MEBS6000 Utility Services

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Steam Systems (I)

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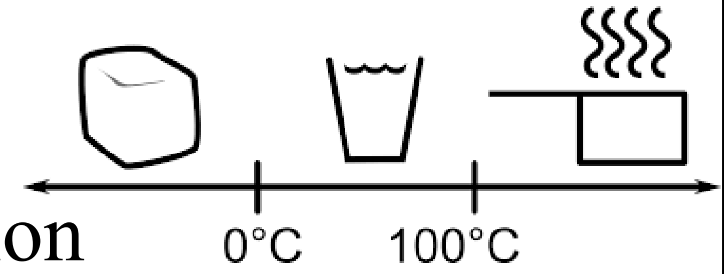
Contents

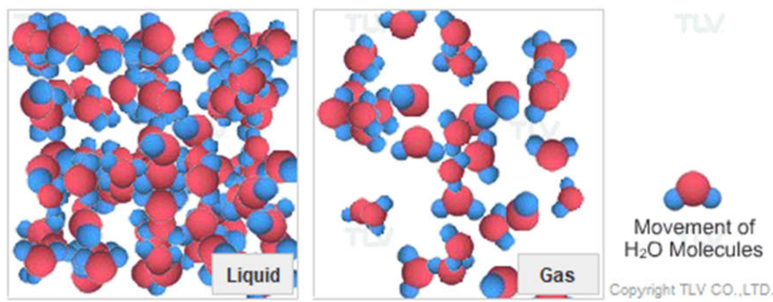
- Properties of steam
- Uses of steam
- Steam system
- Steam traps
- Other components

Properties of steam

- Basic principles
  - Steam: water heated to vaporisation
  - At atmospheric pressure, temperature = 100 ^{o}C

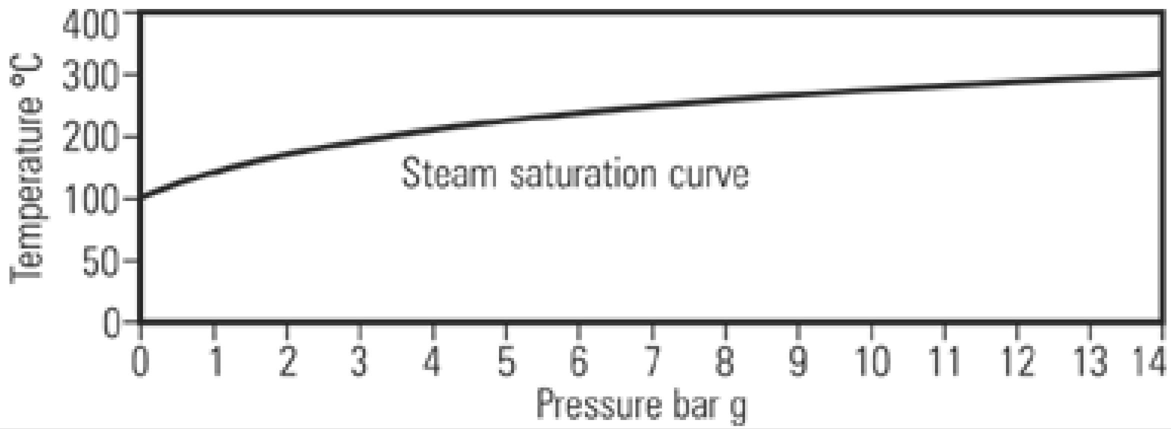


- Three types of heat in steam calculation:
  - Specific heat (capacity) of water (c_{pw}) = 4.2 kJ/kg.K
  - Specific enthalpy of evaporation (h_{fg})
  - Specific enthalpy of steam (h_g)



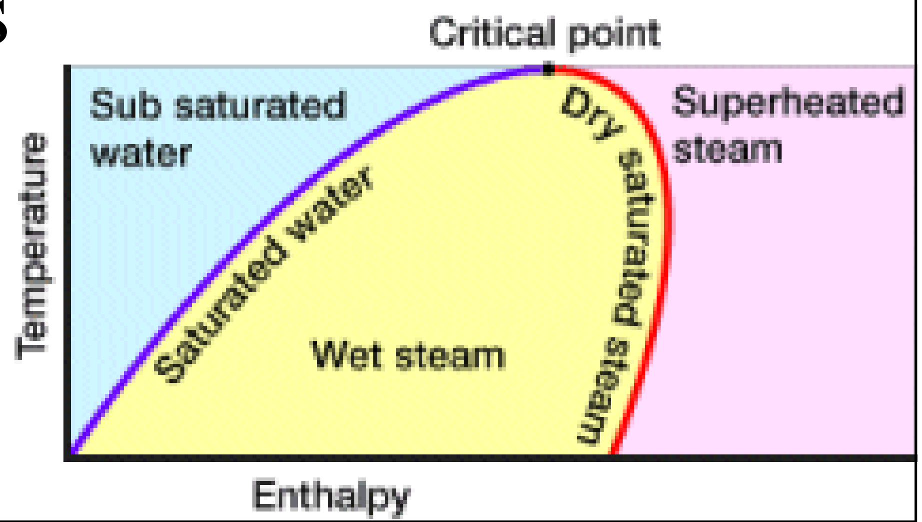
Properties of steam

- Heat transfer
  - Latent heat of evaporation = 2257 kJ/kg at atm pressure (condensable energy content)
  - Sensible heat of water = 419 kJ/kg (0 to 100 °C)
- Flow at high velocity (24-36 m/s) and high temperature (100-198 ºC)



Properties of steam

- Assume you understand the basics well
  - Such as pressure, specific volume, density, temperature, internal energy, enthalpy, entropy and specific heat
  - Review relevant textbooks if you have questions
- Key fundamental concepts
  - Steam tables
  - Dry steam and wet steam
  - Superheated steam



Properties of steam

- Steam tables
  - To determine various steam properties
    - Pressure (absolute or gauge) [1 bar = 100 kPa = 14.5 psi]
    - Temperature [°C or K]
    - Specific enthalpy [kJ/kg]
    - Specific volume (inverse of density) [m^3/kg]
    - Specific heat capacity [kJ/kg.K]
  - Published tables in databooks, such as CIBSE Guide C, Section 4, or IOP Guide
  - Total enthalpy, $h_g = h_f$ (sensible) + h_{fg} (latent)

(See also: https://www2.tlv.com/en-au/steam-info/steam-theory/steam-basics/how-to-read-a-steam-table)

Do you know how to use these steam tables?

Extract from the saturated steam tables

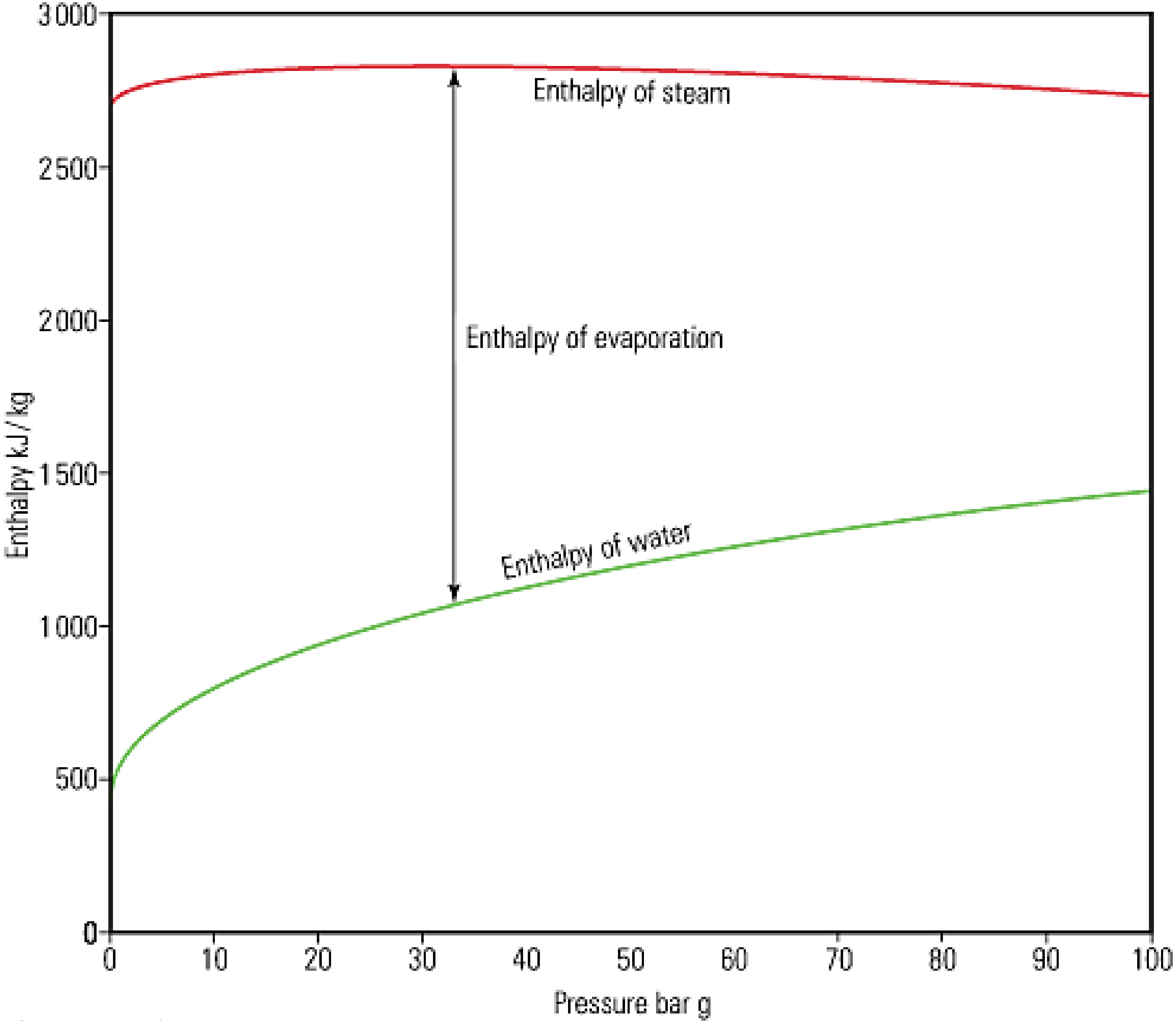
Pressure bar g	Saturation temperature °C	Enthalpy kJ/kg Water h_f	Enthalpy kJ/kg Evaporation h_{fg}	Enthalpy kJ/kg Steam h_g	Volume of dry saturated steam m^3/kg
0	100	419	2 257	2 676	1.673
1	120	506	2 201	2 707	0.881
2	134	562	2 163	2 725	0.603
3	144	605	2 133	2 738	0.461
4	152	641	2 108	2 749	0.374
5	159	671	2 086	2 757	0.315
6	165	697	2 066	2 763	0.272
7	170	721	2 048	2 769	0.240

Extract from superheated steam tables

Absolute pressure bar a	Units	Temperature (°C) 150	200	250	300	400	500
1.013	v_g (m^3/kg)	1.912	2.145	2.375	2.604	3.062	3.519
	u_g (kJ/kg)	2 583	2 659	2 734	2 811	2 968	3 131
	h_g (kJ/kg)	2 777	2 876	2 975	3 075	3 278	3 488
	s_g (kK/kg)	7.608	7.828	8.027	8.209	8.537	8.828

(Online steam tables: https://www.spiraxsarco.com/resources-and-design-tools; https://www.tlv.com/global/AU/calculator/)

The enthalpy/pressure diagram



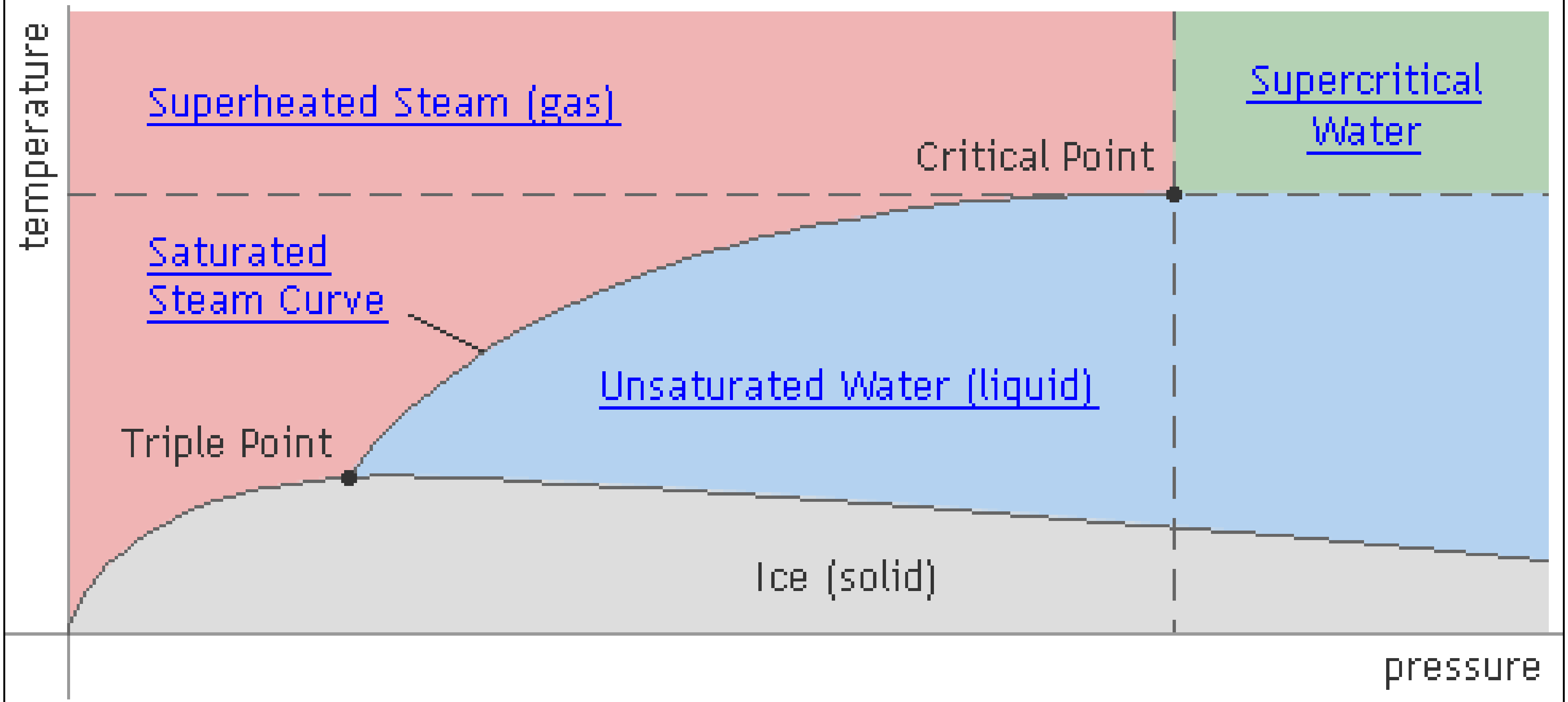
(Source: www.spiraxsarco.com)

Properties of steam

- Types of steam:
  - Saturated steam (Dry)
  - Unsaturated steam (Wet) (with non-vaporized water molecules)
  - Superheated steam (above the saturation curve)
  - Supercritical water (exceeds its critical point)
- Flash steam
  - The steam formed from hot condensate when the pressure is reduced

(See also: https://www2.tlv.com/en-au/steam-info/steam-theory/steam-basics/types-of-steam; https://www2.tlv.com/en-au/steam-info/steam-theory/steam-basics/flash-steam)

Pressure-temperature relationship of water & steam



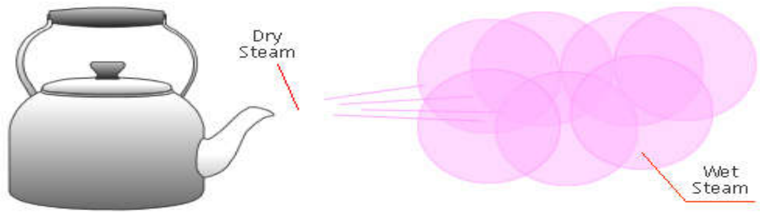
Triple Point : 0°C, 0.61 KPa abs (32°F, 0.09 psia)
Critical Point : 374°C, 22.1 MPa abs (705°F, 3208 psia)

Can you explain the relationship & the points?

(Source: https://www2.tlv.com/en-au/steam-info/steam-theory/steam-basics/types-of-steam)

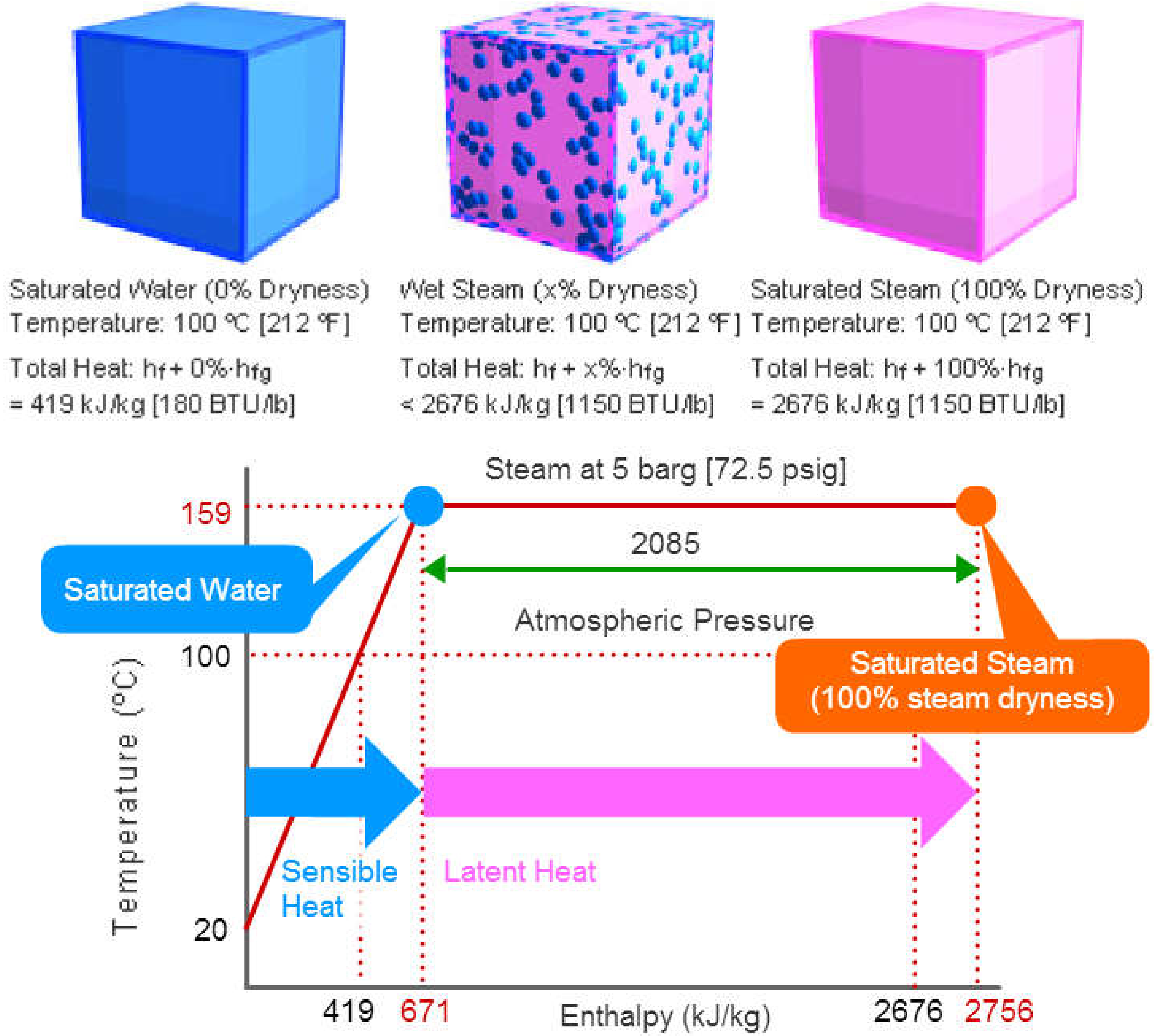
Properties of steam

- Dryness of steam
  - Steam often carries tiny droplets of water
  - *Dryness fraction (χ)* = proportion of completely dry steam present in the steam-moisture mixture
  - Wet steam has a heat content much lower than that of dry saturated steam at the same pressure
    - Actual enthalpy of evaporation = $h_{fg} \, . \, (\chi)$
    - Actual total enthalpy = $h_f + h_{fg} \, . \, (\chi)$



(See also: https://www2.tlv.com/en-au/steam-info/steam-theory/steam-basics/wet-steam-dry-steam)

The relationship between steam dryness and enthalpy



Steam Table (abs)

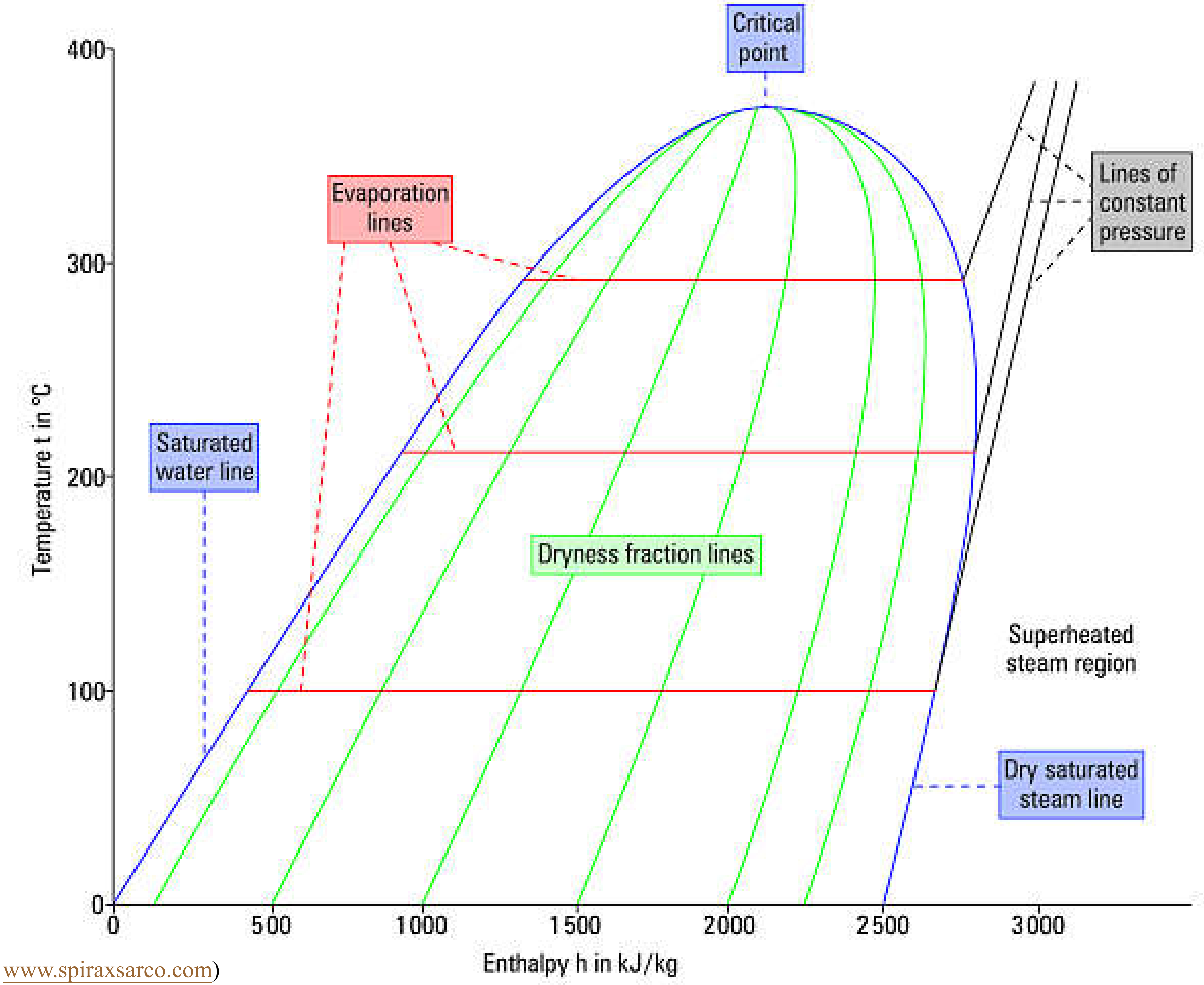
P (bar)	T (°C)	v_f (m³/kg)	v_g (m³/kg)	h_f (kJ/kg)	h_{fg} (kJ/kg)	h_g (kJ/kg)
1	100	0.00104	1.673	419	2257	2676
6	159	0.00110	0.3213	671	2085	2756

(See also: https://www2.tlv.com/en-au/steam-info/steam-theory/steam-basics/wet-steam-dry-steam)

Properties of steam

- <u>Superheated steam</u>
  - If the saturated steam produced in a boiler is exposed to a surface with a higher temperature, its temperature will increase above the evaporating temperature → <u>*Superheated*</u>
  - When superheated steam gives up some of its enthalpy, a fall in temperature without condensation until the saturation temperature has been reached (condensation occurs in saturated steam)

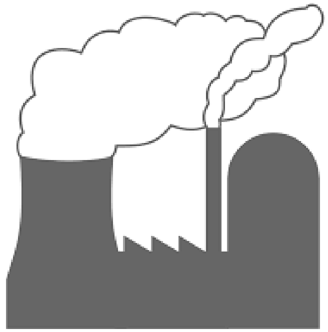
The temperature/enthalpy diagram



(Source: www.spiraxsarco.com)

Uses of steam

- Steam is used:
  - To produce electrical power in power plants
  - As a heating medium for industrial process, heating & hot water in buildings, cooking
  - To provide chilled water using waste heat



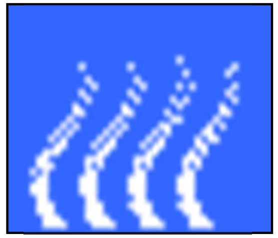
- Common applications in buildings:
  - As a primary medium for distributing heat in factories, hospitals and hotels
  - Means of sterilizing, cooking (Chinese restaurants)
  - Space heating, humidifying air, hot water supply

Industries and processes which use steam

Heavy users	**Medium users**	**Light users**
Food and drinks	Heating and ventilating	Electronics
Pharmaceuticals	Cooking	Horticulture
Oil refining	Curing	Air conditioning
Chemicals	Chilling	Humidifying
Plastics	Fermenting	
Pulp and paper	Treating	
Sugar refining	Cleaning	
Textiles	Melting	
Metal processing	Baking	
Rubber and tyres	Drying	
Shipbuilding		
Power generation		

(Source: https://www.spiraxsarco.com/Learn-about-steam)

Uses of steam



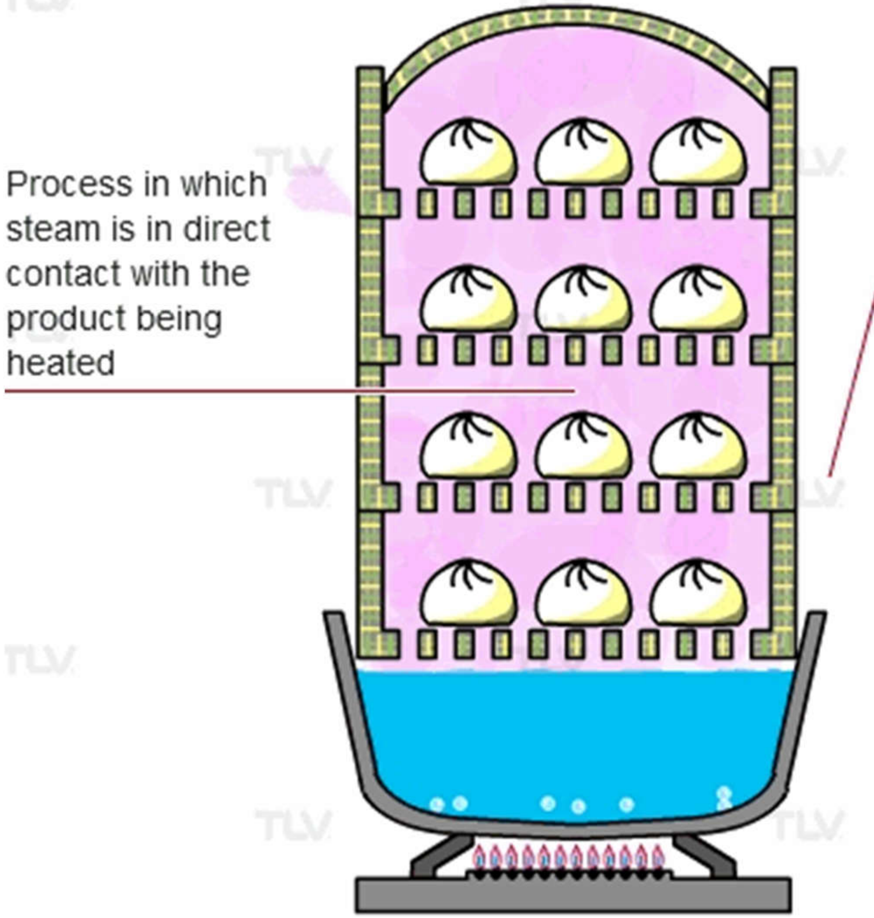
- Steam as a source of heat:
  - <u>Direct steam heating</u>

    - Processes where steam is in direct contact with the product being heated, e.g. steam Chinese dumplings
  - <u>Indirect steam heating</u>
    - Processes where steam is not in direct contact with the product being heated; widely used in industry (with a heat exchanger) because it provides rapid, even heating
    - The water droplets formed during heating will not affect the product

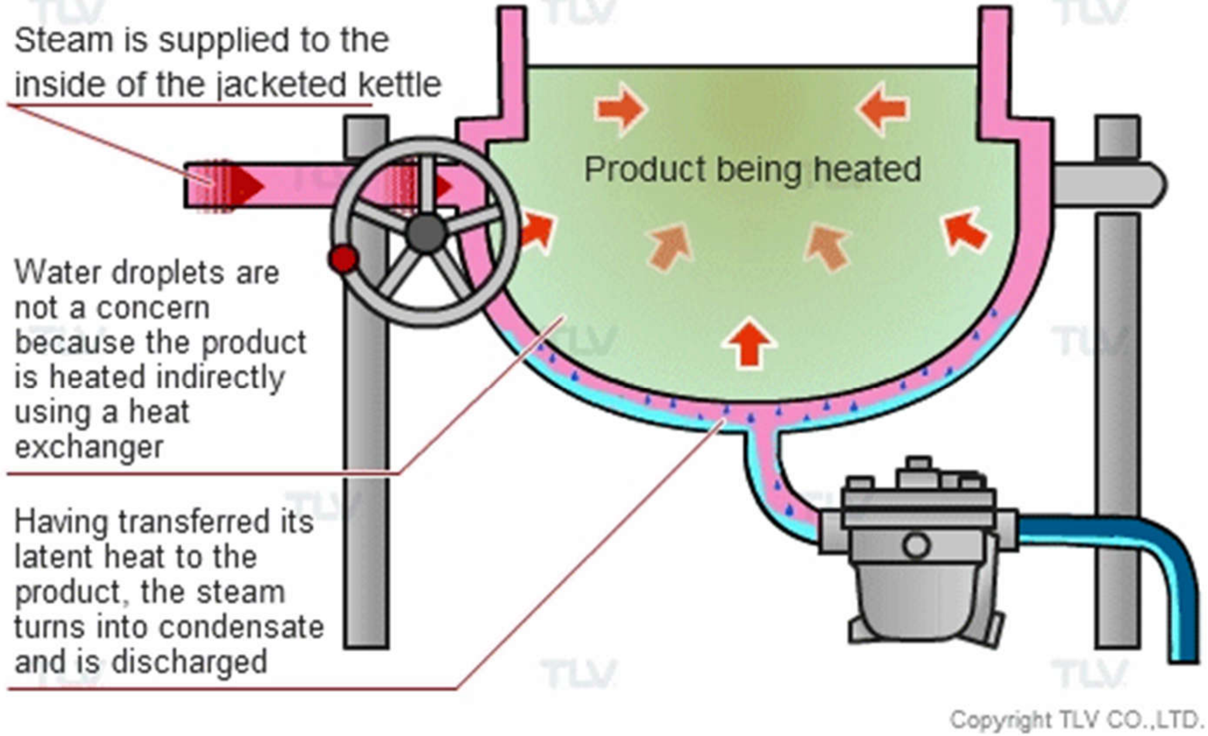
Jacketed kettle

(See also: https://www2.tlv.com/en-au/steam-info/steam-theory/steam-basics/what-is-steam)

Direct and indirect steam heating



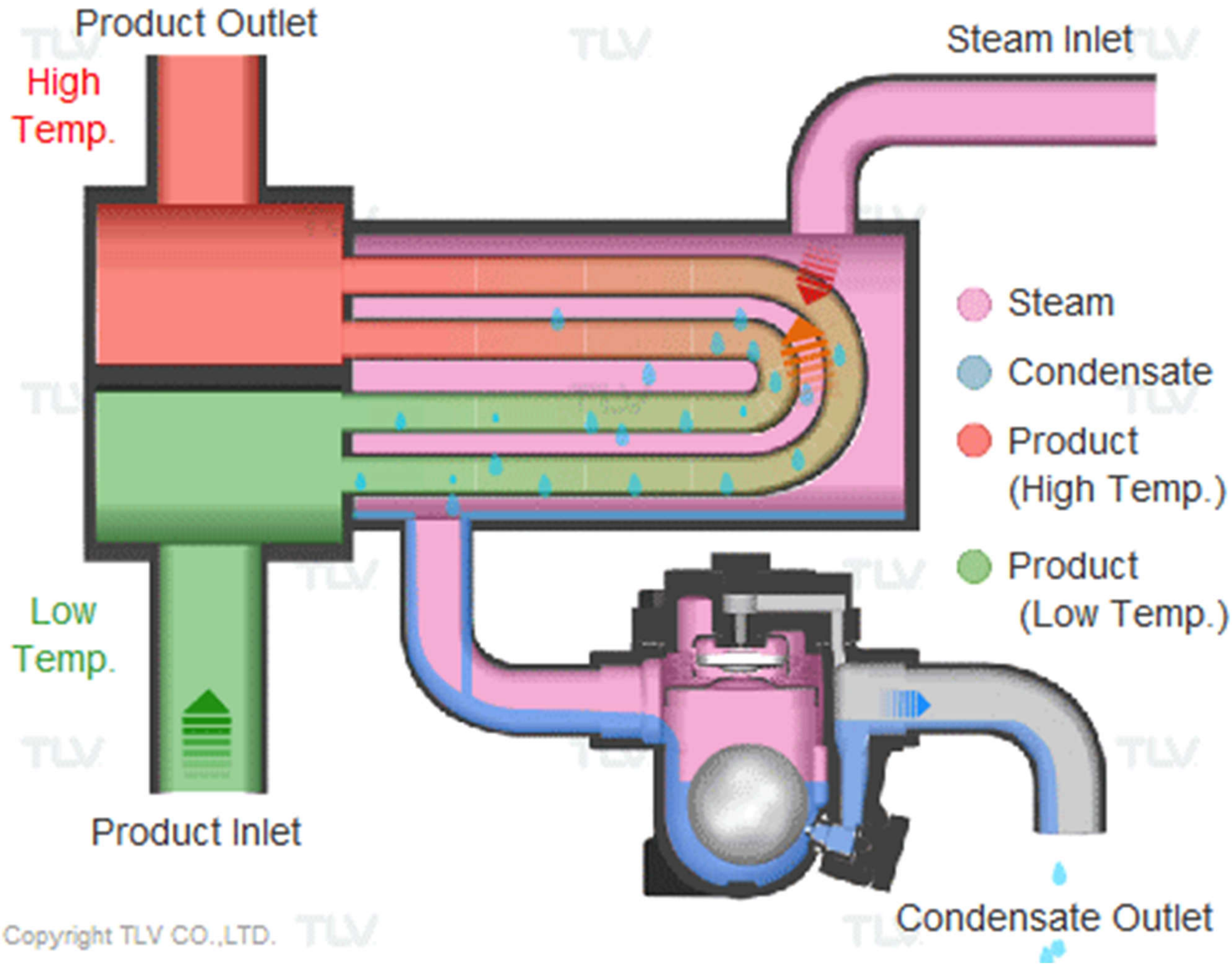
Chinese dumplings being steamed directly



Product being heated indirectly

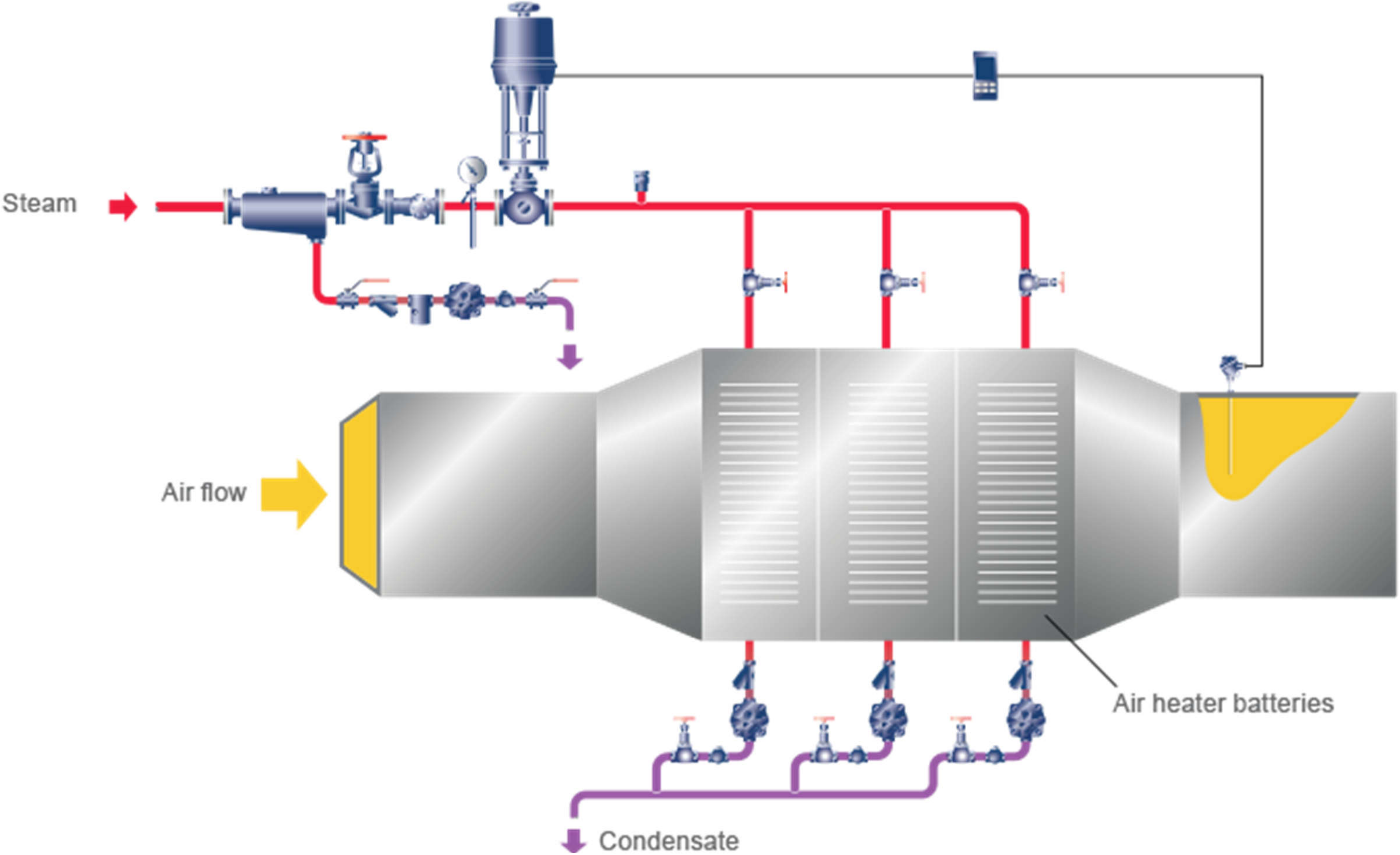
(Source: https://www2.tlv.com/en-au/steam-info/steam-theory/steam-basics/what-is-steam)

Heating application of steam using a shell and tube heat exchanger



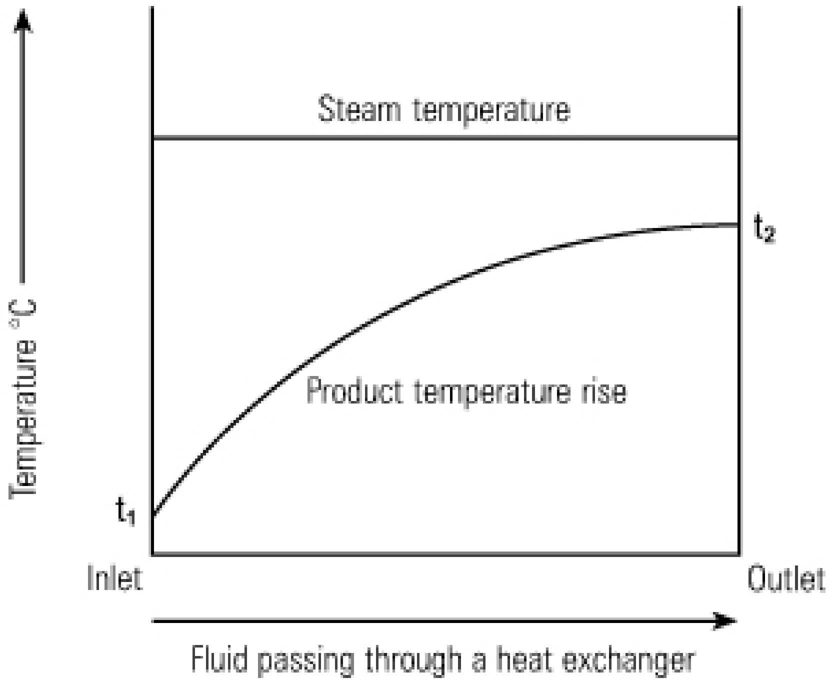
(Source: https://www2.tlv.com/en-au/steam-info/steam-theory/steam-basics/principal-applications-for-steam)

Ducted air system with air heater batteries



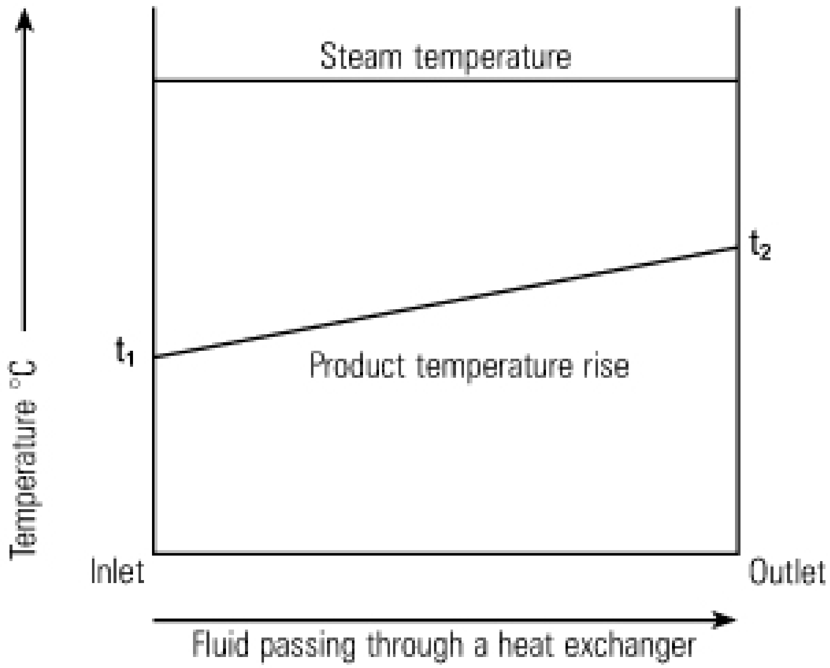
(Source: www.spiraxsarco.com)

Heat transfer equations for steam heating



Log mean temperature difference (LMTD)

$$\Delta T_{LM} = \frac{T_2 - T_1}{\ln\left(\frac{T_s - T_1}{T_s - T_2}\right)}$$

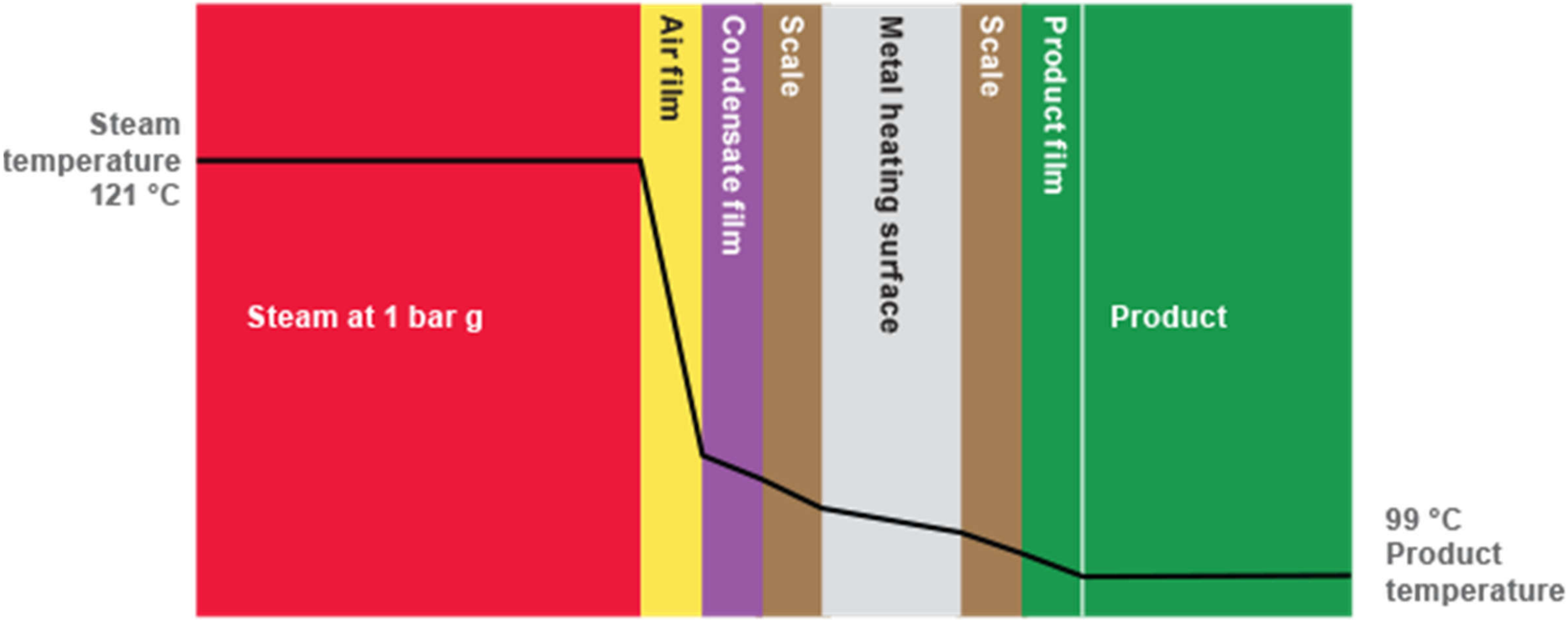


Arithmetic mean temperature difference (AMTD)

$$\Delta T_{AM} = T_s - \left(\frac{T_1 + T_2}{2}\right)$$

(Source: https://www.spiraxsarco.com/Learn-about-steam)

Temperature gradients across heat transfer layers



Equation

$$U = \frac{1}{R_1 + R_2 + R_3 + R_4 + R_5 + R_6}$$

Where:

R_1 = Resistance of the air film

R_2 = Resistance of the condensate film

R_3 = Resistance of the scale film on the steam side

R_4 = Resistance of the of the metal wall

R_5 = Resistance of the scale film on the water side

R_6 = Resistance of the product film

(Source: www.spiraxsarco.com)

Comparison of heating media with steam

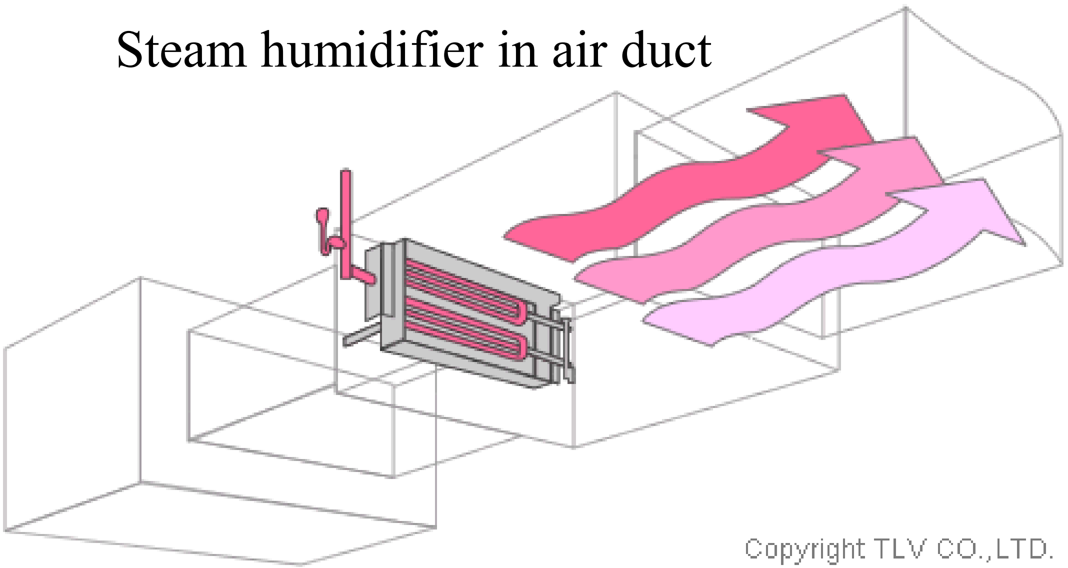
Steam	Hot water	High temperature oils
High heat content Latent heat approximately 2 100 kJ/kg	Moderate heat content Specific heat 4.19 kJ/kg °C	Poor heat content Specific heat often 1.69-2.93 kJ/kg °C
Inexpensive Some water treatment costs	Inexpensive Only occasional dosing	Expensive
Good heat transfer coefficients	Moderate coefficients	Relatively poor coefficients
High pressure required for high temperatures	High pressure needed for high temperatures	Low pressures only to get high temperatures
No circulating pumps required Small pipes	Circulating pumps required Large pipes	Circulating pumps required Even larger pipes
Easy to control with two way valves	More complex to control - three way valves or differential pressure valves may be required	More complex to control - three way valves or differential pressure valves may be required
Temperature breakdown is easy through a reducing valve	Temperature breakdown more difficult	Temperature breakdown more difficult
Steam traps required	No steam traps required	No steam traps required
Condensate to be handled	No condensate handling	No condensate handling
Flash steam available	No flash steam	No flash steam
Boiler blowdown necessary	No blowdown necessary	No blowdown necessary
Water treatment required to prevent corrosion	Less corrosion	Negligible corrosion
Reasonable pipework required	Searching medium, welded or flanged joints usual	Very searching medium, welded or flanged joints usual
No fire risk	No fire risk	Fire risk
System very flexible	System less flexible	System inflexible

(Source: www.spiraxsarco.com)

Uses of steam

- Typical applications for steam in industry: *
  - Heating/Sterilization
  - Propulsion/Drive
  - Motive
  - Atomization
  - Cleaning
  - Moisturization
  - Humidification

Steam humidifier in air duct



(* Further info: https://www2.tlv.com/en-au/steam-info/steam-theory/steam-basics/principal-applications-for-steam)

Uses of steam

- Unique properties of steam for applications:
  - Sterility – sterilizing in hospitals & food industry
  - High heat content – means smaller pipes than a water-based system
  - High heat transfer value (w/ change of state) – means smaller heat exchangers
  - Ease of distribution – no pumps are required
  - Flexibility – can provide the means to heat, cool (absorption chillers) and humidify

Comparison between steam and water for humidification

Factor	**Steam**	**Water**
Cleanliness	Clean and sterile. Can be used in clean areas	Disinfection needed. Care must be taken to avoid formation of stagnant pools. Not suitable for clean areas
Efficiency	Easily absorbed	Carryover normal. Eliminator plates necessary
Heating	No change in air temperature	Reheat battery needed
Cooling	No cooling effect	Can provide evaporative cooling
Controllability	Easily controlled	Difficult to control

(Source: CIBSE, 2015. *Design and Operation of Modern Steam Systems*, CIBSE TM58: 2015)

Uses of steam

- Advantages of steam over hot water systems:
  - No pumps needed: steam flows through system unaided
  - Smaller heat emitters
  - Low density: steam can be used in tall buildings where water systems create excessive pressure
  - Terminal units can be added/removed easily
  - Steam components can be repaired or replaced just by closing the steam supply (no associated draining and refilling a water system)
  - Steam system temperature can be controlled by varying either steam pressure or temperature
- Disadvantages:
  - More complicated, more maintenance & supervision

Uses of steam

- Utilizing latent heat (steam heating) for heat transfer is more effective than utilizing sensible heat (hot water or oil heating), as a much higher amount of energy is released in a shorter period of time

Property	Advantage
Rapid even heating through latent heat transfer	Improved product quality and productivity
Pressure can control temperature	Temperature can be quickly and precisely established
High heat transfer coefficient	Smaller required heat transfer surface area, enabling reduced initial equipment outlay

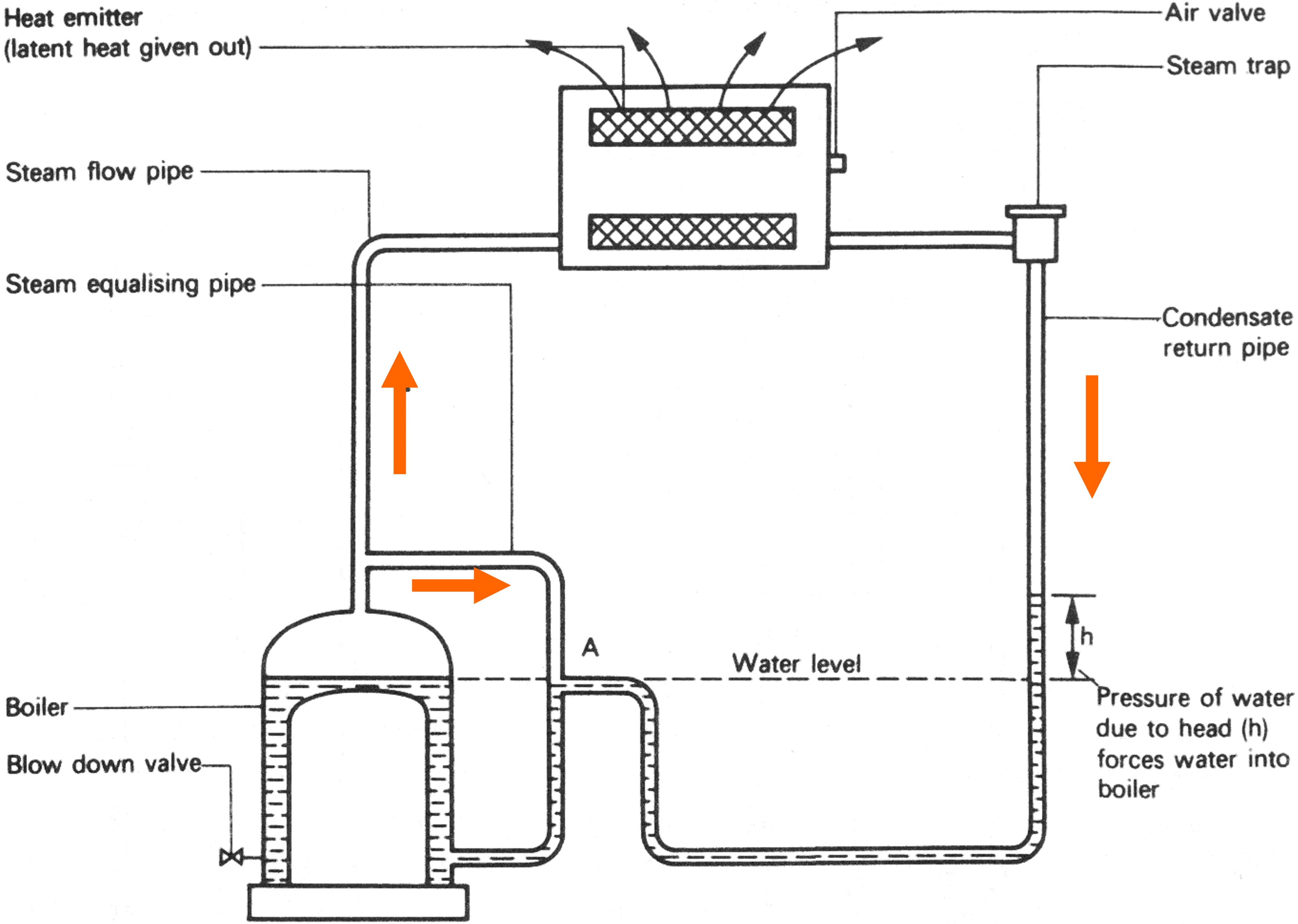
(See also: https://www2.tlv.com/en-au/steam-info/steam-theory/steam-basics/heating-with-steam)

Uses of steam

- Use steam directly for heating
  - Low pressure (LP): up to 35 kPa
  - Medium pressure (MP): 140 to 550 kPa
  - High pressure (HP): 550 to 1400 kPa
- Low pressure steam
  - It has a higher heat content
  - Causes less risk of noise and wear
- Medium or high pressure steam
  - For large installations with long steam mains
  - Requires pressure-reducing set for appliances

Operating principle of steam heating

Why air valve? Where to put it?

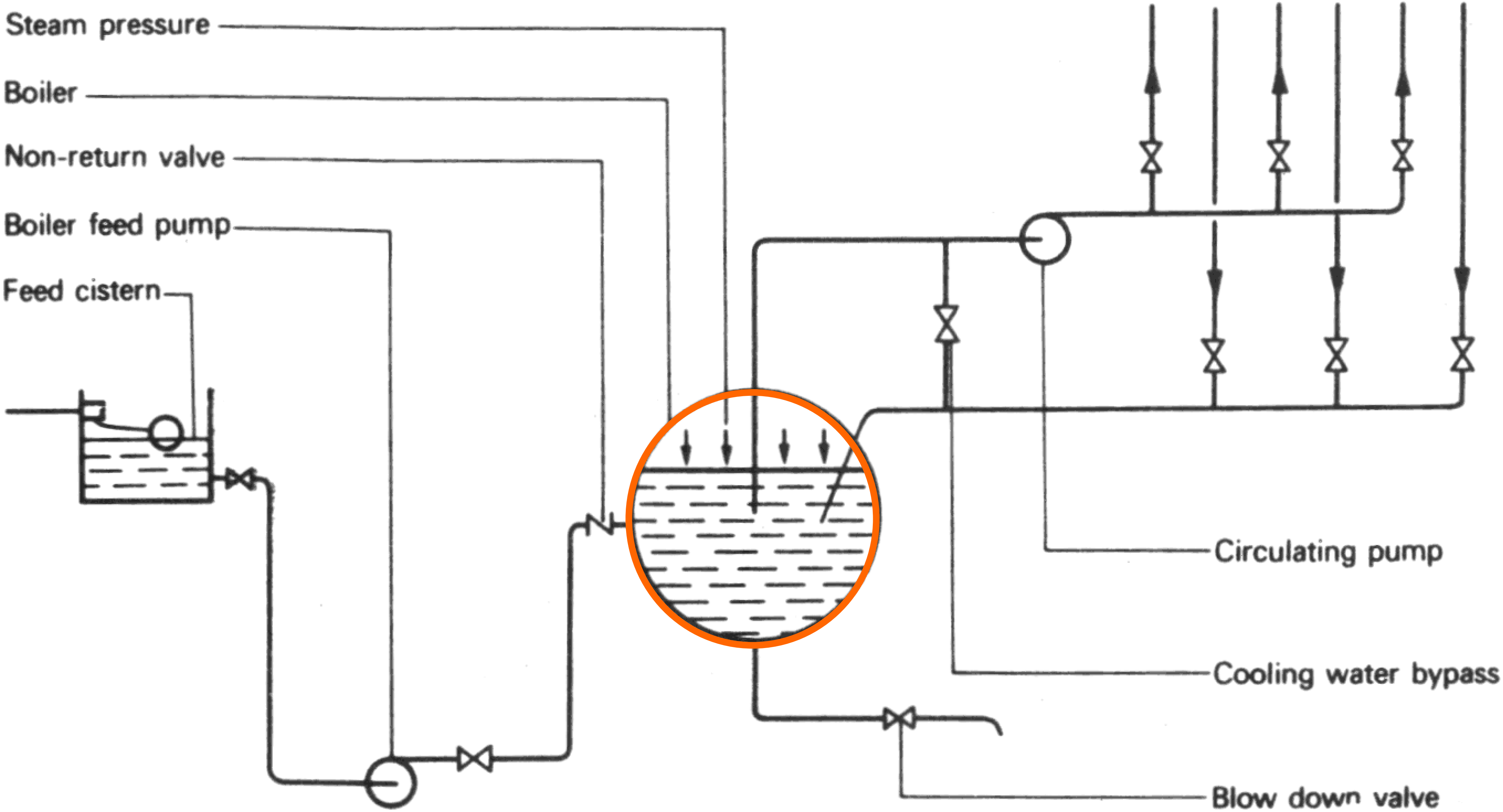


(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Steam system

- Basic arrangements: boiler plant using steam pressurisation
  - Hot water boiler (w/ steam maintained inside)
  - Boiler feed pump & cistern
  - Circulating pump & pipework
  - Cooling water bypass (mixing to control the pressure)
  - Blow down pipe & valve
- Steam & water are at saturation temperature

Boiler plant using steam pressurisation



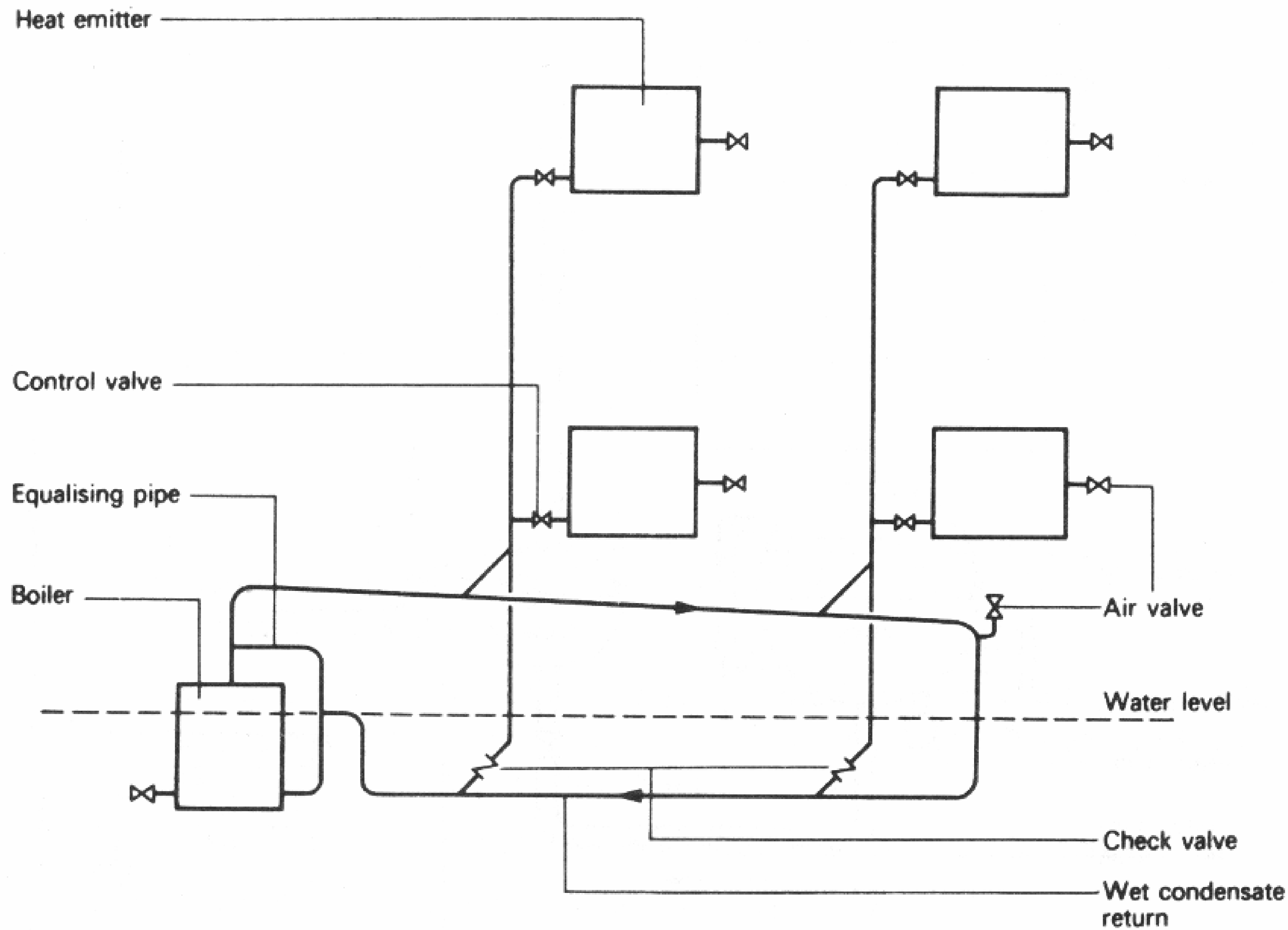
Why blow down?

(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Steam system

- Classification of steam systems:
- By method of condensate return
  - 1) By gravity (runs back to boiler)
  - 2) By automatic pump (pumped back to boiler)
  - 3) By condensate lifting trap
- By pipe layout
  - One pipe or two pipe
  - Up-feed or down-feed

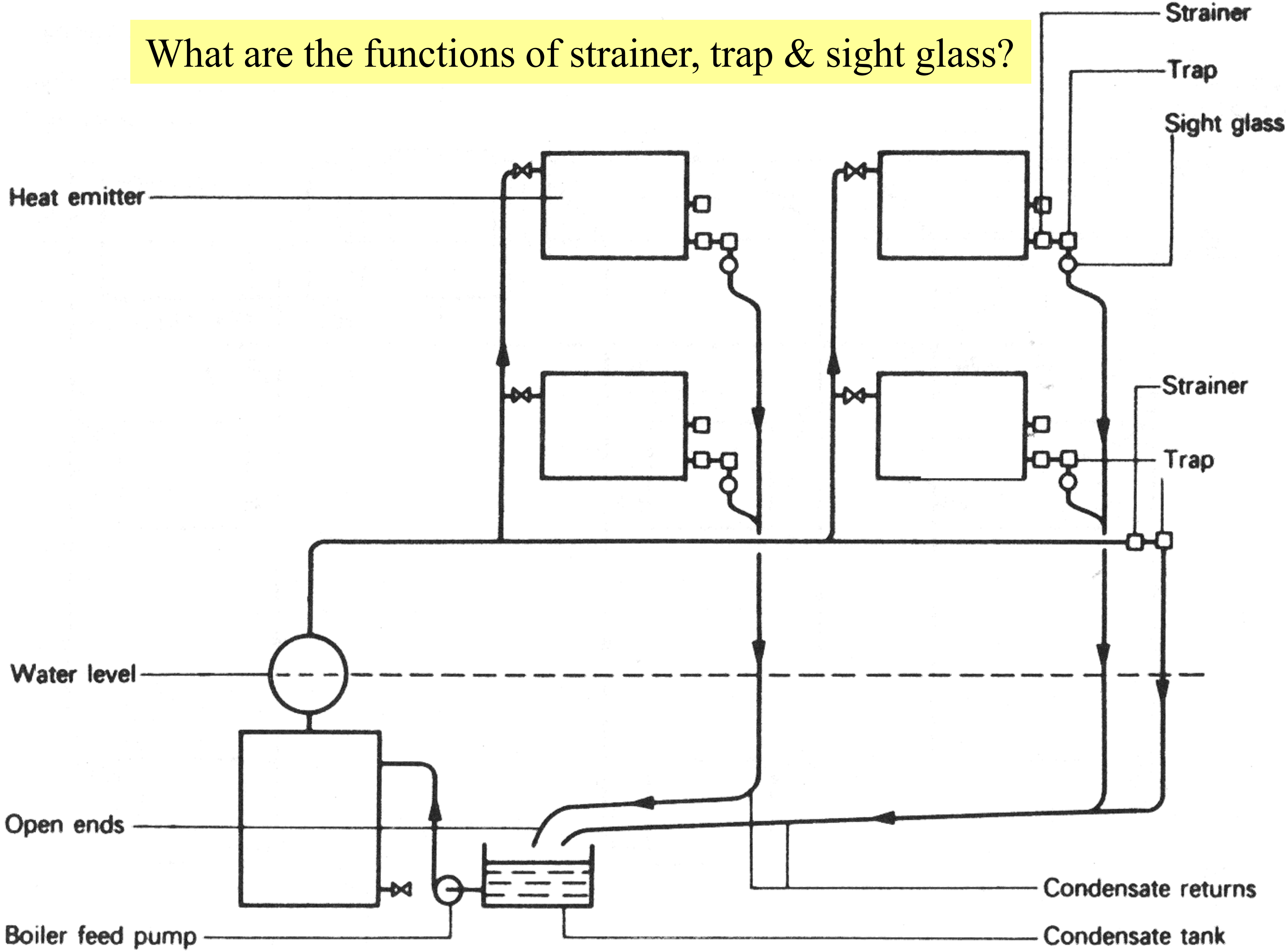
One-pipe gravity steam heating system



(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Two-pipe mechanical steam heating system

What are the functions of strainer, trap & sight glass?

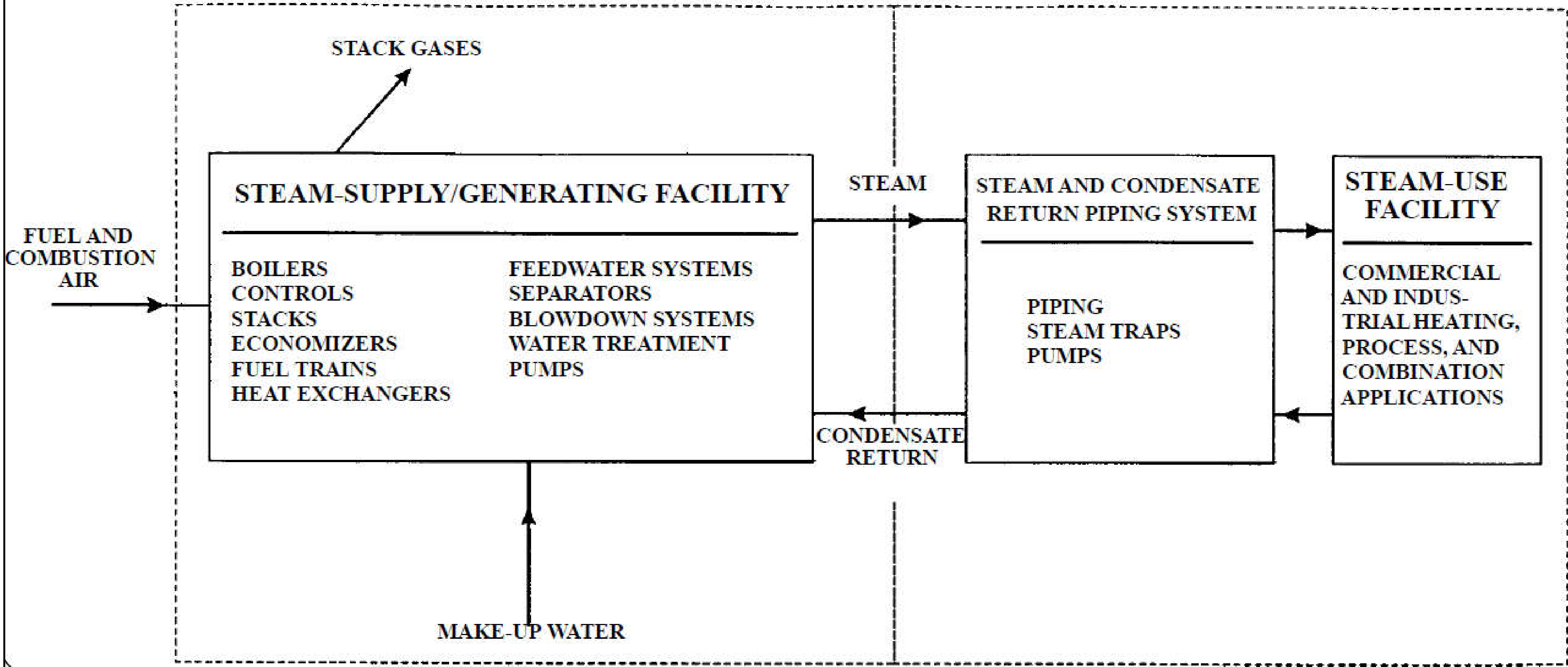


(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Steam system

- A steam system consists of:
  - Steam-supply/generating facility
    - Boilers, feedwater systems, heat exchangers (e.g. economizers), boiler and system controls, fuel and gas handling equipment (e.g., fuel trains, stacks), and steam/water treatment equipment and piping
  - Steam and condensate return/water piping system
    - The steam and condensate loop
  - Steam-use facility
    - For industrial and commercial needs, such as comfort heating, food processing, paper corrugation

Typical steam system

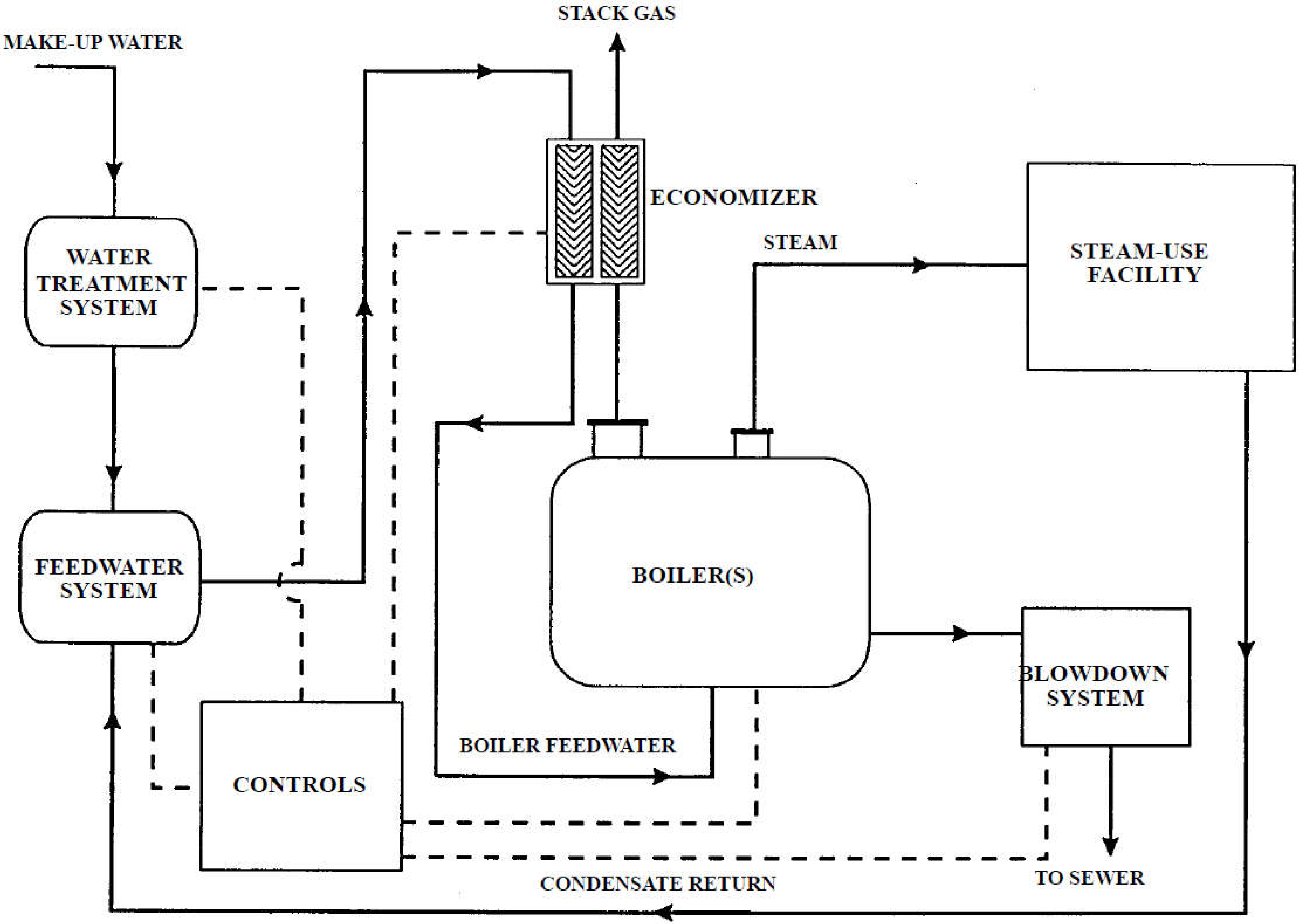


Four steps of the steam and condensate loop:

1. Generation, 2. Distribution, 3. Usage, and 4. Condensate return

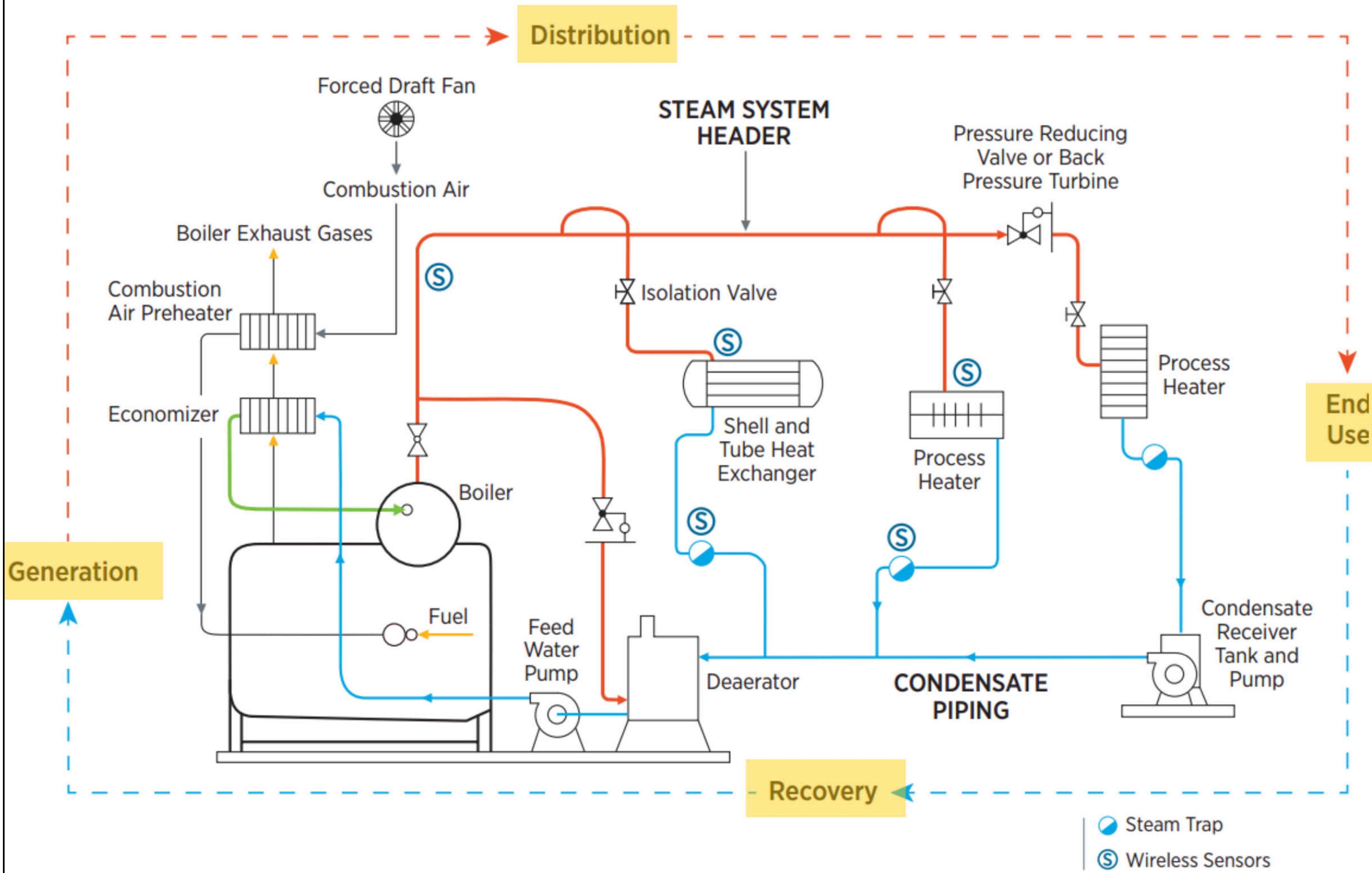
(Source: Cleaver-Brooks http://www.cleaverbrooks.com/)

Schematic diagram of a generic steam-generating facility



(Source: Cleaver-Brooks http://www.cleaverbrooks.com/)

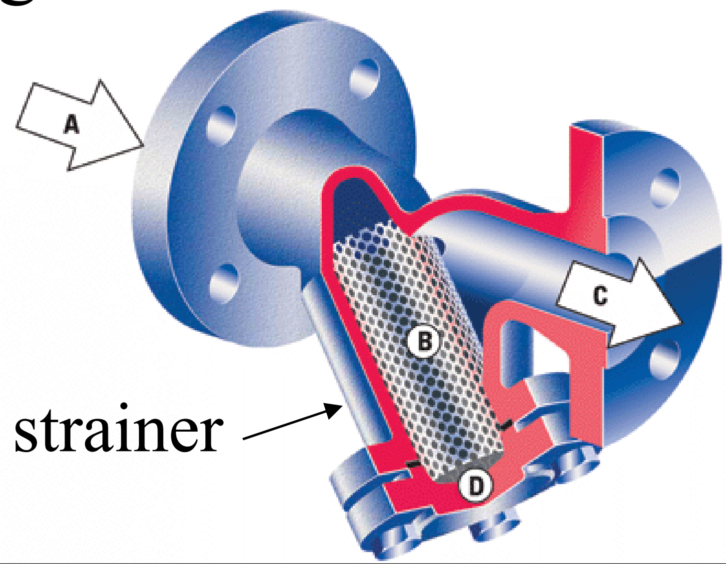
Four principal areas of a steam system



(Source: US-DOE, 2012. *Improving Steam System Performance: A Sourcebook for Industry*, Second Edition https://www.energy.gov/sites/prod/files/2014/05/f15/steamsourcebook.pdf)

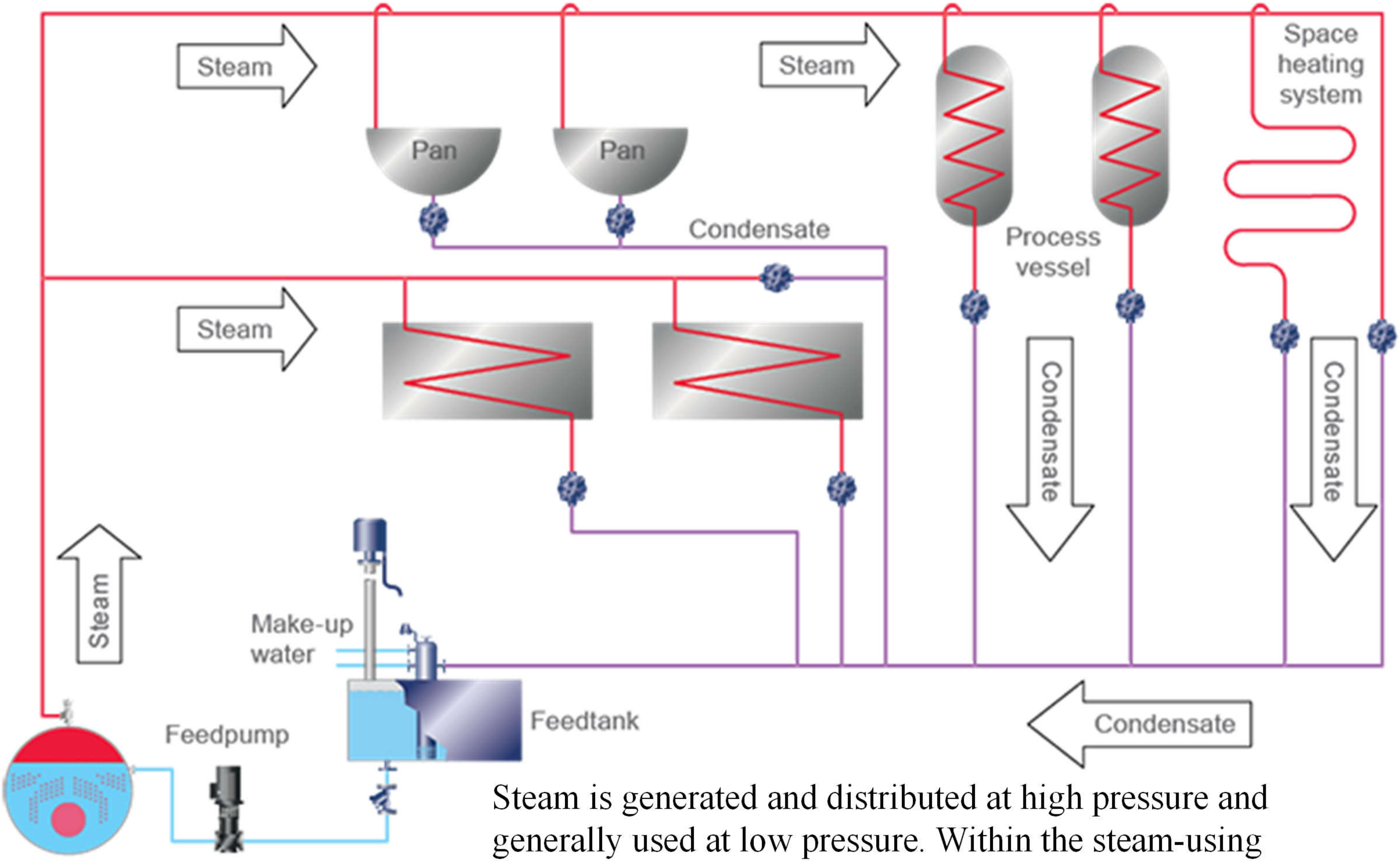
Steam system

- Steam quality: steam should be available at the point of use:
  - In the correct quantity
  - At the correct temperature and pressure
  - Free from air and incondensable gases
  - Clean
  - Dry



Pipeline strainer

A typical basic steam circuit (the steam and condensate loop)



Steam is generated and distributed at high pressure and generally used at low pressure. Within the steam-using equipment, when the steam condenses it gives up its enthalpy of evaporation, transferring heat to the secondary medium.

(Source: www.spiraxsarco.com)

Steam traps

- [Steam traps]
  - Purpose: automatic valve to "trap" the steam and filter out condensate (i.e. condensed steam) and non-condensable gases (e.g. air)
  - Definition by ANSI (American National Standard Institute):
    - "*Self contained valve which automatically drains the condensate from a steam containing enclosure while remaining tight to live steam, or if necessary, allowing steam to flow at a controlled or adjusted rate. Most steam traps will also pass non-condensable gases while remaining tight to live steam.*"

(See also: https://www2.tlv.com/en-au/steam-info/steam-theory/steamtrap-basics/what-is-a-steam-trap)

Steam traps

- Why are steam traps installed?
  - When steam has given up its latent heat, steam condenses and becomes condensate
  - Heating efficiency will suffer if condensate is not removed as rapidly as possible
- Three main groups of steam traps:
  - (a) Thermostatic
  - (b) Mechanical
  - (c) Thermodynamic

Typical types of steam traps

Ball float type

Thermodynamic type

Thermostatic type

Inverted bucket type

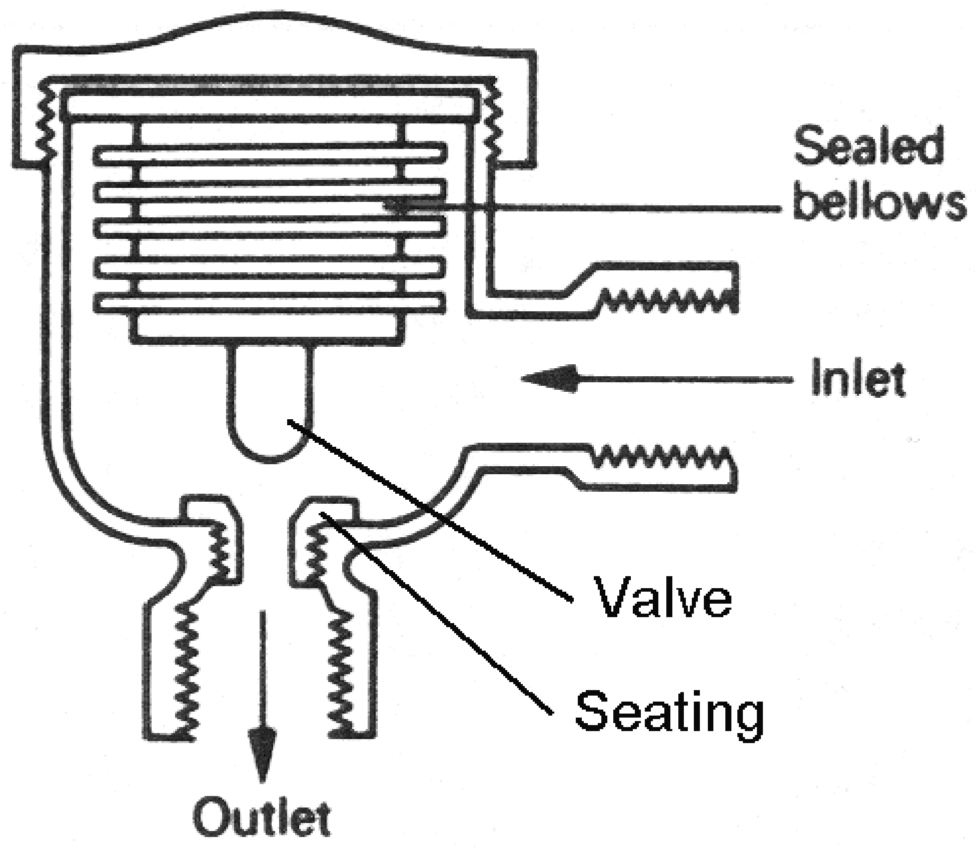
"The duty of a steam trap is to discharge condensate while not permitting the escape of live steam"

New functions in modern steam traps:
e.g. automatic air venting and scale removal

(See also: The History of Steam Traps
https://www2.tlv.com/en-au/steam-info/steam-theory/steamtrap-basics/history-of-steam-traps-pt1
https://www2.tlv.com/en-au/steam-info/steam-theory/steamtrap-basics/history-of-steam-traps-pt2)

(Source: www.spiraxsarco.com)

Thermostatic



Thermostatic steam trap

Operating principle:

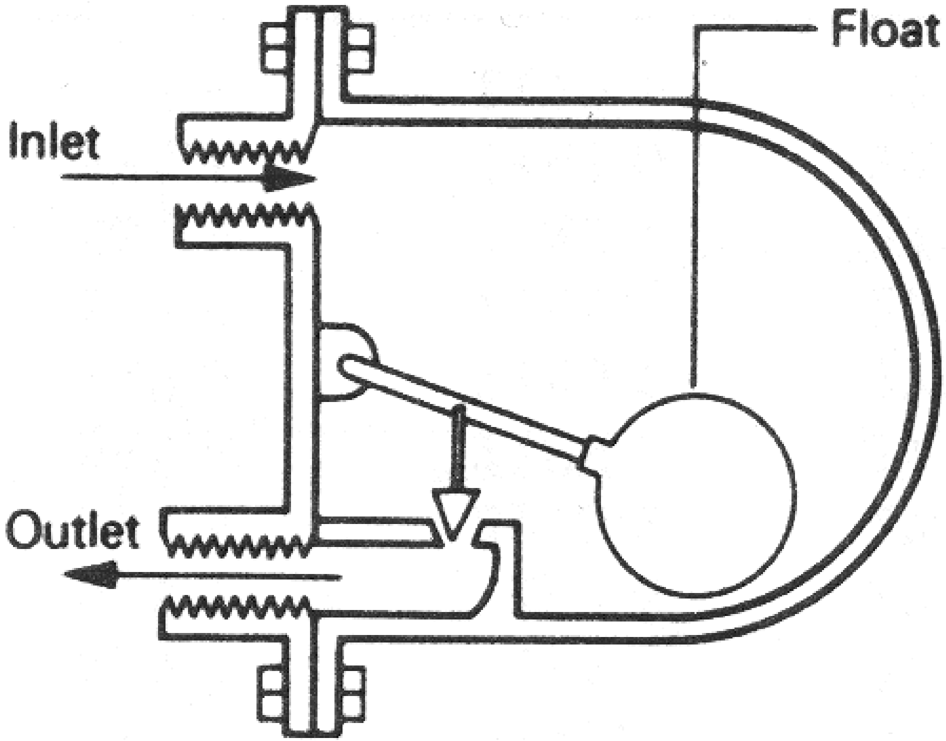
- The closed bellows contains a volatile spirit which has a boiling point suiting the temperature

- When steam enters the traps, the volatile spirit expands → open the bellows, close the valve

- Water (condensate) enters the traps at a temperature lower than steam, the spirit contracts and closes the bellows → open the valve + allow water to flow back to boiler

(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Mechanical



Ball float steam trap

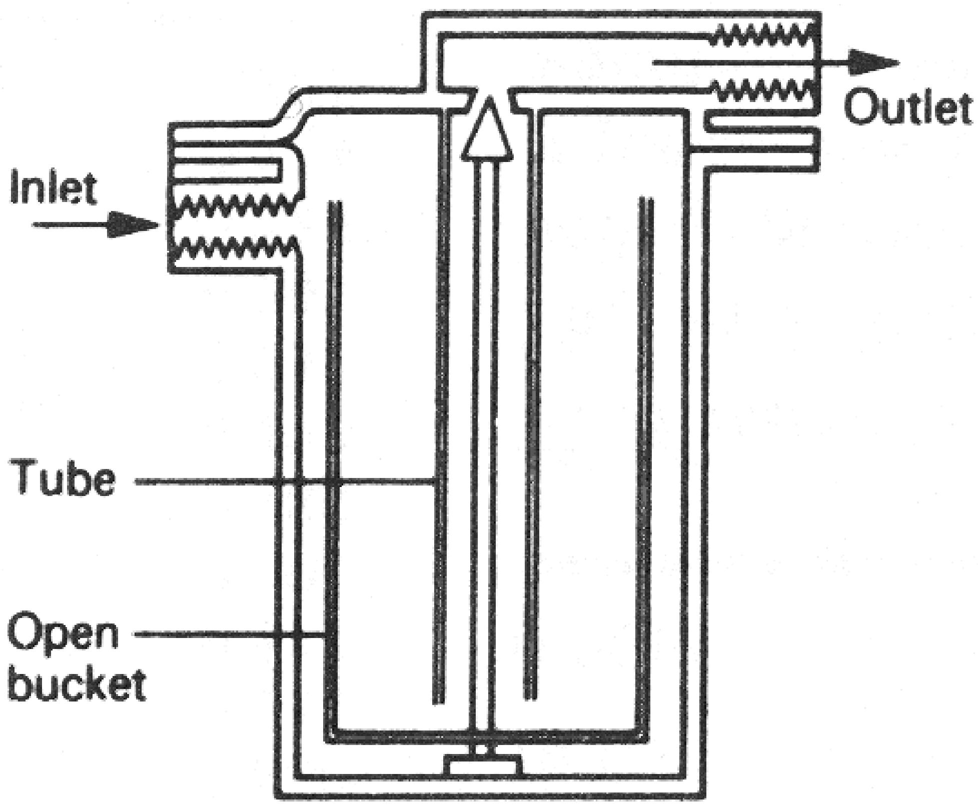
Operating principle:

- Steam enters the trap → ball float valve suspended → weight of float keeps outlet valve close
- Water (condensate) enters trap → float buoyant →opens valve → allow water flowing back to boiler

(See also: https://www2.tlv.com/en-au/steam-info/steam-theory/steamtrap-basics/mechanical-steam-traps)

(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Mechanical



Open bucket steam trap

Operating principle:

• Bucket floats → outlet valve close

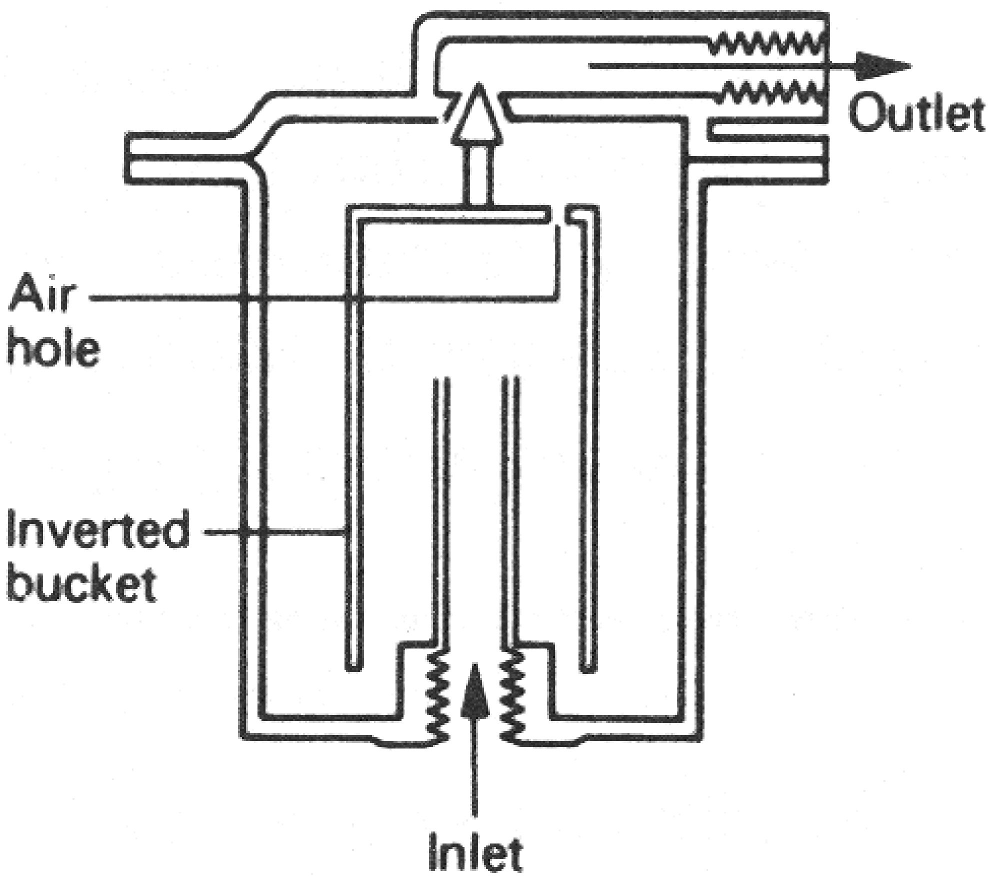
• Water (condensate) enters trap →overflows into bucket → bucket to sink → open the valve

• Steam forces water out of bucket through the tube → bucket is buoyant → closing the valve

(See also: https://www2.tlv.com/en-au/steam-info/steam-theory/steamtrap-basics/mechanical-steam-traps)

(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Mechanical



Inverted bucket steam trap

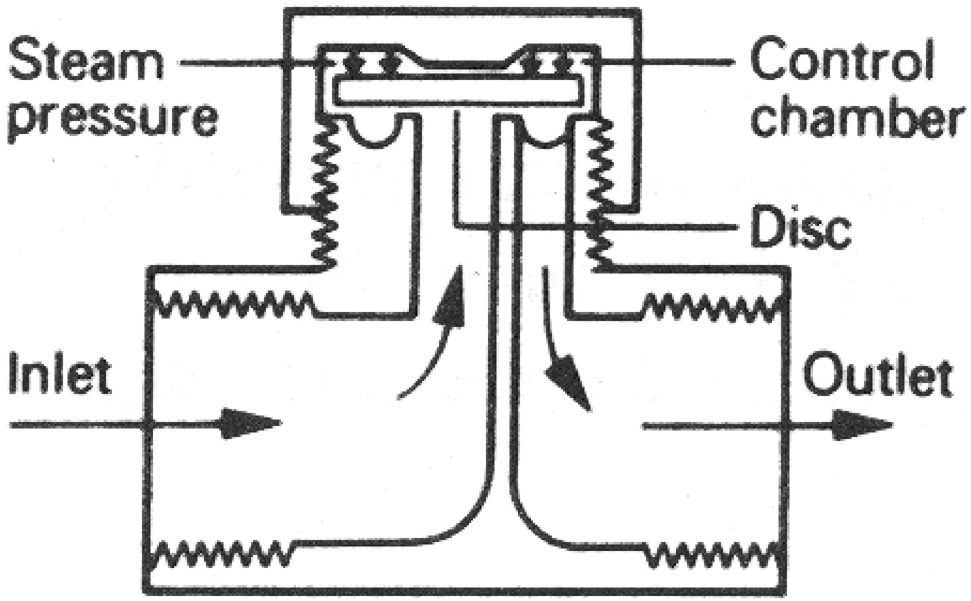
Operating principle:

- Steam enters the trap → bucket is lifted → valve is closed
- Water (condensate) enters trap → bucket fails under its own weight → valve opens → steam pressure forced water out

(See also: https://www2.tlv.com/en-au/steam-info/steam-theory/steamtrap-basics/mechanical-steam-traps)

(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Thermodynamic



Thermodynamic steam trap

Bernoulli principle:

kinetic pressure + potential energy = constant

Operating principle:

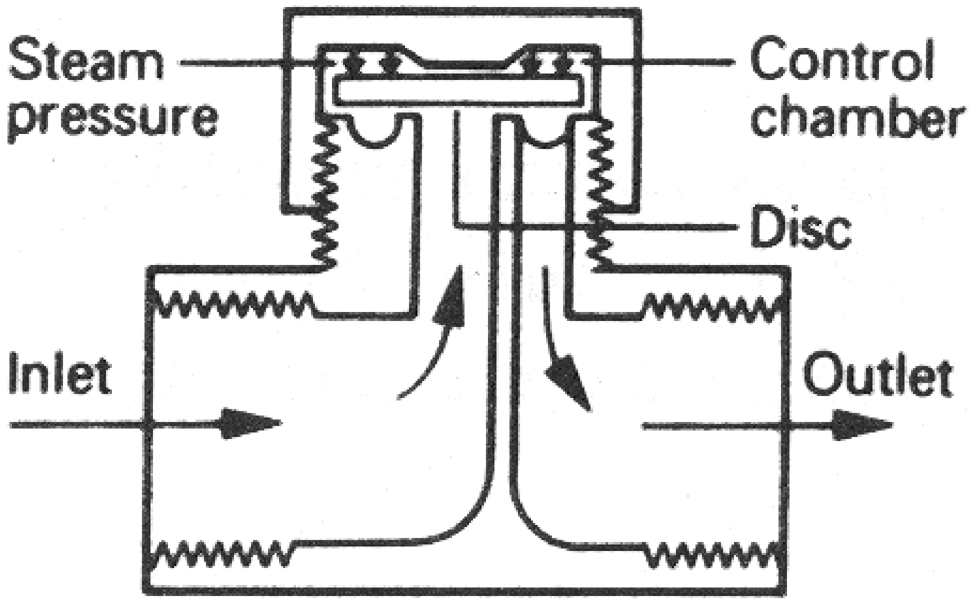
• Steam flows through trap → increase kinetic energy between disc & seating → reduce pressure energy at this point → disc moves nearer the seating until kinetic energy decreases

• Reduction in kinetic energy → increase pressure energy → lift the disc from seating (prevented from doing so by the steam pressure acting upon the top of the disc in the control chamber)

• Area at the top of the disc > area at inlet underneath → the upper pressure forces the disc firmly on to its seat

(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Thermodynamic



Thermodynamic steam trap

Bernoulli principle:
kinetic pressure + potential energy = constant

Operating principle (cont'd):

- Water (condensate) enters trap → steam above disc condenses → reduce pressure → disc forced up→ water flow through trap

- Water (condensate) flows through trap at a lower velocity than steam → insufficient reduction in pressure below the disc → traps remains open until steam enters

(See also: https://www2.tlv.com/en-au/steam-info/steam-theory/steamtrap-basics/how-disc-traps-work)

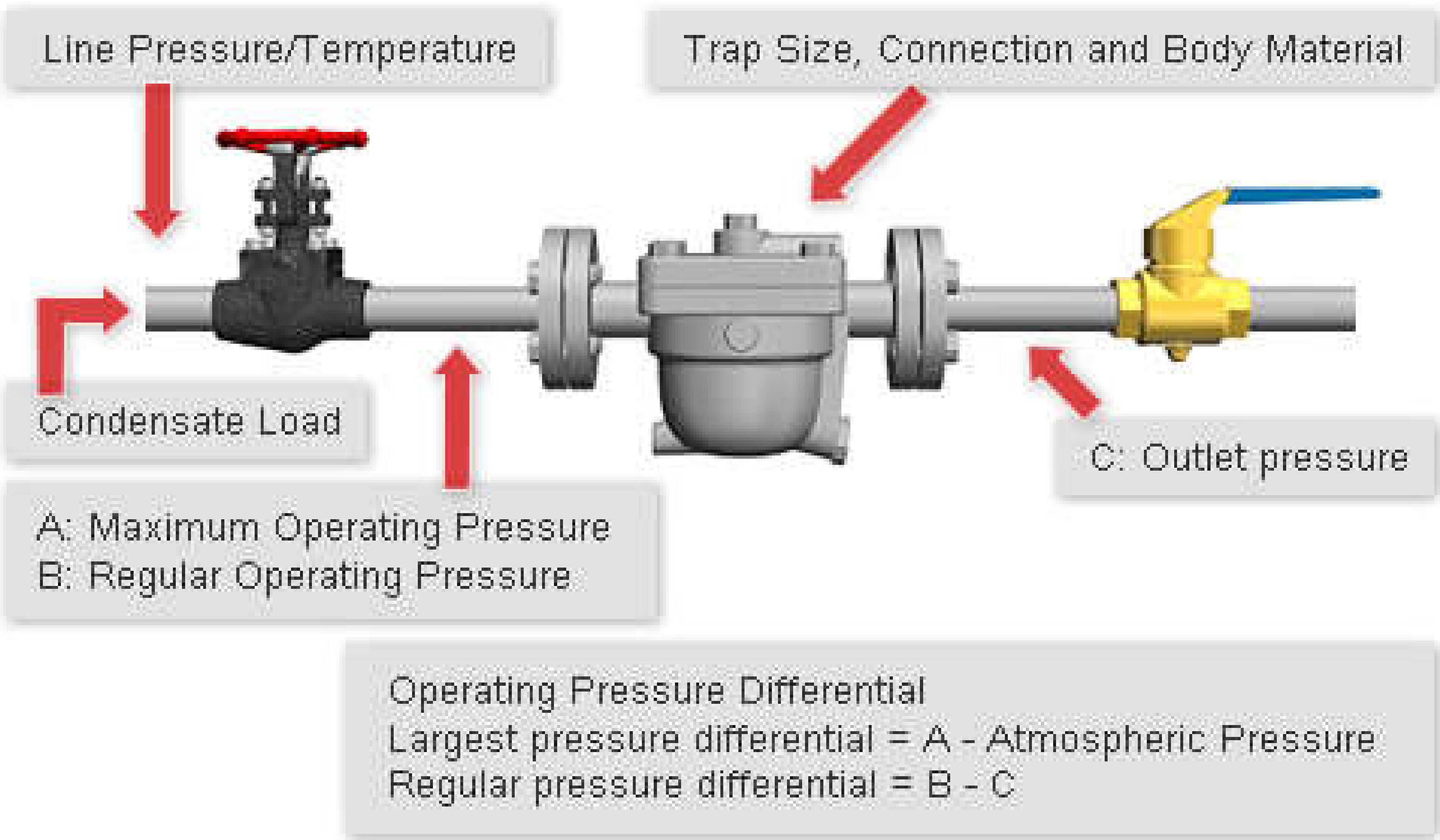
(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Steam traps

- Steam trap selection -- key considerations:
  - Pressure and temperature ratings, discharge capacity, trap type, body material, etc.
  - Selection process:
    - 1. Determine discharge requirements of the steam trap application (e.g. hot or subcooled discharge), and select the matching trap type
    - 2. Select trap model according to operating pressure, temperature, orientation, and any other relevant conditions
    - 3. Calculate application load requirements and apply the trap manufacturer's recommended safety factor
    - 4. Base the final trap selection on lowest Life Cycle Cost (LCC)

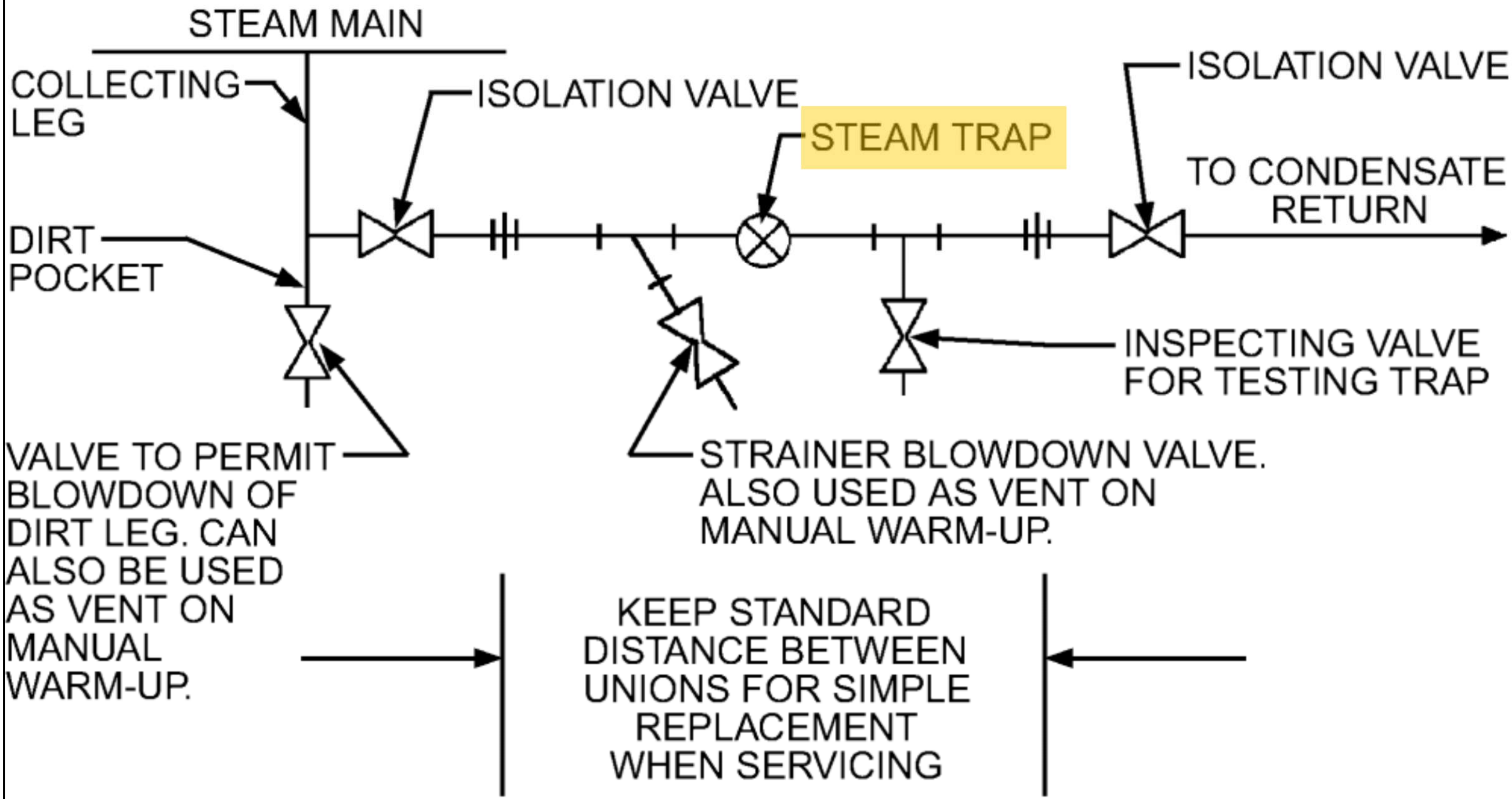
(See also: https://www2.tlv.com/en-au/steam-info/steam-theory/steamtrap-basics/steam-trap-selection-part-1)

Steam trap selection: Understanding specifications



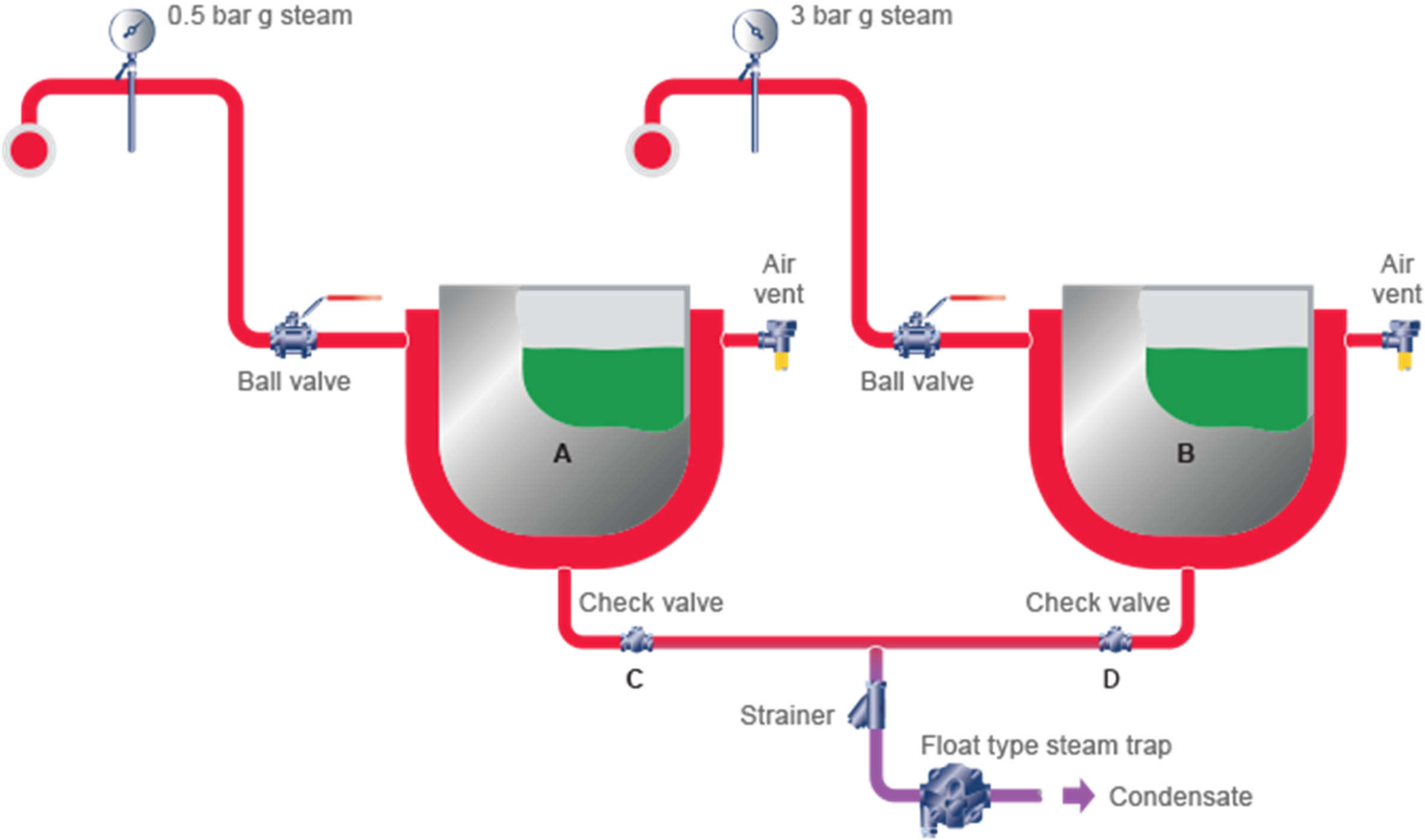
(See also: https://www2.tlv.com/en-au/steam-info/steam-theory/steamtrap-basics/steam-trap-selection-part-2)

Recommended steam trap piping



(Source: ASHRAE, 2020. *ASHRAE HVAC Systems and Equipment Handbook 2020*, SI edition, Chp. 11 Steam Systems)

Group trapping with different process pressures



(Source: www.spiraxsarco.com)

Steam traps

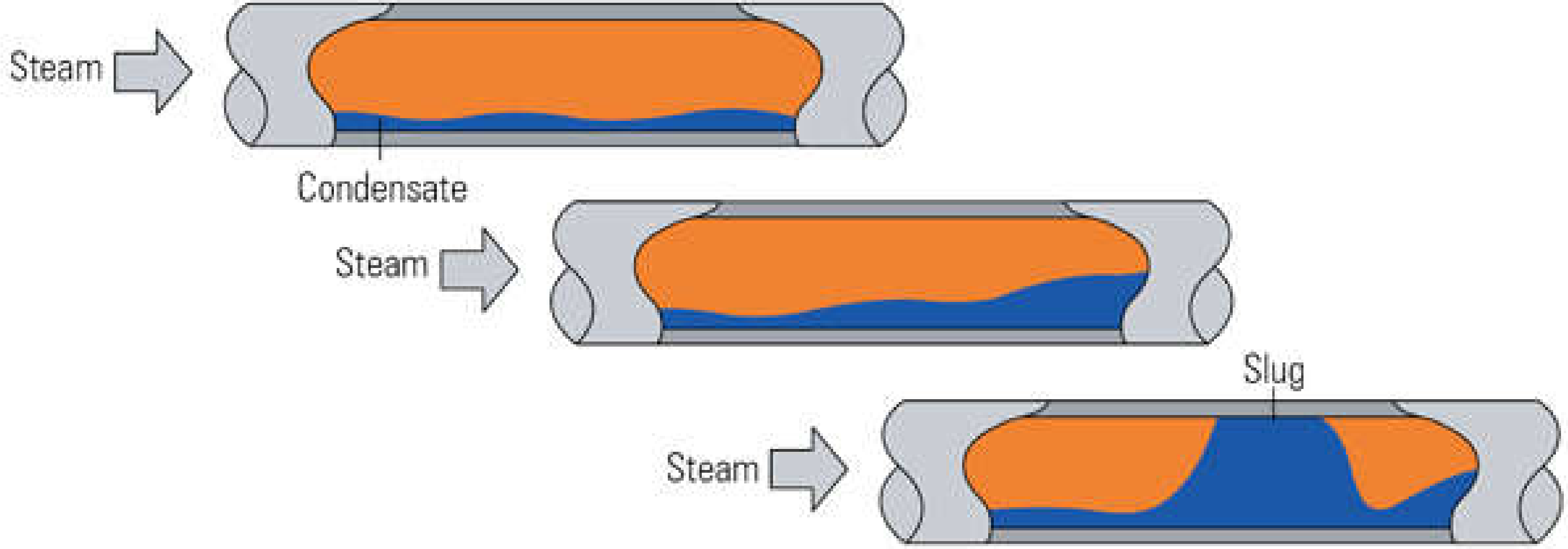
- Steam traps and steam trapping (Learn about steam)
  - https://www.spiraxsarco.com/Learn-about-steam
  - Considerations for Selecting Steam Traps
  - Selecting Steam Traps:- (examples & applications)
    - Canteen Equipment; Oil Transfer/Storage; Hospital Equipment
    - Industrial Dryers
    - Laundries and Presses
    - Process Equipment
    - Space Heating Equipment
    - Steam Mains; Tanks and Vats; Pressure Reducing Valves
  - Testing and Maintenance of Steam Traps
  - Energy Losses in Steam Traps

Steam traps

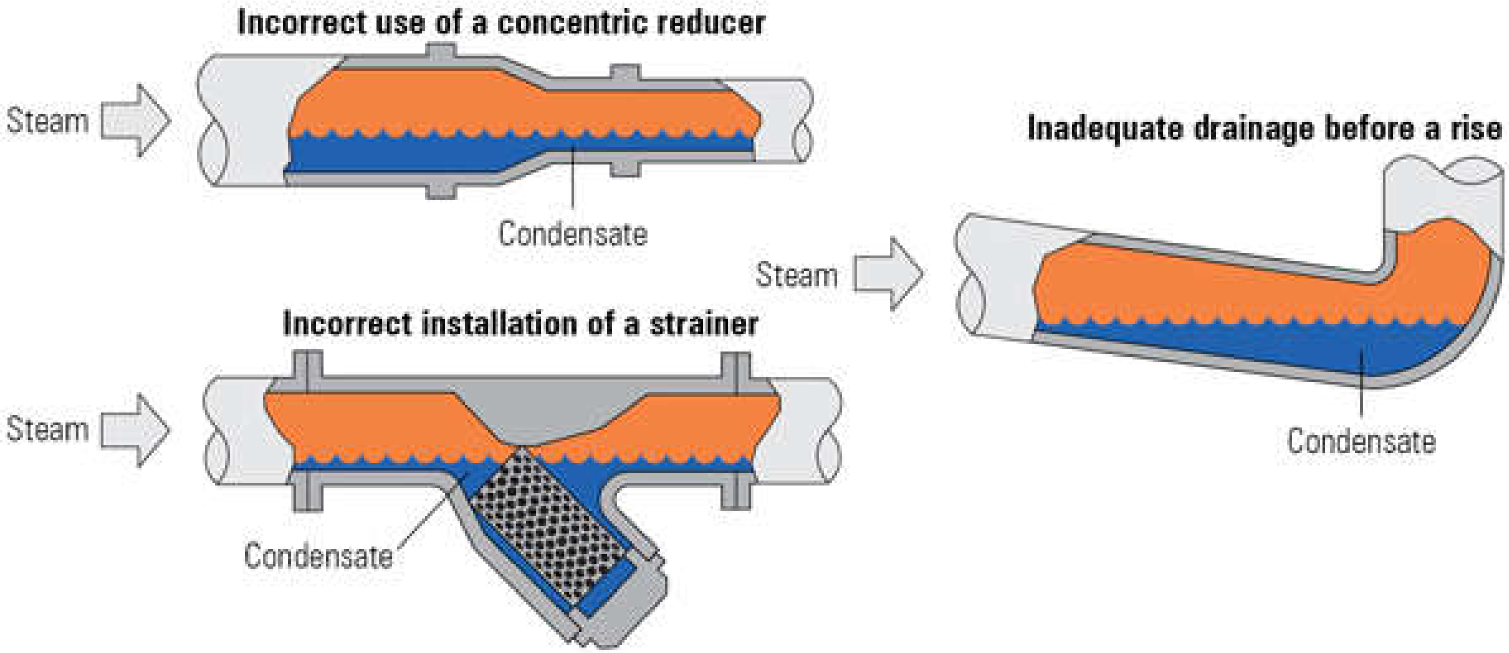
- Steam trap and piping problems (typical):
  - Trap leaking live steam
  - Temperature control trap (to avoid overheating)
  - Trap installation orientation
  - Trap back pressure
  - Double trapping, group trapping
  - Steam locking, air binding
  - Water/Steam hammer (pressure shock/impact)

(Further info: https://www2.tlv.com/en-au/steam-info/steam-theory/steam-basics/trap-leaking-live-steam)

Water hammer -- Formation of a solid slug of water



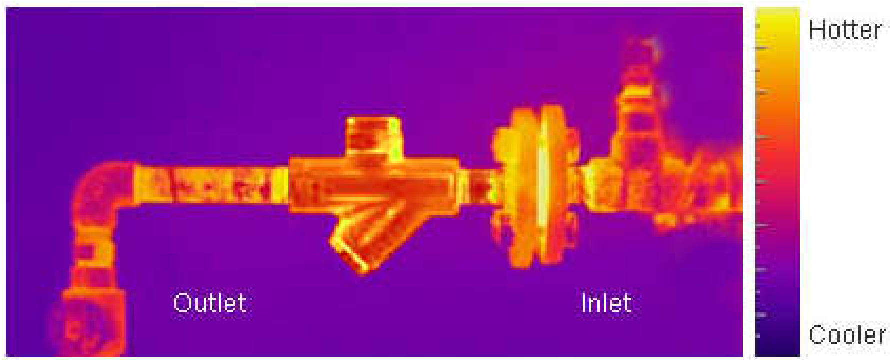
Potential sources of water hammer



(Source: www.spiraxsarco.com) (See also: https://www2.tlv.com/en-au/steam-info/steam-theory/problems/waterhammer-mechanism)

Steam traps

- Steam trap management
  - Steam trap losses - what it costs you
    - e.g. calculate the cost of losses from one trap, calculate steam leakage amounts from holes in piping https://www2.tlv.com/en-au/steam-info/steam-theory/energy-saving/cost-of-steam-trap-losses
  - Steam trap testing
    - Through visual observation
    - Using temperature
    - Using sound



(See also: https://www2.tlv.com/en-au/steam-info/steam-theory/trap-considerations/steam-trap-test)

Other components

- Steam separator
  - Radiant heat loss from piping causes part of the steam to lose some of its latent heat and revert back to water, thereby decreasing steam dryness
    - Steam traps cannot remove moisture entrained in the steam flow
  - Wet steam not only affects heat transfer efficiency, but also causes erosion of piping and critical equipment e.g. turbine blades
    - Should take preventative measures e.g. using a steam separator to remove the entrained condensate

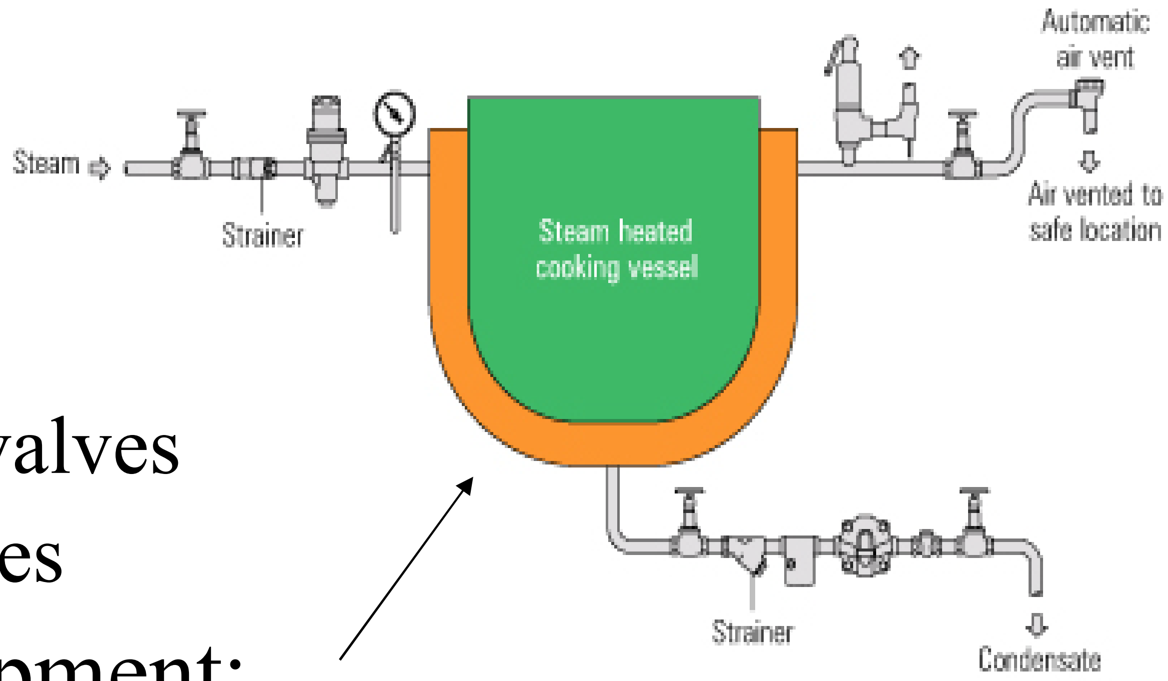
Other components

- Steam separator (cont'd)
  - Four basic separating principles/mechanisms:
    - 1. Mechanical impediment
    - 2. Flow velocity achieved
    - 3. Directional changes
    - 4. Impingement
  - Higher separation efficiency can be achieved by utilizing several of these techniques as opposed to just one
  - Separators can come in models either with or without a built-in trap

(See also: https://www2.tlv.com/en-au/steam-info/steam-theory/other/separators)

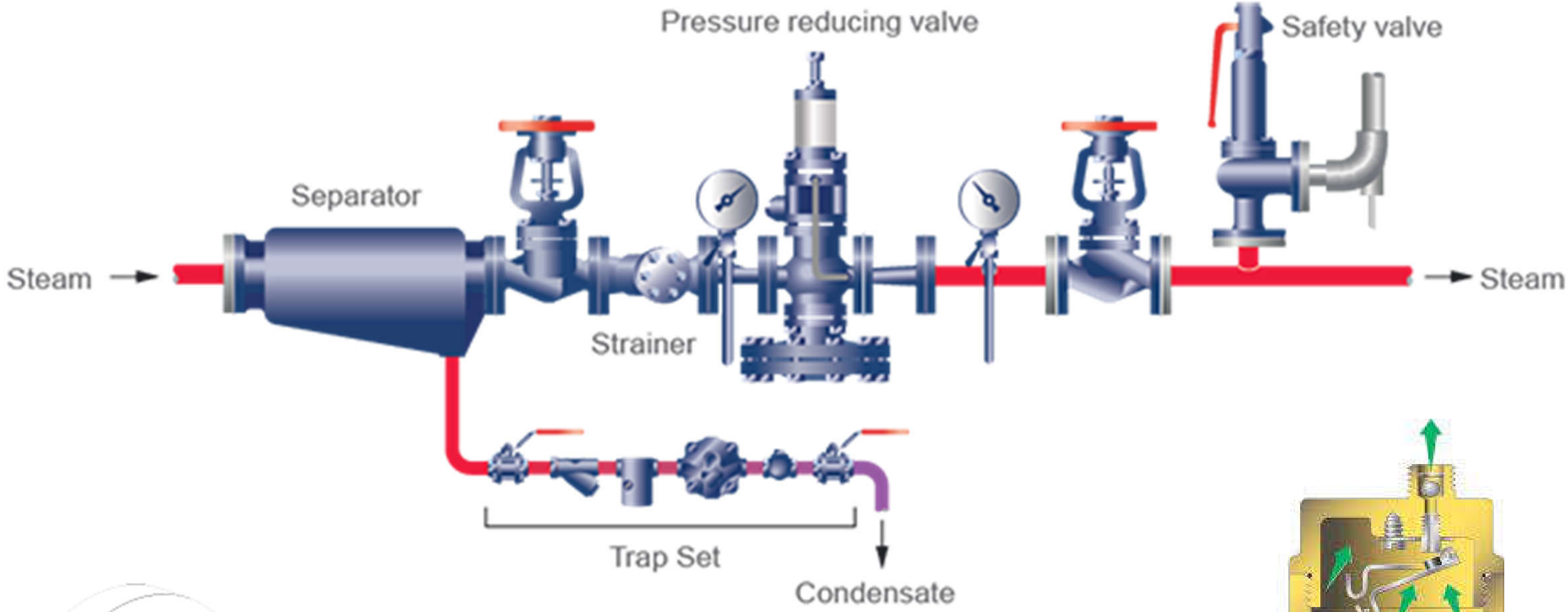
Other components

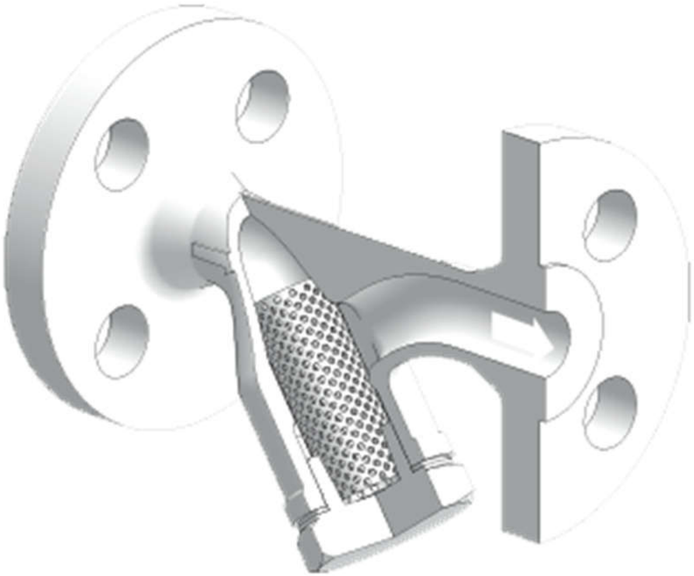
- Typical components:
  - Strainers
  - Automatic air vent
  - Check valves
  - Isolation valves
  - Pressure reducing valves
  - Gauges, sight glasses
- Typical steam equipment:
  - Steam heated cooking vessel (jacketed)



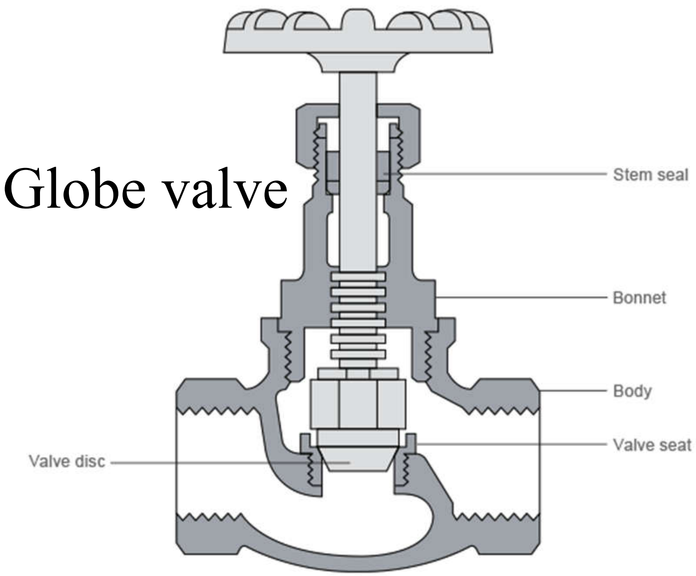
(Source: www.spiraxsarco.com)

Typical pressure reducing valve station





Cut section of a strainer

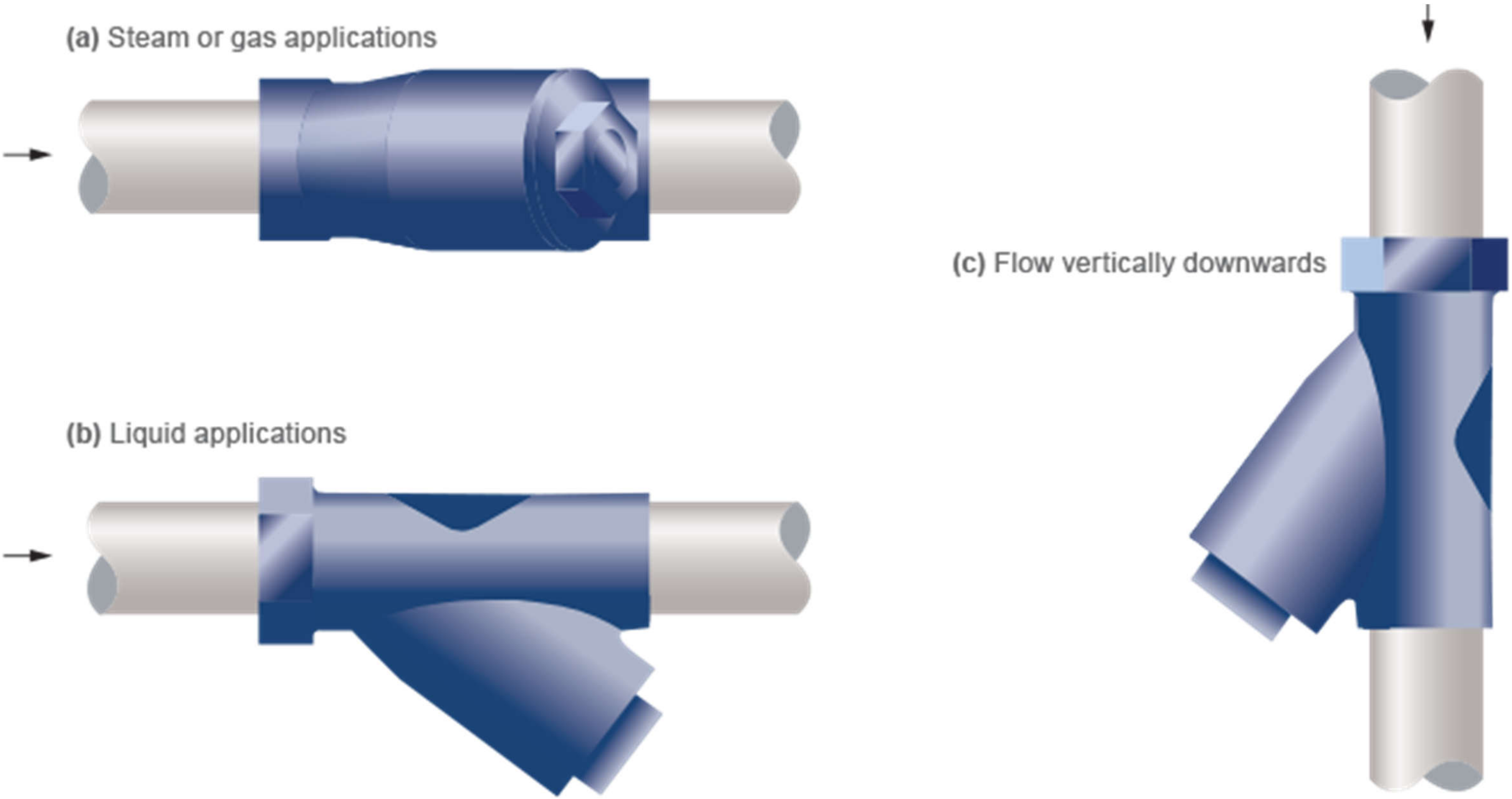


Globe valve

Automatic air vent

(Source: https://www.spiraxsarco.com/)

Correct orientation of strainers



(Source: www.spiraxsarco.com)

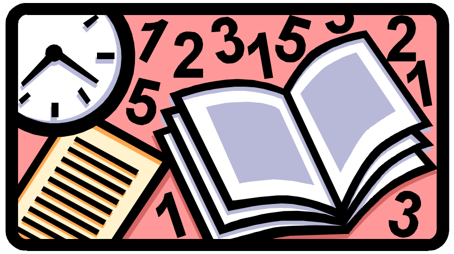
Further Reading

- Training videos:
  
  - What Is Steam? (15:14) https://youtu.be/T9jWTtyYLUs
  - Armstrong University Steam Basics Course (16:19) https://youtu.be/3vr8vlEJY3c
  - Guidelines for Steam System Efficiency (15:18) https://youtu.be/6AkTNNqwtaE
- Learn about steam (Spirax Sarco)
  - https://www.spiraxsarco.com/Learn-about-steam
    - 1. Introduction
    - 2. Steam Engineering Principles and Heat Transfer
    - 10. Steam Distribution
    - 11. Steam Traps and Steam Trapping

Further Reading

- TLV (a steam specialist company)
  - Engineering Calculator http://www.tlv.com/global/AU/calculator/
  - Steam Theory (Sections 1 to 11) https://www2.tlv.com/en-au/steam-info/steam-theory
  - Product Operation Animation https://www2.tlv.com/en-au/products/operation

References



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- Hall F. & Greeno R., 2017. *Building Services Handbook*, 9th ed., Routledge, Oxon & New York.
- IOP, 2002. *Plumbing Engineering Services Design Guide*, [New ed.], Institute of Plumbing, Hornchurch, Essex, UK.
- McCauley, J. F., 1995. *The Steam Trap Handbook*, Fairmont Press, Lilburn, GA.
- Spirax-Sarco, 2007. *The Steam and Condensate Loop*, Spirax-Sarco, Cheltenham.