

bürkert
FLUID CONTROL SYSTEMS

Steam Site Guide

Heat Exchange Applications
SI and US Version

ACADEMY

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Introduction

The aim

Bürkert steam process valves do not sit in blissful isolation in a steam system, somehow separated and unaffected by their neighbours. Process valves are integral to the steam system and their safe operation, performance and longevity depend on the proper selection, sizing and position of the steam components that surround them. Failure to employ both the basic fundamentals and appropriate selection of the steam system elements, will result in poor performance and early failure.

By leading you through a typical heat exchange design process, we hope that it will bring you closer to the steam world.

How to use the guide

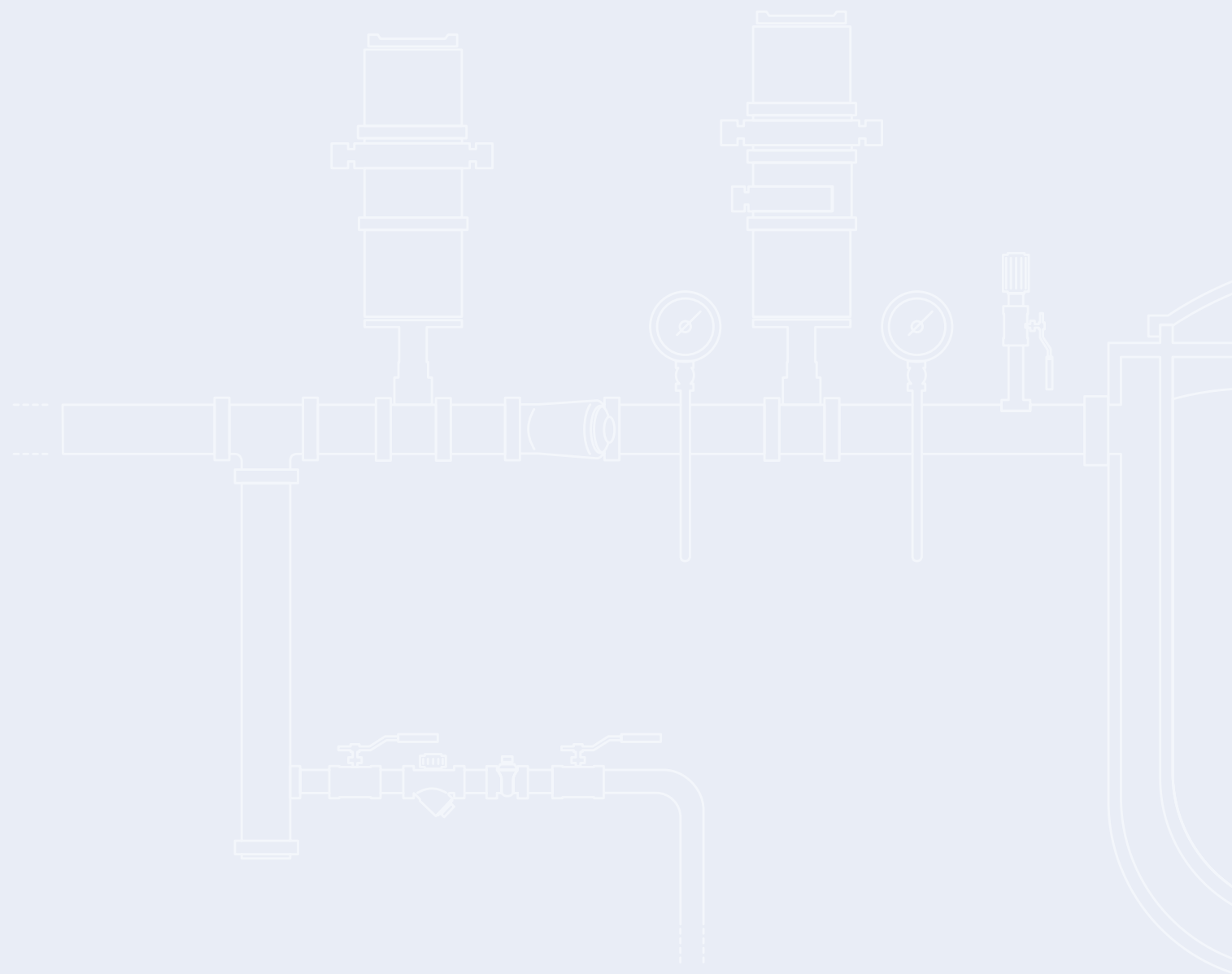
We will take you step by step through the design stages used in a typical steam heat exchange system, the most common application for steam in industry. As you work though this guide, you will learn the building blocks of steam design, that include:

- Estimating a steam load,
- Using a steam table,
- Sizing a steam pipe,
- Steam trap types,
- Sizing a steam trap,
- Calculating flash steam,
- Sizing condensate pipework,
- Designing a complete steam system,
- Practical tips for steam systems.

Once you have worked through the design steps and understood the design process, we hope that you will have a good overall appreciation of how a good steam system should be designed. The individual pages can be used again in the future to assist you on site and act as a reminder when faced with certain steam situations and application challenges.

“TO BETTER UNDERSTAND A STEAM SYSTEM, IS TO BETTER UNDERSTAND BÜRKERT PRODUCTS.”

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Steam Site Guide

Heat Exchange Applications - SI Units

01. Estimating Steam Loads

The correct design of any steam system rests on the accurate estimation of its steam condensation rate, reliably facilitating the sizing of control valves, pipe sizes and steam traps, to give the result you want. In heat transfer applications the steam is required to do two things – produce a change in the product temperature and also maintain the product temperature as heat is lost to its surroundings. In the following pages, the heat loss element has been omitted to aid clarity.

To establish the rate of heat transfer in heat exchange applications, we have two categories:

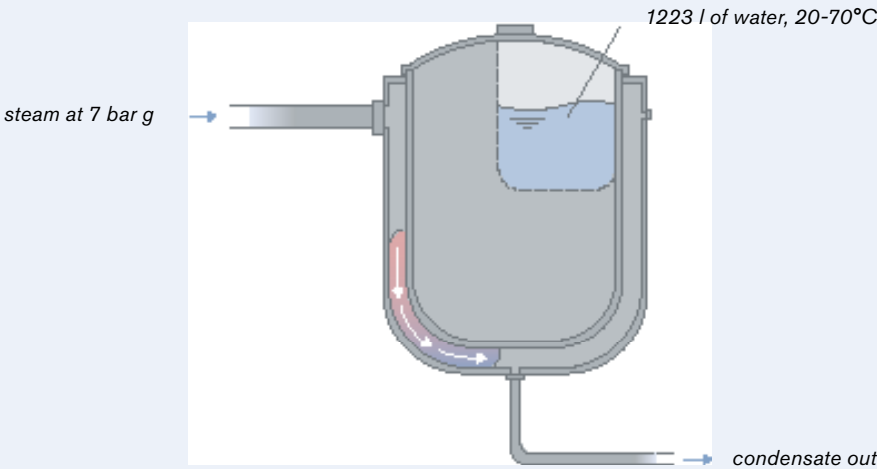
- **Non-flow applications:** heating a fixed mass, single batch within a vessel.
- **Flow applications:** the heated media flows continuously over the heat transfer surface.

Non-flow example

Calculate the heat transfer rate and steam consumption rate of a jacketed cooking pan. We need to heat 1223 litres of water from 20°C to 70°C in 30 minutes and saturated steam is available at 7 bar g. At 7 bar g the specific heat of evaporation (hfg) is 2047 kJ/kg. The jacketed vessel is well insulated and the heat losses are negligible.

$$\dot{Q} = \frac{m \times Cp \times \Delta T}{t} = \frac{1223 \times 4.186 \times 50}{1800} = 142.20 \text{ kJ/s} = 142.20 \text{ kW}$$

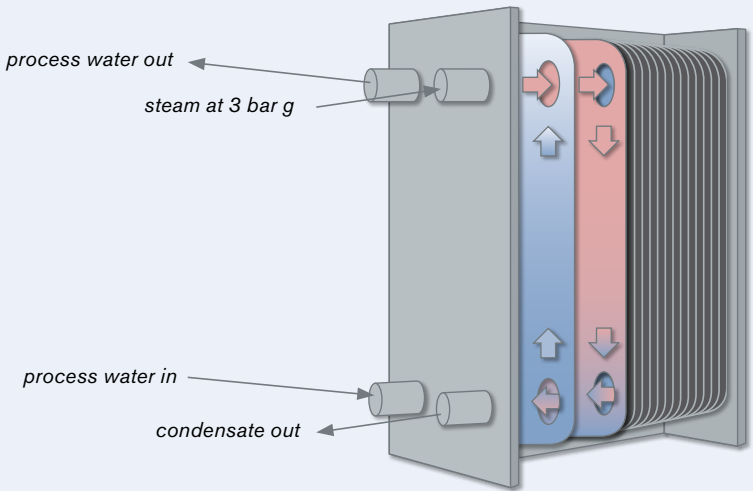
$$\dot{m}_s = \frac{\dot{Q}}{h_{fg}} = \frac{142.20 \text{ kJ/s}}{2047 \text{ kJ/kg}} = 0.069 \text{ Kg/s} = \mathbf{250 \text{ Kg/h}}$$



Flow example

A typical example would be a shell and tube heat exchanger providing heated water for a process. Calculate the mean steam consumption rate to heat a process fluid from 15°C to 70°C, supplied at a rate of 2000 l/h. Saturated steam is available at 3 bar g. The shell and tube heat exchanger is well insulated and the heat losses are negligible.

$$\dot{m}_s = \frac{\dot{m} \times Cp \times \Delta T}{h_{fg}} = \frac{2000 \times 4.186 \times 55}{2133} = \mathbf{216 \text{ kg/h}}$$



- \dot{Q} = Mean heat transfer rate (kW (kJ/s))
- m = Mass of the secondary fluid (kg)
- Cp = Specific heat capacity of the secondary fluid (kJ/kg°C)
- t = Time for heating the process (seconds)
- ΔT = Temperature rise of the secondary fluid (°C)
- \dot{m}_s = Mean rate of steam consumption (kg/s)
- h_{fg} = Specific enthalpy of evaporation (kJ/kg)
- \dot{m} = Mean flow rate of the secondary fluid (kg/h)

Cp examples (kJ/kg°C)		
Water:	4.186	Vegetable Oil: 1.67
Milk:	3.93	Olive Oil: 1.96

02. Steam Table SI Units

Steam Table SI | 09

03. Sizing a Steam Pipe

It is widely appreciated that steam velocity is an important factor in the life and maintenance of a steam pipe. As steam velocity is such a practical issue, it is reasonable that it could form the basis of a sizing method for steam pipes. For relatively short runs (less than 50m), velocities of 15 to 40 m/s are used in saturated steam applications. As a general rule of thumb, 25m/s is adopted as a happy medium. For longer pipe runs, alternative pressure drop method are normally considered.

Oversized pipework:

Higher costs for ancillaries such as strainers, isolation valves, pipe supports and insulation can dramatically and unnecessarily increase both the initial installation cost and the overall cost of ownership. It can also have an effect on the steam systems' operational effectiveness. More condensate can be expected to form, due to the greater heat losses from the larger heat transfer area, requiring more steam trapping or the increased risk of wet steam being offered to the process.

Undersized pipework:

The process itself dictates the mass of steam required at the point of use. If the required mass of steam travels through undersized pipework, you can expect an increase in steam velocity. Steam and condensate travelling at high velocities can be very damaging, increasing the risk of erosion, noise, wire-draw and water hammer. With an increase in velocity, you can also expect a higher pressure drop across the steam pipework, resulting in a lower than expected pressure at the point of use, hindering the application's effectiveness.

Example

An industrial food autoclave condenses 180 kg/h of saturated steam and the steam pressure is 3 bar g. Using the example table to the right, starting on the left hand side, find the steam pressure required and select the desired velocity. Trace a line horizontally across, until you reach a figure greater than the required 180 kg/h. From there trace a line vertically upwards and simply read off the pipe size, which in this example would be 32mm.

Saturated steam pipeline capacities table – Example only

Pressure bar g	Velocity m/s	Pipe size (nominal)									
		15	20	25	32	40	50	65	80	100	125
		Pipeline capacity kg/h									
0.4	15	9	15	25	43	58	95	136	210	362	569
	25	14	25	41	71	97	159	227	350	603	948
	40	23	40	66	113	154	254	363	561	965	1,517
0.7	15	10	18	29	51	69	114	163	251	433	681
	25	17	30	49	85	115	190	271	419	722	1,135
	40	28	48	78	136	185	304	434	671	1,155	1,815
1	15	12	21	34	59	81	133	189	292	503	791
	25	20	35	57	99	134	221	315	487	839	1,319
	40	32	56	91	158	215	354	505	779	1,342	2,110
2	15	18	31	50	86	118	194	277	427	735	1,156
	25	29	51	83	144	196	323	461	712	1,226	1,927
	40	47	82	133	230	314	517	737	1,139	1,961	3,083
3	15	23	40	65	113	154	254	362	559	962	1,512
	25	38	67	109	188	256	423	603	931	1,603	2,520
	40	61	107	174	301	410	676	964	1,490	2,565	4,032
4	15	28	50	80	139	190	313	446	689	1,186	1,864
	25	47	83	134	232	316	521	743	1,148	1,976	3,106
	40	75	132	215	371	506	833	1,189	1,836	3,162	4,970
5	15	34	59	96	165	225	371	529	817	1,408	2,213
	25	56	98	159	276	375	619	882	1,362	2,347	3,688
	40	90	157	255	441	601	990	1,411	2,180	3,755	5,901
6	15	39	68	111	191	261	430	613	947	1,631	2,563
	25	65	114	184	319	435	716	1,022	1,578	2,718	4,271
	40	104	182	295	511	696	1,146	1,635	2,525	4,348	6,834
7	15	44	77	125	217	296	487	695	1,073	1,848	2,904
	25	74	129	209	362	493	812	1,158	1,788	3,080	4,841
	40	118	206	334	579	788	1,299	1,853	2,861	4,928	7,745
8	15	49	86	140	242	330	544	775	1,198	2,063	3,242
	25	82	144	233	404	550	906	1,292	1,996	3,438	5,403
	40	131	230	373	646	880	1,450	2,068	3,194	5,501	8,645
10	15	60	105	170	294	401	660	942	1,455	2,506	3,938
	25	100	175	283	490	668	1,101	1,570	2,425	4,176	6,563
	40	160	280	453	785	1,069	1,761	2,512	3,880	6,682	10,502
14	15	80	141	228	394	537	886	1,263	1,951	3,360	5,281
	25	134	235	380	657	896	1,476	2,105	3,251	5,600	8,801
	40	214	375	608	1,052	1,433	2,362	3,368	5,202	8,960	14,082

04. Steam Trap Types

The sizing and choice of a steam trap is absolutely crucial to the success of a steam system. Their purpose is to keep the useful steam within the process whilst automatically releasing the undesirable condensate and non-condensable gases. An incorrect steam trap selection can have dramatic effects on the steam application. For example:

- Processes are slow to reach temperature and performance is poor.
- Water hammer, erosion, corrosion, leading to high maintenance costs.

For a typical heat exchange process to operate to expected performance levels, the steam space must be filled with clean, dry saturated steam. In simple terms, you can not get the high heat carrying steam in, unless the condensate and non-condensable gases are removed.

There are three basic types of steam trap:

Thermostatic

Operate by reacting to changes in the fluid temperature. When steam gives up its enthalpy of evaporation, the resulting condensate is at the same temperature. As time goes on, the condensate loses further energy, resulting in a fall in condensate temperature. At a predefined sub-saturation-point temperature e.g. sub 12°C, the thermostatic steam trap opens to pass the condensate. When steam is present, the increase in temperature is sensed and the trap closes.

Generally good for: Jacketed vessels, steaming ovens and tunnels, hot tables, autoclaves and sterilisers, laundry equipment, tyre presses, space heating equipment, pressure reducing stations, steam tracer lines, jacketed pipes and ancillaries, steam mains and terminal end drainage.



Mechanical

Operate by sensing changes in fluid density. In the case of the ball float trap type, the ball rises when condensate enters the float trap body. The condensate supports a floating ball on a swinging arm, and this mechanical action uncovers an orifice to release the condensate. When steam is present, the ball drops (as the steam can not support the ball), and the orifice is once again covered. Typically fitted with an additional, smaller thermostatic air vent, to aid the discharge of air and other non-condensable gases. Together they are termed "float and thermostatic" steam traps.

Generally good for: Jacketed vessels, bulk storage tanks, re-torts, digesters, brewing coppers, evaporators and calandrias, autoclaves and sterilisers, laundry equipment, tyre presses, industrial autoclaves, vulcanisers, space heating equipment, pressure reducing stations, steam mains, header and terminal end drainage.



Thermodynamic

Operate by changes in fluid dynamics. Cooler condensate and air travel through an orifice, lift a sealing disc, passing out through the trap unabated. Next, hotter condensate passes through and the localised pressure drop at the orifice results in the formation of flash steam. This causes a drop in pressure under the sealing disc, drawing the sealing disc down, closing the trap. The sealing disc holds flash steam above and below itself. The upper surface area of the sealing disc is greater than below, hence exerts a greater downward force, keeping the trap closed. This situation is maintained whilst live steam is present. As condensate collects at the trap inlet, the trapped flash steam above the sealing disc loses energy, condenses and the sealing disc is released. Condensate discharges.

Generally good for: Digesters and hot tables, laundry equipment, tyre presses, space heating equipment, steam tracer lines and jacketed pipes, separators, steam mains, header and terminal end drainage.



05. Sizing a Steam Trap

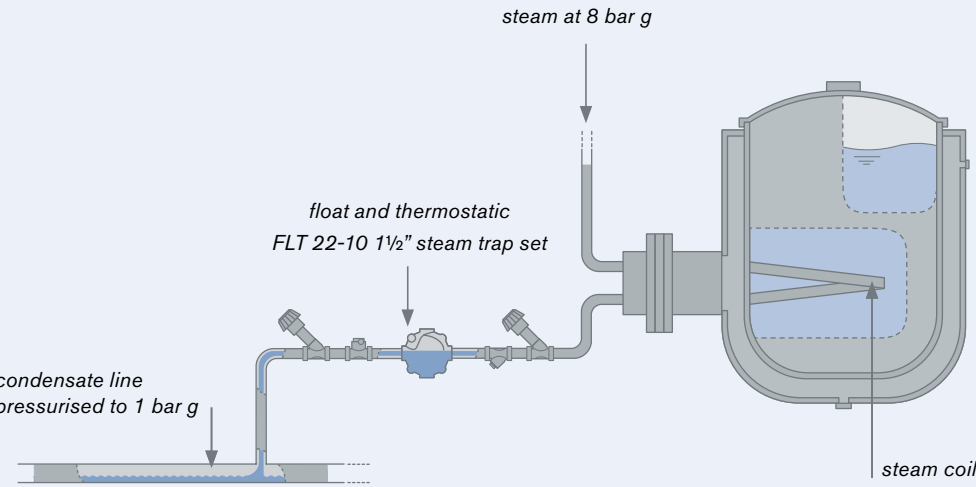
Steam heat exchange applications receive their energy by the action of condensation. When saturated steam comes into contact with a surface at a lower temperature than itself, it condenses and gives some of its energy to the surface. It is vital to know that for every kg of saturated steam condensed in a process, you will create a corresponding kg of condensate. So for example if an application uses 100kg/h of steam, it will produce 100kg/h of condensate. Sizing the steam trap correctly will ensure that the heat transfer surfaces are free of the lower-energy carrying condensate (having already given up a large proportion of its energy by the action of condensation). Only by ensuring that the condensate is successfully removed will you achieve best possible plant performance. Should condensate remain in the steam space, it would reduce the available heat transfer area and thus reduce performance.

Example

A storage tank with a steam coil is calculated to condense steam at a rate of 4000 kg/h. Steam is supplied at 8 bar g and the steam trap discharges into a condensate line pressurised to 1 bar g. The manufacturer of the tank has recommended a float and thermostatic steam trap solution.

Which size float and thermostatic steam trap is required?

Each steam trap will have a method of sizing, either a chart or as shown with a capacity table. The left hand column is the trap model and size, e.g. FLT22-10 1" = Model FLT22, that operates with differential pressures of 10 bar or less, with a 1" port. To select a steam trap, select the correct differential pressure, which in this case is 7 bar. Trace a line down until you reach a figure greater than the required 4000 kg/h. From there trace a line horizontally and simply read off the steam trap selected, which in this example would be a FLT22-10 1 1/2".



Flow rate capacity in kg/h – example only

Model/Size	Differential Pressure (bar)												
	0.5	1	1.5	2	3	4.5	6	7	8	9	10	12	14
FLT22-4.5 1/2" – 1"	230	330	400	440	535	630							
FLT22-10 1/2" – 1"	150	200	250	260	340	400	460	495	520	550	595		
FLT22-14 1/2" – 1"	120	150	180	220	260	380	380	400	425	440	480	510	550

Model/Size	Differential Pressure (bar)												
	0.5	0.7	1.0	1.5	2.0	4.5	7.0	10.0	12.0	14.0	16.0	21.0	
FLT22-4.5 1 1/2"	2400	2800	3400	3900	4500	7300							
FLT22-10 1 1/2"	1500	1750	2000	2600	3000	4000	5400	6200					
FLT22-14 1 1/2"	950	1100	1300	1600	1800	2600	3250	3900	4210	4950	5000		
FLT22-4.5 2"	7550	9050	11000	14000	15500	22500							
FLT22-10 2"	3900	4450	5000	6100	7100	10000	13750	16000					
FLT22-14 2"	1900	2300	2700	3100	3600	5000	6900	8100	9000	9800			

06. Calculating Flash Steam

Flash steam is released from hot condensate when the pressure is reduced, not by the addition of further energy. Flash steam is exactly the same as normal “live steam” supplied by a boiler.

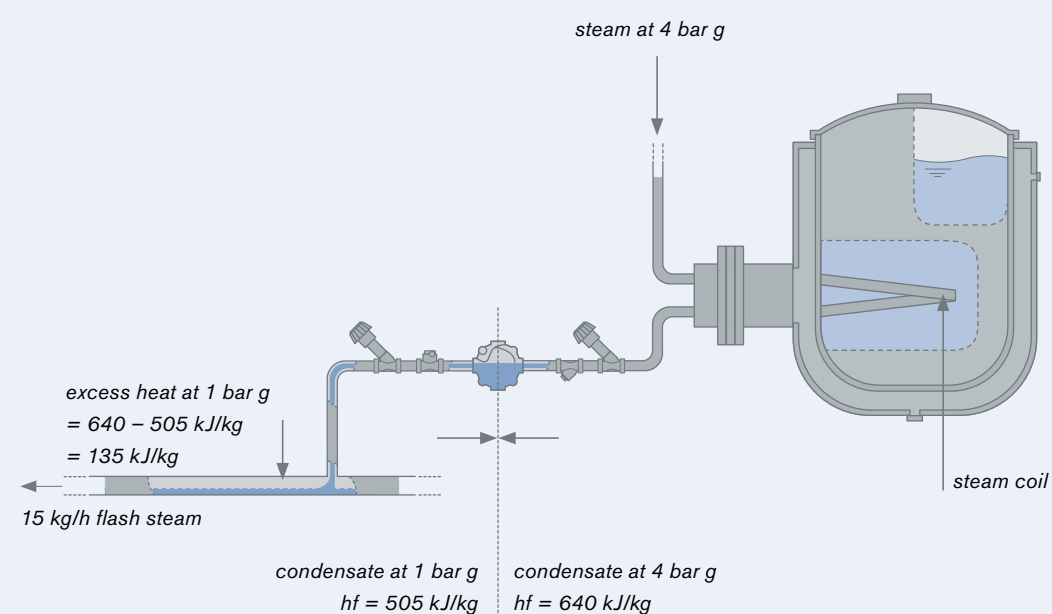
Consider the jacketed vessel shown

The condensate enters the steam trap at 4 bar g and at a temperature of 151°C. The energy present in the condensate at this pressure is a maximum of 640 kJ/kg. The condensate discharges through the steam trap into the condensate return line. The pressure in the condensate return line is 1 bar g. At 1 bar g the maximum amount of energy per kg of condensate is 505 kJ and the maximum temperature is 120°C – see steam tables.

640–505 kJ/kg gives an excess of 135 kJ/kg of energy which evaporates some of the condensate back into steam, an action called “flashing”. The energy needed to produce 1 kg of saturated steam from saturated water at 1 bar gauge is 2201 kJ.

An amount of 135 kJ/kg can therefore evaporate: $135/2201 \text{ kJ} = 0.06 \text{ kg}$ of steam, per kg of condensate or in other words 6% of the condensate into flash steam. If the jacketed vessel is condensing 250 kg/h of steam then the amount of flash steam released would be: $0.06 \times 250 \text{ kg/h}$ of condensate

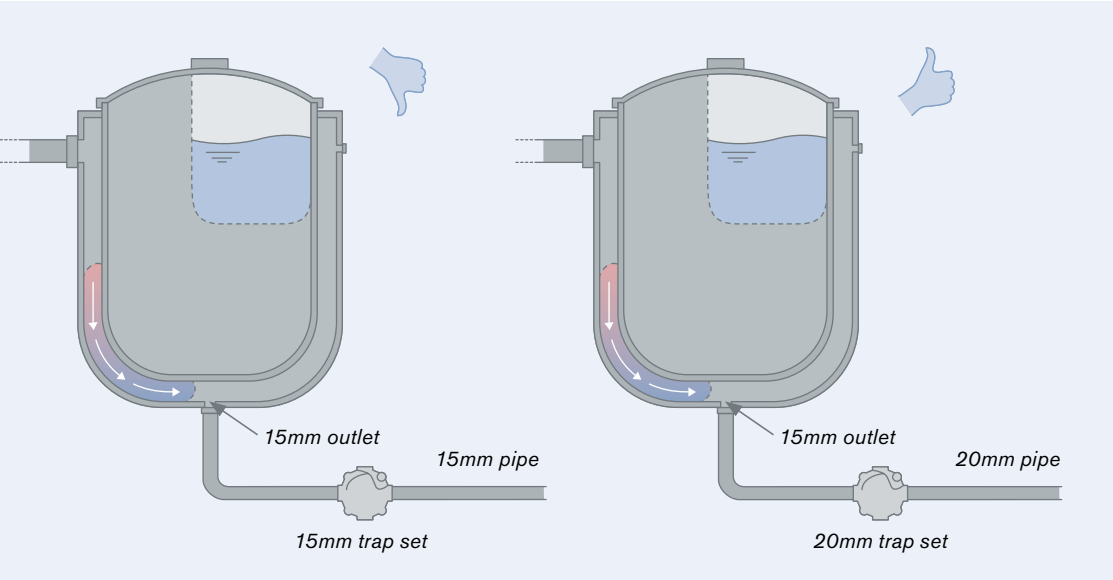
= 15 kg/h of flash steam



Room for Notes

07. Sizing Condensate Pipework

The condensate drain from a process consists of 4 main parts. The process outlet connection, the pipe into the steam trap, the steam trap itself and the condensate discharge pipework. **Never assume that they will all be the same size.** Firstly the process outlet connection supplied by the manufacturer may be generic and not specific for your needs, as the process may conceivably operate at a number of different operating conditions. If the steam trap has been sized correctly, it is typical for the pipe from the process outlet connection to the steam trap inlet connection to be sized the same.



Assuming that there is no significant pressure drop between the process outlet connection and the trap inlet, the pipe will be flooded with condensate. The pipe down-stream of the trap will carry both condensate and flash steam, a two phase flow, due to the pressure drop across the trap. The condensate and flash steam are at the same pressure and temperature.

To give an idea of the differences in volume between the two phases, a process operating at 4 bar g, with a trap discharging into a condensate pipe operating at 0.5 bar g, would result in a condensate pipe with 99% flash steam and 1% condensate by volume. It follows therefore that the trap discharge pipework should consider steam over water as a defining parameter.

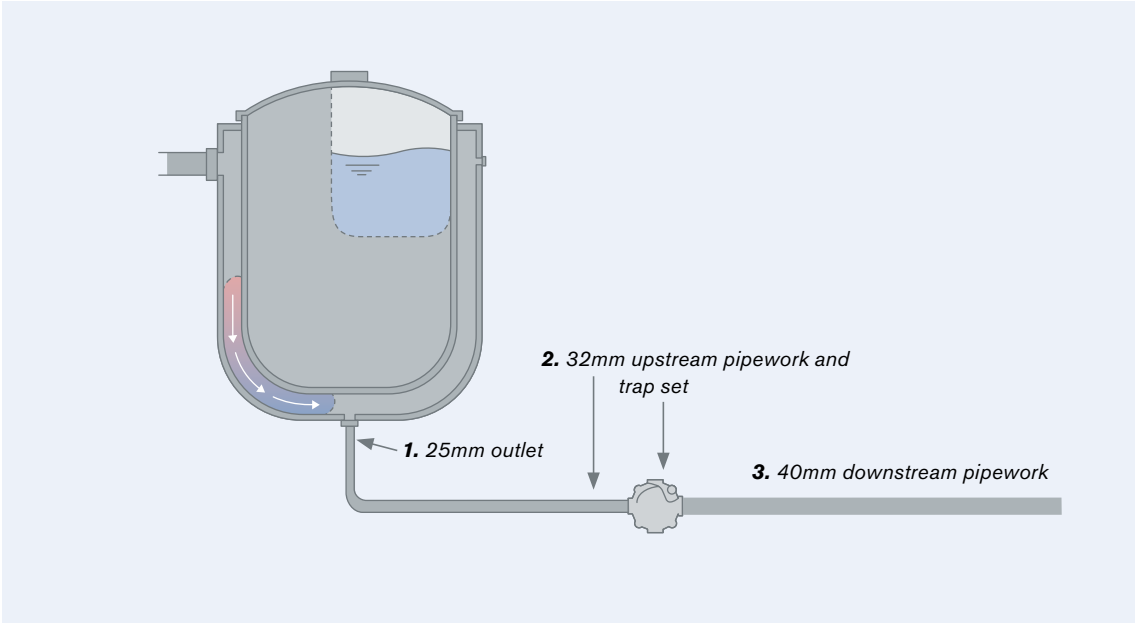
Example

A fruit juice pasteuriser is discharging 750kg/h of condensate at 3 bar g into a steam trap. The trap discharges into a condensate pipe operating at 0.4 bar g. Using the flash steam calculation, the expected result is the formation of 49 kg/h of flash steam. Using the steam pipeline capacities table and a velocity of 25m/s, the condensate pipework would be 32mm.

Pressure bar g	Velocity m/s	Pipe size (nominal)										
		15	20	25	32	40	50	65	80	100	125	150
		Pipeline capacity kg/h										
0.4	15	9	15	25	43	58	95	136	210	362	569	822
	25	14	25	41	71	97	159	227	350	603	948	1,369
	40	23	40	66	113	154	254	363	561	965	1,517	2,191
0.7	15	10	18	29	51	69	114	163	251	433	681	983
	25	17	30	49	85	115	190	271	419	722	1,135	1,638
	40	28	48	78	136	185	304	434	671	1,155	1,815	2,621

Due to flash steam present after the steam trap, it is possible to have three different sizes in the condensate discharge line.

- 1. The process connection provided by the process plant manufacture,
- 2. The steam trap port size,
- 3. Condensate discharge pipework.



08. Designing a Steam System

Design brief

Design a fixed boiling pan steam system, designed to heat 1500 Litres of cooking sauce (similar properties to water) from 10°C to 80°C, in half an hour. Saturated steam is available at 4 bar g and the heat exchanger requires 3 bar g. The condensate back pressure is known to be 1 bar g. The boiling pan manufacturer has used a 50mm steam inlet connection and a 10mm air vent and condensate connection. Heat losses are negligible.

Step 1: Estimate the steam load

Using sections 01 & 02, “Estimating steam loads” and “Steam table SI”

$$\dot{Q} = \frac{m \times C_p \times \Delta T}{t} = \frac{1500 \times 4.186 \times 70}{1800} = 244.18 \text{ kJ/s} = 244.18 \text{ kW}$$

$$\dot{m}_s = \frac{\dot{Q}}{h_{fg}} = \frac{244.18 \text{ kJ/s}}{2133 \text{ kJ/kg}} = 0.1144 \text{ kg/s} = 412 \text{ kg/h}$$

Step 2: Size the inlet steam pipework

Using section 03, “Sizing a steam pipe”

Steam at 4 bar g, at a rate of 412 kg/h steam load @ 25m/s = 50mm

Step 3: Size the steam on/off shut off valve

The on/off shut-off valve should be the same size as the pipework = 50mm port

Step 4: Size the steam trap (and trap set) before an isolating valve

½" (15mm), the standard choice for applications within a process area = 15mm

Step 5: Size the steam control valve

Using Bürkert Smart Sizer program, size the control valve = Kvs 21 DN50 port, 32mm diameter orifice

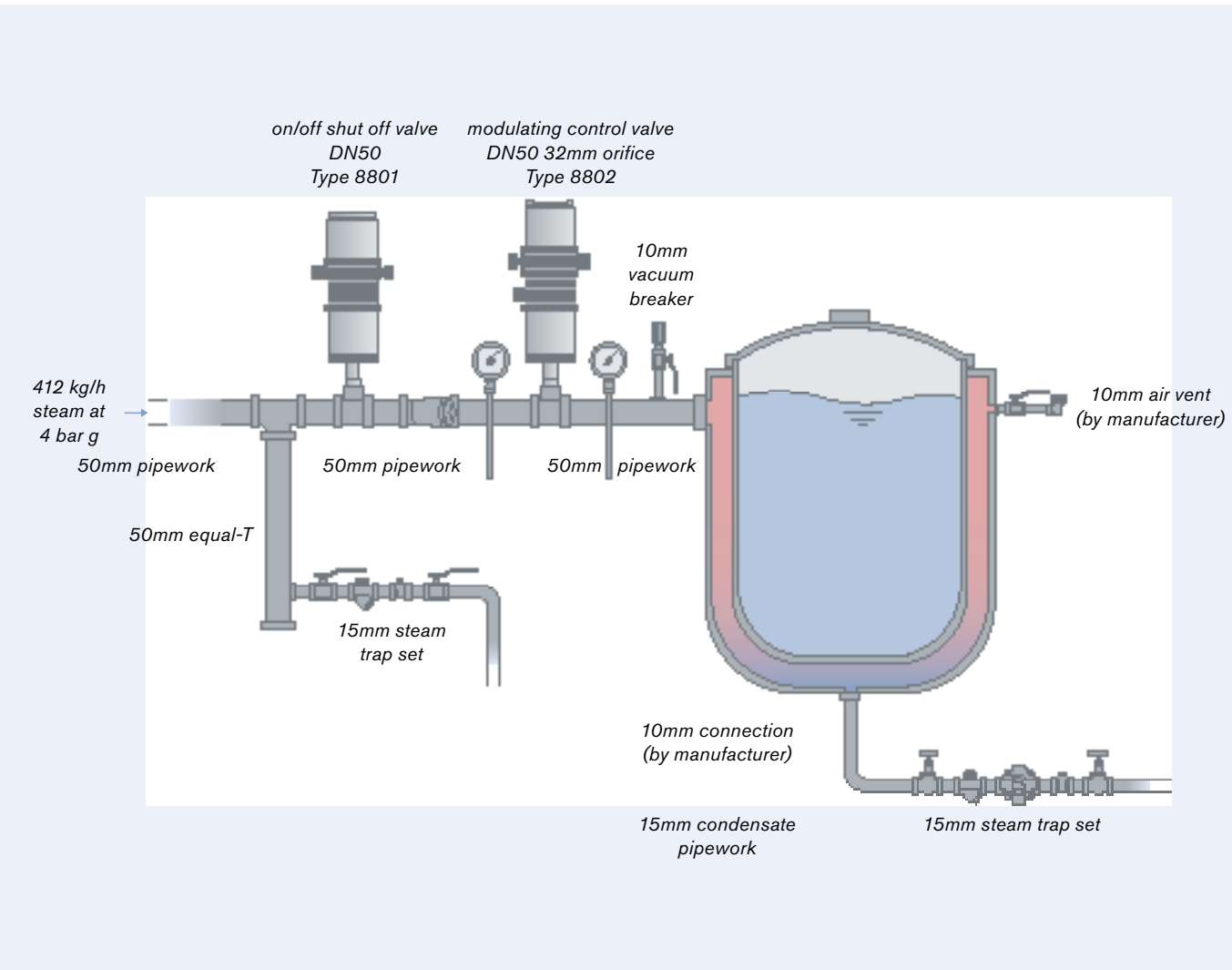
Step 6: Size the steam trap

Using section 05 “Sizing a steam trap” = FLT22-4.5 ½" (or ¾", 1" same capacities, different ports)

Step 7: Calculate flash steam and size condensate pipework

Using sections 06 & 07, “Calculating flash steam” and “Sizing a steam pipe” = 15mm

0.045 x 412 kg/h of condensate = 18.54 kg/h
As steam volume is far greater than condensate, it is accepted that condensate pipework is sized using steam pipework tables.
Therefore 18.54 kg/h at 1 bar g



09. Practical Tips For Steam Heat Exchange Applications

Water hammer is not acceptable and should not be tolerated.

If you hear it, leave the area. Inform the process supervisor. It is the most destructive force on a steam system. It is not a normal situation and should never be tolerated. It can damage equipment and injure or even kill personnel.

Do not oversize control valves.

An oversized control valve is costly, it will find controlling the process difficult and spend prolonged periods in the almost closed position, risking wire-draw and premature failure. Wire-draw is an action where condensate cuts a path through the valve trim, passing steam even when closed.

You must always consider velocities and noise when sizing a control valve.

Sizing a control valve on mass flow and pressure drop alone is not correct. The optimum velocity at the valve outlet should be between 10–40m/s and the noise no greater than 85dB.

Steam valves should be opened and closed with care and slowly.

This allows any build up of condensate to flow gently to the next drain pocket. It will also reduce the risk of thermal shock. Especially important during warm up periods.

Install a strainer before a control valve.

It is not uncommon for foreign particles to be present inside a steam pipe. Particularly in older pipes there will be rust fragments and carbonate deposits, that could damage a valve. Foreign matter can lodge in a control valve trim or score the trim, causing the premature failure of the control valve. It is possible for a foreign particle to lodge itself between the plug and seat of a control valve, forcing it partly open, exposing the control valve to damage through wire-drawing.

Install pressure gauges before and after a control valve.

They provide the information needed to understand the conditions inside the system. A great aid during commissioning and afterwards when operating the steam system.

Condensate produced by a process must be removed.

Condensate holds roughly 5–6 times less energy than saturated steam. If a heat transfer process is flooded with condensate, the results will be poor and you risk water hammer.

Condensate should normally be returned to the boiler feed water tank.

Condensate still holds its specific enthalpy of water with roughly 16 % of the original steam energy still remaining, depending on the pressures. By returning the hot condensate back to the boiler you reduce energy losses, water usage and water treatment chemicals.

A rising condensate line from a process can cause a “stall” condition.

“Stall” conditions are particularly problematic in modulating steam control applications. “Stalling” occurs when the pressure available is not sufficient to force the condensate out of the heat transfer area, resulting in water logging and poor heat transfer performance. An alternative is to allow the condensate to gravity feed into a condensate pumping set.

An undersized or incorrect type of steam trap can waterlog a process.

Undersize the steam trap and condensate will back up and waterlog the steam space. Even if you have sized your steam control valve correctly, the process will still waterlog if the steam trap is undersized. The correct type of trap is also important. A thermostatic style trap for example relies on a certain amount of energy loss to operate. This delay could hold back condensate and waterlog the steam space.

Steam strainers should be fitted in the horizontal plane, baskets on the side.

Strainers left in the “belly down” position, create a weir of condensate and thus provide a source of wet steam. However, belly down is acceptable on a condensate line (as part of the steam trap set) as it will be flooded already.

Fit air vents to a heat transfer device, end of lines and high points.

Air is a tremendously effective insulator and can collect in pockets and also form thin films on heat transfer surfaces. Not only does it insulate, but when it mixes with steam, it will reduce the heat transfer efficacy, contributing to the pressure of the mixture, but not to the available heat content.

Fit vacuum breakers to all heat transfer devices.

When a heat exchange system shuts down, the trapped steam will collapse, and the reduction in volume causes a vacuum in the steam space, powerful enough to implode the plant equipment. Vacuum breakers automatically replace the lost volume with outside air, relieving the vacuum and avoiding the implosion.

Never run steam lines uphill.

A gentle fall away in the direction of the flow will aid condensate drainage. A gradient of 1:100 is normally acceptable.

Fit drain pockets at regular intervals, low points and before on/off control valves.

Even with the most efficient lagging, condensate will form in steam pipework, due to radiated losses to the surrounding air. It is recommended to fit a drain pocket at regular intervals of 30–50m and at the base of a lift. Fitting a drain pocket and trap set before an on/off valve or control valve will remove the risk of trapped condensate being released at high velocities, which can result in valve damage and water hammer.

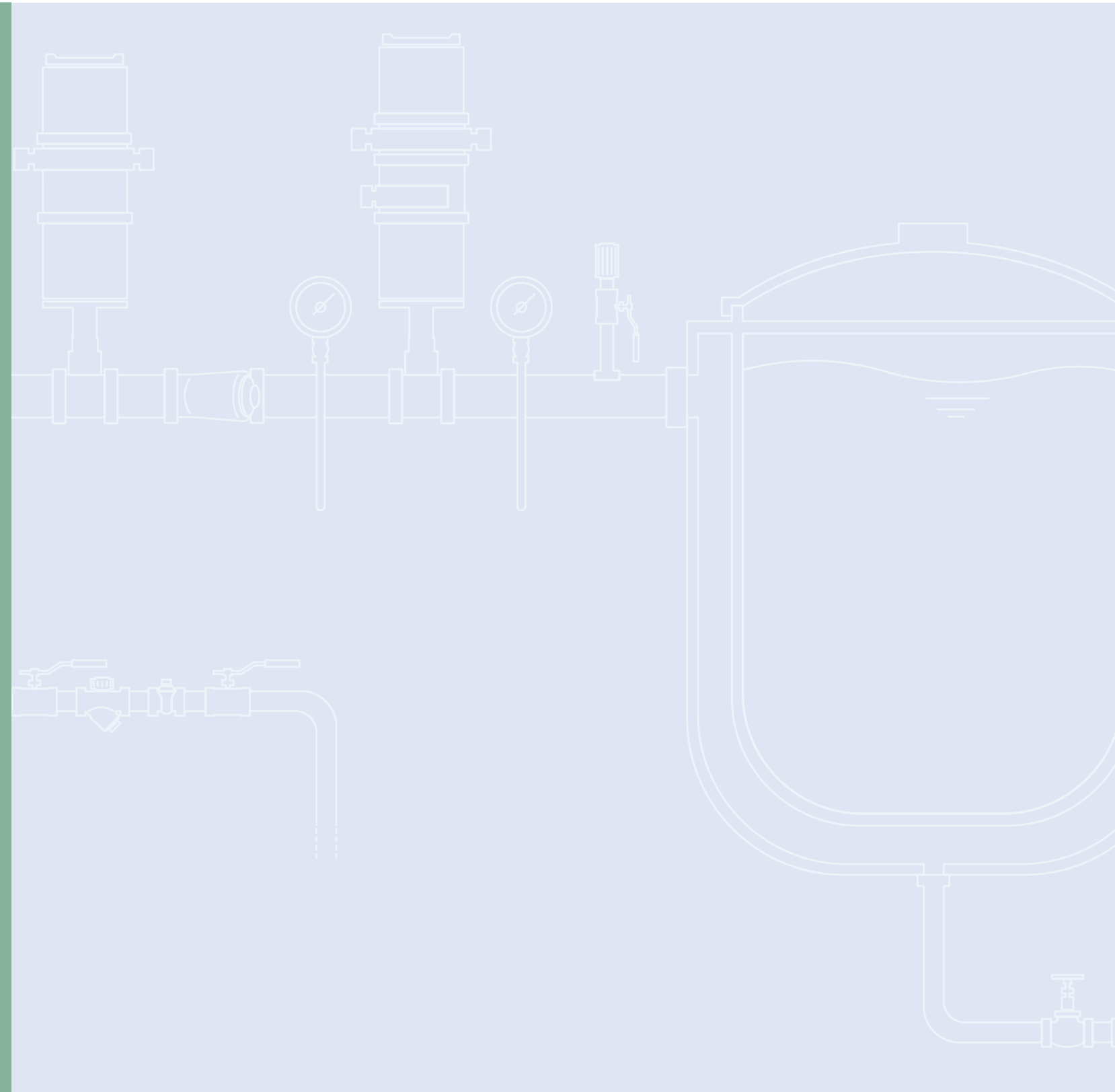
Fit “equal T” drain pockets.

As a general rule, for steam mains up to 100mm (4"), the drain pocket should be the same size as the steam main, hence the term “equal T”. The trap set connection is set at least 25mm from the bottom of the drain pocket. Fit a removable flange or threaded plug to periodically remove the accumulated debris during down times.

Steam take-offs should be made from the top of the vertical steam main.

This ensures that the steam in the branch line is as dry as possible, reducing the risk of erosion and water hammer in the branch line.

And most importantly of all, RESPECT STEAM.



Steam Site Guide

Heat Exchange Applications - US Units

01. Estimating Steam Loads

The correct design of any steam system rests on the accurate estimation of its steam condensation rate, reliably facilitating the sizing of control valves, pipe sizes and steam traps, to give the result you want. In heat transfer applications the steam is required to do two things – produce a change in the product temperature and also maintain the product temperature as heat is lost to its surroundings. In the following pages, the heat loss element has been omitted to aid clarity.

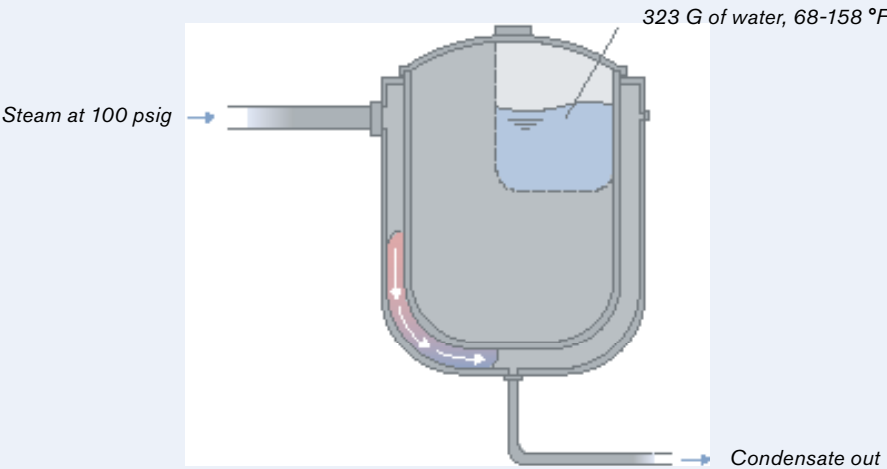
To establish the rate of heat transfer in heat exchange applications, we have two categories:

- **Non-flow applications:** heating a fixed mass, single batch within a vessel.
- **Flow applications:** the heated media flows continuously over the heat transfer surface.

Non-flow example

Calculate the steam consumption of a jacketed cooking pan. We need to heat 323 US gallons of water from 68 °F to 158 °F in 30 minutes and saturated steam is available at 100 psig. At 100 psig the latent heat is 880 Btu/lb. The energy to heat the vessel and further heat losses are omitted for clarity.

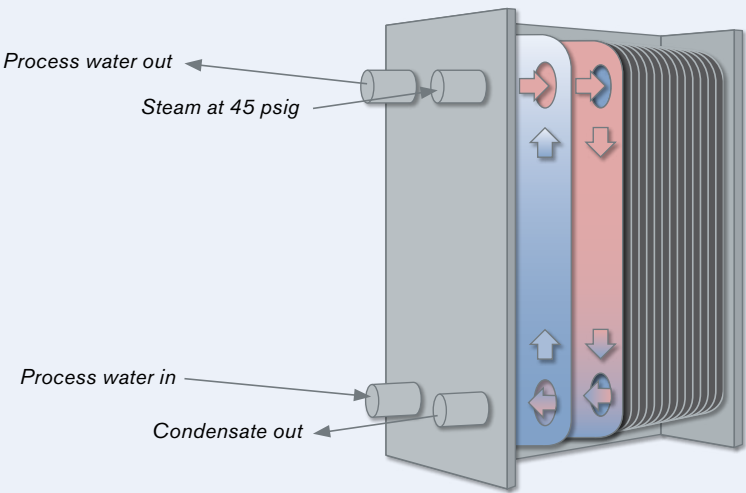
$$\dot{m}_s = \frac{G \times SG \times C_p \times \Delta T \times 8.33}{L \times T} = \frac{323 \times 1 \times 1 \times 90 \times 8.33}{880 \times 0.5} = 550 \text{ lb/h}$$



Flow example

A typical example would be a plate and frame heat exchanger providing heated water for the process. Calculate the mean steam consumption rate to heat a process water from 60 °F to 158 °F, supplied at a rate of 530 US gallons/h. Saturated steam is available at 46 psig which has a latent heat of 917 Btu/lb. The energy to heat the exchanger and further losses are omitted for clarity.

$$\dot{m}_s = \frac{GPH \times SG \times C_p \times \Delta T \times 8.33}{L} = \frac{530 \times 1 \times 1 \times 98 \times 8.33}{917} = 471 \text{ lb/h}$$



- \dot{m}_s = Mean rate of steam consumption (lb/h)
- G = US Gallons
- GPH = US Gallons per hour
- SG = Specific gravity of liquid
- C_p = Specific Heat Capacity (Btu/lb °F)
- ΔT = Temperature rise of the secondary fluid (°F)
- L = Latent Heat (Btu/lb)
- T = Time (hours)

Cp Examples			
Water:	1	Vegetable Oil:	0.4
Milk:	0.94	Olive Oil:	0.47

02. Steam Table US Units

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03. Sizing a Steam Pipe

It is widely appreciated that steam velocity is an important factor in the life and maintenance of a steam pipe. As steam velocity is such a practical issue, it is reasonable that it could form the basis of a sizing method for steam pipes. For relatively short runs (less than 160 feet), velocities of 50 to 120 ft/s are used in saturated steam applications. As a general rule of thumb, 80 ft/s is adopted as an acceptable engineering practice. For longer pipe runs, alternative pressure drop methods are normally considered.

Oversized pipework:

Higher costs for ancillaries such as strainers, isolation valves, pipe supports and insulation can dramatically and unnecessarily increase both the initial installation cost and the overall cost of ownership. It can also have an effect on the steam systems' operational effectiveness. More condensate can be expected to form, due to the greater heat losses from the larger heat transfer area, requiring more steam trapping or the increased risk of wet steam being offered to the process.

Undersized pipework:

The process itself dictates the mass of steam required at the point of use. If the required mass of steam travels through undersized pipework, you can expect an increase in steam velocity. Steam and condensate travelling at high velocities can be very damaging, increasing the risk of erosion, noise, wire-draw and water hammer. With an increase in velocity, you can also expect a higher pressure drop across the steam pipework, resulting in a lower than expected pressure at the point of use, hindering the application's effectiveness.

Example

An industrial food autoclave condenses 400 lb/h of saturated steam and the steam pressure is 40 psig. Using the example table to the right, starting on the left hand side, find the steam pressure required and select the desired velocity. Trace a line horizontally across, until you reach a figure greater than the required 400 lb/h. From there trace a line vertically upwards and simply read off the pipe size, which in this example would be 1 1/2".

Saturated steam pipeline capacities table – Example only

Pressure psig	Velocity ft/s	Pipe size (nominal)									
		1/2"	3/4"	1"	1 1/4"	1 1/2"	2"	2 1/2"	3"	4"	5"
		Pipeline capacity lb/h									
5	50	12	26	45	70	100	190	280	410	7600	1250
	80	19	45	75	115	170	300	490	710	1250	1800
	120	29	60	110	175	245	460	700	1000	1800	2900
10	50	15	35	55	88	130	240	365	550	950	1500
	80	24	52	95	150	210	380	600	900	1500	2400
	120	35	72	135	210	330	590	850	1250	2200	3400
20	50	21	47	82	123	185	320	520	740	1340	1980
	80	32	70	120	190	260	520	810	1100	1900	3100
	120	50	105	190	300	440	840	1250	1720	3100	4850
30	50	26	56	100	160	230	420	650	950	1650	2600
	80	42	94	155	250	360	655	950	1460	2700	3900
	120	62	130	240	370	570	990	1550	2100	3950	6100
40	50	32	75	120	190	260	505	790	1100	1900	3100
	80	51	110	195	300	445	840	1250	1800	3120	4900
	120	75	160	290	460	660	1100	1900	2700	4700	7500
60	50	43	95	160	250	360	650	1000	1470	2700	3900
	80	65	140	250	400	600	1000	1650	2400	4400	6500
	120	102	240	410	610	950	1660	2600	3800	6500	10300
80	50	53	120	215	315	460	870	1300	1900	3200	5200
	80	85	190	320	500	730	1300	2100	3000	5000	8400
	120	130	290	500	750	1100	1900	3000	4200	7800	12000
100	50	63	130	240	360	570	980	1550	2100	4000	6100
	80	102	240	400	610	950	1660	2550	3700	6400	10200
	120	150	350	600	900	1370	2400	3700	5000	9100	15000
120	50	74	160	290	440	660	1100	1850	2600	4600	7000
	80	120	270	450	710	1030	1800	2800	4150	7200	11600
	120	175	400	680	1060	1520	2850	4300	6500	10700	17500
150	50	90	208	340	550	820	1380	2230	3220	5500	8800
	80	145	320	570	900	1250	2200	3400	4900	8500	14000
	120	215	450	850	1280	1890	3400	5300	7500	13400	20600

04. Steam Trap Types

The sizing and choice of a steam trap is absolutely crucial to the success of a steam system. Their purpose is to keep the useful steam within the process whilst automatically releasing the undesirable condensate and non-condensable gases. An incorrect steam trap selection can have dramatic effects on the steam application. For example:

- Processes are slow to reach temperature and performance is poor.
- Water hammer, erosion, corrosion, leading to high maintenance costs.

For a typical heat exchange process to operate to expected performance levels, the steam space must be filled with clean, dry saturated steam. In simple terms, you can not get the high heat carrying steam in, unless the condensate and non-condensable gases are removed.

There are three basic types of steam trap:

Thermostatic

Operate by reacting to changes in the fluid temperature. When steam gives up its enthalpy of evaporation, the resulting condensate is at the same temperature. As time goes on, the condensate loses further energy, resulting in a fall in condensate temperature. At a predefined sub-saturation-point temperature e.g. sub 12°C, the thermostatic steam trap opens to pass the condensate. When steam is present, the increase in temperature is sensed and the trap closes.

Generally good for: Jacketed vessels, steaming ovens and tunnels, hot tables, autoclaves and sterilisers, laundry equipment, tyre presses, space heating equipment, pressure reducing stations, steam tracer lines, jacketed pipes and ancillaries, steam mains and terminal end drainage.



Mechanical

Operate by sensing changes in fluid density. In the case of the ball float trap type, the ball rises when condensate enters the float trap body. The condensate supports a floating ball on a swinging arm, and this mechanical action uncovers an orifice to release the condensate. When steam is present, the ball drops (as the steam can not support the ball), and the orifice is once again covered. Typically fitted with an additional, smaller thermostatic air vent, to aid the discharge of air and other non-condensable gases. Together they are termed “float and thermostatic” steam traps.

Generally good for: Jacketed vessels, bulk storage tanks, retorts, digesters, brewing coppers, evaporators and calandrias, autoclaves and sterilisers, laundry equipment, tyre presses, industrial autoclaves, vulcanisers, space heating equipment, pressure reducing stations, steam mains, header and terminal end drainage.



Thermodynamic

Operate by changes in fluid dynamics. Cooler condensate and air travel through an orifice, lift a sealing disc, passing out through the trap unabated. Next, hotter condensate passes through and the localised pressure drop at the orifice results in the formation of flash steam. This causes a drop in pressure under the sealing disc, drawing the sealing disc down, closing the trap. The sealing disc holds flash steam above and below itself. The upper surface area of the sealing disc is greater than below, hence exerts a greater downward force, keeping the trap closed. This situation is maintained whilst live steam is present. As condensate collects at the trap inlet, the trapped flash steam above the sealing disc loses energy, condenses and the sealing disc is released. Condensate discharges.

Generally good for: Digesters and hot tables, laundry equipment, tyre presses, space heating equipment, steam tracer lines and jacketed pipes, separators, steam mains, header and terminal end drainage.



05. Sizing a Steam Trap

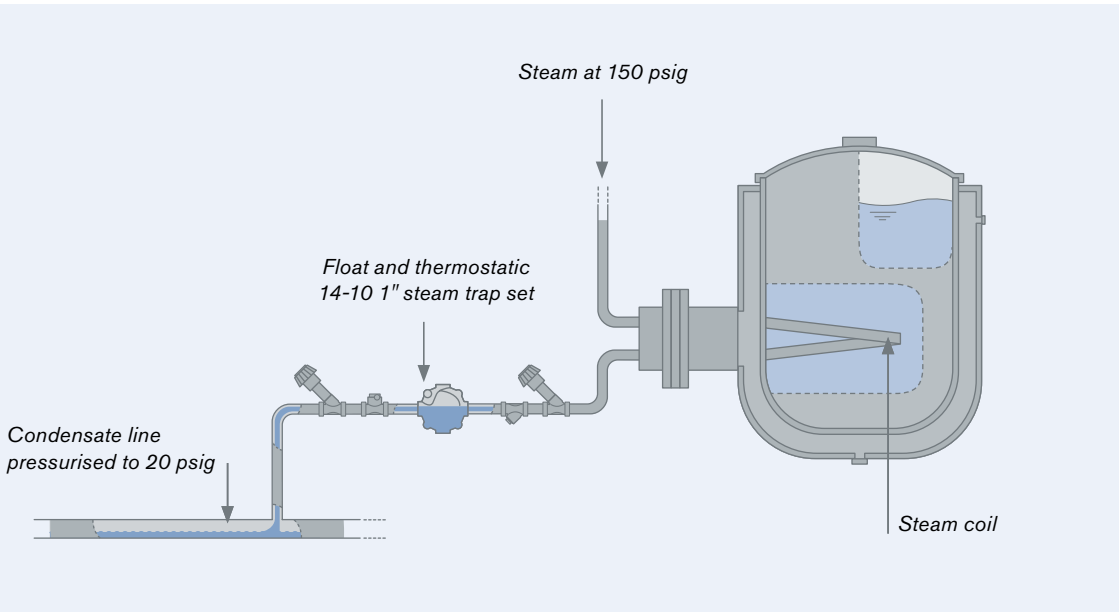
Steam heat exchange applications receive their energy by the action of condensation. When saturated steam comes into contact with a surface at a lower temperature than itself, it condenses and gives some of its energy to the surface. It is vital to know that for every lb of saturated steam condensed in a process, you will create a corresponding lb of condensate. So for example if an application uses 100lb/h of steam, it will produce 100lb/h of condensate. Sizing the steam trap correctly will ensure that the heat transfer surfaces are free of the lower-energy carrying condensate (having already given up a large proportion of its energy by the action of condensation). Only by ensuring that the condensate is successfully removed will you achieve best possible plant performance. Should condensate remain in the steam space, it would reduce the available heat transfer area and thus reduce performance.

Example

A storage tank with a steam coil is calculated to condense steam at a rate of 1000 lb/h. Steam is supplied at 150 psig and the steam trap discharges into a condensate line pressurised to 20 psig. The manufacturer of the tank has recommended a float and thermostatic steam trap solution.

Which size float and thermostatic steam trap is required?

Each steam trap will have a method of sizing, either a chart or as shown with a capacity table. The left hand column is the trap model and size, e.g. FLT14-4.5 1/2" = Model FLT14, that operates with differential pressures of 4.5 bar or less, with a 1/2" port. To select a steam trap, select the correct differential pressure, which in this case is 130 psi. Trace a line down until you reach a figure greater than the required 1000 lb/h. From there trace a line horizontally and simply read off the steam trap selected, which in this example would be a FLT14-10 1".



Flow Rate Capacity in lb/h – Example only

Differential Pressure (psi)													
Model/Size	7.0	14.5	20.0	30.0	45.0	65.0	90.0	100.0	115.0	130.0	145.0	170.0	200.0
FLT14-4.5 1/2" – 3/4"	441	617	705	794	882	1091							
FLT14-10 1/2" – 3/4"	242	309	386	419	507	617	661	527	772	860	893		
FLT14-14 1/2" – 3/4"	154	220	264	309	342	419	463	485	496	507	573	617	661

Differential Pressure (psi)													
Model/Size	7.0	14.5	20.0	30.0	45.0	65.0	90.0	100.0	115.0	130.0	145.0	170.0	200.0
FLT14-4.5 1"	507	727	882	970	1179	1389							
FLT14-10 1"	331	441	551	617	749	882	1014	1091	1146	1212	1312		
FLT14-14 1"	264	331	419	485	573	705	838	882	937	970	1085	1124	1212
FLT14-4.5 1 1/2" – 2"	5291	7496	8598	9921		16094							
FLT14-10 1 1/2" – 2"	3307	4409	5732	6614		8818		11905			13669		
FLT14-14 1 1/2" – 2"	2094	2866	3527	3968		5732		7165			8598	9281	90913

06. Calculating Flash Steam

Flash steam is released from hot condensate when the pressure is reduced, not by the addition of further energy. Flash steam is exactly the same as normal “live steam” supplied by a boiler.

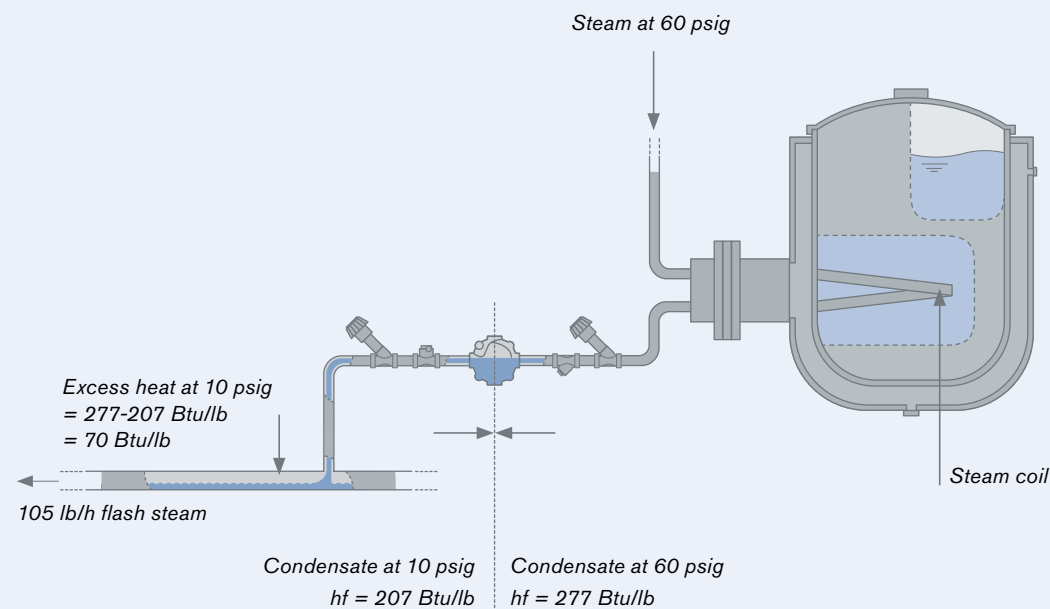
Consider the jacketed vessel shown

The condensate enters the steam trap at 60 psig and at a temperature of 307 °F. The energy present in the condensate at this pressure is a maximum of 277 Btu/lb. The condensate discharges through the steam trap into the condensate return line. The pressure in the condensate return line is 10 psig. At 10 psig, the maximum amount of energy per kg of condensate is 207 Btu/lb and the maximum temperature is 239 °F – see steam tables.

277-207 Btu/lb gives an excess of 70 Btu/lb of energy which evaporates some of the condensate back into steam, an action called "flashing". The energy needed to produce 1 lb of saturated steam from saturated water at 10 psig is 953 Btu/lb.

An amount of 70 Btu/lb can therefore evaporate: $70/953 \text{ Btu} = 0.07 \text{ lb}$ of steam, per lb of condensate or in other words 7 % of the condensate into flash steam. If the jacketed vessel is condensing 1500 lb/h of steam then the amount of flash steam released would be: $0.07 \times 1500 \text{ lb/h}$ of condensate

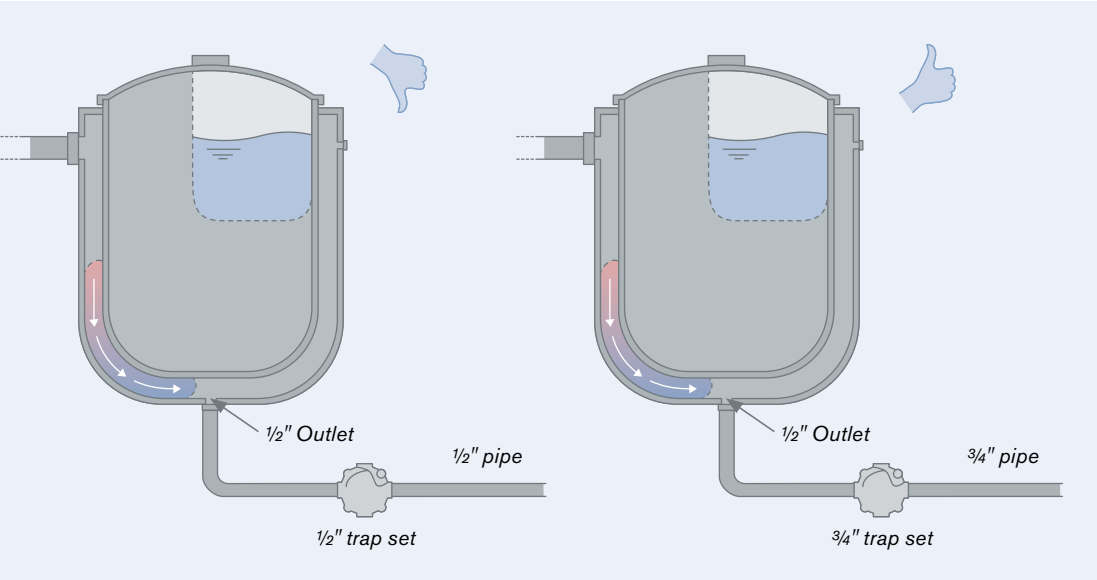
= 105 lb/h of flash steam



Room for Notes

07. Sizing Condensate Pipework

The condensate drain from a process consists of 4 main parts. The process outlet connection, the pipe into the steam trap, the steam trap itself and the condensate discharge pipework. **Never assume that they will all be the same size.** Firstly the process outlet connection supplied by the manufacturer may be generic and not specific for your needs, as the process may conceivably operate at a number of different operating conditions. If the steam trap has been sized correctly, it is typical for the pipe from the process outlet connection to the steam trap inlet connection to be sized the same.



Assuming that there is no significant pressure drop between the process outlet connection and the trap inlet, the pipe will be flooded with condensate. The pipe down-stream of the trap will carry both condensate and flash steam, a two phase flow, due to the pressure drop across the trap. The condensate and flash steam are at the same pressure and temperature.

To give an idea of the differences in volume between the two phases, a process operating at 60 psig, with a trap discharging into a condensate pipe operating at 7 psig, would result in a condensate pipe with 99 % flash steam and 1 % condensate by volume. It follows therefore that the trap discharge pipework should consider steam over water as a defining parameter.

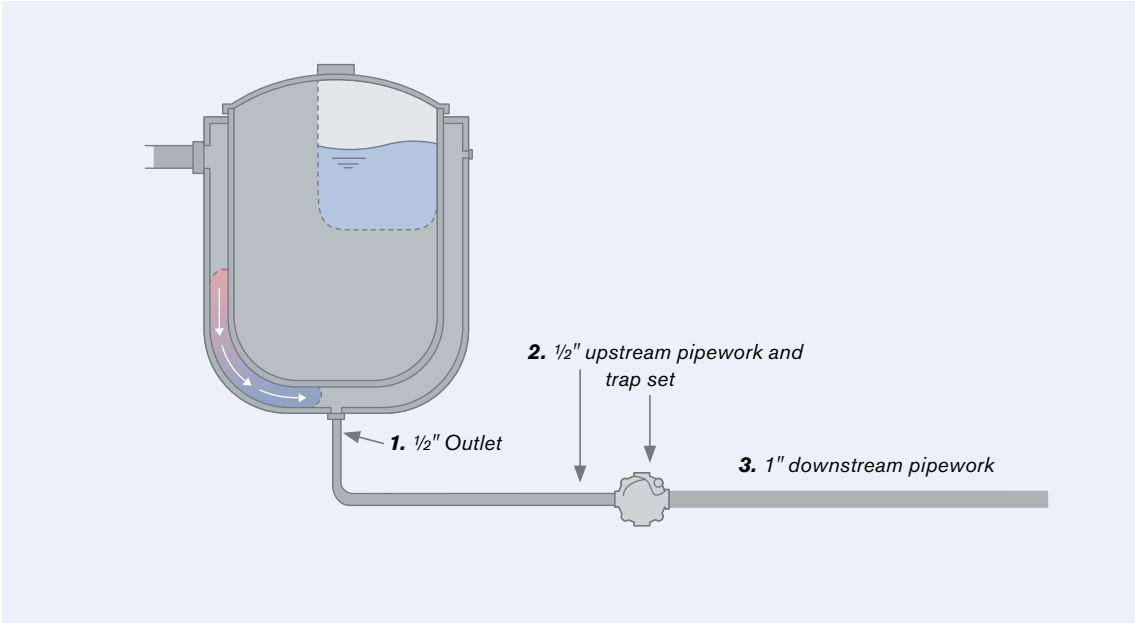
Example

A fruit juice pasteuriser is discharging 800 lb/h of condensate at 46 psig into a steam trap. The trap discharges into a condensate pipe operating at 5 psig. Using the flash steam calculation, the expected result is the formation of 55 lb/h of flash steam. Using the steam pipeline capacities table and a velocity of 80 ft/s, the condensate pipework would be 1".

Pressure psig	Velocity ft/s	Pipe size (nominal)										
		1/2"	3/4"	1"	1 1/4"	1 1/2"	2"	2 1/2"	3"	4"	5"	
		Pipeline capacity lb/h										
5	50	12	26	45	70	100	190	280	410	760	1250	
	80	19	45	75	115	170	300	490	710	1250	1800	
	120	29	60	110	175	245	460	700	1000	1800	2900	
10	50	15	35	55	88	130	240	365	550	950	1500	
	80	24	52	95	150	210	380	600	900	1500	2400	
	120	35	72	135	210	330	590	850	1250	2200	3400	

Due to flash steam present after the steam trap, it is possible to have three different sizes in the condensate discharge line.

- 1. The process connection provided by the process plant manufacture,
- 2. The steam trap port size,
- 3. Condensate discharge pipework.



08. Designing a Steam System

Design Brief

Design a fixed boiling pan steam system, designed to heat 400 US gallons of cooking sauce (similar properties to water) from 50 °F to 180 °F, in half an hour. Saturated steam is available at 80 psig and the heat exchanger requires 55 psig. The condensate back pressure is known to be 10 psig. The boiling pan manufacturer has used a 2" steam inlet connection and a ½" air vent and condensate connection. Heat losses are negligible.

Step 1: Estimate the steam load

Using sections 01 & 02, "Estimating steam loads" and "Steam table US Units"

$$\dot{m}_s = \frac{G \times SG \times C_p \times \Delta T \times 8.33}{L \times T} = \frac{400 \times 1 \times 130 \times 8.33}{909 \times 0.5} = 954 \text{ lb/h}$$

Step 2: Size the inlet steam pipework

Using section 03, "Sizing a steam pipe"

Steam at 80 psig, at a rate of 954 lb/h steam load @ 80 ft/s

= 2"

Step 3: Size the steam on/off shut off valve

The on/off shut-off valve should be the same size as the pipework

= DN50 / 2"

Step 4: Size the steam trap (and trap set) before an isolating valve

½" (15mm), the standard choice for applications within a process area

= ½"

Step 5: Size the steam control valve

Using Bürkert Smart Sizer program, size the control valve

= Cv 24.36 DN 50 / 2" port,
32mm diameter orifice

Step 6: Size the steam trap

= Float and thermostatic
steam trap
1" Port. (14-4.5)

Step 7: Calculate flash steam and size condensate pipework

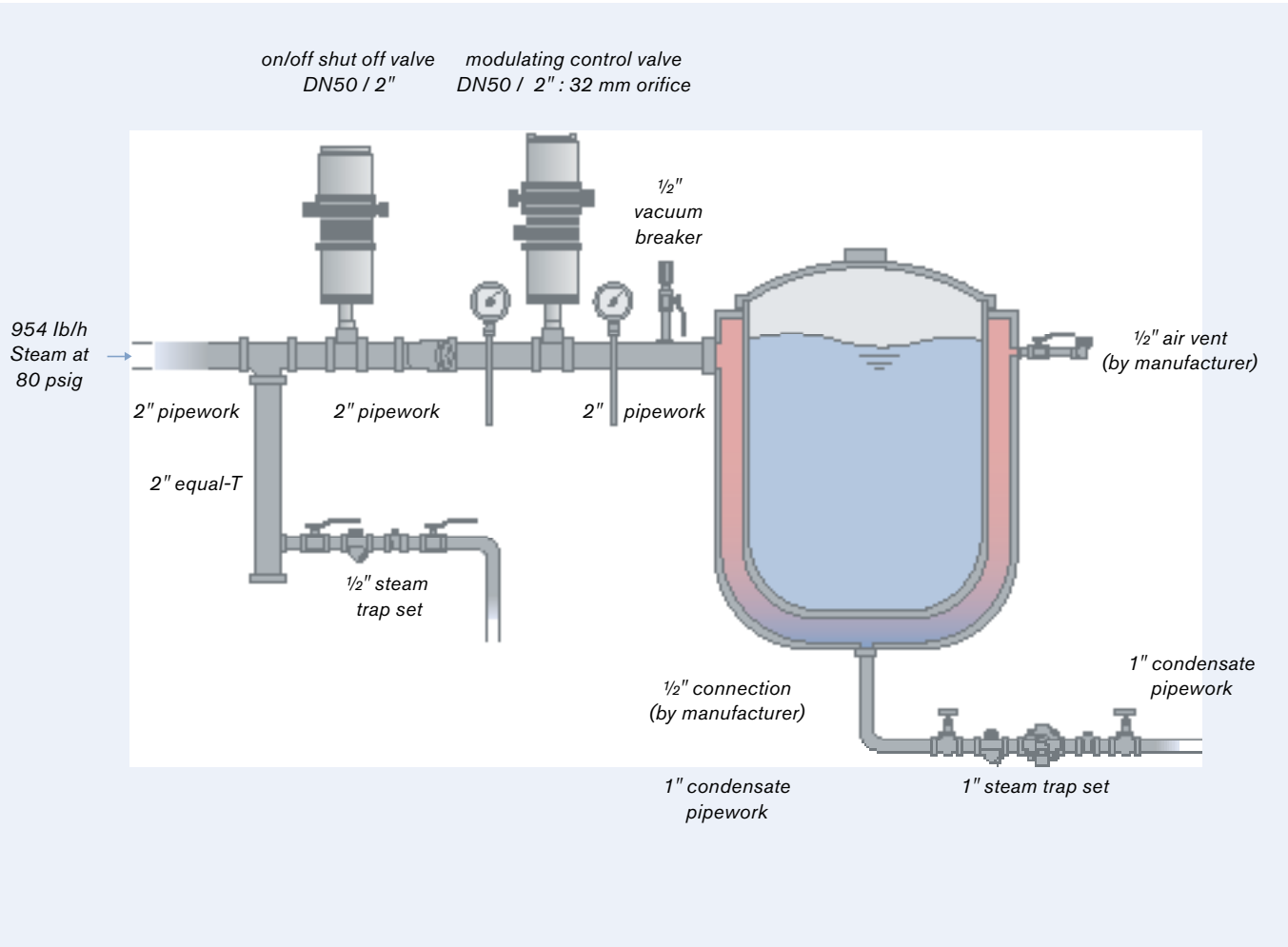
Using sections 06 & 07, "Calculating flash steam" and "Sizing a steam pipe"

= 1"

0.067 x 954 lb/h of condensate = 63.9 lb/h

As steam volume is far greater than condensate, it is accepted that condensate pipework is sized using steam pipework tables.

Therefore 63.9 lb/h at 10 psig



09. Practical Tips For Steam Heat Exchange Applications

Water hammer is not acceptable and should not be tolerated.

If you hear it, leave the area. Inform the process supervisor. It is the most destructive force on a steam system. It is not a normal situation and should never be tolerated. It can damage equipment and injure or even kill personnel.

Do not oversize control valves.

An oversized control valve is costly, it will find controlling the process difficult and spend prolonged periods in the almost closed position, risking wire-draw and premature failure. Wire-draw is an action where condensate cuts a path through the valve trim, passing steam even when closed.

You must always consider velocities and noise when sizing a control valve.

Sizing a control valve on mass flow and pressure drop alone is not correct. The optimum velocity at the valve outlet should be between 32-131 ft/s and the noise no greater than 85 dB.

Steam valves should be opened and closed with care and slowly.

This allows any build up of condensate to flow gently to the next drain pocket. It will also reduce the risk of thermal shock. Especially important during warm up periods.

Install a strainer before a control valve.

It is not uncommon for foreign particles to be present inside a steam pipe. Particularly in older pipes there will be rust fragments and carbonate deposits, that could damage a valve. Foreign matter can lodge in a control valve trim or score the trim, causing the premature failure of the control valve. It is possible for a foreign particle to lodge itself between the plug and seat of a control valve, forcing it partly open, exposing the control valve to damage through wire-drawing.

Install pressure gauges before and after a control valve.

They provide the information needed to understand the conditions inside the system. A great aid during commissioning and afterwards when operating the steam system.

Condensate produced by a process must be removed.

Condensate holds roughly 5–6 times less energy than saturated steam. If a heat transfer process is flooded with condensate, the results will be poor and you risk water hammer.

Condensate should normally be returned to the boiler feed water tank.

Condensate still holds its specific enthalpy of water with roughly 16 % of the original steam energy still remaining, depending on the pressures. By returning the hot condensate back to the boiler you reduce energy losses, water usage and water treatment chemicals.

A rising condensate line from a process can cause a “stall” condition.

“Stall” conditions are particularly problematic in modulating steam control applications. “Stalling” occurs when the pressure available is not sufficient to force the condensate out of the heat transfer area, resulting in water logging and poor heat transfer performance. An alternative is to allow the condensate to gravity feed into a condensate pumping set.

An undersized or incorrect type of steam trap can waterlog a process.

Undersize the steam trap and condensate will back up and waterlog the steam space. Even if you have sized your steam control valve correctly, the process will still waterlog if the steam trap is undersized. The correct type of trap is also important. A thermostatic style trap for example relies on a certain amount of energy loss to operate. This delay could hold back condensate and waterlog the steam space.

Steam strainers should be fitted in the horizontal plane, baskets on the side.

Strainers left in the “belly down” position, create a weir of condensate and thus provide a source of wet steam. However, belly down is acceptable on a condensate line (as part of the steam trap set) as it will be flooded already.

Fit air vents to a heat transfer device, end of lines and high points.

Air is a tremendously effective insulator and can collect in pockets and also form thin films on heat transfer surfaces. Not only does it insulate, but when it mixes with steam, it will reduce the heat transfer efficacy, contributing to the pressure of the mixture, but not to the available heat content.

Fit vacuum breakers to all heat transfer devices.

When a heat exchange system shuts down, the trapped steam will collapse, and the reduction in volume causes a vacuum in the steam space, powerful enough to implode the plant equipment. Vacuum breakers automatically replace the lost volume with outside air, relieving the vacuum and avoiding the implosion.

Never run steam lines uphill.

A gentle fall away in the direction of the flow will aid condensate drainage. A gradient of 1:100 is normally acceptable.

Fit drain pockets at regular intervals, low points and before on/off control valves.

Even with the most efficient lagging, condensate will form in steam pipework, due to radiated losses to the surrounding air. It is recommended to fit a drain pocket at regular intervals of 100-160 feet and at the base of a lift. Fitting a drain pocket and trap set before an on/off valve or control valve will remove the risk of trapped condensate being released at high velocities, which can result in valve damage and water hammer.

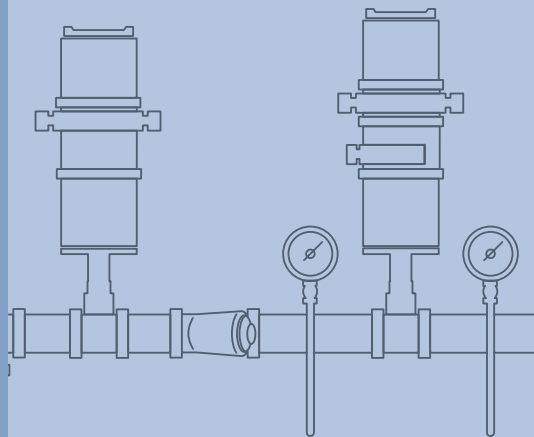
Fit “equal T” drain pockets.

As a general rule, for steam mains up to 100mm (4"), the drain pocket should be the same size as the steam main, hence the term “equal T”. The trap set connection is set at least 1" from the bottom of the drain pocket. Fit a removable flange or threaded plug to periodically remove the accumulated debris during down times.

Steam take-offs should be made from the top of the vertical steam main.

This ensures that the steam in the branch line is as dry as possible, reducing the risk of erosion and water hammer in the branch line.

And most importantly of all, RESPECT STEAM.



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