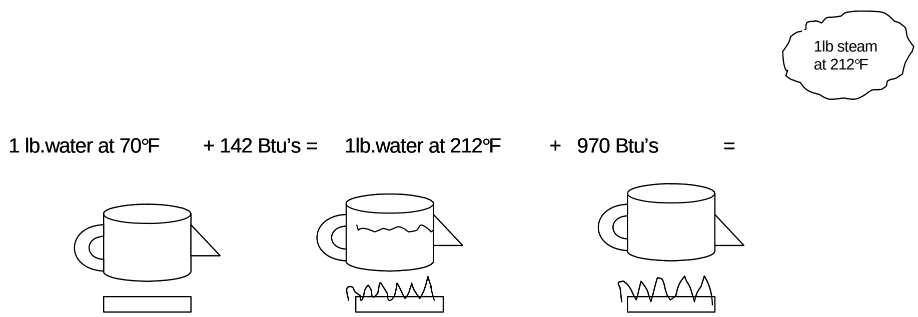
STEAM AND TRAP FUNDAMENTALS

Nick Westerberg
Westerberg and Associates
Newman Lake, WA

Steam is an invisible gas that is generated by adding heat energy to water, usually from burning fuel in a boiler. Energy must be added to raise the temperature of water to the boiling point. More heat must be added to the water to cause it to change into steam without any further increase in temperature.



Fundamentals of Steam and Water: BTU

In order to understand steam and its basics we must first have an understanding of BTU. An Englishmen named Thomas Tredgold, in the early 1800's, was sitting in his favorite establishment drinking a pint (which weighs about a pound) when he decided that a BTU would be the quantity of heat it took to raise one pound of water one degree Fahrenheit. Mr. Tredgold made it up and we all accepted it. He just came up with a term that makes us think of a quantity of heat. It's a term of measurement like "inch", "gallon" or "degree Fahrenheit."

We have to remember not to take this information too seriously, so 1 BTU will raise one pound of water 1°F and it will also raise 55 cubic feet of air 1°F. The energy contained by liquid water is then -

Water	BTU/LB
32°F	00
100°F	68
132°F	100
212°F	180

Total Heat of Steam

Steam has two basic kinds of heat in it, sensible and latent. The quantity of these is expressed as so many BTU per pound.

The sensible heat in water raises the temperature of the water to the boiling point. At this point the latent heat added will convert the water into steam.

The total heat in the steam is sensible heat plus the latent heat as shown in the following chart and in the steam table.

Volume

Volume of steam varies with pressure. Steam under a pressure of 200 psig occupies a space of 2.13 (ft^3/lb). The same pound of steam at 5 psig occupies a volume of 20.09(ft^3/lb) The energy content in a 2.1 cubic foot space would be very different for 5-psig steam than 200-psig steam. The 5 psig would have a total heat content of 121.4 btu/lb, while the 200-psig steam in the same space would have a total heat content of 1199 Btu.

Gage Pressue	Absolute PSIA	Steam Temp.°F	Sensible Heat,BTU	Latent Heat,BTU	TTL Heat BTU	Spec.Vol V ,Steam
29.743	0.08854	32	0	1075.8	1075.8	3306
29.515	0.2	53.14	21.21	1063.8	1085	1526
27.886	1	101.74	69.7	1036.3	1106	333.6
19.742	5	162.24	130.13	1001	1131.1	73.52
9.562	10	193.21	161.17	982.1	1143.3	38.42
7.536	11	197.75	165.73	979.3	1145	35.14
5.49	12	201.96	169.96	976.6	1146.6	32.4
3.454	13	205.88	173.91	974.2	1148.1	30.06
1.418	14	209.56	177.61	971.9	1149.5	28.04
0	14.696	212	180.07	970.3	1150.4	26.8
1.3	16	216.32	184.42	967.6	1152	24.75
2.3	17	219.44	187.56	965.5	1153.1	23.39
5.3	20	227.96	196.16	960.1	1156.3	20.09
10.3	25	240.07	208.42	952.1	1160.6	16.3
15.3	30	250.33	218.82	945.3	1164.1	13.75
20.3	35	259.28	227.91	939.2	1167.1	11.9
25.3	40	267.25	236.03	933.7	1169.7	10.5
30.3	45	274.44	243.36	928.6	1172	9.4
40.3	55	287.07	256.3	919.6	1175.9	7.79
50.3	65	297.97	267.5	911.6	1179.1	6.66
60.3	75	307.6	277.43	904.5	1181.9	5.82
70.3	85	316.25	286.39	897.8	1184.2	5.17
80.3	95	324.12	294.56	891.7	1186.2	4.65
90.3	105	331.36	302.1	886	1188.1	4.23
100	114.7	337.9	308.8	880	1188.8	3.88
110.3	125	344.33	315.68	875.4	1191.1	3.59
120.3	135	350.21	321.85	870.6	1192.4	3.33
125.3	140	353.02	324.82	868.2	1193	3.22
130.3	145	355.76	327.7	865.8	1193.5	3.11
140.3	155	360.5	333.24	861.3	1194.6	2.92
150.3	165	365.99	338.53	857.1	1195.6	2.75
160.3	175	370.75	343.57	852.8	1196.5	2.6
180.3	195	379.67	353.1	844.9	1198	2.34
200.3	215	387.89	361.91	837.4	1199.3	2.13

To Summarize Steam Advantages

- Steam is safe to pipe and use.
- Steam is safe to generate in the boiler.
- It is easy to control process steam temperatures with accessories.
- Steam is well-known and respected as being predictable and safe.
- Water is one of the cheapest and most abundant materials on the earth.
- Treatment and preparation costs are moderate.
- The generation, use, and behavior of steam is one of the basic processes upon which the industrial revolution was founded.

Flash Steam

When hot condensate or boiler water under pressure, is released to a lower pressure, part of it is re-evaporated, becoming what is known as flash steam. If water is heated under pressure the boiling point is higher than 212°F, so the sensible heat required is greater. The higher the pressure and the higher the boiling temperature the higher the heat content. If pressure is reduced, a certain amount of sensible heat is released. This excess heat will be absorbed in the form of latent heat, causing part of the water to "flash" into steam.

Condensate at steam temperature and under 100-psig pressure has a heat of 308.8 BTU per pound. If this condensate is discharged to atmospheric pressure (0 psig), its heat content instantly drops to 180 BTU per pound. The surplus of 128.8 BTU re-evaporates or flashes a portion of the condensate. The percentage that will flash to steam can be computed using the formula or the chart on the following page.

$$\%\text{ Flash steam} = \frac{SH - SL}{H} \times 100$$

SH = Sensible heat in the condensate At the higher pressure before discharge

SL = Sensible heat in the condensate As the lower pressure to which Discharge takes place.

H = Latent heat in the steam at the Lower pressure to which the Condensate has been discharged.

$$\%\text{ Flash steam} = \frac{308.8 - 180}{970.3} \times 100 = 13.3\%$$

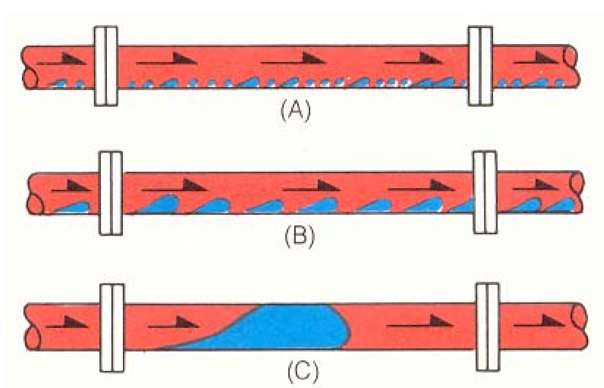
Water Hammer

Picture a horizontal steam main partially filled with condensate. Let's say it's not draining because the pitch is wrong. Steam enters the main and goes to the top because it's a relatively light gas. As it passes over the water, it cools, condenses and suddenly shrinks to 1/1600th its volume as steam.

Initial steam pressure psig	Saturated Steam Temperature °F	Flash-Tank Pressure, PSIG										
		0	5	10	20	30	40	50	75	100	125	150
25	267	5.7	4.1	3.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	298	9.0	7.4	6.2	4.3	2.6	1.0	0.0	0.0	0.0	0.0	0.0
75	320	11.3	10.8	8.6	6.7	5.0	3.7	2.5	0.0	0.0	0.0	0.0
100	338	13.3	11.7	10.6	8.7	7.0	5.7	4.6	2.2	0.0	0.0	0.0
125	353	14.8	13.4	12.2	10.3	8.7	7.4	6.3	3.8	1.7	0.0	0.0
150	366	16.8	14.8	13.7	11.8	10.2	8.8	7.8	5.4	2.3	1.6	0.0
175	377	17.4	16.0	15.0	13.0	11.6	10.0	9.0	6.7	4.6	3.0	1.5
200	388	18.7	17.5	16.2	14.4	12.8	11.5	10.4	8.0	6.0	4.4	2.8
225	397	19.7	18.2	17.0	15.4	13.8	12.4	11.4	9.0	7.0	5.4	3.8
250	406	20.7	19.2	18.2	16.4	15.0	13.6	12.5	10.0	8.2	6.6	5.0
300	422	22.4	21.0	20.0	18.2	16.7	15.5	14.4	11.0	10.0	8.5	7.0
350	436	24.0	22.7	21.6	20.0	18.4	17.0	16.0	13.8	12.0	10.4	8.9
400	448	25.5	24.2	23.0	21.5	20.0	18.7	17.7	15.6	13.5	12.0	10.5
450	459	26.8	25.3	24.4	22.7	21.2	20.0	19.0	16.8	15.0	13.4	12.0
500	470	28.2	26.7	25.7	24.0	22.6	21.4	20.4	18.2	16.4	14.6	13.4
550	480	29.2	27.8	27.0	25.3	23.7	22.6	21.6	19.5	17.5	16.0	14.7
600	489	30.2	28.8	28.0	26.4	25.0	23.6	22.7	20.5	18.7	17.3	16.0

This leaves a vacuum directly above the water. The water leaps up to fill the vacuum and crashes into the pipe. That's the "Clang" you hear at the beginning of a water hammer episode. Notice, how a sucking sound usually precedes the "Clang!" That's the steam condensing above the condensate. The sucking sound is the sound of the vacuum being formed. After the initial shot, the water slams back to the bottom of the pipe and surges forward in a small wave. More steam, urged on by the vacuum, comes roaring down the main. This steam flies over the top of the waves, driving it forward and getting caught between the crests of the waves. It condenses again. "Clang" And again "Clang" And again "Clang"

Now things are really starting to move inside our systems. The gathering waves are soaring toward the end of the main. We get a world-class bang when that mass of incompressible water slams into the end of the main. "Crash". You can avoid this type of water hammer by following good piping practices. Don't let the water lay in the pipes between cycles, and don't let it rush backward down a riser into the advancing steam.



It has been proven that the theoretical figure of 54 psi for each foot per second of velocity that is stopped by a valve is essentially correct, and with the closure of a valve, a pressure of 540 psi above system pressure is possible with a flow velocity of 10 feet per second.

In a condensate or liquid application the media is flowing through a pipe and there is a definite amount of energy in the liquid (mass times velocity). If the energy is stopped it must be used in some way. If the liquid is relatively incompressible and if the flow is stopped suddenly, the energy of the liquid is used expanding and increasing the diameter of the pipe and equipment. The increase of pressure energy under this condition is known as water hammer, which is often accompanied by a sound or clank like that of a hammer striking a pipe, followed by vibration of the piping.

FLOW	2"		2 1/2"		3"		4"	
GPM	V	hf	V	hf	V	hf	V	hf
25	2.72	1.3						
30	3.26	2.46	2.27	1.00				
35	3.8	3.28	2.65	1.33	1.7	0.46		
40	4.35	4.21	3.03	1.71	1.94	0.59		
45	4.89	5.26	3.41	2.13	2.18	0.73		
50	5.43	6.42	3.79	2.59	2.43	0.86	1.4	0.23
60	6.52	9.09	4.54	3.65	2.91	1.21	1.67	0.32
70	7.61	12.2	5.3	4.89	3.4	1.61	1.95	0.42
80	8.69	15.8	6.05	6.31	3.88	2.07	2.23	0.41
90	9.78	19.8	6.81	7.89	4.37	2.58	2.51	0.65
100	10.9	24.3	7.57	9.66	5.33	3.15	2.79	0.79

Water Hammer In Steam Lines

1. Steam pipes must be pitched away from the boiler toward a drip trap station. Drip trap stations must be installed ahead of any risers, at the end of the main and every 300 to 500 feet along the steam piping.

2. Drip traps must be installed ahead of all steam regulating valves to prevent the accumulation of condensate when the valve is in a closed position.

3. "Y" Strainers installed in steam lines should have the screen and dirt pocket mounted horizontally to prevent condensate from collecting in the screen area and being carried along in slugs when steam flow occurs.

4. All equipment using a modulating steam regulator on the steam supply must provide gravity condensate drainage from the steam traps. Lifts in the return line must be avoided.

Water Hammer In Condensate Return Lines

1. Whenever possible, use gravity return lines. Properly sized return lines allow condensate to flow in the bottom portion of the pipe and flash steam to flow in the top of the pipe. The top portion also allows efficient air venting during start

up of the system.

2. Water hammer can occur in pumped discharge lines. A condensate unit is pumping condensate near saturation temperature to an overhead horizontal run and then drops down into a vented boiler feed tank. A negative pressure develops in the horizontal pipe due to the piping drop into the vented receiver. When the pressure falls below saturation temperature, water hammer can occur. A 12 foot vertical drop can allow 190°F condensate to flash and cause water hammer. This condition can be remedied by either creating a back pressure at the low point or by installing a swing check valve open to atmosphere in the horizontal pipe. The swing check will open, allowing air to enter and the vertical water column to drain away.

3. Boiler feed pump discharge lines from a deaerator or pre-heat unit usually run overhead. A check valve or regulating valve is installed near the boiler and a check valve is usually installed off the discharge side of the pump. If the check valve at the pump discharge does not hold tight, condensate drains back to the boiler feed unit, allowing the condensate in the discharge to flash. A steam pocket forms at the high point. The result is water hammer when the pump starts. This can be corrected by replacing the check valve.

Condensate

Returning condensate back to the boiler is good practice because you require less makeup and less fuel to heat the water and chemicals to treat the water. With less condensate discharging into the sewer system your disposal costs will go down. The return of high purity condensate also reduces energy losses due to boiler blow-down. Tremendous fuel savings occur as most returned condensate is relatively hot (130°F to 225°F), reducing the amount of cold makeup water 50°F to 60°F that must be heated.

Consider the following example: A steam system returns an additional 10,000 lbs/hr of condensate at 180°F due to system modifications. Assume this system operates 8000 hours annually with an average boiler efficiency of 82%, and makeup water temperature of 55°F. The water and sewage costs for the plant are $0.002/gallon and the water treatment cost is $0.002/gallon. The fuel cost is $5.00 per Million Btu (MBtu)*. Assuming a 12% flash steam loss*, calculate the overall annual savings as shown at the top of the next page.

Purpose of Steam Trapping

A properly functioning steam trap should do the following:

1. Automatically remove condensate from the heat exchange area promoting heat exchanger efficiency.
2. Retain steam in the heat exchange space.
3. Vent CO2 and non-condensables, which affect heat exchanger efficiency.
4. Corrosion and erosion reduction.
5. Handle dirt and scale.
6. Provide long life and dependable service

Annual water, sewage, and chemical savings = (1 – Flash Steam Fraction) x (Condensate Load in lbs/hr) x Annual Operating Hours x (Total Water Costs in $/gallon) ÷ (Water Density in lbs/gallon)

$$\frac{(1 - 0.12) \times 10{,}000 \times 8{,}000 \times \$0.004}{8.34} = \$33{,}760$$

Annual Fuel Savings = (1 – Flash Steam Fraction) x (Condensate Load in lbs/hr) x Annual Operating Hours x (Makeup Water Temperature rise in °F) x (Fuel Cost in $/Btu) ÷ Boiler Efficiency

$$\frac{(1 - 0.012) \times 10{,}000 \times 8{,}000 \times (180 - 55) \times \$5.0}{0.82 \times 10^6} = \$60{,}243$$

Total Annual Savings Due to Return of an Additional 10,000 lbs/hr of Condensate = $33,760 + $60,243 = $94,003

*When saturated condensate is reduced to some lower pressure, some condensate flashes off to steam again. This amount is the flash steam loss.
**Natural Gas cost estimate = $5.00 Million MBtu, Water treatment cost = $2.00/1,000 gallons, Water &Sewage cost = $2.00/1,000 gallons

Benefits from a properly functioning steam trap are:

1. Maximum temperature maintenance in the heat exchange area.
2. Maximum fuel economy because heat is being utilized at the correct point and not being discharged to other areas.
3 Maximum performance from heat exchange equipment because air is removed from the exchange surface.
4. Quick heat up of equipment accomplished by the rapid removal and purging of air and non-condensables.
5. Reduced maintenance and labor costs for the owner.
6. There is **no** perfect and universal steam trap. Each trap has its own set of performance and operating characteristics. Decisions must be made as to which properties are the most important and most appropriate for the given application. Then select a trap that most closely fits the requirement.

Steam Trap Selection and Installation
Selection of the trap

1. Establish criteria for selection.
   - What is the condensate load, run and start up?
   - Is the steam pressure constant or modulated?
   - Is the process subject changing conditions?
   - What is the condensate going to discharge into?
   - What is the back pressure on the trap?
   - What are the ambient conditions the trap will experience?
   - Is the trap installed above or below the process?
   - What size trap do I need, pipe size or capacity size?
   - Where will the trap come from?
   - Will the vendor be there to help me when I need them?
   - How much will it cost?

2. Size the trap for the expected condensing load and apply an appropriate safety

factor recommended by the manufacture to account for start up and process upset. The load is determined by the surface area in the exchanger, the temperature differential between the steam and the process, the quality of the steam (1% air can reduce heat exchange) and other factors. Questions that will need to be answered to select the right sized vary from application to application. Some of the more universal questions are listed below.

a. What is the area of heat exchange surface?
b. What is the BTU exchange rate of the heat exchanger?
c. Is the steam pressure modulated?
d. Is the steam heating the process directly or indirectly?
e. What is the specific heat of the material being heated?

3. Standardization of traps in the facility based on the following criteria:

a. Availability of the traps
b. Ease of maintenance
c. Dependability of the trap
d. Cost effectiveness can be tracked to determine best total value for the customer
e. Dependability of the vendor to assist and service the needs of the management, operations and maintenance personnel.

Safety Load Factors

The safety load factor is a number used to help select the proper size steam trap for maximum condensate load. It is based on the judgement of an individual with experience in steam trapping and is used in trap calculations to compensate for the lack of exact knowledge about the condensate load a trap will actually experience. Estimates of condensing rates in the heat exchange equipment are rough approximations at best. Pressure and condensate temperature estimates are often significantly in error because of the unexpected or uncontrollable system variations and fluctuations.

The way to calculate the real steam trap capacity:

Condensate load x safety load factor = desired trap capacity.

Safety Load Table Of Factors	
Autoclaves	**3--4**
Blast Coils	**3--4**
Dry Cans	**2--3**
Dryers	**3--4**
Dry Kilns	**3--4**
Fan System Heating Service	**3--4**
Greenhouse Coils	**3--4**
Hospital Equipment	**2--3**
Water Heaters	**4--6**
Kitchen Equipment	**2--3**
Paper Machines	**3--4**
Pipe Coils (still air)	**3--4**
Platen Presses	**2--3**
Purifiers	**3--4**
Seperators	**3--4**
Steam Jacketed Kettles	**4--5**
Steam Main Drip	**3--4**
Submerged Surfaces	**5--6**
Tracer Lines	**2--3**
Unit Heaters	**3--4**

Doc's Dry Kiln Coil Sizing

As we look to size carbon steel S/40 fin pipe for lumber dry kilns I would like you to consider this simple approach. Take the total lineal footage from the dry kiln pipe coil and simply add up all of the total footage, example… 13 rows 2" fin pipe

Take the total length of each coil row and multiply this number by the total number of rows in the coil bank.

Our example shows a 2" fin pipe length of 10'feet and a total of 13 rows. Therefore it would look like this 10'ft x 13 ea rows = total lineal length 130'ft

If we multiply this length by the appropriate condensing rate for the specific size (see chart below) 130'ft x 3.5 lb/hr per ft (2") = 455 lb/hr per coil

But to size the steam trap for the coil you will multiply 455 x 3 (S.L.F) = Trap size 1365 lb/hr .

1"S/40 carbon steel fin pipe condensing factor.	= 3.00 lb/hr per foot length
1 ¼"S/40 carbon steel fin pipe condensing factor	= 3.13 lb/hr per foot length
1 ½"S/40 carbon steel fin pipe condensing factor	= 3.25 lb/hr per foot length
2" S/40 carbon steel fin pipe condensing factor	= 3.50 lb/hr per foot length