it can send shock waves throughout the system. This form of water hammer can damage equipment, and it signals that condensate is not being drained from the system. Obviously, condensate in the heat transfer unit takes up space and reduces the physical size and capacity of the equipment. Removing it quickly keeps the unit full of steam (Fig. CG-5). As steam condenses, it forms a film of water on the inside of the heat exchanger. Non-condensable gases do not change into liquid and flow away by gravity. Instead, they accumulate as a thin film on the surface of the heat exchanger—along with dirt and scale. All are potential barriers to heat transfer (Fig. CG-3).

**The need to remove air and CO<sub>2</sub>.** Air is always present during equipment start-up and in the boiler feedwater. Feedwater may also contain dissolved carbonates, which release carbon dioxide gas. The steam velocity pushes the gases to the walls of the heat exchangers, where they may block heat transfer. This compounds the condensate drainage problem, because these gases must be removed along with the condensate.

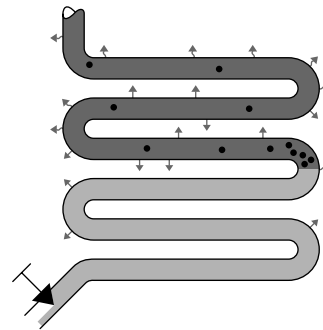


**Figure CG-3.** Potential barriers to heat transfer: steam heat and temperature must penetrate these potential barriers to do their work.

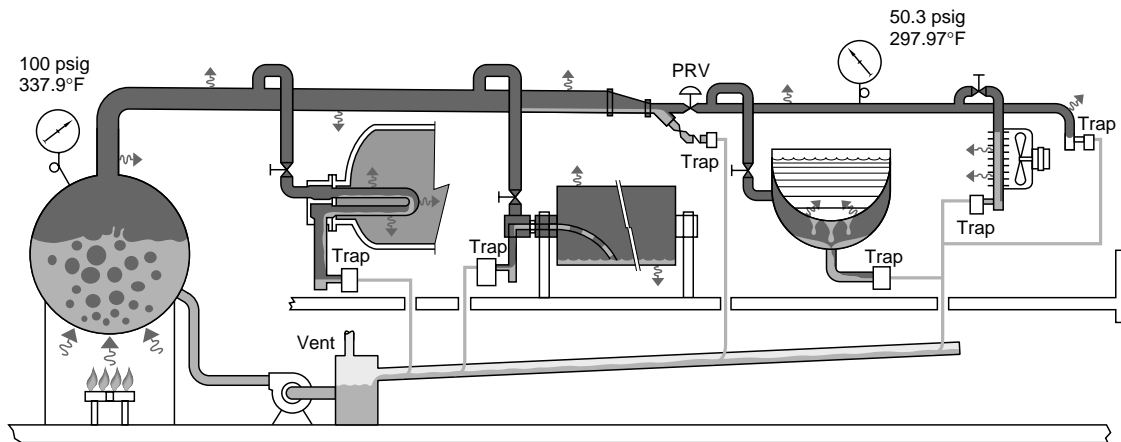


**Figure CG-4.** Condensate allowed to collect in pipes or tubes is blown into waves by steam passing over it until it blocks steam flow at point A. Condensate in area B causes a pressure differential that allows steam pressure to push the slug of condensate along like a battering ram.

Condensate    Steam    Vapor



**Figure CG-5.** Coil half full of condensate can't work at full capacity.



**Figure CG-6.** Note that heat radiation from the distribution system causes condensate to form and, therefore, requires steam traps at natural low points or ahead of control valves. In the heat exchangers, traps perform the vital function of removing the condensate before it becomes a barrier to heat transfer. Hot condensate is returned through the traps to the boiler for reuse.

## Effect of Air on Steam Temperature

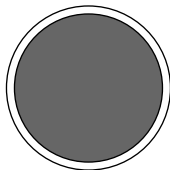
When air and other gases enter the steam system, they consume part of the volume that steam would otherwise occupy. The temperature of the air/steam mixture falls below that of pure steam. Figure CG-7 explains the effect of air in steam lines. Table CG-2 and Chart CG-5 show the various temperature reductions caused by air at various percentages and pressures.

## Effect of Air on Heat Transfer

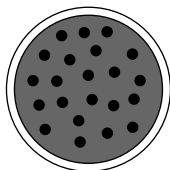
The normal flow of steam toward the heat exchanger surface carries air and other gases with it. Since they do not condense and drain by gravity, these non-condensable gases set up a barrier between the steam and the heat exchanger surface. The excellent insulating properties of air reduce heat transfer. In fact, under certain conditions as little as 1/2 of 1% by volume of air in steam can reduce heat transfer efficiency by 50% (Fig. CG-8).

Pressure (psig)	Temp. of Steam, No Air Present (°F)	Temp. of Steam Mixed With Various Percentages of Air (by Volume) (°F)		
		10%	20%	30%
10.3	240.1	234.3	228.0	220.9
25.3	267.3	261.0	254.1	246.4
<b>50.3</b>	<b>298.0</b>	<b>291.0</b>	<b>283.5</b>	<b>275.1</b>
75.3	320.3	312.9	304.8	295.9
100.3	338.1	330.3	321.8	312.4

**Figure CG-7.** Chamber containing air and steam delivers only the heat of the partial pressure of the steam, not the total pressure.



Steam chamber 100% steam  
 Total pressure 100 psia  
 Steam pressure 100 psia  
 Steam temperature 327.8°F



Steam chamber 90% steam and 10% air  
 Total pressure 100 psia  
 Steam pressure 90 psia  
 Steam temperature 320.3°F

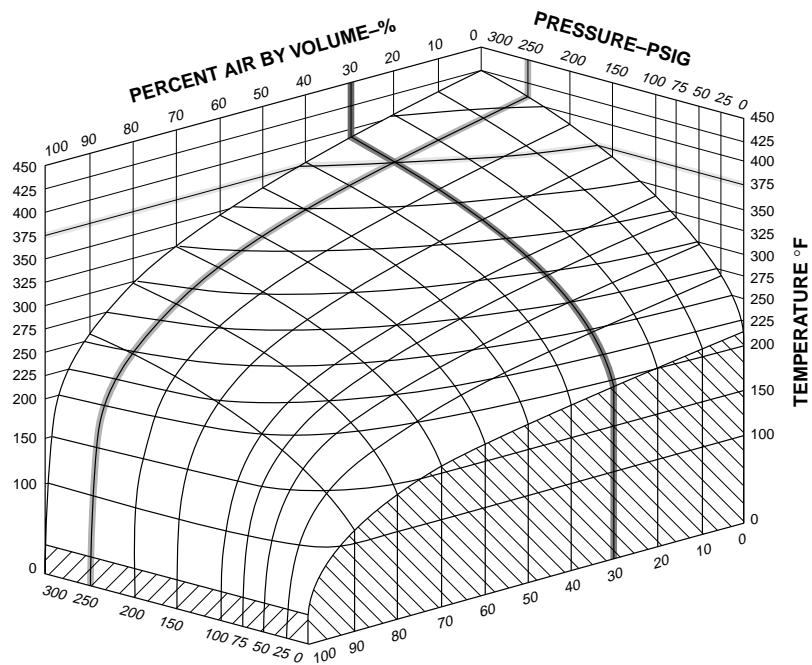
When non-condensable gases (primarily air) continue to accumulate and are not removed, they may gradually fill the heat exchanger with gases and stop the flow of steam altogether. The unit is then "air bound."

## Corrosion

Two primary causes of scale and corrosion are carbon dioxide (CO<sub>2</sub>) and oxygen. CO<sub>2</sub> enters the system as carbonates dissolved in feedwater and, when mixed with cooled condensate, creates carbonic acid. Extremely corrosive, carbonic acid can eat through piping and heat exchangers (Fig. CG-9). Oxygen enters the system as gas dissolved in the cold feedwater. It aggravates the action of carbonic acid, speeding corrosion and pitting iron and steel surfaces (Fig. CG-10).

## Eliminating the Undesirables

To summarize, traps must drain condensate because it can reduce heat transfer and cause water hammer. Traps should evacuate air and other non-condensable gases because they can reduce heat transfer by reducing steam temperature and insulating the system. They can also foster destructive corrosion. It's essential to remove condensate, air and CO<sub>2</sub> as quickly and completely as possible. A *steam trap*, which is simply an automatic valve that opens for condensate, air and CO<sub>2</sub> and closes for steam, does this job. For economic reasons, the steam trap should do its work for long periods with minimum attention.



**Chart CG-5. Air Steam Mixture**

Temperature reduction caused by various percentages of air at differing pressures. This chart determines the percentage of air with known pressure and temperature by determining the point of intersection between pressure, temperature and percentage of air by volume. As an example, assume system pressure of 250 psig with a temperature at the heat exchanger of 375°F. From the chart, it is determined that there is 30% air by volume in the steam.

## What the Steam Trap Must Do

The job of the steam trap is to get condensate, air and CO<sub>2</sub> out of the system as quickly as they accumulate. In addition, for overall efficiency and economy, the trap must also provide:

- 1. Minimal steam loss.** Table CG-3 shows how costly unattended steam leaks can be.
- 2. Long life and dependable service.** Rapid wear of parts quickly brings a trap to the point of unavailability. An efficient trap saves money by minimizing trap testing, repair, cleaning, downtime and associated losses.
- 3. Corrosion resistance.** Working trap parts should be corrosion-resistant in order to combat the damaging effects of acidic or oxygen-laden condensate.
- 4. Air venting.** Air can be present in steam at any time and especially on start-up. Air must be vented for efficient heat transfer and to prevent system binding.
- 5. CO<sub>2</sub> venting.** Venting CO<sub>2</sub> at steam temperature will prevent the formation of carbonic acid. Therefore, the steam trap must function at or near steam temperature since CO<sub>2</sub> dissolves in condensate that has cooled below steam temperature.
- 6. Operation against back pressure.** Pressurized return lines can occur both by design and unintentionally. A steam trap should be able to operate against the actual back pressure in its return system.

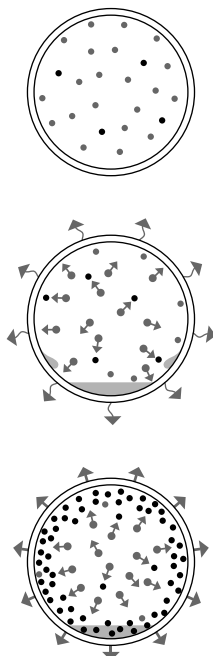
- 7. Freedom from dirt problems.** Dirt is an ever-present concern since traps are located at low points in the steam system. Condensate picks up dirt and scale in the piping, and solids may carry over from the boiler. Even particles passing through strainer screens are erosive and, therefore, the steam trap must be able to operate in the presence of dirt.

A trap delivering anything less than all these desirable operating/design features will reduce the efficiency of the system and increase costs. When a trap delivers all these features the system can achieve:

1. Fast heat-up of heat transfer equipment
2. Maximum equipment temperature for enhanced steam heat transfer
3. Maximum equipment capacity
4. Maximum fuel economy
5. Reduced labor per unit of output
6. Minimum maintenance and a long trouble-free service life

Sometimes an application may demand a trap without these design features, but in the vast majority of applications the trap which meets all the requirements will deliver the best results.

**Figure CG-8.** Steam condensing in a heat transfer unit moves air to the heat transfer surface, where it collects or "plates out" to form effective insulation.



Condensate      Steam



**Figure CG-9.** CO<sub>2</sub> gas combines with condensate allowed to cool below steam temperature to form carbonic acid, which corrodes pipes and heat transfer units. Note groove eaten away in the pipe illustrated.



**Figure CG-10.** Oxygen in the system speeds corrosion (oxidation) of pipes, causing pitting such as shown here.

Figs. CG-9 and CG-10 courtesy of Dearborn Chemical Company.

**Table CG-3. Cost of Various Sized Steam Leaks at 100 psi**  
(Assuming steam costs \$5.00/1,000 lbs)

Size of Orifice (in)	Lbs Steam Wasted Per Month	Total Cost Per Month	Total Cost Per Year
1/2	835,000	\$4,175.00	\$50,100.00
7/16	637,000	3,185.00	38,220.00
3/8	470,000	2,350.00	28,200.00
5/16	325,000	1,625.00	19,500.00
1/4	210,000	1,050.00	12,600.00
3/16	117,000	585.00	7,020.00
1/8	52,500	262.50	3,150.00

The steam loss values assume clean, dry steam flowing through a sharp-edged orifice to atmospheric pressure with no condensate present. Condensate would normally reduce these losses due to the flashing effect when a pressure drop is experienced.