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Common Steam System Design Mistakes

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ABSTRACT

A steam system for a brewery is a sophisticated collection of equipment that includes a boiler, piping, condensate return system, and steam traps that will last decades when properly installed. All too often these systems are installed or serviced by a contractor unfamiliar with the unique properties of steam, and as a result, the system does not operate properly or efficiently. Steam systems are used in breweries because they provide better temperature control: faster heating due to the larger heating surface in a steam kettle or tun, and more uniform heating due to the steam itself. For the steam system to provide trouble-free operation for the brewery, it requires a two-pronged approach. First, the system has to be designed or installed by someone familiar with the dynamics of steam. Second, the system requires regular maintenance by someone skilled in steam system operation. The installation of the steam boiler and system requires the proper sizing and design of a piping system that meets the specifications of the boiler manufacturer. This article discusses proper steam piping, steam pressure control settings, pipe insulation, and how proper water treatment is crucial for a steam boiler. A steam system should provide several decades of trouble-free operation if it is installed and maintained correctly.

The following examples are issues I have seen in my three-plus decades of steam sales, maintenance, and consulting.

Find a Steam Expert

A steam system is an older technology and trickier to design than a hydronic or hot water system. Most steam experts are long gone, and the remaining ones are difficult to find.

How do you find a steam expert for your brewery? I suggest visiting HeatingHelp.com, as it is filled with boiler experts from all over the world. You can ask questions and have them answered in about an hour. The other way to find an expert is to ask other local brewers. They may be able to tell you who they used and how the installer was to work with on their project.

"Do you have a steam boiler with a bottom discharge?" one caller asked. I had never heard of a boiler with a bottom discharge, but before saying so, I asked, "Why do you need a bottom steam outlet?"

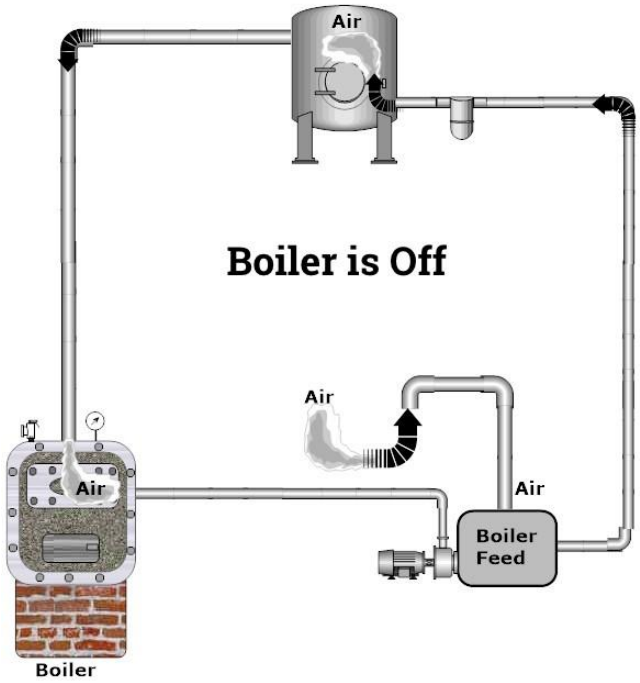
"Because steam is hotter than air. Heat always rises, my installer says," he said confidently.

"So, do you have a boiler with a bottom discharge?" he asked again. I was the third company he had called with that question. I wanted to say, "You really should find an installer who understands steam because steam can be made to go up or down or sideways. It does that because of pressure differential," but I didn't. Instead, I offered to meet him and his installer at the job site and help determine what he needed.

Understanding Steam Systems

To understand how steam works, remember this axiom: Pressure goes from high to low, always. Steam system operation is based on ounces of pressure differential, and a small difference in pressure changes the dynamics of the system. For example, if two boilers are connected with a common equalizing pipe, a one-ounce difference in steam pressure between two boilers could mean a water level difference of 1¾″ between the boilers. One of the basic tenets of steam systems is this: two gases (steam and air) cannot occupy the same space.

The piping and part of the boiler are filled with air if the boiler is off. When the burner starts, the water inside the boiler is heated and becomes steam. The volume of water expands to 1,600 times its volume when it changes state to steam vapor. The steam zooms out of the boiler at speeds between 20 and 40 miles per hour, push-



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ing the air ahead of it. The air is vented out of the piping through the steam traps and the air vents on the boiler feed or condensate tank. At the end of the brewing process and the boiler is shut off, the steam condenses, and the volume of space that was filled with steam is suddenly empty. Air rushes in to take the place of the steam. Anything that hinders this cycle will cause problems with the system. This could include sagging pipes, defective steam traps, or closed control valves. I like to think the steam system breathes: the boiler exhales steam when on and inhales air when off. The following are the most common problems I see on steam boiler projects.

Sizing

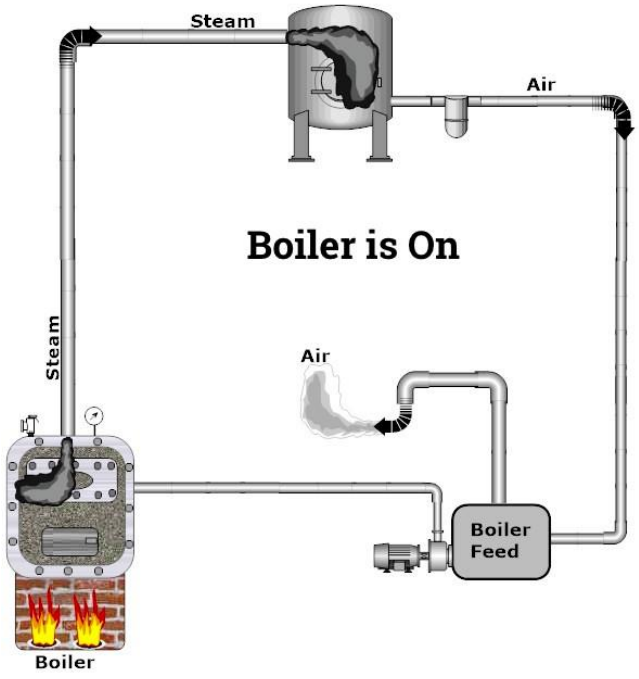
When sizing a steam system, it has to be sized for the connected load. This includes all the piping and the vessels. Another sizing consideration is whether you will be operating all the steam-consuming components simultaneously or separately.

For example, I like using Blaine Clouston's* rules for brewery steam sizing. They are as follows:

Brew kettle	32,000 BTU/h/bbl
Hot liquor heating from 60 to 175°F in 4 h	19,500 BTU/h/bbl
Mash vessel	29,000 BTU/h/bbl

*Mr. Blaine Clouston is a mechanical engineer and the owner of Simplified Stainless Systems in Saanichton, BC, Canada. He has been designing breweries for over 25 years.

If you plan to operate the brew kettle at the same time as the mash tun, you will need a boiler almost double in size, which increases your installation costs. However, an oversized boiler will tend to short cycle, which means the burner will turn on and off quickly, and this could negatively affect the batch. The other question is, will you be growing? If so, will the boiler and piping be large enough for future expansion? Unexpected growth in your brewery could mean the steam system may be undersized. An undersized boiler will never be able to keep up with the process. Since it is impossible to see into the future, I urge my customers to slightly oversize the main steam pipe that feeds the brewery. The added costs are minimal; this will allow you to add a new boiler in the future if needed.



How the steam pushes the air from the piping and out the boiler feed unit vent.

Near-Boiler Piping

The near-boiler piping is crucial to the proper operation of your brewery; it is used to dry the steam. The steam is called dry when it is hot enough to withstand cooling a little without condensing into water. The near-boiler piping is the piping directly attached to the boiler. If the piping is undersized or incorrectly installed, it will lead to wet steam or carryover. Wet steam or carryover is water that is pulled from the boiler and causes the steam to collapse prematurely. Carryover also increases water treatment costs because the water containing the treatment chemicals leaves the boiler and is sent into the system. Think of it like this: imagine you are sitting around a campfire trying to make s'mores and someone keeps squirting water on the flame. Carryover does that. It causes the steam to collapse prematurely, and you have to add more heat, making your process take much longer. Most modern steam boilers are designed to yield a steam velocity around 40 feet per second. If you are using a cast iron sectional steam boiler for your brewery, these boilers require extra piping called a "swing joint," which is used to absorb the expansion and contraction of the piping.

System Piping

When I was first in the trade, I was taught to use schedule 40 black iron pipe for the low-pressure steam piping and schedule 80 pipe, which is 50% thicker, for the condensate piping. The reason for the thicker pipe in the condensate return piping is because carbonic acid forms in the pipe due to carbon dioxide from the air reacting with water. The acid will corrode the bottom of the pipe.

During one of the steam classes I led, an installer asked, "Can I use copper for the steam piping? Copper is used for high-pressure refrigerants with pressures around 400 psi."

It is a good question, and the Copper Development Association does have guidelines for the use of copper for steam systems. It references the ASME Boiler and Pressure Vessel Code, which states copper tubing and fittings can be used for temperatures up to 400°F and pressures up to 120 psi, easily within the parameters of a low-pressure steam system. However, my concern with using copper is the differences in thermal expansion and contraction compared with steel and iron. Copper can handle the temperatures and pressures of a steam system, but it expands at a much higher rate than steel, and I believe it would eventually leak at any interfaces, which is dangerous.

A newer development in piping for steam systems is pipe press fittings. Also, grooved fittings can now be used with low-pressure steam. Both of these reduce the installation labor for steam piping. Consult with your boiler manufacturer and installer to see if these might be an option for you.

Pipe Pitch

The steam piping is usually pitched (i.e., angled from horizontal) at a rate of ¼″ to ½″ per every 10 feet away from the boiler. The pipe is pitched so the condensate water does not

pool in one place. If the condensate pools, the steam zooming through the pipe can pick up the water and slam it into the closest fitting. This slamming water causes loud banging and can destroy control valves or even break a fitting apart.

Another concern with standing water inside a pipe is "condensate-induced water hammer." This is a hazardous phenomenon as the cool water causes rapid condensation of the steam and can generate overpressures above 1,500 psi or ten times the pressure rating of standard pipe fittings.

Pressure Control Settings

"This pop safety valve keeps opening, and I lose all my steam. I think the safety valve is defective," one frustrated caller said.

"What is the steam pressure setting on the boiler?" I asked.

"Fifteen. Why?" he asked.

"There's your problem."

Although the boiler is rated for 15 psi, it should not operate that high. My vehicle has a top speed on the speedometer of 120 miles per hour or 193 kilometers per hour. Just because the vehicle is capable of operating at that speed does not mean I should operate it at that speed all the time. Similarly, the steam pressure control on the boiler should be set no higher than 11–12 psi. If you operate the boiler at pressures higher than 12 psi, you risk either opening the pop safety valve and losing all your steam or tripping the high-pressure limit control. If the manual reset pressure control trips, the boiler will not start again until the boiler pressure drops and the manual reset button is pushed.

Some believe you have to operate the boiler at 15 psi to get a rolling boil. However, as I explained to the caller, the BTU difference is insignificant between 11 and 15 psi. Steam at 15 psi has a total of 1,163 BTUs, while steam at 11 psi has a total of 1,161 BTUs—only two BTUs less. A BTU is equivalent to the heat produced by burning a wooden matchstick. If the pressure control and the pop safety valve are both set for 15 psi, you will risk popping the safety valve when the pressure is that high. If you check the pop safety valve operating instructions, many suggest operating the boiler at a few psi less than the 15 psi setpoint.

Another advantage of using lower pressure steam is the steam volume. The volume of steam at 11 psi is 16 cubic feet, and the volume of steam at 15 psi is 14 cubic feet. You would need to generate 14% more steam to fill the pipes and vessels at 15 psi than you would at 11 psi. This increases your operating costs.

I suggest the following settings for the boiler pressure controls:

Manual reset limit control	14 psi
Operating pressure control	11 psi

If the boiler has a firing rate control that varies the firing rate of the burner, I would set this control for 11 psi and move the operating control up to 12 psi.

A pop safety relief valve piped into a drip pan ell.

Pipe Insulation

Steam pipe insulation is required to ensure dry steam is delivered throughout the brewery. If the insulation is missing, the steam could condense prematurely and lower the system temperature and efficiency. In addition, the excess condensate caused by premature condensation could overwhelm the steam traps because they were sized to handle condensate from an insulated pipe. This could lead to a stalled trap, which will cause banging from water hammer and unbalanced steam distribution. Another consideration is that an uninsulated steam pipe loses 80 times more heat than an insulated pipe, which could make the room very warm. Industry expert Dan Holohan suggests insulating the condensate pipes to reduce the formation of carbonic acid, which is generated in the condensate piping.

There are mixed opinions about insulating the boiler feed tank. I suggest you contact the tank manufacturer. While insulation will slow the heat loss of the tank into the boiler room, there may be some unintended consequences. According to Xylem/Hoffman Pump, tank insulation may allow elevated condensate temperatures, which could negatively affect the pump operation. For example, if condensate temperature is close to the boiling temperature of the water, it could flash to steam and ruin the pump. The pump is designed to pump water and not a vapor. If this occurs, the boiler will go off on low water and shut down the process. Other factors to consider when insulating a boiler feed tank are that insulation could impede access to the tank and could promote rust of the tank from trapped moisture.

Water Treatment

Water treatment is crucial for steam boilers to maximize equipment life. I have seen boilers fail after only a few years because the water treatment was not done. Water treatment is usually a chemical or compound added to the boiler water to inhibit corrosion, reduce scale buildup, extend boiler and pipe life, and maintain efficiency. The chemical treatment is usually a combination of several components, typically consisting of an oxygen scavenger, a corrosion inhibitor, and a pH/alkalinity adjustment. The oxygen scavenger removes the oxygen in the boiler water so the oxygen cannot consume the metal. The corrosion inhibitor, as the name suggests, reduces the corrosion at or below the water line of the boiler. The pH/alkalinity adjustment tries to keep the boiler water pH levels where the boiler manufacturer recommends.

A water softener should be part of any boiler water treatment program because it will remove the solids of the boiler feedwater. The solids are typically magnesium, calcium, and iron. If these were allowed to enter the boiler, they would cause scale to form. Scale impedes heat transfer, so your boiler has to work longer and harder. Also, the scale will eventually destroy the tube. Scale typically forms on the hottest surfaces inside the boiler.

The best water treatment is to have a tight, non-leaking system. Any leaks found in the boiler room or from the steam system piping should be repaired promptly. When there are leaks

in the steam system, this allows fresh makeup water to be introduced. This new water has to be softened and treated chemically. This increases your costs. I recommend installing a water meter on the makeup water line, as it will help you determine if your system is leaking. All steam systems will leak a small amount during normal operations. The losses come from the vents and are usually about 2% of the water volume per month. A competent water treatment professional should be consulted, as proper water treatment can save thousands of dollars in repairs.

Where to Feed the Water Treatment

The water treatment for a steam system is usually piped into the boiler feed tank. However, some boiler feed manufacturers will void the warranty if the treatment chemicals are fed directly to the boiler feed tank. The tank manufacturer should be consulted for the proper location. Water treatment for a steam system is usually introduced with a small injection pump.

Venting the Boilers

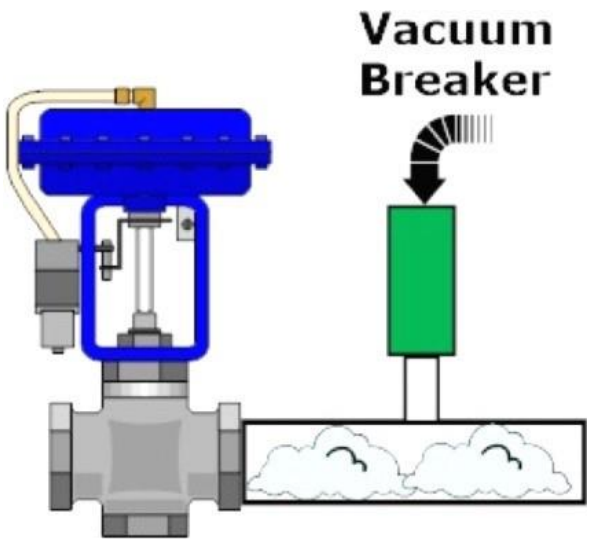
Most low-pressure steam boilers are category 1 appliances and can be vented into a traditional flue or chimney. If using an existing chimney, verify the size and integrity of the flue before connecting the new boiler. There are a couple of caveats on venting the boiler. The 2012 International Fuel Gas Code 503.10.8 requires the maximum horizontal length of the flue connector shall be no more than 75% of the height of the vertical chimney or stack, unless it is a "B-vent," and then the horizontal connector can be the same length as the chimney height. If the chimney height is over 30 feet high, a draft control should be installed, typically a barometric damper. Excess draft in the boiler can cause over-firing, which leads to unstable water levels, which could shut it off or cause water carryover.

How Draft Affects the Boiler

A customer was experiencing boiler problems; the burner kept tripping on low water. When on site, I saw the water was pouring down the inside of the top of the boiler gauge glass, which meant the water inside the boiler was surging. This surging is like a tsunami inside the boiler, causing the water to rock back and forth. I knelt and viewed the burner flame. The flame was being sucked inside the boiler tubes, meaning that the boiler was over-firing. The next test was the chimney draft on the boiler, which was designed for –0.05″ water column. The reading showed a draft reading of –0.5″ water column, ten times the recommended level. The high draft caused the surging inside the boiler and the low water cutoff to trip. Once the draft was correctly adjusted, these problems went away.

Steam Traps

Steam traps are integral to the safe and efficient operation of the steam system. Steam traps are typically installed at the outlet of the steam main, and at the outlets of the mash tun and kettle, and they have a couple of duties. The trap allows the air to vent from the piping so the steam can reach the vessel. Once the steam is there, the trap closes until the steam surrenders the latent heat and reverts to condensate. The trap then opens to allow the condensate out of the kettle or mash tun. After the boiler is shut off, the trap opens and lets air back into the piping and vessels to prevent a vacuum as the steam cools and condenses. The average life of a steam trap is between 6 and 10 years, and they should be checked each year to verify they are operating correctly. There are rebuild kits available that allow you to remove the lid and replace the internal cage unit.



A vacuum breaker can be installed after the valve to break a vacuum that may form when the valve shuts off and the steam condenses.

Control Valves

The control valves on your kettle or mash tun can be a headache if not installed correctly. As stated earlier, the piping system will either have steam or air, depending on whether the boiler is on or off. If the valves are closed, the air cannot enter, and the system goes into a vacuum. Vacuum inside a steam system can do strange things and create havoc. At one brewery, the vacuum pulled the water from the condensate tank into the boiler, flooding it. When the valves opened, it sounded like a Blue Man Group concert with all the banging. A simple vacuum breaker installed on the kettle solved the problem.

Beware of Good Intentions

The International Plumbing Code 701.7 specifies that the boiler blowdown temperature entering the building drain must be below 140°F. A customer hired a new maintenance person, who took it upon himself to pipe all the boiler blowdown piping in the boiler room directly into the floor drain. He did not like the water spilling onto the floor. In a short time, the hot condensate blowdown melted the building's PVC drain piping, making it look like cooked spaghetti. The owner had to replace much of the drain piping, which was conveniently located behind walls and cabinets. A blowdown tank and cooler were installed to fix the problem, and these should be part of any steam boiler plant.

In Conclusion

A properly designed steam system can last several decades, or it can be ruined within a few years. The deciding factor is consistent boiler maintenance. All steam systems require maintenance. If ignored, the steam system will self-destruct rapidly. Read the manual: the manufacturer will tell you the necessary tasks to keep the boiler running correctly. The lack of proper maintenance is the leading cause of steam boiler failures and boiler accidents.