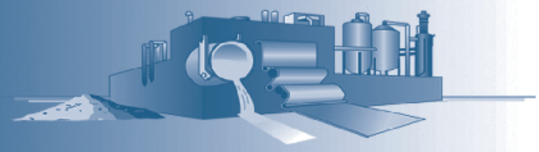

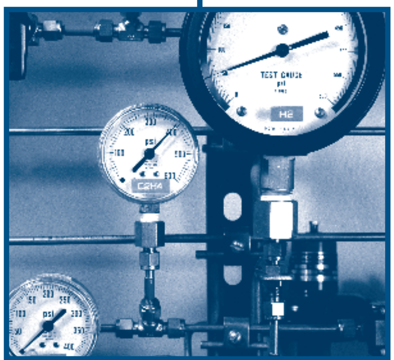

A BestPractices
Steam Technical
Brief

Steam Pressure Reduction: Opportunities and Issues

U.S. Department of Energy
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Steam Pressure Reduction: Opportunities and Issues

◆ Introduction

Steam generation systems are found in industry and in the commercial and institutional sectors. Some of these plants employ large watertube boilers to produce saturated steam at pressures of 250 pounds per square inch (psig) or lower. They distribute steam for use in process applications, building heating, humidification, domestic hot water, sterilization autoclaves, and air makeup coils.

Oversized boiler plants and steam distribution systems utilizing saturated steam are potential candidates for reducing the steam system operating pressure. Steam systems can have large excess capacity in boilers, valves, pumps, and piping. This can also be true for peak winter conditions.

What is Steam Pressure Reduction?

Steam pressure reduction is the lowering of the steam pressure at the boiler plant by means of the pressure setting on the boiler plant master control.

Steam pressure reduction affects mainly the high pressure part of the steam system. Within practical limits, pressure-reducing valves (PRVs) will adjust the pressure at lower levels to the previous set points. This means that most of the savings benefits from pressure reduction occurs in the high pressure section of the steam system.

◆ Summary

1. Steam pressure reduction has the potential to save fuel consumed by a steam system. The amount of capital investment may be minimal for the appropriate application of this efficiency measure. The amount of fuel that can be saved varies with the design and maintenance of the existing system.
2. The potential to effectively reduce steam pressure most commonly applies to oversized steam systems in industry and institutions. These steam systems supply steam for process applications and building heating. They are often oversized for summer operation and the peak load period. The operator of the plant must judge whether a boiler plant is oversized.
3. Before the steam plant owner attempts to reduce steam pressure, an assessment of the boiler plant and steam system should be made. This should include an analysis of the average and peak steam loads in relation to the plant capacity. Data on piping, insulation, and steam trap condition should be collected. Piping drawings should be used to map out critical steam loads and the test procedure.
4. While energy savings can result from reducing steam pressure, there are a significant number of areas where steam pressure reduction can reduce the operational effectiveness of the steam system. These areas should be properly accounted for and understood.
5. Steam pressure reduction should be tested to establish the critical minimum pressure at a steam load that is above average but below peak. This will also provide an estimate of savings.
6. If, prior to reducing boiler steam pressure, the boiler is already having carryover issues, these should be addressed before considering reducing the boiler steam pressure.

◆ Steam System Losses and Savings Through Pressure Reduction

A List of Boiler and Steam System Losses

It is useful to summarize the typical causes of boiler and steam system losses. Most of these losses vary with steam pressure (and temperature) and can potentially be reduced by lowering the steam pressure at the boiler.

Some of the main potential losses in a steam system are noted in Figure 1. Only the energy losses that can be reduced by lowering steam pressure will be discussed in this technical brief, and are listed below:

- Steam leaks from high-pressure components (e.g. valves and piping)
- Combustion loss
- Boiler blowdown loss
- Steam supplied to the deaerator
- The enthalpy savings effect.
- Flash steam loss through high-pressure condensate receiver vents
- Boiler radiation and convection loss
- High-pressure steam piping heat loss
- High-pressure steam trap leakage

Losses

When steam pressure is reduced at the boiler, it is only reduced on the high-pressure side of the system. PRVs, which lower the main steam pressure automatically, respond to maintain the pressure on the downstream side of the valve at the set point, for example, 15 psig. Therefore, losses occurring downstream of the PRV or a backpressure steam turbine are not reduced by lowering the boiler pressure.

The following example illustrates the potential savings from steam pressure reduction. In a steam system operating at an average steam load of 38,500 pounds per hour (lb/hr) with one watertube boiler supplying steam and another on standby, the operating pressure at the boiler was reduced from 130 psig to 80 psig. The average fuel input to the boiler plant before steam pressure reduction is 49.3 million British thermal units per hour (MMBtu/hr). The plant is modeled using the boiler combustion efficiency as tested over a range of pressures, and with estimates of the size, length, and pressures of distribution and condensate return piping for purposes of calculating radiation losses. Typical losses from radiation and steam trap leakage based on actual surveys of other facilities are applied.

Combustion Loss

Dry flue gas loss as defined by the American Society of Mechanical Engineers (ASME) Power Test Code

Figure 1. Boiler and Steam System Losses

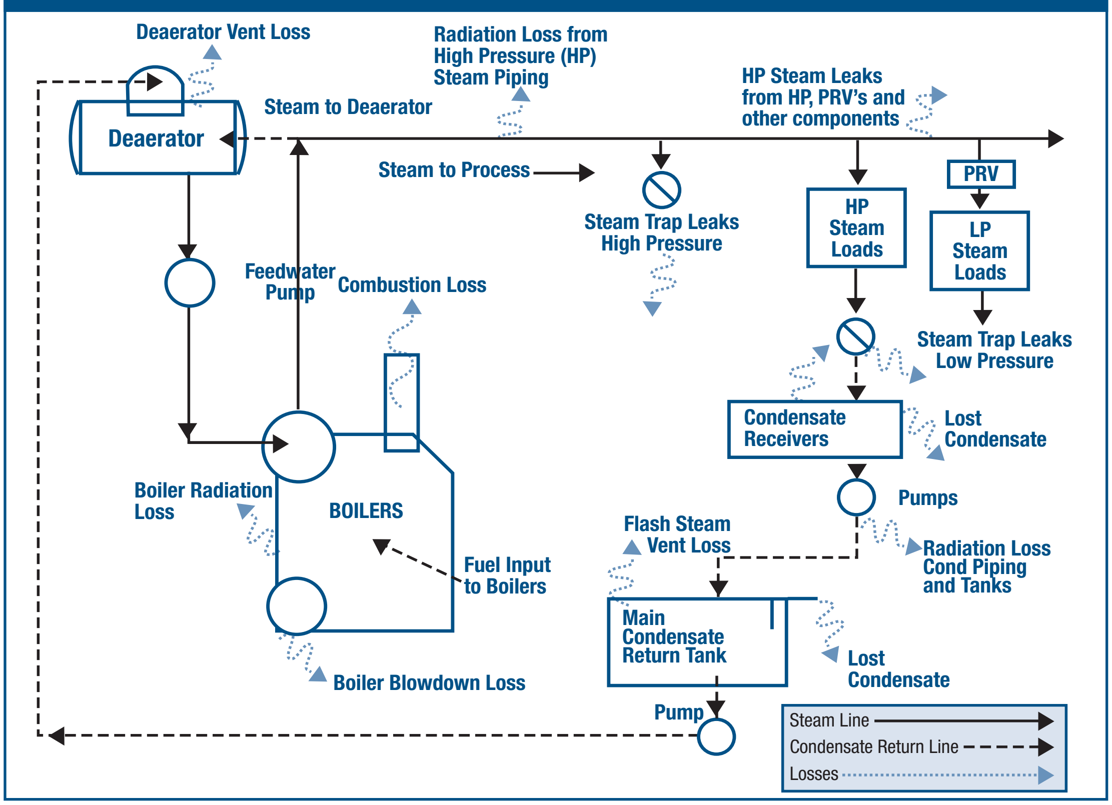
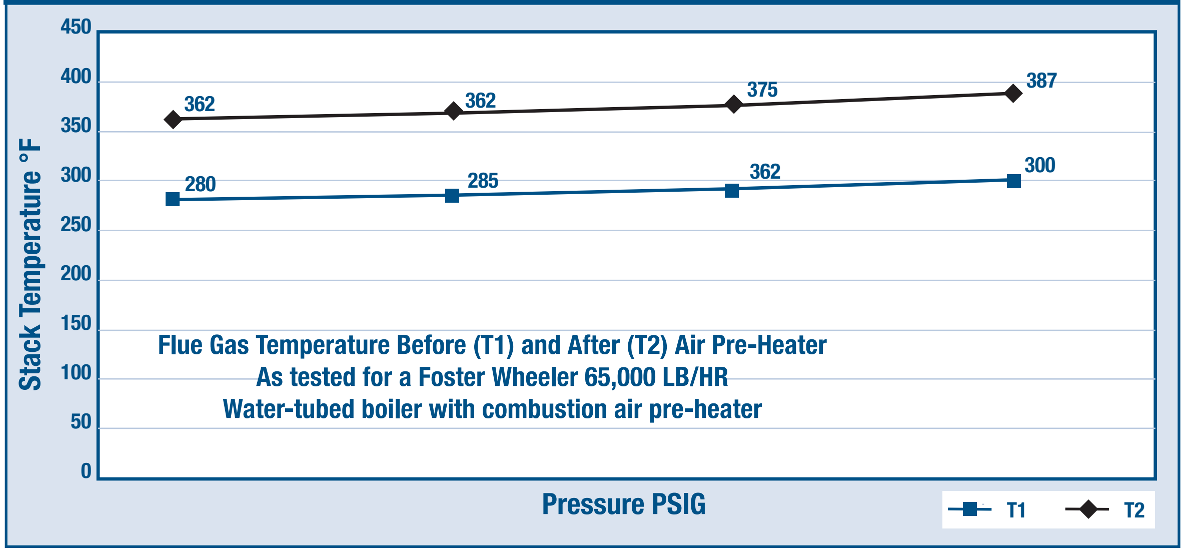


Figure 2. Stack Temperature Vs. Boiler Pressure



varies directly in proportion to the boiler's net stack temperature (the difference between the flue gas temperature and combustion air temperature). When boiler pressure is lowered, a lower stack temperature results. This, in turn, causes slightly improved combustion efficiency. If the boiler already has an economizer or air preheater, the savings will be somewhat lower. The best way to establish the temperature reduction and savings for a given boiler is to conduct a combustion test at different pressures and constant load. Figure 2 shows the relationship between pressure and stack temperature for a test on a 65,000 lb/hr watertube boiler operating at a constant output of 38,500 lb/hr. As tested, the boiler stack temperature varies linearly with steam pressure. A savings of 0.4% to 0.8% of the fuel input can be expected from lower stack temperature.

Boiler Radiation and Convection Loss

For watertube boilers, radiation loss can be estimated using the American Boiler Manufacturers Association (ABMA) standard radiation loss chart. Radiation losses can also be calculated for any type of boiler, from basic principles using measurements of the boiler surface temperature, area, and emissivity. In this example, the radiation loss is calculated from basic principles.

The general formula for calculating radiation loss is:

Radiation Loss (Btu/hr), $H_R = 1.74 \times 10^{-9} \times e\,(T_1^4 - T_2^4)$

where 1.74×10^{-9} = Boltzmann's constant

e = Surface emissivity which depends on the specific material and condition (typically 0.9)

T_1 = The surface temperature as measured (°R)

T_2 = The ambient temperature as measured (°R)

Heat transfer from the surface to the ambient air is increased by the flow of air across the surface. This is called convective heat transfer and must be added to the previously calculated radiation loss. For guidance on calculating convective loss as a function of air velocity, refer to the basic heat transfer texts, for example, *Thermal Insulation* by John F. Malloy (see Reference list).

For this example, when steam pressure was reduced from 130 psig to 80 psig, the actual temperature readings on the boiler surface showed an average reduction from 150°F to 140°F. Using the ABMA standard radiation loss chart, this would yield a savings of 0.2% of the fuel input.

However, the ABMA chart does not apply to firetube boilers. Firetube boiler shell loss estimates should be obtained by contacting the boiler manufacturers, or from basic principles and measurements of surface temperature.

Boiler Blowdown Loss

When boiler pressure is reduced, the blowdown loss is also reduced. If the energy from blowdown is being recovered through a blowdown heat recovery system, there will be no further savings by reducing the boiler pressure. If however, blowdown water is being drained and flash steam is being vented, savings will result from steam pressure reduction. In the current example, reducing boiler pressure from 130 psig to 80 psig reduces the sensible heat in the boiler water from 328 Btu/lb to 294 Btu/lb. Assuming a blowdown rate of 4%, the savings is approximately 0.1% of initial fuel input.

High Pressure Steam Piping Heat Loss

Heat loss from steam and condensate piping takes place in two stages. First, heat is conducted from hot steam through the walls and insulation surrounding the pipe to the outer surface. Then, heat is lost by radiation and convection to the ambient air.

A good way to make the calculations required to estimate the heat loss per foot of pipe is to use the BestPractices Steam 3E-Plus, developed by the North American Insulation Manufacturers Association (NAIMA). The software is free and is available at www.eere.energy.gov/industry/bestpractices/, www.naima.org, or www.pipeinsulation.org.

Steam Leaks from High Pressure Valves, Piping, and Other Components

External steam leaks occur in piping, joints, valves, and other components for various reasons. In large steam systems there are always some leaks. The degree of leakage depends on how well the system is maintained. Leaks in pipes may be caused by corrosion, erosion, water hammer, faulty design, or poor installation. Joints of any type—welded, threaded, or flanged—can leak because the original connection was flawed. Valves leak externally through their connections to piping or through the valve-stem packing or other paths. Pressure relief valves are notorious for leaking. Valves may also leak internally due to poor seats causing losses or pressure increases in downstream equipment.

The volume of steam leaking from a given source is difficult to measure. For purposes of including steam leakage as a loss factor in this report, the total leakage in each section of the steam system has been based on an equivalent round hole, 1/4 inch in diameter. Lowering the boiler pressure reduces the leakage rate in the high pressure part of the system only. In order to estimate the leakage through this hole and the savings from lowering the boiler pressure, the following formula is used:

Steam flow through a sharp-edged orifice: $W = 24.24 \times Pa \times D^2$ (Napier's Equation)

where
- W = leakage rate in lb/hr
- Pa = the absolute pressure drop across the orifice in pounds per square inch absolute (psia)
- D = the diameter of the leaking orifice in inches.

For example: Steam operating pressure = 130 psig
Absolute pressure = 130 + 14.7 = 144.7 psia
Diameter of orifice = 0.25 inches

$$W = 24.24 \times 144.7 \times (0.25)^2 = 210.5 \text{ lb/hr}$$

At lowered pressure, 80 psig, the new leakage rate is:

$$W = 24.24 \times 94.7 \times (0.25)^2 = 137.7 \text{ lb/hr}$$

High Pressure Steam Trap Leakage

Poor steam trap maintenance is a major cause of losses in steam systems. Many steam plant owners do not have a scheduled maintenance program for steam traps.

Lowering the main steam pressure is not a substitute for regular trap maintenance. However, based on the condition of the average steam distribution system, a reduction in boiler pressure can, for this example system, result in savings of 0.6% of fuel input. The savings are realized only on the high pressure section of the steam system.

Steam trap manufacturing and service companies provide routine testing services which can identify blocked, leaking, or "blow-through" defective traps. Normally, the service includes a calculation for each defective trap of the amount of steam leaking through the orifice. Companies perform the estimates in different ways, employing considerable experience and judgment. The calculation is not as simple as one would make for dry steam blowing through an orifice from a high pressure (130 psig) to atmosphere. Other factors affecting the steam loss that are taken into consideration include:

- A leak that is only a partial opening of the trap orifice, as compared to a "blow through"
- The flow co-efficient (Cv) of the steam trap
- Condensate may also be passing through the leaking orifice
- The possibility of a pressurized condensate return line
- The normal variation (reduction) of trap inlet pressure when variable process loads are involved.

These factors act in various combinations to impose additional resistance to the flow of steam through the leaking trap orifice and result in a reduction in the theoretical steam loss as determined from Napier's equation or other methods. In practice, the final result of the leak calculation for an individual trap may be between 10% and 100% of the theoretical value.

Nevertheless, a reduction in the main steam pressure will reduce the leakage in high pressure traps. A conservative estimate would be that the steam leak losses are proportional to the absolute pressure (in psia) of the high-pressure steam.

For example, a high pressure, 3/4-inch trap with an orifice size of 1/8 inch and inlet pressure of 130 psig is estimated to be leaking 20 lb/hr of steam after deducting 66% of the theoretical leakage for the above factors listed above. When estimating the leakage rate if the steam pressure at the inlet is lowered to 80 psig, the new leakage rate is approximately:

[(80 + 14.7) psia / (130 + 14.7) psia] x 20 lb/hr = 13.0 lb/hr

◆ Flash Steam Loss Through High-Pressure Condensate Receiver Vents

Large steam systems have multiple local condensate receivers which collect hot condensate and pump it back to the boiler plant. It is not uncommon to have multiple receivers located in various process departments or buildings. Steam flashes as the condensate is lowered in pressure from the load pressure to the condensate system pressure.

In the high-pressure section of the steam system, flash steam losses will be directly reduced by lowering the steam pressure. When a steam trap passes condensate from the working pressure (130 psig) to the condensate system pressure (2 psig), the condensate contains excess energy above the liquid saturation level at the lower pressure. This excess energy causes some of the liquid to flash into steam.

The percentage of flash steam to total liquid can be calculated by using the following formula:

$$\textit{Percent Flash Steam} = \frac{(h_{F1} - h_{F2})}{h_{FG2}} \times 100\%$$

where
h_{F1} = Enthalpy (sensible) of condensate at Pressure P1, inlet of steam trap
h_{F2} = Enthalpy (sensible) of condensate at Pressure P2, outlet of steam trap
h_{FG2} = Enthalpy (latent) of flash steam at P2

For example: For : P1 = 130 psig and P2 = 2 psig
h_{F1} = 328 Btu/lb
h_{F2} = 187 Btu/lb
h_{FG2} = 966 Btu/lb

$$\text{Percent flash steam @ 130 psig} = \frac{(328 - 187)}{966} \times 100 = 15\%$$

Lower the Main Boiler Pressure to 80 psig

$$\text{Percent flash steam @ 80 psig} = \frac{(294 - 187)}{966} \times 100 = 11\%$$

From the example listed above, it can be observed that a reduction in boiler pressure will directly result in a reduction in flash steam as condensate passes through steam traps from high to low pressure. This savings applies only to the high-pressure system. Also, note that this estimate is only valid if all of the flash steam generated in dropping from the high pressure to 2 psig is vented; therefore, this calculation can be an overestimate of the potential savings. Another factor to consider is the possibility that flash losses are being recovered by means of a vent condenser. If this is the case, there is no savings associated with pressure reduction.

Steam Supplied to the Deaerator

The quantity of steam supplied to the deaerator is determined by the amount of energy required to heat a mixture of hot condensate and cold makeup water to the saturation temperature at the operating pressure of the deaerator, say 227°F at 5 psig. This steam represents a loss which can be minimized by good maintenance and management practices.

There will be a small reduction in steam supplied to the deaerator when the main pressure is reduced. Reductions in steam leaks, steam trap leaks, and flash vent losses all contribute to a reduction in the boiler makeup water rate and therefore to a reduction in the amount of steam supplied to the deaerator. The reduction in deaerator steam can be calculated by doing a steam system mass and energy balance analysis. The Steam System Assessment Tool (SSAT) can be used for such analyses, and can be downloaded from the U.S. Department of Energy website at www.eere.energy.gov/industry/bestpractices/software.html.

The Enthalpy Savings Effect

Table 1 shows the enthalpy and temperature difference between steam produced at 130 psig and at 80 psig. The energy supplied to steam loads comes from the latent energy in the steam and not from the sensible energy. Once the steam condenses it is no longer part of the heat transfer process. When the steam is being used at the pressure that the steam is being generated, it requires less steam (in pounds) to supply the required latent energy at a lower pressure than at a higher pressure. In this case, 0.972 lb of steam at 80 psig supplies the same amount of energy as 1 lb of steam at 130 psig.

The boiler supplies the same 866 Btu of latent energy to the load, regardless of the pressure. Otherwise, the energy supplied to the load will be insufficient.

The reduction in enthalpy is a savings that occurs because of differences in the condensate condition as it returns to the boiler plant from the load.

Condensate loses energy due to flashing as it is reduced in pressure from the load to a much lower pressure through steam traps. It also loses energy and temperature from piping radiation loss as it is transferred from

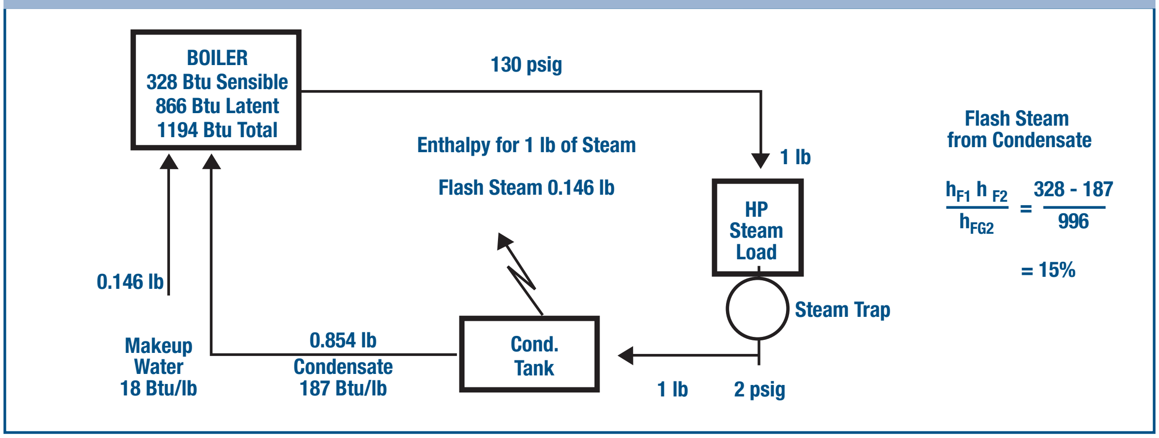
Table 1. Enthalpies and Temperatures for Steam Lowered in Pressure from 130 psig (saturated) to 80 psig by Reducing Boiler Pressure

Pressure	130 psig Case A	80 psig (reduced pressure)	80 psig Case B
Mass (lb)	1	1	0.0972 lb
Enthalpy			
Sensible	328 Btu	294 Btu	286 Btu
Latent	866 Btu	891 Btu	866 Btu
Total Enthalpy	1194 Btu	1185 Btu	1152 Btu
Steam Temperature	356°F	324°F	324°F

the load back to the boiler plant. Condensate from lower pressure steam loses less energy from flash than condensate from high-pressure steam. The result is that at lower pressure, the boiler must supply less energy to the condensate to raise it from the feedwater condition to the saturation point. After this, the boiler still supplies the same 866 Btu needed to vaporize the feedwater.

The examples below show this enthalpy reduction in simple terms (no deaerator is shown for simplification). The final result—a savings of 4.1%—is theoretical and only for purposes of illustration. An energy and mass balance analysis balance model, such as the SSAT, is a good tool to accurately estimate fuel savings from steam pressure reduction, including the enthalpy savings.

130 psig CASE A

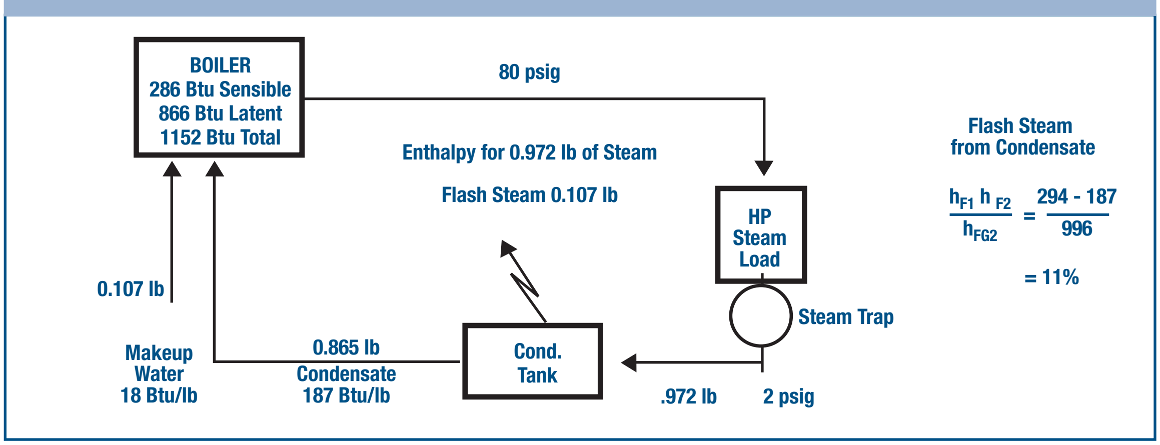


Calculation of energy required from boiler to heat feedwater and to vaporize 1 lb of steam

Energy in condensate return	0.854 lb x 187 Btu/lb	=	160 Btu
Energy in makeup water at 50°F	0.146 lb x 18 Btu/lb	=	3 Btu
Total sensible energy supplied by feedwater		=	163 Btu
Total energy required at saturation temperature:		=	328 Btu

Energy to be supplied to feedwater (sensible)	165 Btu	(328 - 163) Btu
Latent energy required to vaporize feedwater	+ 866 Btu	
Total energy required to be supplied by boiler:	**= 1,031 Btu**	**(A)**

80 psig CASE B



Calculation of energy required from boiler to heat feedwater and to vaporize 0.972 lb of steam

Energy in condensate return	0.865 lb x 187 Btu/lb	=	162 Btu	
Energy in makeup water at 50°F	0.107 lb x 18 Btu/lb	=	2 Btu	
Total sensible energy supplied by feedwater		=	164 Btu	
Total energy required at saturation temperature:		=	286 Btu	
Energy to be supplied by boiler (sensible)			122 Btu	(286 - 164) Btu
Latent energy required to vaporize feedwater			+ 866 Btu	
Total energy required to be supplied by boiler:		**=**	**988 Btu**	**(B)**

Energy Savings = (A) - (B) = 1031 - 988 Btu = 43 Btu = 4.1% of initial energy

It was noted earlier that the enthalpy savings effect, though real, will only occur for the portion of a steam system where the steam is used at the pressure produced by the boiler. For example, in a system where steam is generated at 130 psig, let down through a PRV to a pressure of 30 psig, and used at the 30 psig pressure, the enthalpy savings effect as described above does not occur. This is because the energy requirement for the 30 psig steam use would not change as a result of the pressure upstream of the PRV, as long as that pressure is above 30 psig. This can easily be demonstrated using the BestPractices SSAT software. Users can set up a model system as described above, reduce the model operating pressure to 80 psig, keep the 30 psig steam demand constant. and see only a minor change in overall steam production.

◆ Potential Problems and Limits to Steam Pressure Reduction

Boiler Carryover in Watertube Boilers from Reduced Operating Pressure

Reducing the boiler operating pressure in watertube boilers can lead to reduced steam quality going into the steam system. Lowering the boiler pressure can increase entrainment of liquid droplets.

As steam bubbles in a boiler rise through the water and reach the surface, they break through the final layer of water and enter the steam space. This causes entrainment of water droplets, and these water droplets can be entrained into the rising steam. The size of the steam bubbles produced—and the potential for droplet entrainment—is directly related to steam pressure. Lowering the steam pressure leads to larger-sized bubbles, higher steam velocities out of the boiler, and higher potential levels of entrainment.

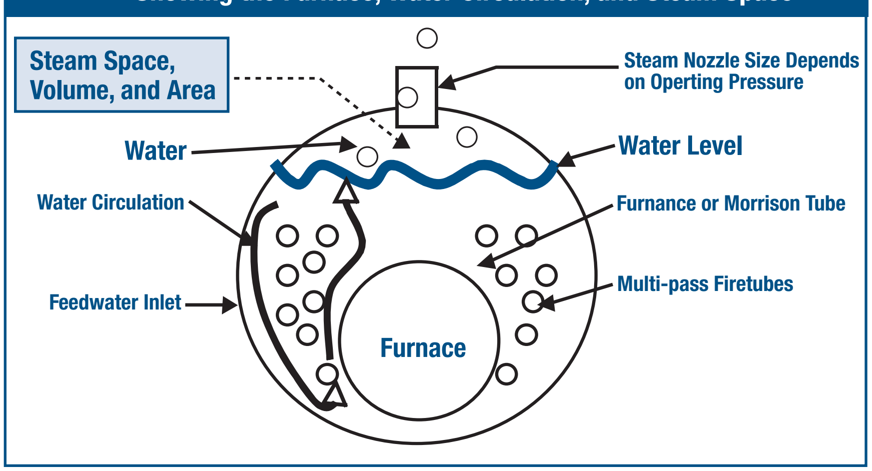
Reducing the quality of steam entering the overall steam system can cause reduction on the overall efficiency of the use of steam—heat transfer from the steam/droplet mixture will be less effective—and can lead to premature failure of steam system components such as valves and steam traps. There is no way to effectively calculate when lowering steam pressure will cause this effect, but it is a real concern that should be addressed by observation of how the steam quality responds to lowering the steam pressure.

Boiler Carryover in Firetube Boilers from Reduced Operating Pressure

For this discussion, the assumption is that the boiler is oversized and normally operates at a firing rate well below its rated capacity.

Firetube boilers are capable of operating at varying steam pressures

Figure 3. Cross Section of a Firetube Boiler from the Burner End Showing the Furnace, Water Circulation, and Steam Space



within a wide range with few negative consequences. Manufacturers of firetube boilers specify the same boiler model and size with no change in output rating over an operating range from 15 psig to 250 psig, and there is no derating of the boiler as pressure is lowered, as there is with a watertube boiler.

One item to be considered is the possibility of increased carryover when firetube boilers operate at reduced pressures. The amount of boiler water carryover is partly a consequence of the basic firetube design.

In a firetube boiler, the design parameter which affects carryover and thus steam quality, is the steam space. The steam space is defined by the nominal volume and surface area of the space above the water in the boiler. For a given boiler size, each boiler make and model has a different specification for steam space. A larger steam space volume and water surface area results in less carryover of water into the steam system. A comparison of specifications of five different makes of firetube boilers showed that for a 750 BHP boiler, the steam space volume varies by 48% from the smallest to the largest.

For a boiler operating under normal pressure conditions of 130 psig at a constant output when the pressure is reduced to 80 psig, the velocity of steam evaporating from the surface of the water increases, tending to cause increased carryover.

For the owner considering the possibility of steam pressure reduction, the first question to ask is whether there is a problem with carryover (wet steam) before pressure reduction. Depending on the boiler design, the average firing rate, and the nature of load variation, there may or may not be an existing problem. If there is, steam pressure reduction will probably increase the problem. A steam separator or mist eliminator may be required.

A reduction in steam pressure can also cause an increase in specific volume and, for a given mass flow, an increase in velocity. Firetube boilers are equipped with a nozzle at the steam outlet which delivers steam to the system. This nozzle is designed to deliver steam at a velocity of approximately 4,000 to 5,000 feet per minute (ft/min). When the steam pressure is reduced, the velocity will increase for a given output. It may be necessary to change out the steam nozzle for a larger size to accommadate the increased velocity.

The manufacturer should be consulted before deciding to operate a firetube boiler at a reduced pressure. A test for carryover should be conducted before and after pressure reduction. An indication of carryover can be obtained by measuring the conductivity of condensate gathered as near as possible to the outlet of the boiler.

Boiler Circulation – Potential for Tube Overheating in Watertube Boilers

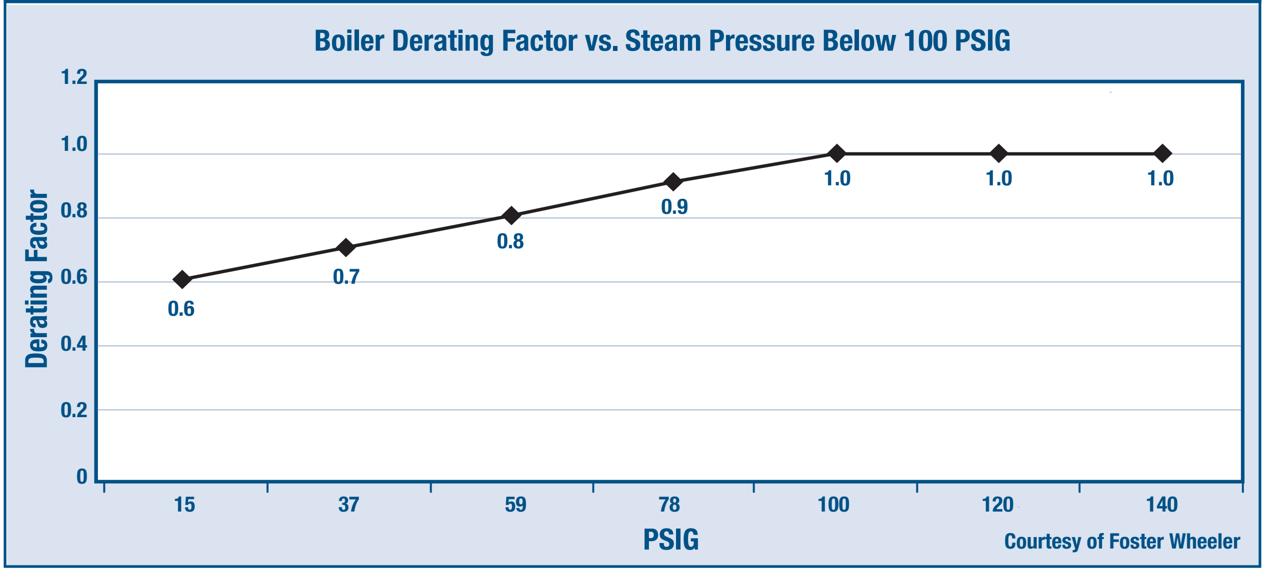
It is unlikely that operators of steam systems producing and utilizing superheated steam will wish to reduce the steam pressure. This section's discussion pertains to saturated steam systems.

Circulation in a watertube boiler occurs because of the density difference between the downcomer and the riser. The fluid in the downcomer is all water and therefore denser than the fluid in the riser, which is a mixture of steam and water. The rate of the resulting water circulation depends on the difference in the average density between the unheated downcomer and the steam-water mixture in the riser.

Heat transfer from the fire (boiler furnace) to the feedwater and the two-phase mixture requires the maintenance of an unbroken film of water on the inside of the entire length of the tube. A reduction in overall steam pressure tends to increase backpressure in the riser tube to the feedwater in the downcomer, creating a nonwetted area near the top of the riser. This is called "steam blanketing"—departure from nucleate boiling—and is undesirable. It can result in the overheating of the riser tube. Another potential problem that can result from poor circulation is increased deposits on the boiler tubes.

Boiler Performance at Maximum Rated Load, Rated Pressure. Watertube boilers are designed for a specific maximum steam flow at a maximum boiler drum pressure. The number, diameter and pressure rating of the tubes are fixed. At maximum steam output and pressure, circulation is adequate to prevent steam blanketing. At maximum steam output, there is adequate cooling to the tubes. At maximum output, the moisture content of steam entering the drum is high and drum separator components must remove it in order to supply dry steam to the process.

Figure 4. Boiler Derating Factor vs. Steam Pressure Below 100 psig



Boiler Performance at Low Load, Rated Pressure. On low-fire, such as 20% of rated output, water and steam flow circulation is reduced, creating a condition which can result in unwetted tube surface in the riser; The same problem is experienced with low operating pressure.

Boiler manufacturers recommend that boilers be derated when operating at lower pressures. That is, depending on the rated pressure and operating pressure, the boiler should not be fired at rated input. Figure 4 represents the fuel input derating factor for a typical packaged watertube boiler. It shows the allowable fuel input compared to the rated capacity under reduced steam pressure conditions. The base case comparison is for boilers rated at a maximum of 250 psig.

Boiler owners who are considering steam pressure reduction should consult their boiler supplier.

Steam Piping – Steam Velocity, Pressure Drop and Temperature

Steam Velocity in Piping. A conservative guideline is to select the pipe diameter to limit steam velocity for saturated steam to no more than 80 feet per second (ft/sec) (4,800 ft/min). High velocity steam, exceeding 120 ft/sec, (7,200 ft/min) causes a number of problems, including erosion of piping and other components, and noise in piping.

Steam velocity is a function of flow, pressure, and internal pipe diameter. The following formula shows this relationship. In order to plan a pipe-run to limit velocity to 80 ft/sec, all of these variables must be estimated in advance.

$$V = \frac{2.4 \times Q \times V_S}{A}$$

where
V = Steam velocity in ft/min
Q = Steam flow in lb/hr
A = Internal pipe area
V_S = Specific volume of steam at operating pressure in cu ft/lb

Reducing the pressure increases the steam velocity and therefore the potential for problems mentioned above. An estimate should be made of the steam velocity before and after the pressure decrease, keeping in mind that the actual peak steam flow is much lower than the design maximum, and the steam velocity may be within conservative limits even if the pressure is reduced.

For example, a 6-inch diameter, Schedule 80 pipe is designed to carry a peak steam flow of 16,730 lb/hr at 130 psig with a maximum velocity of 80 ft/sec (4,800 ft/min). The actual peak steam load is only 10,000 lb/hr. This is below the design peak of 16,730 lb/hr because the system is oversized. If estimating the steam velocity at the actual peak steam load at 130 psig and at 80 psig:

130 psig:

$$V = \frac{2.4 \times 10{,}000 \times V_S}{A} = \frac{2.4 \times 10{,}000 \times 3.12}{26.1} = 2{,}869 \text{ ft/min} = 47.8 \text{ ft/sec}$$

80 psig:

$$V = \frac{2.4 \times 10{,}000 \times 4.67}{A} = 4{,}294 \text{ ft/min} = 71.6 \text{ ft/sec}$$

The steam velocity has risen after pressure reduction. Because the original piping was oversized, the velocity remains below the 80 ft/sec standard set as a good practice. Every case where steam pressure reduction is under consideration should be analyzed for steam velocity before and after pressure reduction.

Steam Pressure Drop. The pressure drop through pipes, valves, and bends increases as the main boiler pressure is reduced. With a reduction in the main boiler pressure, this drop is felt through the high pressure side of the system up to the first pressure reduction stations.

The science of calculating pressure drop of fluids through piping is well established. However, the task of estimating the pressure drop between two points in a large steam system is complex and time consuming. There are many variables involved, especially where compressible fluids are concerned. In practice, variables such as the pipe friction coefficient may not be known, especially for pipes that have been installed for many years.

The formula below describes the relationship between steam pressure drop (Δ P), flow (Q), pipe diameter (D), and specific volume (V_S) for steam flow in a pipe. It shows that the pressure drop is proportional to the increase in V_S. If the operating pressure is reduced, the pressure drop in piping will increase by the ratio of the specific volume of steam at the new pressure compared to the initial pressure.

$$\Delta P = 0.00134 \times \frac{f\, V_S (Q)^2}{D^5}$$

where
- ΔP = Pressure drop in pounds per 100 ft. of pipe
- f = Coefficient of friction for the pipe (0.006 is typical)
- V_S = Specific volume of steam at the operating pressure
- D = Internal pipe diameter (inches)
- Q = Steam flow in lb/hr

A simple pressure and flow problem can be solved graphically using charts such as those found in the Spirax Sarco "Hook-Ups" book. This chart provides the following solution when comparing the pressure drop for 130 psig and 80 psig using the piping example listed above.

Δ P for 130 psig, 6 inch diameter, Schedule 80 pipe = 0.65 psi per 100 ft. of pipe

Δ P for 80 psig, 6 inch diameter, Schedule 80 pipe = 0.96 psi per 100 ft. of pipe

The acceptable pressure drop in the steam system up to the first level of pressure reduction depends on the ability of the pressure-reducing station to maintain the required outlet pressure while operating with a lower inlet pressure. This depends on the type of valve, whether it is oversized for the peak load it carries, its condition, and its design, including the flow coefficient.

In a pilot-operated PRV that is somewhat oversized and in good working condition, problems with pressure at the outlet occur when pressure drops to approximately 50% of the original operating pressure. This is specific to each situation.

Before implementing steam pressure reduction, estimate the pressure drop at various steam loads from the boiler plant to important locations in your steam system.

Steam Temperature. The temperature of saturated steam at any pressure is available in any steam table. In the pressure ranges of interest—250 psig or lower—the operating temperature can be expected to drop by 30°F to 60°F, depending on the initial and final operating pressure.

There are many processes that operate at a specific pressure because a certain minimum temperature is required. Examples include autoclaves in hospitals—40 to 60 psig—and drying or baking ovens in the food industry, which operate at 100 psig. This process limitation will make it impossible to reduce the boiler pressure below the specific temperature/pressure required.

Pressure Reducing Stations

The purpose of the PRV is to take steam at high pressure and reduce it to the operating level of the steam utilizing equipment. A PRV actively controls the downstream pressure at a desired pressure set point. Most equipment, especially in the types of steam systems investigated here, does not operate at the boiler plant pressure. Steam loads such as air heating coils, humidifiers, and heat exchangers for water heating operate at pressures ranging from 5 to 30 psig.

Small direct-acting PRVs are inexpensive and are designed for lower flows of approximately 2,500 lb/hr or less. They are often dedicated to a single coil or heat exchanger. Pilot-operated PRVs are designed for larger loads. They regulate the downstream pressure within close limits under varying loads. Pilot-operated PRVs can respond to a wide range of inlet pressures and outlet loads if they are in good condition.

In practice, the reduction of the main steam pressure will probably cause some PRVs in a large steam system to fail to control the downstream pressure adequately. This depends on type (pilot or direct acting), size, and maintenance condition.

If a PRV cannot handle the required steam volume flow increase, it may be possible to increase the main port size without changing out the valve body. If that fails, the valve may have to be replaced.

Influence of Steam Pressure Reduction on Flowmeters

The lowering of the main steam pressure will require the recalibration of differential pressure type flowmeters. The vast majority of steam flowmeters installed in industry are orifice-plate type meters which depend on the absolute operating pressure to produce an accurate mass-flow reading. Most of these are inaccurate due to neglect and should be recalibrated anyway. These meters read mass steam flow usually in lb/hr. When steam pressure is lowered, steam flowmeters will read too high on mass flow.

Steam plant owners wishing to operate at lower steam pressure should thoroughly assess the existing steam plant metering.

The following formula may be used for saturated steam to manually correct the mass flow reading from an orifice plate on a steam boiler outlet when the operating pressure has been reduced:

$$CF = \sqrt{\frac{V_S\ (\text{Actual})}{V_S\ (\text{Design})} \times \frac{V_S\ (\text{Design})}{V_S\ (\text{Actual})}}$$

where CF = Mass Flow Correction Factor

V_S (Actual) = Specific volume of steam at the actual operating pressure.

V_S (Design) = Specific volume of steam at the original design pressure.

For example: The original design pressure is 130 psig.

The new actual operating pressure is 80 psig.

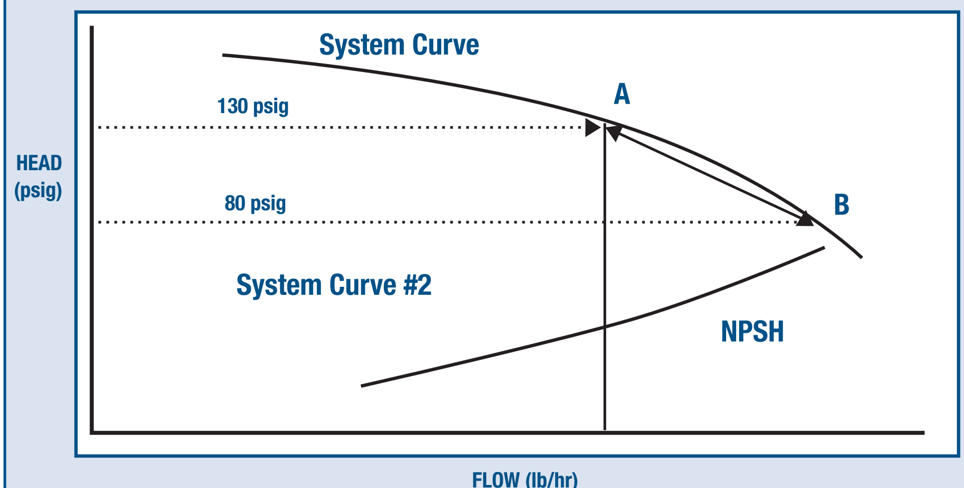
$$CF = \sqrt{\frac{4.67}{3.12} \times \frac{3.12}{4.67}} = 0.82$$

The manufacturer of the meter should be contacted for detailed meter data, including accurate correction factor curves and advice on repair or replacement.

Feedwater Pumps - Cavitation

When steam pressure is decreased, the feedwater pump will supply water to the boiler under a different operating condition. The pump is acting against the head of the piping system, boiler pressure and the feedwater control valve. With reduced pressure, the pump will attempt to operate at a different point on its operating curve.

Figure 5. Feedwater Pump Flow



1. Reducing the steam pressure from 130 psig to 80 psig causes the pump to try to operate farther out on the system curve. The operating point moves from (A) to (B). The pump flow capacity increases as it pumps against a lower head in the steam drum. This situation requires a greater Net Positive Suction Head because the increased flow causes increased pressure drop through the pump and piping.
2. If the NPSH supplied at the inlet of the pump by the deaerator pressure and the drop in elevation to the pump is inadequate, cavitation will occur.
3. It may be necessary to restrict the flow by means of an orifice downstream of the feedwater pump. Cavitation can be detected by listening to the pump.

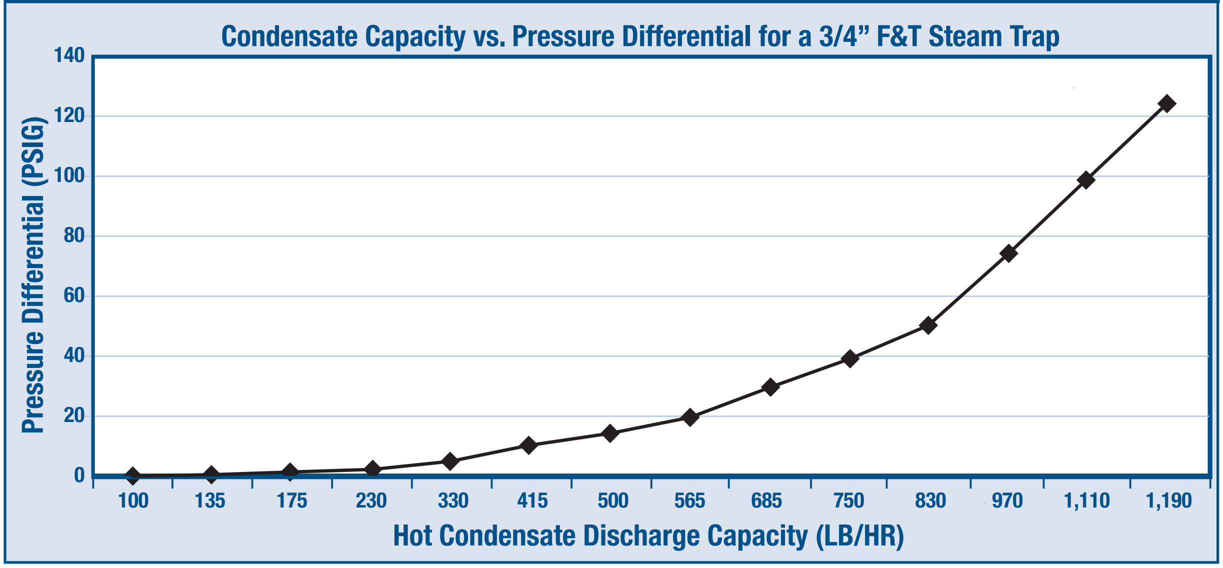
Steam Traps - The Effect of Reduced Operating Pressure

A reduction in steam boiler pressure takes place only at the highest pressure level of the system. Pressure reduction at the boiler affects only the equipment operating at high pressure. The affected items are drip leg traps on high pressure steam lines and users at the main steam pressure.

Steam loads at lower pressures, supplied by PRVs, do not see a change in the pressure as long as the PRVs are still able to supply the specified pressure to these loads.

The concern with steam pressure reduction is the possibility that the installed steam trap may not be able to discharge the required flow of condensate. This would result in water logging of the steam-consuming equipment.

Figure 6. Condensate Capacity vs. Pressure Differential for a ¾-inch F&T Steam Trap



Condensate Discharge Capacity vs. Differential Pressure – Basic Steam Trap Performance. Steam traps of all types are designed to operate at a wide range of pressures. The condensate discharge capacity of a trap varies with the pressure differential across the trap.

Figure 6—from manufacturer's specifications—illustrates the simple relationship between differential pressure across a steam trap and the condensate discharge capacity of the trap.

This steam trap is able to discharge condensate over a very large range of pressures. The designer selects the trap for a nominal pressure at the trap inlet of 130 psig, knowing that the trap will see lower pressures as the steam flow is regulated by the control valve and the pressure drop through the steam system. Figure 6 shows that as the differential pressure across the trap decreases, its ability to discharge condensate decreases. The curve, however, is nonlinear. The reduction in capacity is much greater as the pressure drops incrementally.

Example 1- The effect of steam pressure reduction on high pressure drip legs. Plant operators often express the concern that at reduced pressure steam traps may not handle the required condensate flow, especially on steam main drip legs.

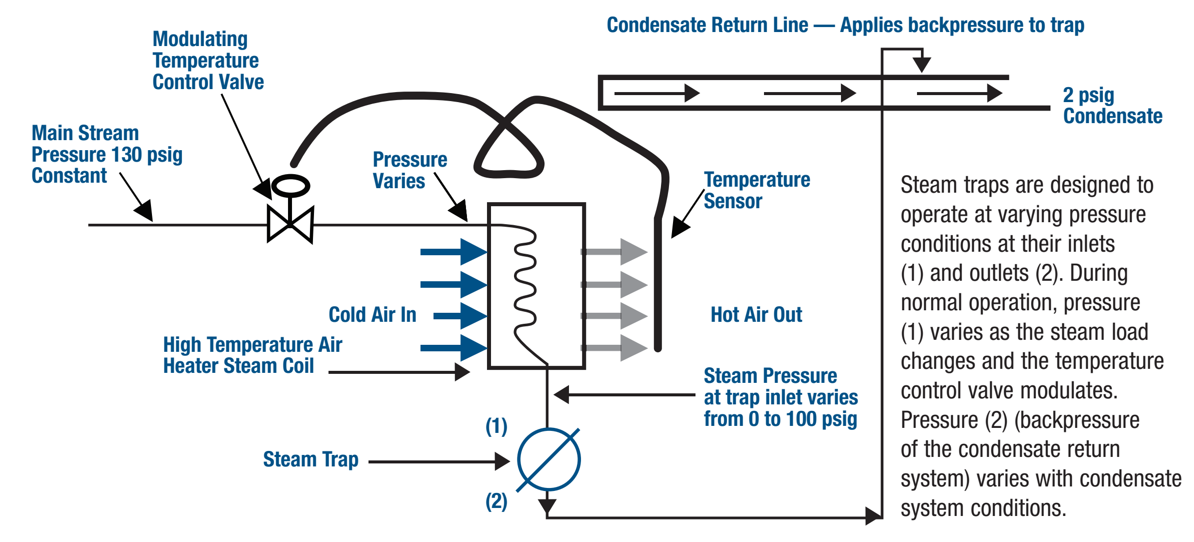
Steam boiler headers and high-pressure mains are equipped with drip legs to remove the condensate which forms in the system under normal load conditions and under warmup conditions. The steam traps operate at the full boiler pressure. The standard practice for this application is to install a drip leg of adequate diameter and length to capture and store a significant amount of condensate during warmup. Because the pressure is zero at warmup, only the head of condensate which collects in the drip leg pushes the condensate through the trap to the return line located below the steam line.

In most cases, based on a 1-hour warmup time and typical piping insulation standards, the condensate load is approximately double the main steam load for which the steam trap has been sized.

If the drip leg steam traps have been applied according to standard practice, a reduction in steam pressure of up to 50% should not affect their capacity to drain condensate either under load or warmup conditions.

Example 2 - The effect of steam pressure reduction on a high-pressure, temperature-controlled steam coil operating at full boiler pressure. Pressure reduction to a high-pressure steam coil may have a negative impact on the operation of the coil operating at full pressure because of the reduced condensate discharge

Figure 7. Makeup Air Heater with Modulating Temperature Control Valve



capability. The analysis below can be applied to a wide range of equipment. Any steam utilization appliance which drains condensate naturally may suffer the same performance problems described in this example. Dryers, water heaters, reactors, and other equipment can be substituted in this example.

The illustration above shows a steam coil in a makeup air unit operating at the main system pressure (130 psig), controlled by a modulating valve. This application is chosen because even in normal conditions, when constant high pressure steam is supplied to the coil, it can present problems. The makeup air unit is supplied with cold outdoor air, the temperature often below the freezing point.

Operating at Normal Steam Pressure: 130 psig. The ability of the steam trap to remove condensate from the coil depends upon two opposing pressures: a) the internal pressure of the coil and b) the backpressure applied to the trap by the condensate return system.

In order to remove condensate through the trap, the pressure in the coil must be greater than the backpressure of the condensate return. The focus of the opposing pressures is the steam trap. When the heating load is high, the temperature control valve is open and the pressure in the coil is high. When the heating load is low, the control valve modulates toward the closed position, reducing the steam pressure in the coil. The opposing pressure of the condensate return system will be constant. At some low load condition, there can be zero or even negative pressure in the coil. In this condition, the steam trap is unable to remove condensate because the opposing force, the condensate system backpressure, is greater than the pressure in the coil. This condition is called “stall”. When stall occurs, condensate backs up into the coil, causing it to flood. If the coil is not properly protected by good design (proper drainage) and by having a vacuum breaker located at its inlet, it will cease to supply the heating load.

Main Steam Pressure is Lowered: 80 psig. The operation of the heating coil, the control valve and the steam trap are all affected as follows when the main steam pressured is lowered to 80 psig:

1. The capacity of the coil to deliver energy to the load is reduced because the maximum flow through the coil is lower. The pressure drop through the coil increases as the steam density decreases. Coil manufacturers provide performance specifications which specify their capacity at various steam pressures. Based on the pressures used in this example, 130 psig to 80 psig, the maximum rated flow through a heating coil will be reduced by approximately 20%. Therefore, at low pressure, the makeup air unit may not be able to deliver enough heat to satisfy the building heating, ventilation, and air conditioning requirement.
2. The ability of the steam trap to remove condensate at full load is decreased. As the main steam pressure

inlet to the coil drops from 130 psig to 80 psig, and the pressure drop across the coil increases, the positive pressure at the steam trap is lowered significantly. Its ability to remove the required amount of condensate is therefore reduced.

3. The sizing of the temperature control valve becomes an issue. If the control valve has been initially oversized for the actual maximum heating load and steam flow, it may be adequate to supply the reduced steam flow at reduced pressure for the peak load. However, the control valve presents an additional pressure drop to the system and, if it cannot open wide enough to supply the load at the reduced pressure, the result will be inadequate heat delivered to the load.

The two examples above show that a reduction in the main steam pressure may or may not impact the capacity of steam traps on the high pressure side to remove condensate. There are many other applications which may be affected by pressure reduction and steam trap performance.

The effect of lowering steam pressure on these traps can best be assessed by testing and observation. Steam pressures, as observed at pressure gauges at various points in the steam system, are a good guideline to the effect of lowering steam pressure. The occurrence of waterhammer is also an indication of a problem.

In practice, for steam pressure reduction up to two-thirds of the original operating pressure, there are very few cases of traps unable to remove condensate.

Backpressure Steam Turbines - Capacity and Flow Implications of Pressure Reduction

Backpressure steam turbines are used extensively in industry as prime movers for blowers, pumps, and electric generators. The most common type is the small, single stage turbine employed within the boiler plant.

These units take saturated steam at the inlet at boiler pressure. As steam passes through the turbine, work and power are produced at the shaft. The pressure drops to a lower level and the steam which is exhausted at the outlet is used to heat the deaerator.

The following is a sample calculation for the amount of power produced at the shaft of the turbine:

Variables:
Actual steam rate: **ASR** in lb of steam per kilowatt output
Output of the turbine: **kw** (kilowatt)
Steam mass flow: **m** 6000 lb/hr
Enthalpy of steam at the turbine inlet: **h1** (dry saturated) at 130 psig (145 psia)
Enthalpy of steam at the turbine exhaust: **h2** (isentropic at 5 psig (20 psia))
Isentropic turbine efficiency taking into account steam leakage and mechanical loss: **e = 45%**

The basic input/output performance for a backpressure steam turbine operating at 130 psig is described by the following formula:

$$\text{ASR} = \frac{3413}{(\text{h1} - \text{h2}) \times \text{e}} = \frac{3413}{150 \times 45\%} = 50.56 \text{ lb/kw-hr}$$

Output of turbine: kw = 6,000 lb/hr / 50.56 lb/kw-hr = 118.7 kw

The output power of the turbine depends on the mass flow of steam, the turbine efficiency, and the difference in enthalpy between the inlet and the exhaust of the turbine. In practice, the enthalpy of steam at the exhaust is determined by the backpressure and the turbine efficiency. In this case, the exhaust is piped to the deaerator at 5 psig.

If steam pressure at the turbine inlet is reduced, the enthalpy (h1) is also reduced, causing a reduction in the turbine output power. The turbine will try to respond automatically, through its governor, to increase the steam flow in order to maintain the speed and power output. If the turbine is already operating at maximum output and speed, it will be unable to do this, resulting in a loss of power.

Example 1: 130 psig

Calculate the power output for a backpressure turbine operating at an inlet pressure of 130 psig, 45% isentropic efficiency and outlet pressure of 5 psig with a steam flow of 6,000 lb/hr.

Answer: 118.7 kw

Example 2: 80 psig

Calculate the power output for a backpressure turbine operating at an inlet pressure of 80 psig, 45% efficiency and outlet steam pressure of 5 psig with a steam flow of 6,000 lb/hr.

Answer: Using the same method as above, turbine output kw = 92.8 kw

Example 3:

What is the steam flow at the lower pressure required to provide the original 118.7 kw?

Answer: 7,676 lb/hr

If the original power output is to be maintained, the turbine must be capable of handling a steam flow which is 28% greater than the steam flow at the higher pressure. It is recommended that owners investigate their turbine operations before proceeding with steam pressure reduction.

◆ Testing Steam Pressure Reduction

Introduction

We recommend a conservative approach to the lowering of boiler steam pressure. Testing should be conducted in three phases:

- Preliminary data collection and analysis
- Short term test – 8-hour test
- Long-term performance monitoring – 1-year evaluation.

Preliminary Data Collection and Analysis

Boiler Load vs. Capacity. It is important to analyze the cyclical and seasonal steam load in relation to boiler capacity before embarking on a program to reduce steam pressure. The basic premise of pressure reduction is that boilers, steam piping, and components are oversized.

The plant owner should establish this by analyzing the steam load in relation to system capacity over a 1-year period. This exercise involves a detailed analysis of plant logs including fuel consumption and steam production data. The conclusion of this analysis should be that the boiler plant and steam system capacity exceeds the average steam load by a wide margin. The peak steam load is also important. If peak loads (winter) approach the plant capacity, the boiler plant manager can consider reducing steam pressure at times of low load but increase steam pressure during high load periods.

While boiler overcapacity is a necessary condition for steam pressure reduction, grossly oversized boilers will suffer from circulation problems on low fire. This will be aggravated by lowering the steam pressure.

Under normal load conditions, if the smallest boiler is grossly oversized for the summer load, steam pressure reduction should not be considered. That is, if the average summer steam load requires one boiler to fire on low fire all summer—for example, 20% of full load input—the boiler is already operating with poor circulation. Steam pressure should not be reduced. Instead, the installation of a smaller summer boiler should be considered.

In addition, if the boiler is already experiencing frequent boiler carryover, it is not likely to be a good candidate for steam pressure reduction.

Consult the Boiler Manufacturer. The boiler manufacturer should be consulted with regard to the effect of lower pressure on the operation of the boiler. The manufacturer should provide the owner with a guide to the upper and lower limit of firing rate for various pressure possibilities. Some manufacturers can provide, for a fee, a computerized simulation analysis of the circulation flows for a specific model of boiler.

Steam Distribution System Data - Drawings and Surveys. An estimate of the energy savings from steam pressure reduction can be made using some of the concepts presented in this technical brief. If drawings of the steam distribution and condensate piping are available, these can be used to estimate the lengths and diameters of piping. A physical survey is required to establish the level of insulation. In any case, this would be a good time to conduct both a steam trap survey and an insulation survey. Data collected can be used for maintenance purposes and also to estimate the losses and savings from steam pressure reduction.

Short-term Testing

Purpose of the Short-term Test. The purpose of this test is to observe metered fuel consumption and to discover obvious problems in the boiler plant and steam distribution system. Primarily, the operation of main PRVs should be observed to be sure that they respond adequately to reduced pressure. This test will establish, for a given steam load, the lowest feasible pressure. A short test can be conducted within approximately 6 to 8 hours by several people. If possible, the test should be conducted with a single boiler in operation.

Ideally, the test should be conducted at a time of steady load, above the average steam load for the system, but not at the peak steam load. For the types of steam systems discussed here, the best time to test is at night when daily cyclical loads, such as domestic hot water production, do not interfere with readings. This is also a good time to test because the effects of the sun and wind on building heating load may be minimized. If the weather and loads are highly variable, causing large swings in the heating load, it will be difficult to obtain good readings.

Method – Short-term Test

1. Set up a ***plant log sheet*** describing the various plant and steam system readings and observations. Include such items as: time, boiler pressure, header pressure, boiler stack temperature before and after economizer, steam flow, steam flow correction factor, deaerator pressure and temperature, gas or oil flow, feedwater pump pressure, and any other plant data which may be useful.
2. Set up a steam system log sheet describing readings and observations about the steam system. Field observers will have to move around the steam distribution system to various important points and observe the operation of equipment, for example, air handling unit temperatures. Most steam systems have some pressure gauges located at various points. If not, it will be necessary to install a few pressure gauges strategically, to determine whether the low pressure part of the system is in fact operating correctly.
3. Begin the test by taking all readings in the boiler plant at the normal operating pressure. Take these readings several times over a period of 30 minutes to 1 hour. Communicate with the field observers to be sure that they have completed their rounds and readings. Walkie-talkies and cell phones are a big help.
4. Lower the boiler plant pressure by approximately 10 pounds per square inch increments until inadequate pressure in some part of the low pressure system is observed. Each step will take approximately 1 hour depending on the size of the steam distribution system.

Long-term Performance Monitoring. The short-term testing can be used to establish a comfortable reduced pressure operating point. Because this point was established at a steam load which was above average, but less than the peak load, the plant will operate at levels above and below the test level. At lower steam loads, downstream pressure at the farthest point from the boiler plant will not be a problem; at higher loads it may be. Monitoring the pressure at critical points in the steam system will establish whether it is necessary to increase steam pressure under peak conditions.

Following the initial testing and while operating at the reduced pressure, daily readings and inspections should be made. These inspections should be done when the steam load varies from the original test load. PRVs which do not perform properly may be discovered, and may have to be replaced or refurbished.

The boilers should be inspected for signs of tube overheating at the time of normal annual inspection.

◆ Conclusions

Steam generation conditions in some manufacturing facilities and institutions are at saturated steam pressures below 250 psig. These facilities may be candidates for steam pressure reduction if the systems are oversized for the steam load they carry.

Every steam system has site-specific operating characteristics. The savings achievable by steam pressure reduction vary case by case. The amount of savings depends on many factors, including the design and sizing of the steam distribution system, system maintenance, and the percent pressure reduction.

Some areas where steam savings can result due to steam pressure reduction include:

- Boiler combustion loss and fuel reduction
- Boiler radiation loss
- Boiler blowdown loss
- "Enthalpy savings effect" for high-pressure steam use
- High-pressure radiation loss for steam piping and components
- High-pressure steam leaks from piping, components, and through PRVs
- High-pressure steam trap leaks
- Steam supplied to the deaerator.

Some areas where steam pressure reduction can result in steam system problems include:

- Increased boiler carryover
- Potential for boiler tube overheating in watertube boilers
- Increased steam velocity in piping
- Increased steam pressure drops
- Failure of some steam system PRVs
- Need for flowmeter recalibration
- Feedwater pump cavitation problems
- Reduction in steam trap performance
- Reduced output power from steam turbines.

It is the responsibility of the steam plant owner to conduct tests and inspections before establishing a lower steam pressure operating point. Plant owners should conduct short term and long term tests and inspections to verify the proper operation of the steam distribution system. Some problems which may be encountered are listed in this technical brief.

Plant owners should fix defective steam traps, steam leaks, and insulate steam and condensate piping before reducing steam pressure.

We further advise boiler plant owners to consult the boiler manufacturer in order to assess the effects of a lower operating pressure on the boiler. Typically, watertube boilers rated for a maximum steam pressure of 250 psig are designed to operate at full fuel input at pressures as low as 100 psig. Below 100 psig, watertube boilers may need to be derated with respect to fuel input.

◆ Acknowledgements

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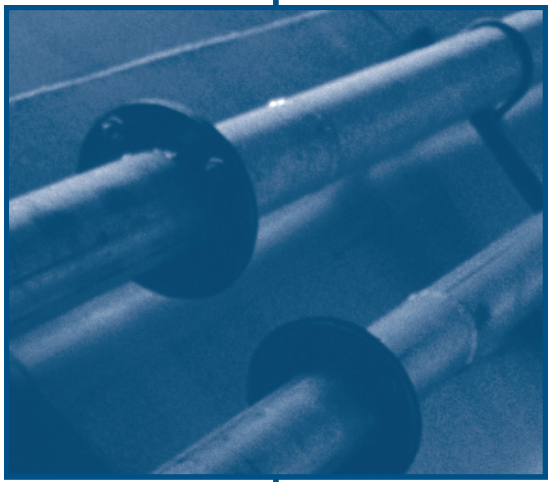

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