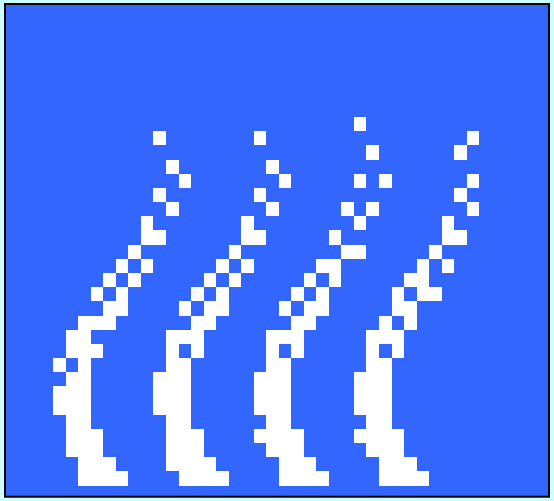
MEBS6000 Utility Services

http://www.hku.hk/mech/msc-courses/MEBS6000/index.html



Session 4:
Fuel Gas Supply and Steam Systems

Dr. Benjamin P.L. Ho
Department of Mechanical Engineering
The University of Hong Kong
E-mail: benjamin.ho@hku.hk

Sept 2010

Contents for this Session

- Fuel Gas Supply
  - Town Gas, LPG
  - Properties, prices, delivery, pipe sizing
- Steam Systems
  - Properties of steam
  - Uses of steam
  - System components
  - Design considerations
  - Steam pipe sizing

Fuel Gas Supply

Town Gas (TG)

- Produced by naphtha and natural gas
- Chemical Composition
  - Carbon Dioxide 16.3% – 19.9%
  - Carbon Monoxide 1.0% – 3.1%
  - **Methane** 28.2% – 30.7%
  - **Hydrogen** 46.3% – 51.8%
  - Nitrogen and Oxygen 0% – 3.3%
- Physical Properties
  - Calorific Value 17.27 MJ/m^3
  - Specific Gravity 0.52
  - Limits of flammability 5% - 40%

Fuel Gas Supply

Liquefied Petroleum Gas (LPG)

- A product of crude oil refinery
- Chemical Composition
  - About 75% butane and 25% propane
- Physical Properties
  - Calorific Value 104.9 MJ/m^3 (42.6 MJ/kg)
  - Specific Gravity 2.05 (*LPG will sink to the ground if leaked out*)
  - Limits of flammability 2% - 10%

Fuel Gas Supply

Use of Fuel Gas in Hong Kong

- Cooking, hot water supply, refrigeration, heating (space, cloth dryers, dishwashers, etc.)
  - >70% TG, <30% LPG
- LPG vehicles
  - Taxis, Light Buses

Fuel Gas Supply

Economics

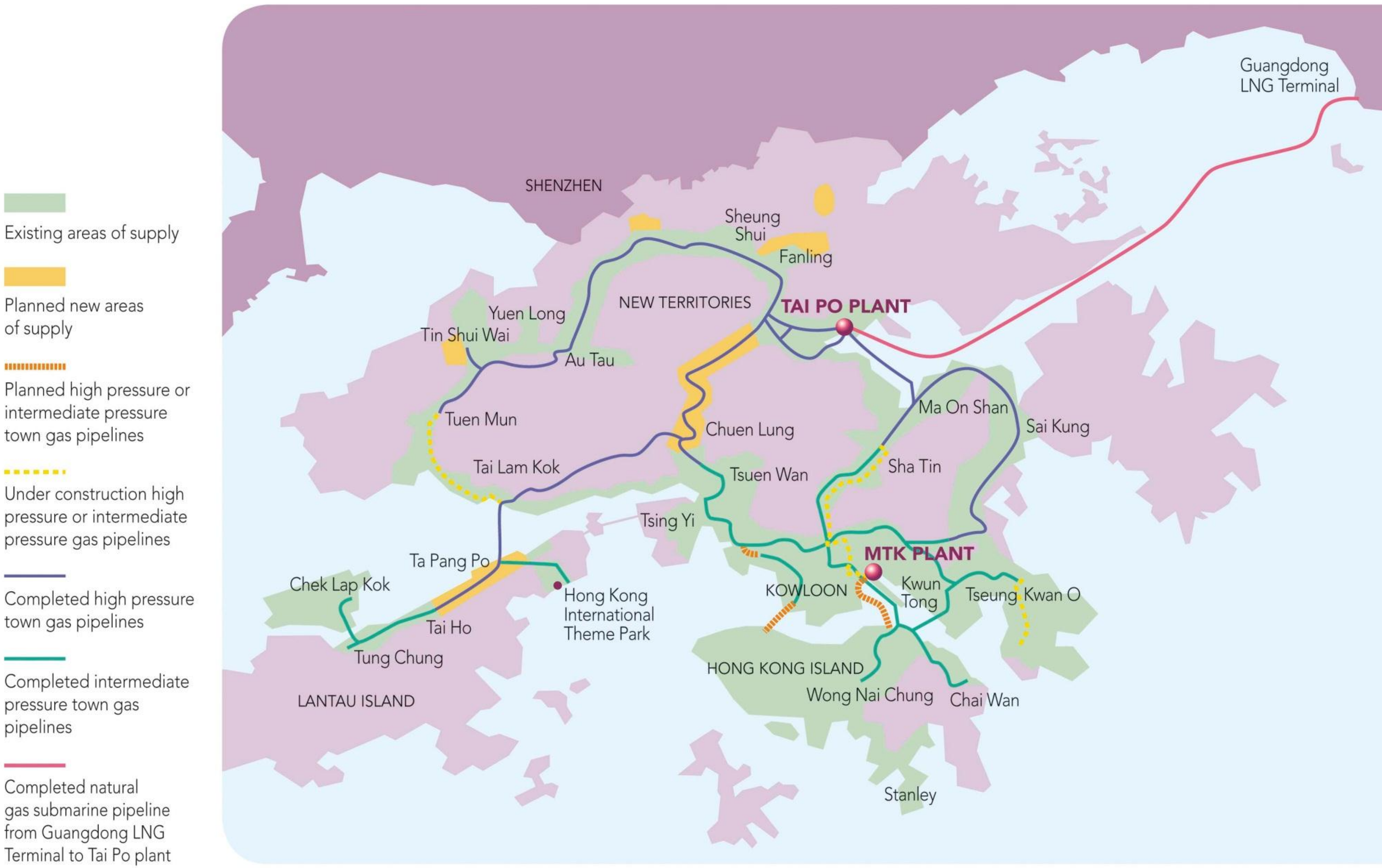
- TG – **21.9 cents / MJ** (first 500MJ, cheaper thereafter) + fuel cost adjustment **3.5 cents / MJ**
- LPG –
  - Cylinder Wholesale Price $10.2 / kg
  - Domestic Piped-in Price $31.79 / m^3
- the cost of consumption is best to be compared on a per MJ basis
  - Cylinder = $10.2/kg ÷ 42.6 MJ/kg = **23.9 cents/MJ**
  - Piped-in = $31.79/$m^3$ ÷ 104.9 MJ/m3 = **30.3 cents/MJ**

Fuel Gas Supply

Delivery

- **TG** is manufactured at its Tai Po and Ma Tau Kok plants then delivered under high pressure to its piping network grid (6.8 – 7.1kPa)
- Pressure is reduced before entering building premises which has a main riser and consumer pressure
(**1.0 – 1.5kPa**)

Towngas Network in Hong Kong



(Source: www.towngas.com*)*

Fuel Gas Supply

Delivery

- **LPG** is manufactured overseas and delivered to Hong Kong by vessels
- Stored in the LPG tanks then deliver to site either at cylinder (unitary) or to be filled into storage tanks at the premises (central supply)
- LPG is in liquid state when stored in tanks (70kPa), thus a vaporizer is required to convert LPG to gaseous state (7kPa) before delivery to consumers
- Operating pressure at consumer side is **3 kPa**

Fuel Gas Supply

Pipework Sizing

- The Pole Formula is used for determining the flow of gas in pipes. It is a simplification of the Darcy equation

$$Q = 0.0071\sqrt{\frac{d^5 \times h}{s \times l}}$$

  - Q = flow (m^3/h)
  - d = diameter of pipe (mm)
  - h = pressure drop (mbar)
  - l = length of pipe (m)
  - s = specific gravity of gas (density of gas / density of air)
- available pressure drop from meter to furthest outlet at **150Pa**, while leaving sufficient pressure at the index point (for pressure loss at the gas appliance)

Fuel Gas Supply

Pipework Sizing

- Consider a household using 1 gas water heater + 1 double burner table top cooker
  - Gas water heater = 126 MJ/hr
  - Double burner cooker = 41.8 MJ/hr (both burner included)
  - Total = 168MJ/hr = (168MJ/hr ÷ 17.27MJ/m^3) = 9.73m^3/hr
- Consider
  - Overall pressure drop = 100Pa = 1 mbar
  - Equivalent length of pipe = 20m
- d = 28.7mm

$$Q = 0.0071\sqrt{\frac{d^5 \times h}{s \times l}}$$

$$9.73 = 0.0071\sqrt{\frac{d^5 \times 1}{0.52 \times 20}}$$

- Common gas pipe into domestic flat = 32mm

Steam Systems

Properties of steam

- Basic thermodynamics
  - Steam: water heated to vaporization
  - At atmospheric pressure, temperature = 100℃
  - At higher pressure, vaporization temperature > 100℃
  - A steam phase diagram best illustrates this phenomenon

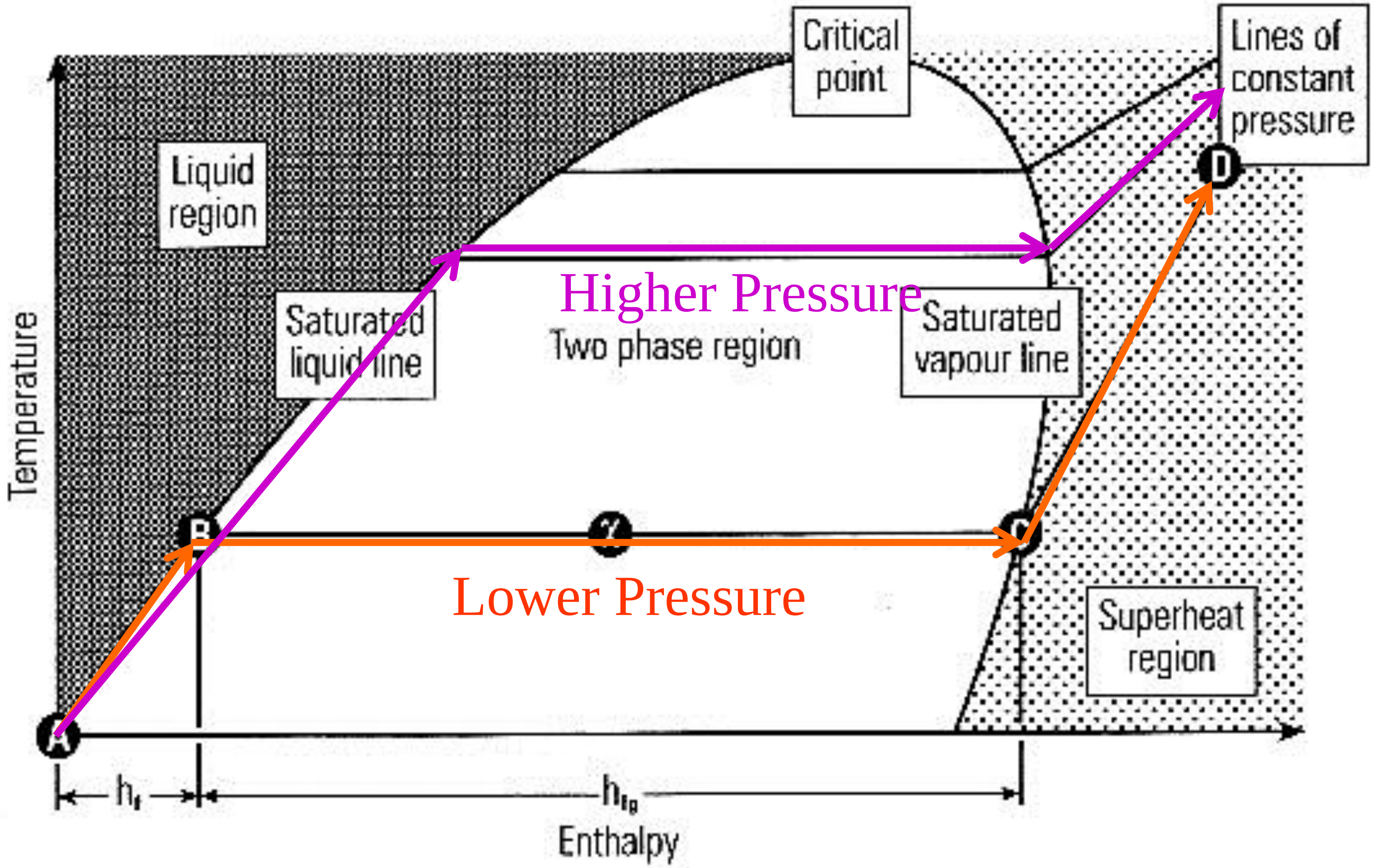


Fig. 2.2.3 Temperature enthalpy phase diagram

(Source: The Steam and Condensate Loop)

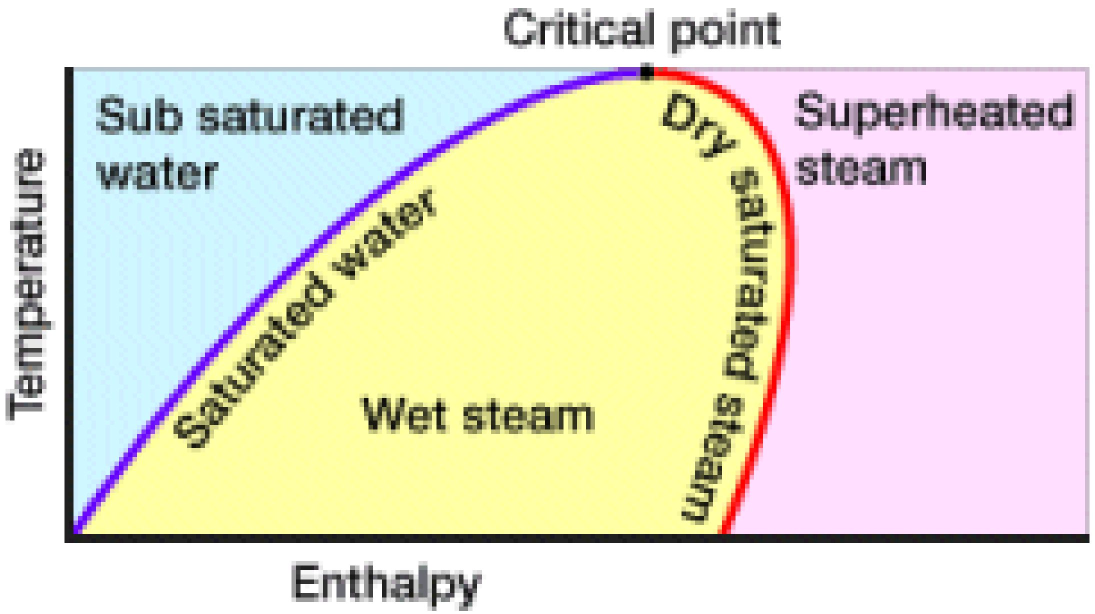
Properties of steam

Three types of heat in steam calculation:

- Specific heat of water (h_f)
  - Liquid water heated up to vaporization
- Specific enthalpy of evaporation (h_{fg})
  - Liquid water changes phase to form vapor (gaseous state)
- Specific enthalpy of steam (h_g)
  - $h_g = h_f + h_{fg}$

Properties of steam

- Heat values of water and steam can be found in Steam Tables
  - Dry steam and wet steam
  - Superheated steam



Properties of steam

- Steam tables
  - To determine various steam properties
    - Pressure
    - Temperature
    - Specific enthalpy
    - Specific volume (inverse of density)
    - Specific heat capacity
  - Published tables in databooks, such as CIBSE Guide C, Section 4, or IOP Guide
  - Total enthalpy, $h_g = h_f$ (sensible) + h_{fg} (latent)

Do you know how to use these steam tables?

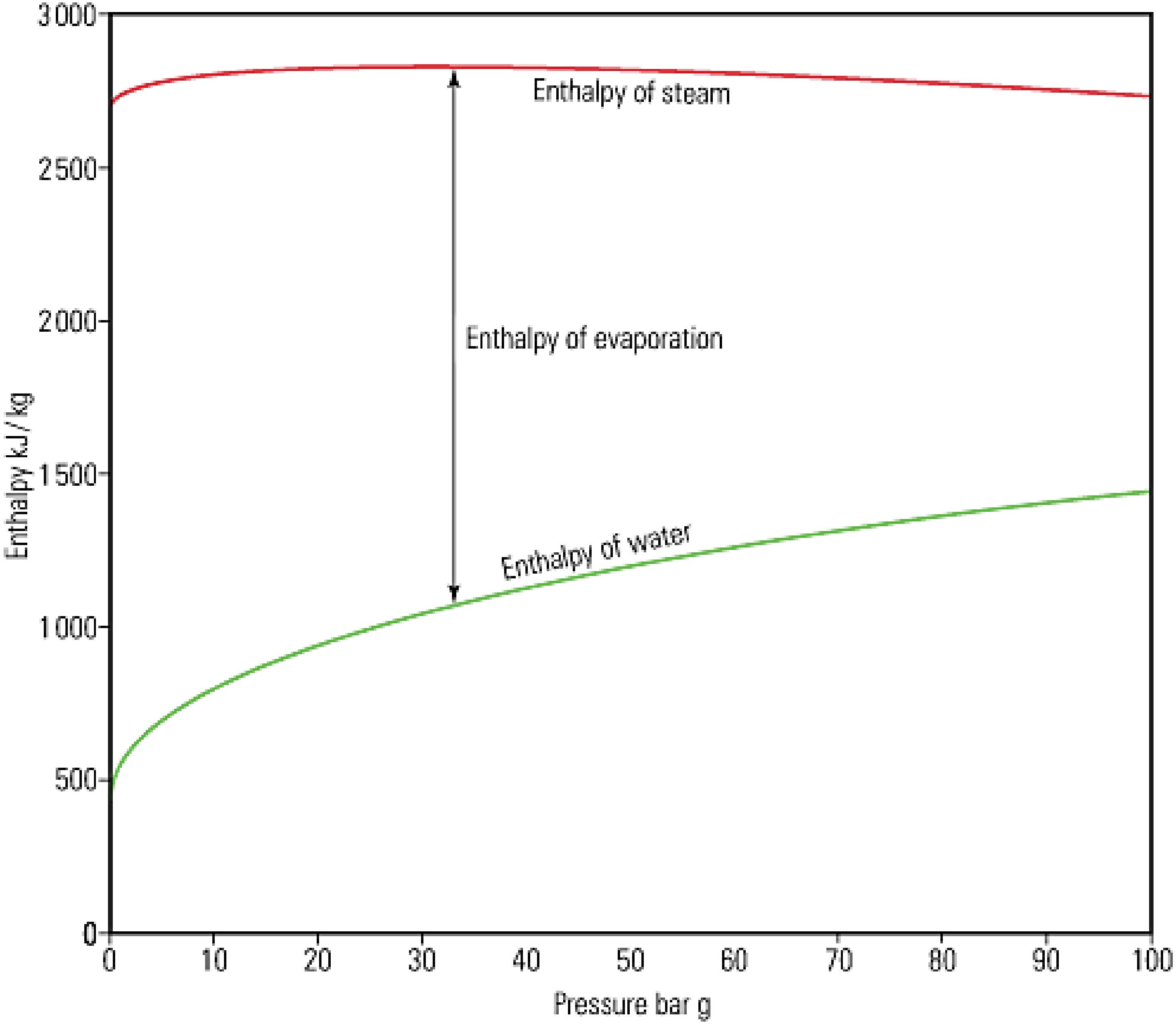
Extract from the saturated steam tables

Pressure bar g	Saturation temperature °C	Enthalpy kJ/kg			Volume of dry saturated steam m^3/kg
		Water h_f	Evaporation h_{fg}	Steam h_g	
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

(Source: www.spiraxsarco.com/learn)



The enthalpy/pressure diagram

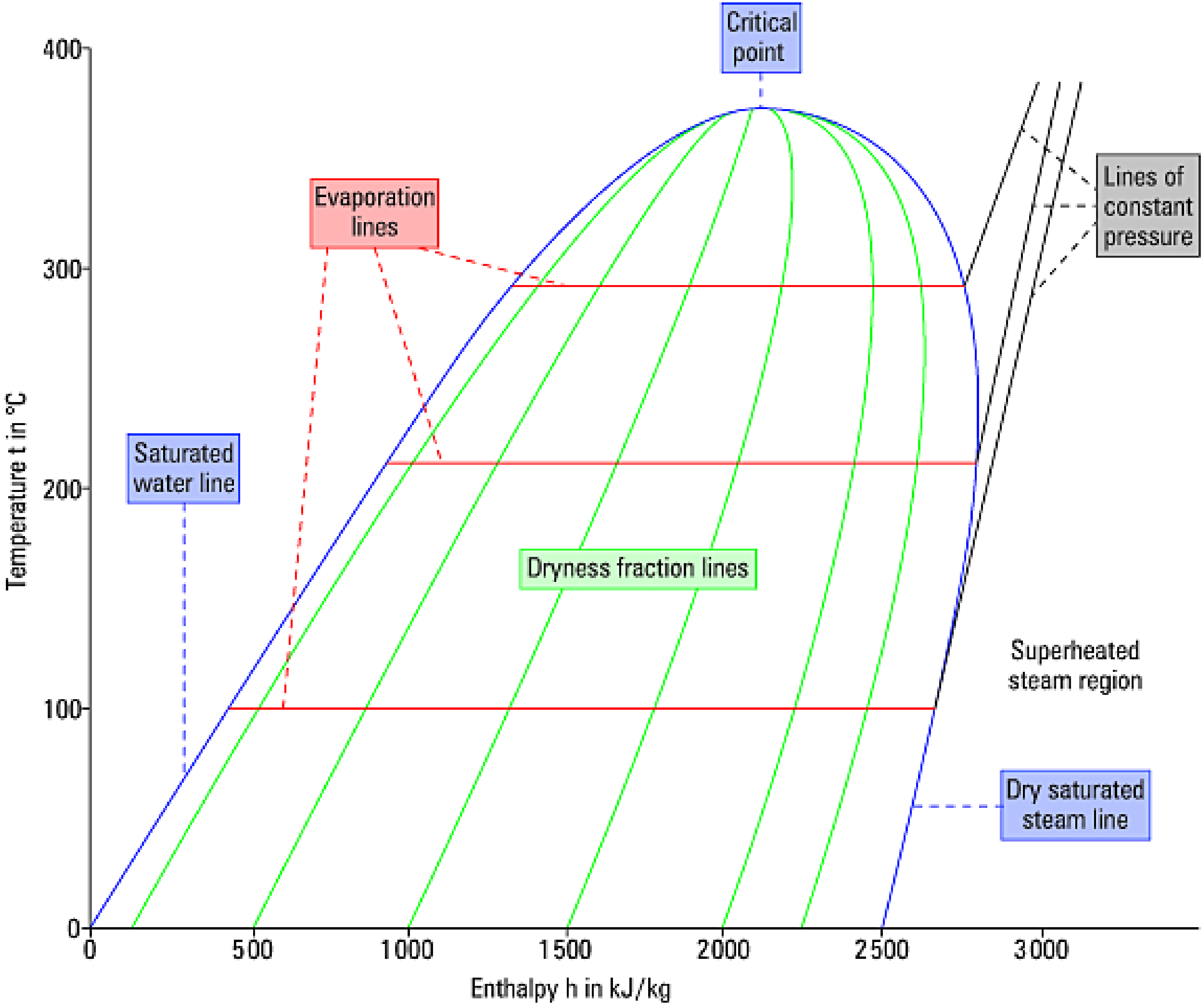
(Source: www.spiraxsarco.com/learn)

Properties of steam

- <u>Dryness of steam</u>
  - Steam often carries tiny droplets of water
  - *Dryness fraction (χ)* = proportion of completely dry steam present in the steam-moisture mixture
    - $\chi = 1$ for complete dryness
  - Wet steam has a heat content substantially lower than that of dry saturated steam at the same pressure
    - Actual enthalpy of evaporation = $h_{fg} \cdot (\chi)$
    - Actual total enthalpy = $h_f + h_{fg} \cdot (\chi)$

Properties of steam

- Superheated steam
  - If the saturated steam produced in a boiler is exposed to further heating, its temperature will increase above the evaporating temperature → *Superheated*
  - When superheated steam gives up some of its enthalpy (e.g. heat loss to pipes), a fall in temperature will not cause condensation, until the temperature drops to saturation temperature when condensation begins



The temperature/enthalpy diagram

(Source: www.spiraxsarco.com/learn)

Uses of steam

- Steam is used:
  - As a heating medium for industrial process, heating & hot water in buildings, cooking
  - To produce electrical power in power plants
- Common applications:
  - As a primary medium for distributing heat in factories, hospitals and hotels
  - Means of sterilizing, cooking (Chinese restaurants)
  - Space heating
  - Hot water supply (via calorifiers)

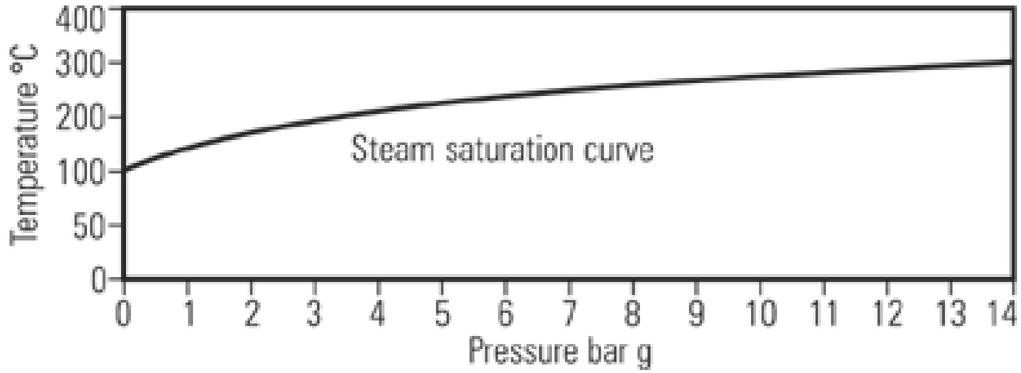
Industries and processes which use steam

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: www.spiraxsarco.com/learn)

Uses of steam

- Heat transfer
  - Heat of evaporation = 2,257 kJ/kg at atm pressure (slightly higher heat at higher pressure)
  - Sensible heat of water = 419 kJ/kg (0 to 100 ℃)
- Flow at high velocity (24-36 m/s) and high temperature (100-198 ℃)

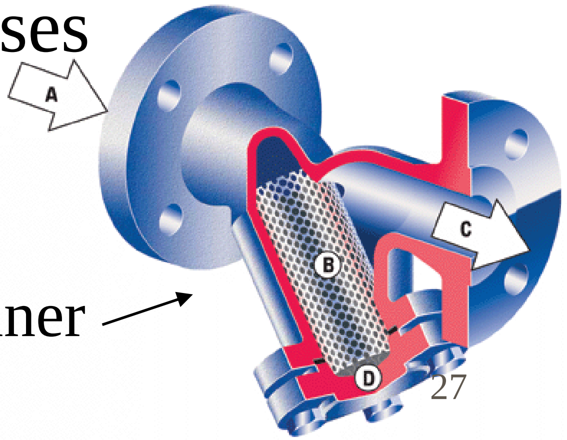


Uses of steam

- 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
  - Higher risk if not properly maintained

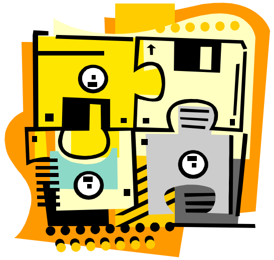
Uses of steam

- Steam quality: a term governing the property of steam
- 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

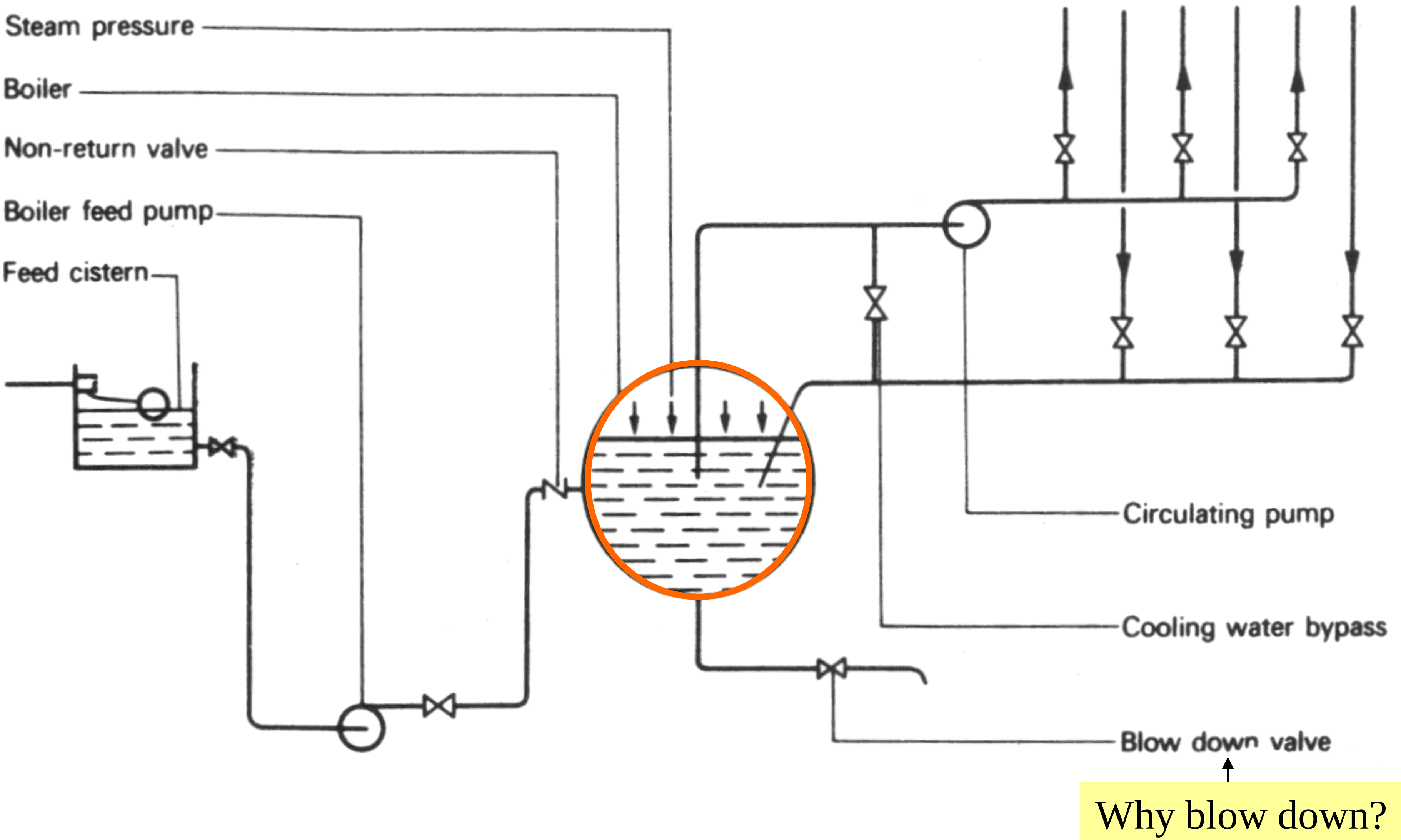


Pipeline strainer

System components



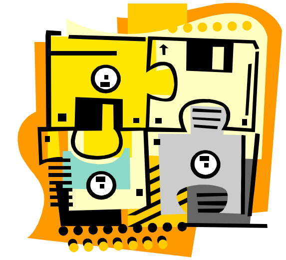
- Basic arrangements
  - Boiler plant using steam pressurization
    - Hot water boiler (w/ steam maintained inside)
    - Boiler feed pump & cistern
    - Circulating pump & pipework
    - Cooling water bypass (mixing to control the pressure)
  - Steam & the water are at saturation temperature



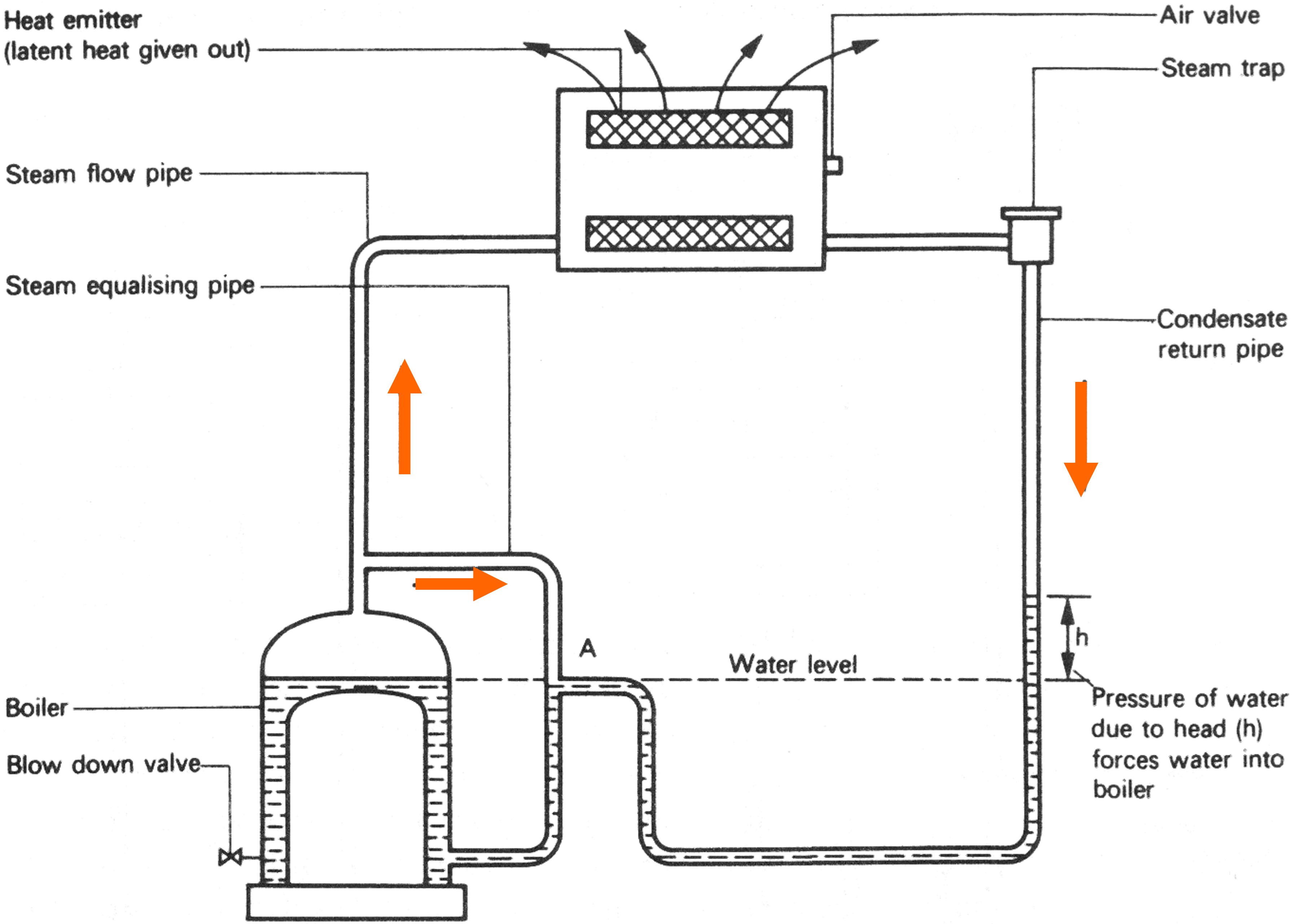
Boiler plant using steam pressurisation

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

System components



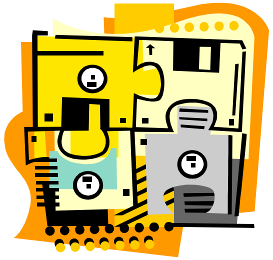
- Use steam directly for heating
  - Low pressure: up to 35 kPa (gauge pressure)
  - Medium pressure: 140 to 550 kPa
  - High pressure: 550 to 1400 kPa
- Low pressure steam
  - It has a higher heat content
  - Causes less risk of noise and wear
- Medium or high pressure
  - For large installations with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



Operating principle of steam heating

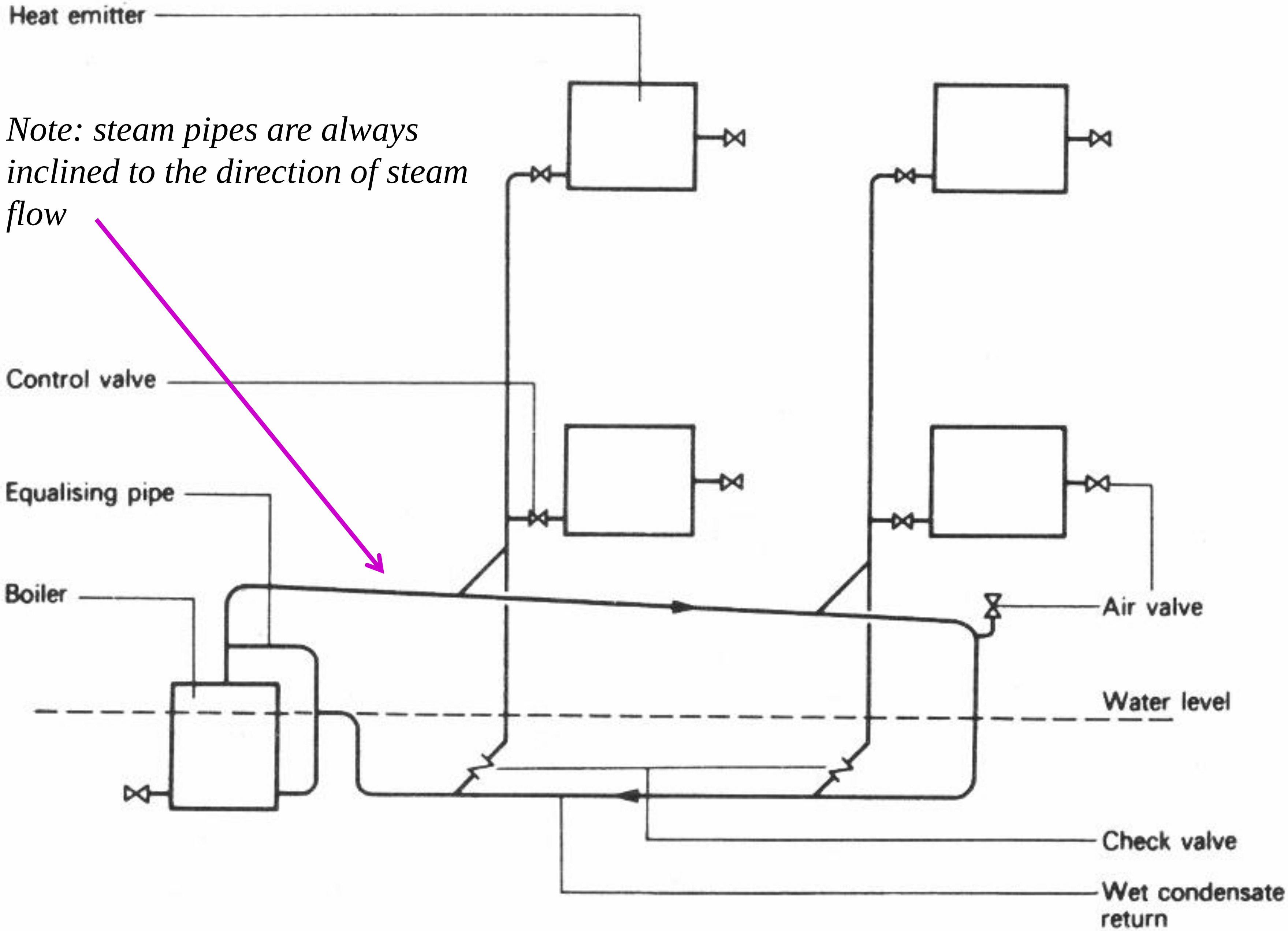
(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

System components



- Classification of steam systems:
  - By method of condensate return
    - Gravity
    - Mechanical
  - By pipe layout
    - One pipe or two pipe
    - Up-feed or down-feed

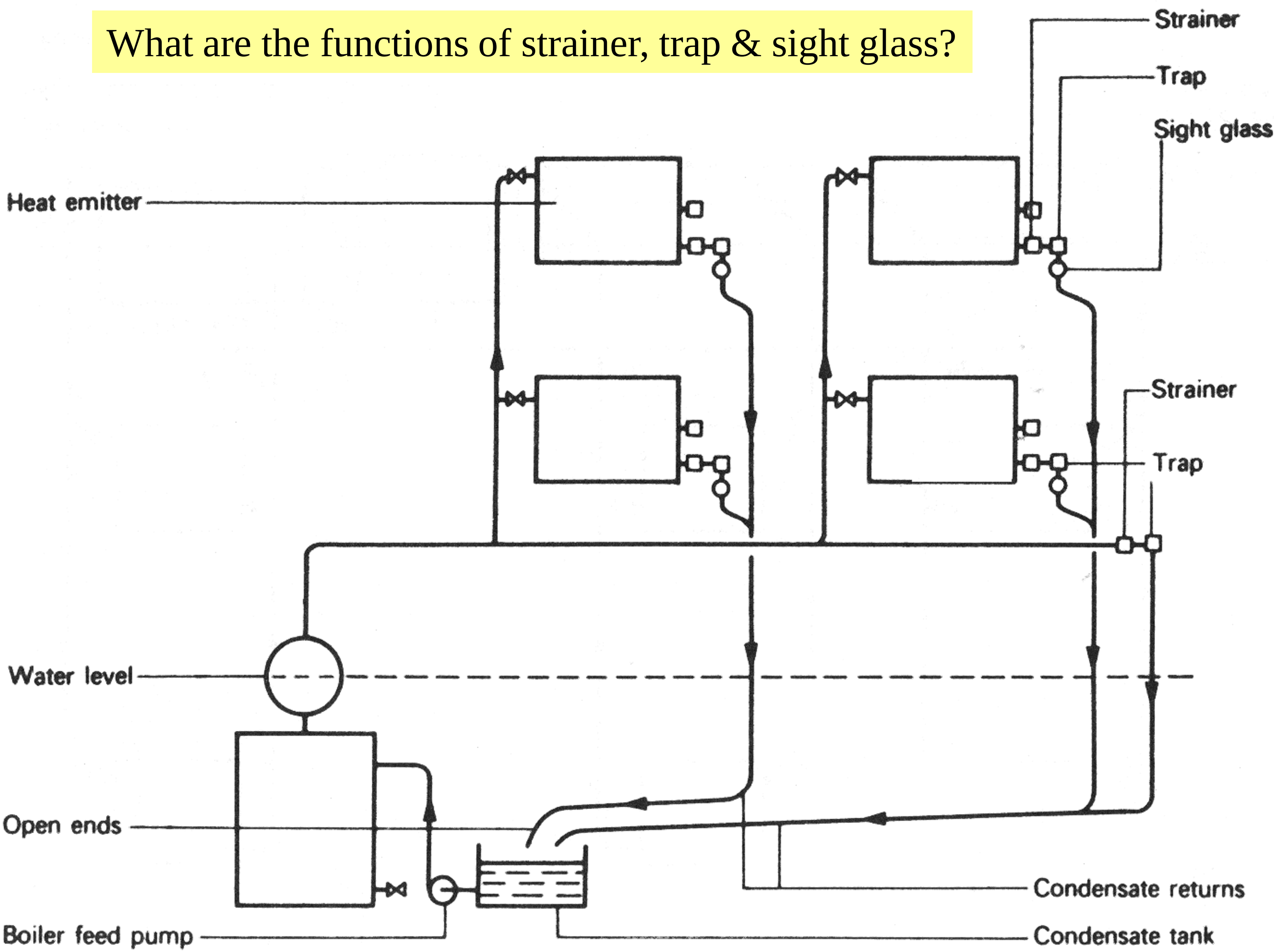
Note: steam pipes are always inclined to the direction of steam flow



One-pipe gravity steam heating system

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

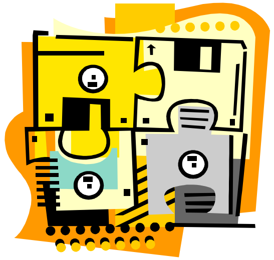
What are the functions of strainer, trap & sight glass?



Two-pipe mechanical steam heating system

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

System components



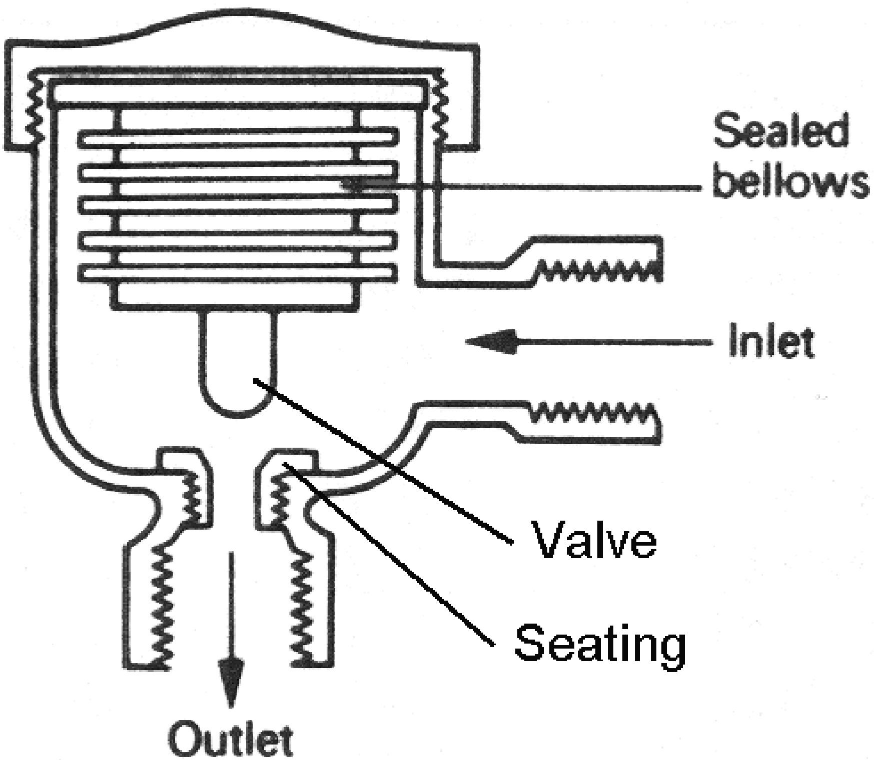
- Steam traps
  - Purpose: to remove condensate inside appliances, pipelines or heat exchangers
  - Condensate returns to boiler
    - By gravity (runs back to boiler)
    - By automatic pump (pumped back to boiler)
    - By condensate lifting trap
  - Three main groups of steam traps: thermostatic, mechanical and thermodynamic

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

Typical types of steam traps

(Source: www.spiraxsarco.com/learn)

Thermostatic



Thermostatic steam trap

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

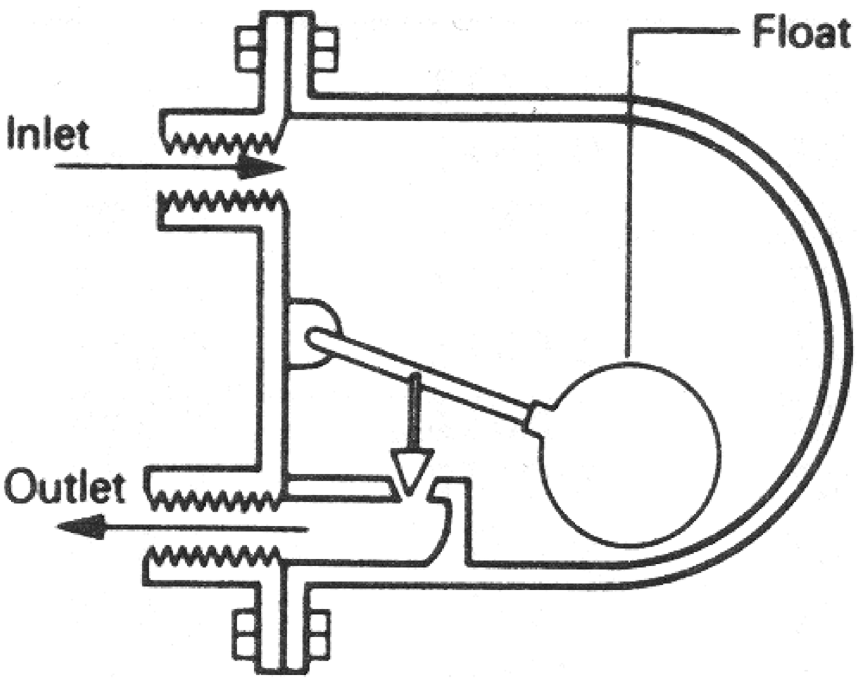
Operating principle:

- 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

Mechanical



Ballfloat steam trap

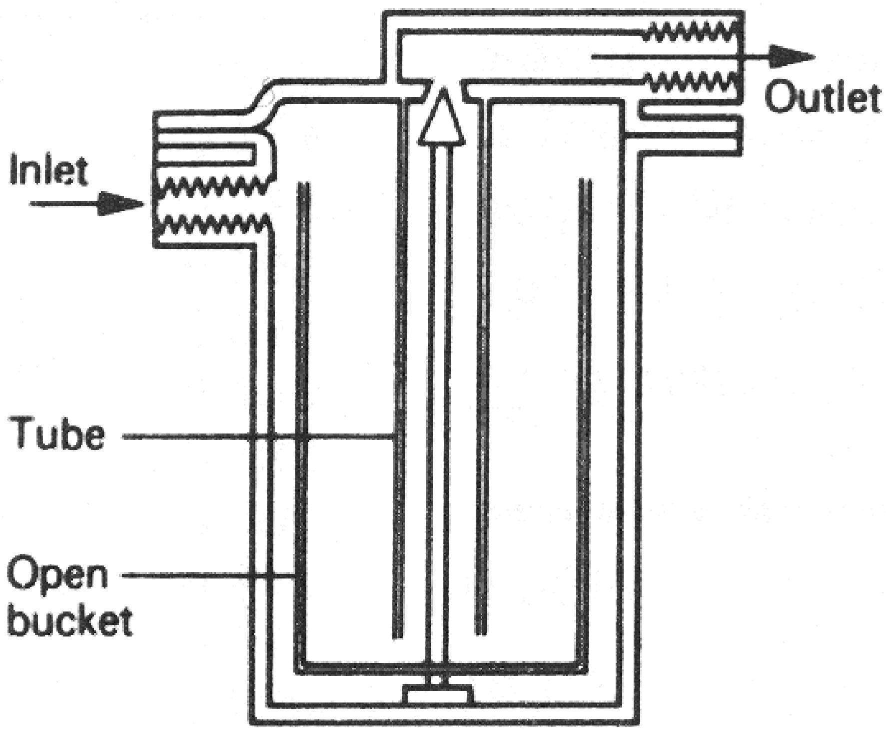
Operating principle:

- 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

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

Mechanical



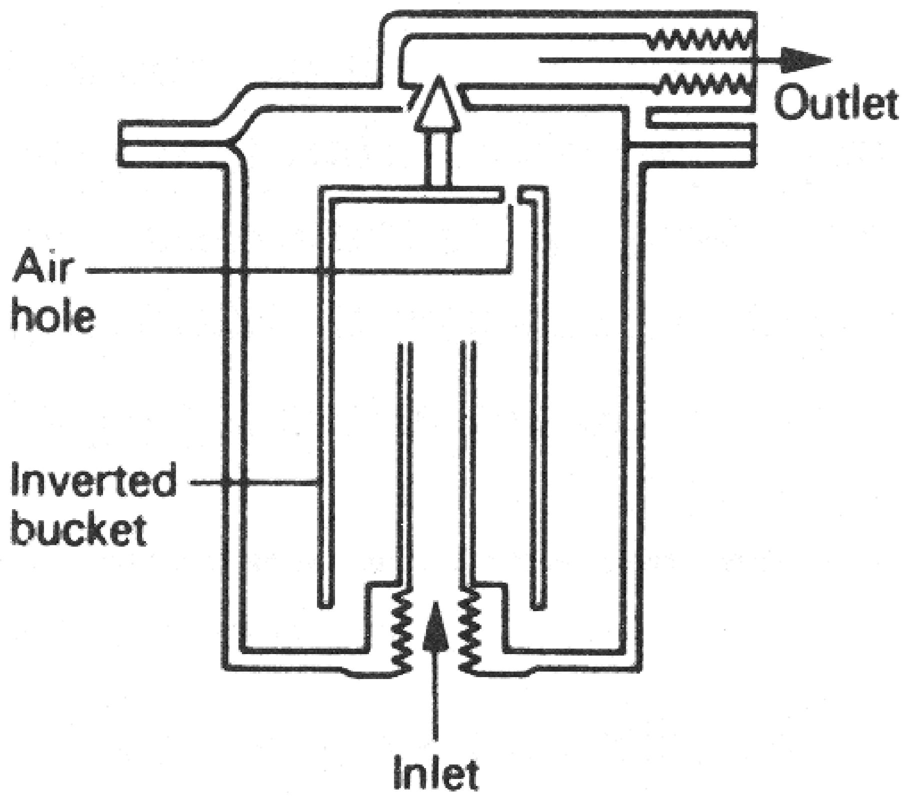
Open bucket steam trap

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

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

Mechanical



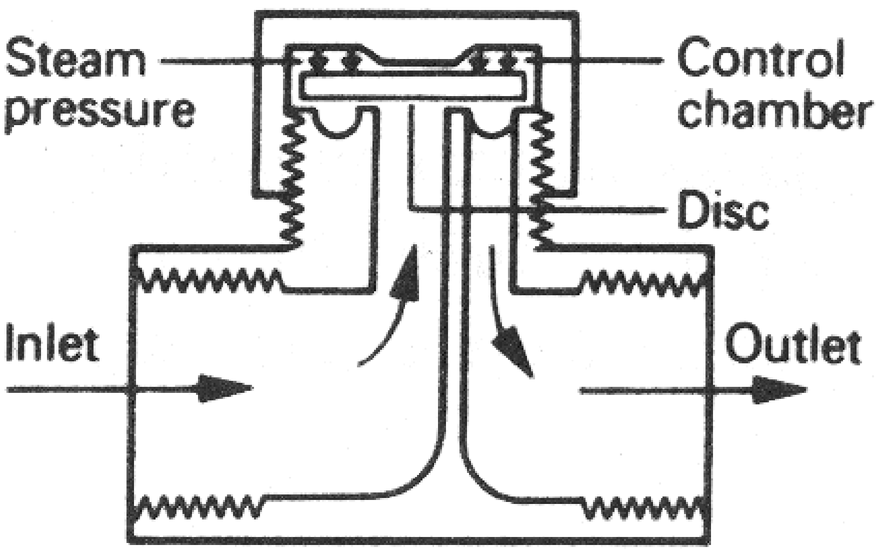
Inverted bucket steam trap

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

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

Thermodynamic



Thermodynamic steam trap

Bernoulli principle:
kinetic pressure + potential energy = constant

Operating principle:

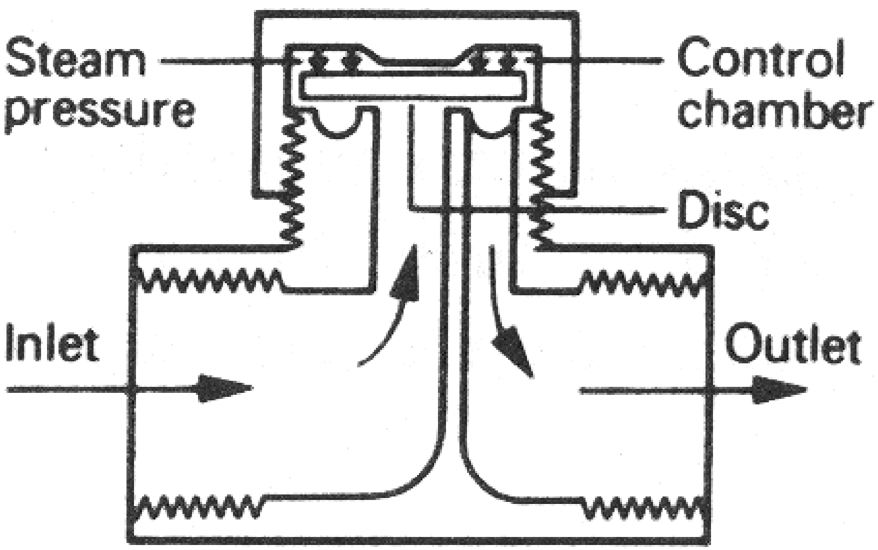
• Steam flows through trap → increase kinetic energy between disc & seating → reduce pressure energy at this point → disc moves nearer the seating until kinetic energy decreases

• 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):

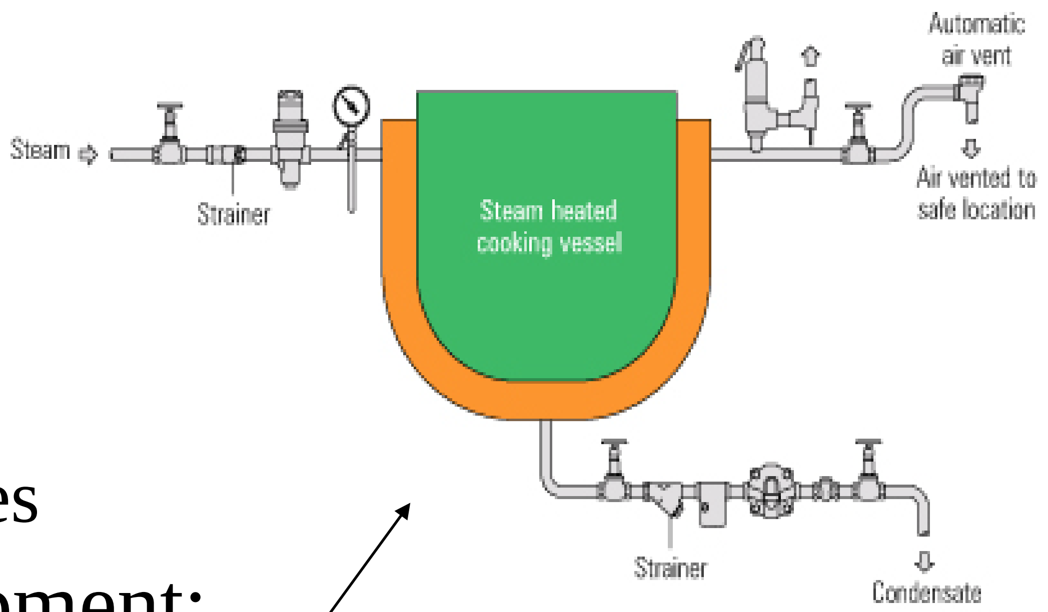
- Water (condensate) enters trap → steam above disc condenses → reduce pressure → disc forced up→ water flow through trap

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

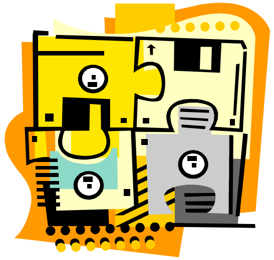
(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

System components

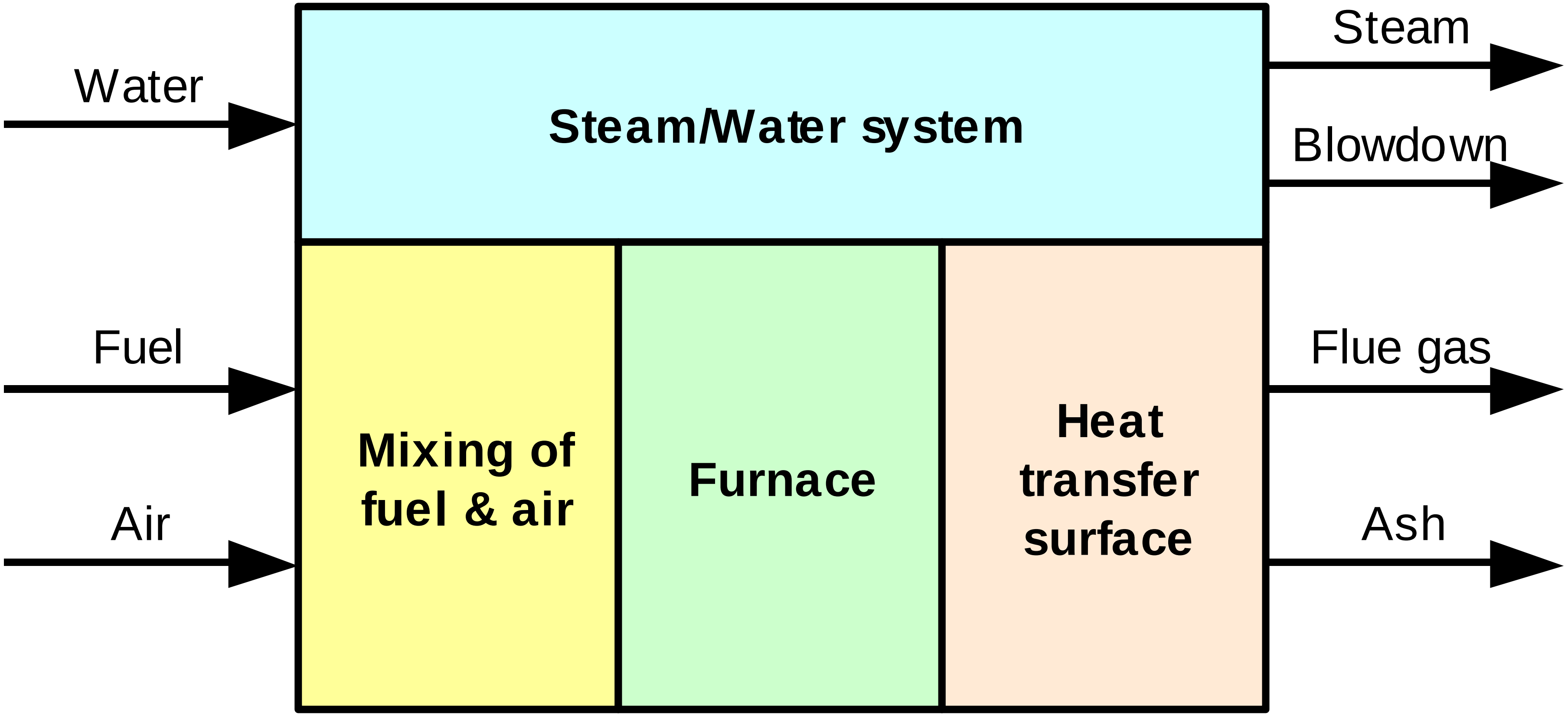
- Other components
  - Steam separators
  - Strainers
  - Automatic air vent
  - Check valves
  - Isolation valves
  - Gauges, sight glasses
- Typical steam equipment:
  - Steam heated cooking vessel



System components



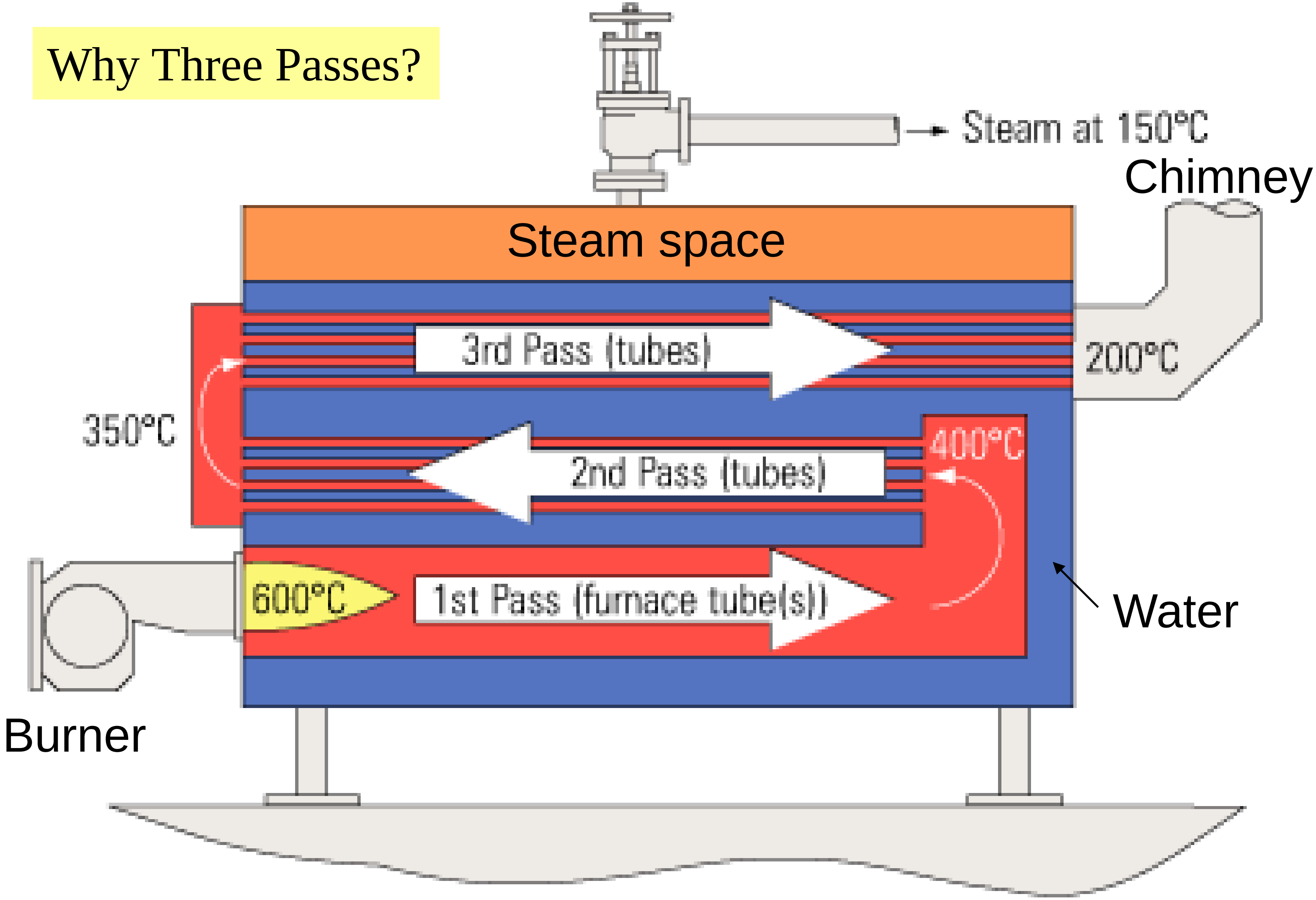
- Boilers – classified according to:
  - Type of working fluid or heat carrier used
    - Such as steam and hot water
  - Physical arrangement of the working fluid
    - Fire tube: flue gas products flow through boiler tubes
    - Water tube: water circulates within boiler tubes
  - Combustion gases/fuels
    - Natural gas, town gas, diesel, etc.
    - Gas & oil replace coal for fuel of boiler/furnace
      - Easier to handle & less pollution product



Basic diagram of a boiler

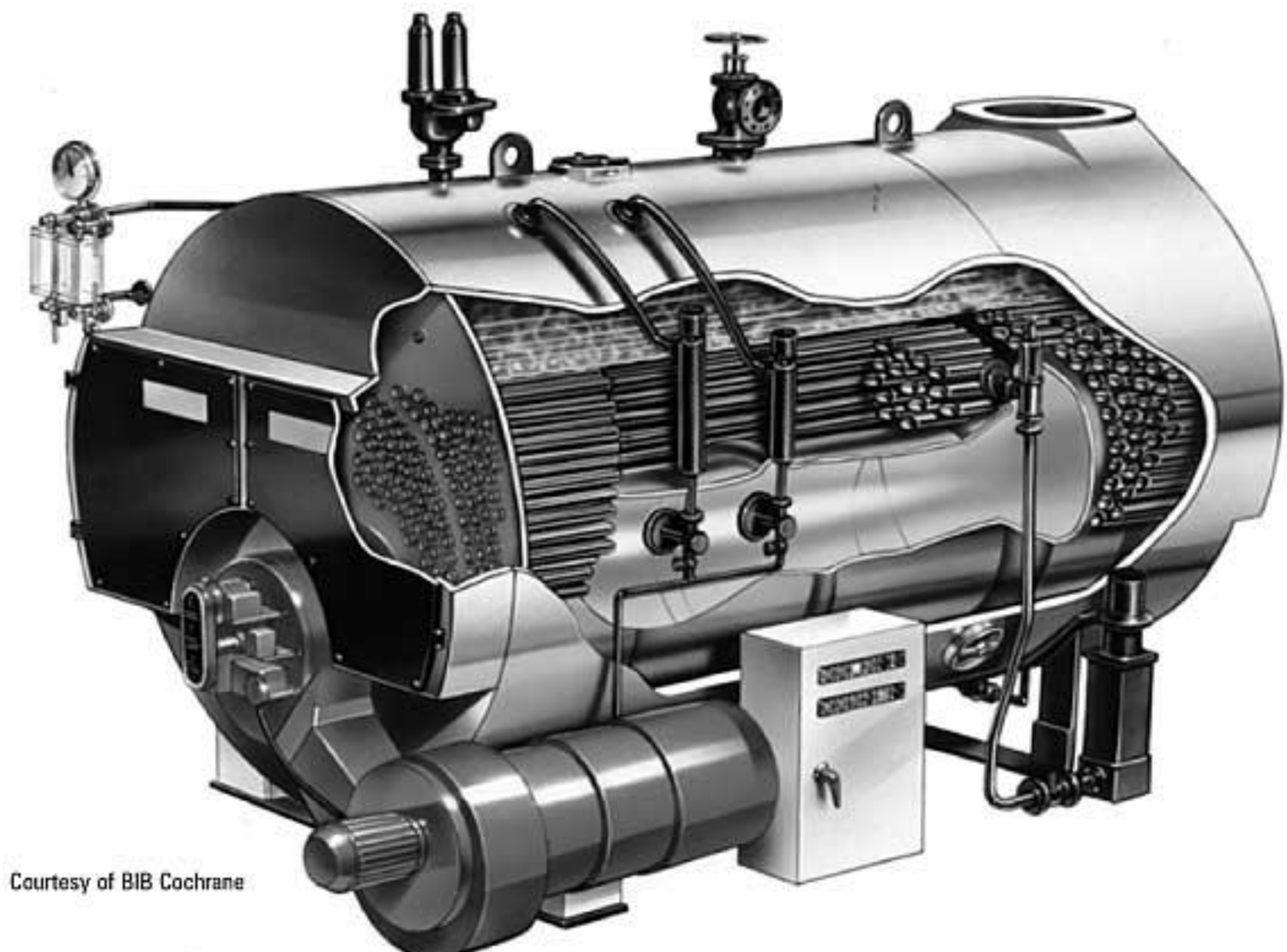
Blowdown: removal of suspended solids due to chemical dosing of boiler feedwater (twice a day)

Why Three Passes?



Typical heat path through a smoke tube shell boiler

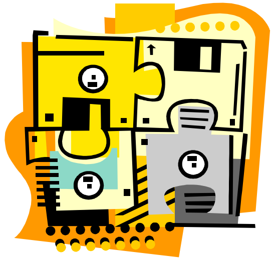
(Source: www.spiraxsarco.com/learn)



Modern packaged boiler

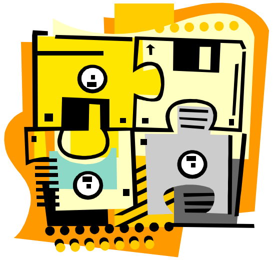
(Source: www.spiraxsarco.com/learn)

System components

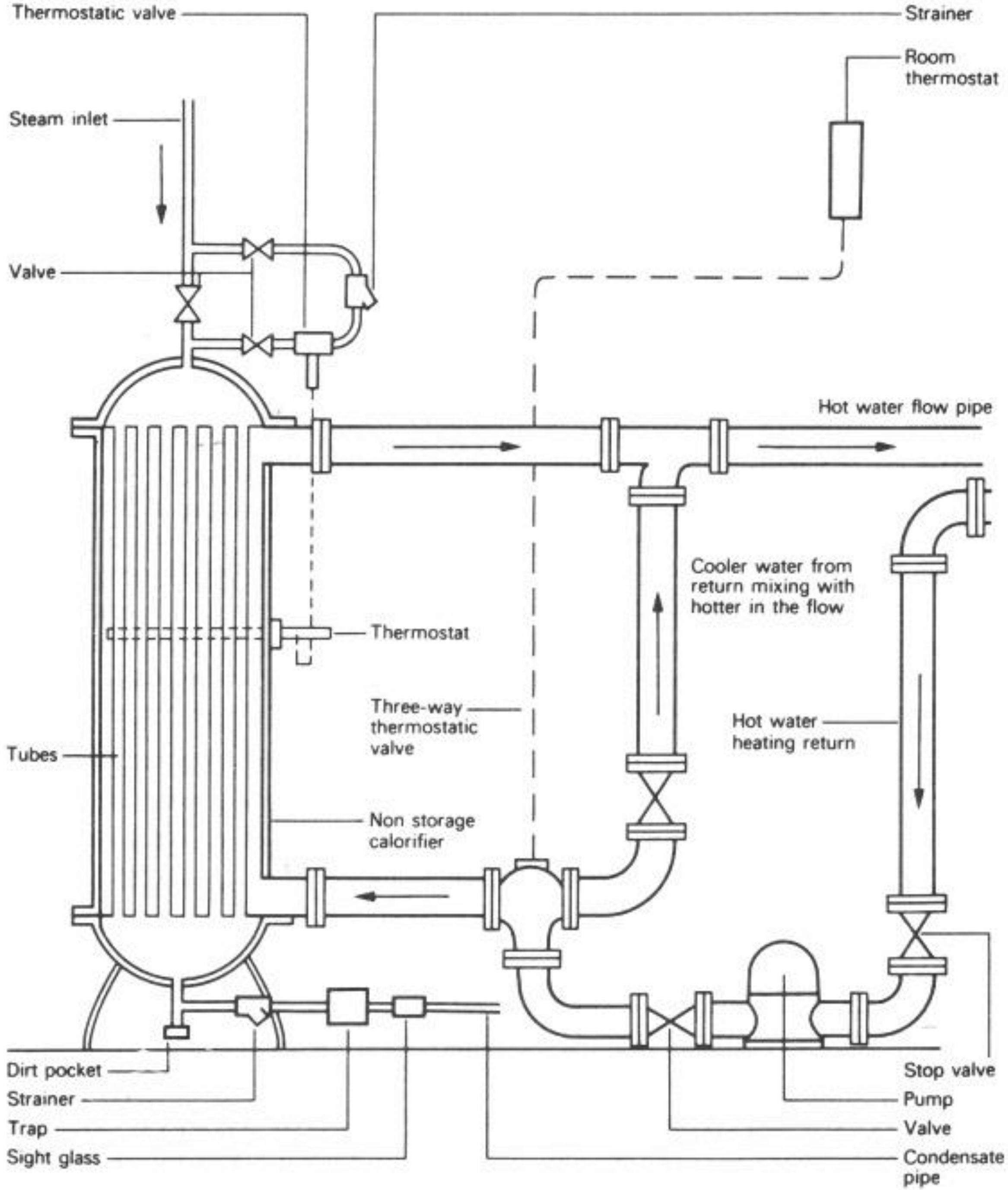


- Steam boilers (high and low pressure)(ASTM)
  - High-pressure > 100 kPa (gauge)
    - Reduce size of boiler & steam piping (due to density)
    - But decrease boiler efficiency
    - Good for heat load at long distance
  - Low-pressure <= 100 kPa (gauge)
    - Simpler in both design & operation
    - No pressure-reducing valves are required
    - Water chemical treatment less costly & complex

System components



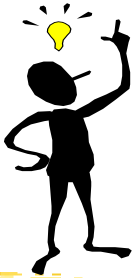
- Hot water boilers (high and low temperature)
  - High-temperature hot water (HTHW) boiler
    - Water at temp. > 121 ^{o}C or pressure > 1,100 kPa
    - Carry greater heat; reduce pumping & piping costs
  - Low-temperature hot water (LTHW) boiler
    - Water at temp. < 96 ^{o}C or pressure <= 1,100 kPa
- Calorifiers
  - Provide storage & allow heat exchange (common)
  - Non-storage calorifiers can also be used for providing hot water for space heating (see figure)



Non-storage type calorifier

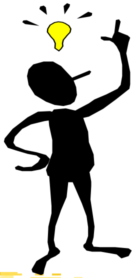
(Source: Hall, F. and Greeno, R., 2008. *Building Services Handbook*)

Design considerations

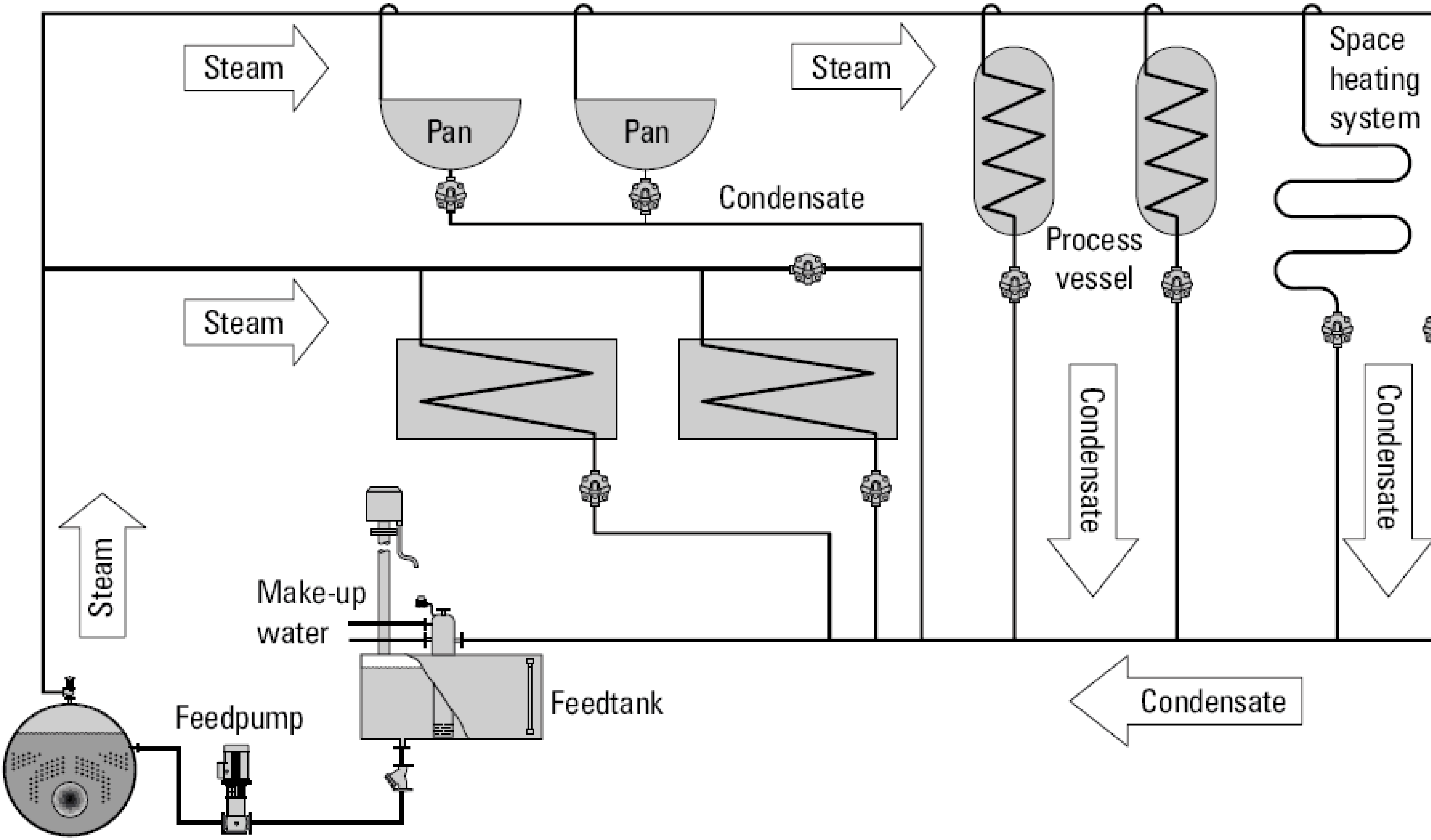


- Methods of estimating steam consumption
  - Calculation - By analysing the heat output on an item of plant using heat transfer equations
  - Measurement - By direct measurement, using flowmetering equipment (for an existing plant)
  - Thermal rating - design rating displayed on the equipment name-plate (in kW). The steam consumption required in kg/h will depend on the recommended steam pressure
    - Steam flow rate (kg/h) = (Load in kW x 3600) / h_{fg}

Design considerations



- Efficient steam distribution system:
  - Steam of the right quality and pressure is to be supplied, in the right quantity, to the steam using equipment
- Major issues of steam system design
  - Sufficient pressure difference
  - Pipeline velocity
  - Condensate return
  - Safety issues
  - Testing & commissioning
  - Operation & maintenance

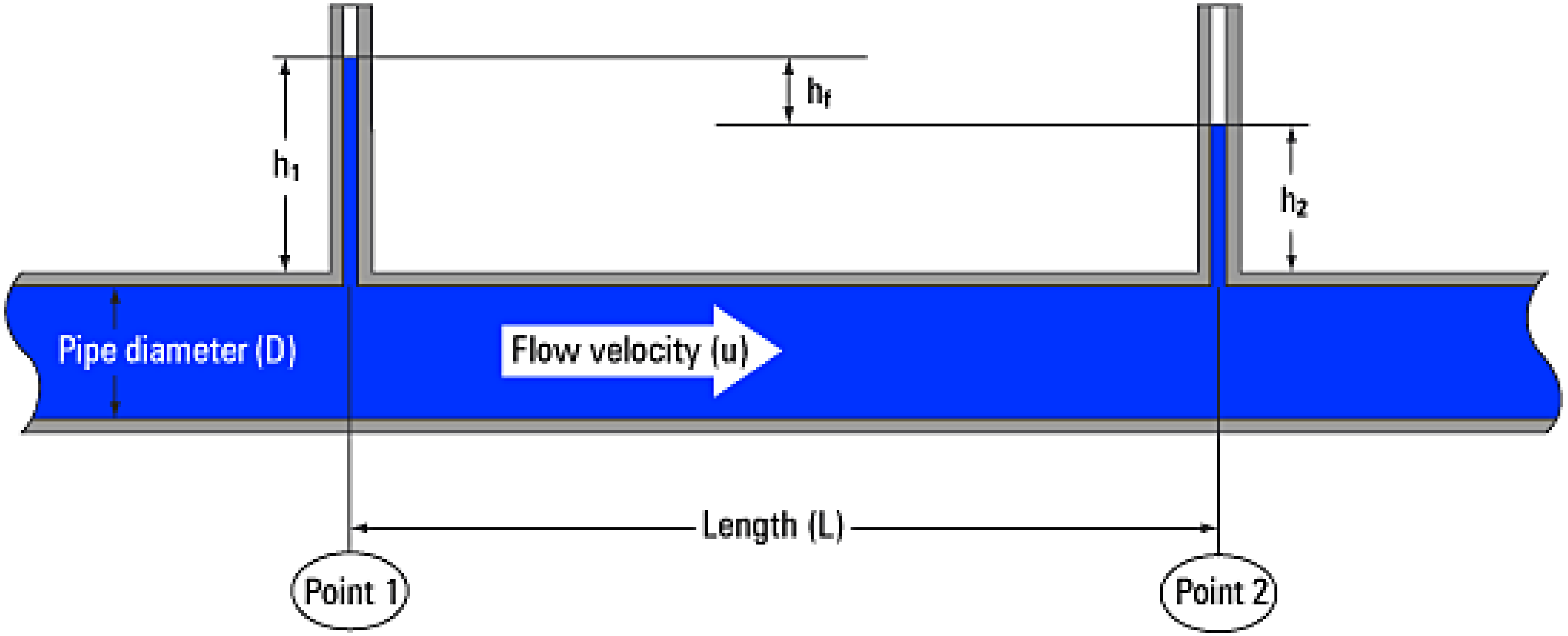


A typical basic steam circuit

(Source: www.spiraxsarco.com/learn)

Design considerations

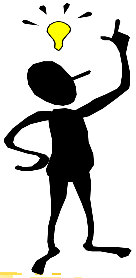
- Steam pipe sizing
  - Info. required:
    - Initial or final steam pressure, temperature & quality (e.g. 100kPa supply pressure, 80kPa condensate return)
    - Steam flow rate
    - Length of the pipe
    - Permissible pressure drop
    - Permissible velocity of flow
  - Detailed pipe sizing procedure & data can be found in the further reading materials



D'Arcy equation: $$h_f = \frac{f \cdot L \cdot u^2}{2 \cdot g \cdot D}$$

where h_f = head loss to friction (m)
f = friction factor (dimensionless)
L = length (m)
u = flow velocity (m/s)
g = gravitational constant (9.81 m/s^2)
D = pipe diameter (m)

Design considerations



- Steam pipe sizing (cont'd)
  - Friction factor can be difficult to determine, especially for turbulent steam flow. As a result, some graphs, tables and slide rules are produced to relate steam pipe sizes to flowrates and pressure drops, e.g. the "pressure factor" method:
    - $F = (P_1 - P_2) / L$
      - F = pressure factor
      - P_1 = factor based on the inlet pressure
      - P_2 = factor based on the pressure at a distance of L metres
      - L = equivalent length of pipe (m)

Appendix

Table 10.2.5 Pressure drop factor (F) table

Pressure bar a	Pressure factor (F)
0.05	0.0301
0.10	0.0115
0.15	0.0253
0.20	0.0442
0.25	0.0681
0.30	0.0970
0.35	0.1308
0.40	0.1694
0.45	0.2128
0.50	0.2610
0.55	0.3140
0.60	0.3716
0.65	0.4340
0.70	0.5010
0.75	0.5727
0.80	0.6489
0.85	0.7298
0.90	0.8153
0.95	0.9053
1.013	1.0250

Pressure bar g	Pressure factor (F)
0	1.025
0.05	1.126
0.10	1.230

Pressure bar g	Pressure factor (F)
2.05	8.748
2.10	9.026
2.15	9.309
2.20	9.597
2.25	9.888
2.30	10.18
2.35	10.48
2.40	10.79
2.45	11.40
2.50	11.41
2.55	11.72
2.60	12.05
2.65	12.37
2.70	12.70
2.75	13.03
2.80	13.37
2.85	13.71
2.90	14.06
2.95	14.41
3.00	14.76
3.10	15.48
3.20	16.22
3.30	16.98
3.40	17.75
3.50	18.54
3.60	19.34
3.70	20.16

Pressure bar g	Pressure factor (F)
7.60	64.84
7.70	66.31
7.80	67.79
7.90	69.29
8.00	70.80
8.10	72.33
8.20	73.88
8.30	75.44
8.40	77.02
8.50	78.61
8.60	80.22
8.70	81.84
8.80	83.49
8.90	85.14
9.00	86.81
9.10	88.50
9.20	90.20
9.30	91.92
9.40	93.66
9.50	95.41
9.60	97.18
9.70	98.96
9.80	100.75
9.90	102.57
10.00	104.40
10.20	108.10
10.40	111.87

Table 10.2.6 Pipeline capacity and pressure factor table

Factor F	Pipe size (mm)												
	15	20	25	32	40	50	65	80	100	150	200	250	300
	Capacity (kg/h)												
0.00016						30.40	55.41	90.72	199.1	598.2	1 275	2 329	3 800
0.00020					16.18	34.32	62.77	103.0	225.6	662.0	1 437	2 623	4 276
0.00025				10.84	17.92	38.19	69.31	113.2	249.9	735.5	1 678	2 904	4 715
0.00030				11.95	19.31	41.83	75.85	124.1	271.2	804.5	1 733	3 172	5 149
0.00035			6.86	12.44	20.59	43.76	80.24	130.0	285.3	845.3	1 823	3 346	5 530
0.00045		3.62	7.94	14.56	23.39	50.75	92.68	150.9	333.2	979.7	2 118	3 884	6 267
0.00055		4.04	8.99	16.18	26.52	57.09	103.8	170.8	373.1	1 101	2 382	4 338	7 057
0.00065		4.46	9.56	17.76	29.14	62.38	113.8	186.7	409.8	1 207	2 595	4 781	7 741
0.00075		4.87	10.57	19.31	31.72	68.04	124.1	203.2	445.9	1 315	2 836	5 172	8 367
0.00085		5.52	11.98	21.88	35.95	77.11	140.7	230.2	505.4	1 490	3 215	5 861	9 482
0.00100	1.96	5.84	12.75	23.50	38.25	81.89	148.6	245.2	539.4	1 579	3 383	6 228	10 052
0.00125	2.10	6.26	13.57	24.96	40.72	87.57	159.8	261.8	577.9	1 699	3 634	6 655	10 639
0.00150	2.39	7.35	15.17	28.04	45.97	98.84	179.3	295.1	652.8	1 908	4 091	7 493	11 999
0.00175	2.48	7.51	16.30	29.61	49.34	103.4	188.8	311.1	686.5	2 017	4 291	7 852	13 067
0.0020	2.84	8.58	18.63	33.83	56.39	118.2	215.8	355.5	784.6	2 305	4 904	8 974	14 956
0.0025	3.16	9.48	20.75	37.25	61.30	132.0	240.5	391.3	881.7	2 456	5 422	10 090	16 503
0.0030	3.44	10.34	22.5	40.45	66.66	143.4	262.0	429.8	924.4	2 767	6 068	11 033	18 021
0.0040	4.17	12.50	26.97	48.55	80.91	173.1	313.8	514.9	1 128	3 330	7 208	13 240	21 625
0.0050	4.71	14.12	30.40	54.92	90.23	196.1	354.0	578.6	1 275	3 727	8 189	14 858	24 469
0.0060	5.25	15.69	35.80	60.31	99.05	215.8	392.3	647.3	1 412	4 148	9 072	16 476	26 970
0.0080	6.08	18.34	39.23	70.12	116.2	251.5	456.0	750.3	1 648	4 879	10 543	19 173	31 384
0.0100	6.86	20.64	44.13	79.44	130.4	283.9	514.9	845.9	1 863	5 492	11 867	21 576	35 307
0.0125	7.35	22.20	47.28	81.00	140.1	302.1	547.3	901.9	1 983	5 867	12 697	23 074	37 785
0.0150	8.27	25.00	53.33	95.62	157.2	342.0	620.6	1 020	2 230	6 620	14 251	25 974	42 616
0.0175	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Pipe Sizing Example

- Boiler producing steam at 7 bar
- Minimum pressure at heater = 6.6 bar (relates to steam temp.)
- Consider a heater steam load = 270 kg/h
- The overall equivalent length of pipe = 165m
- Take heat loss from pipework = 3.5% of load per 100m

Thus

- Revised steam load = 270 + 270 (3.5% $\times$ 165/100) = 286 kg/h

- Steam Pressure Drop Factor Table
  - 6.6 bar = 51.05
  - 7 bar = 56.38
- $F = (P_1 - P_2) / L$
- $F = (56.38 - 51.05) / 165$
- $F = 0.032$

6.60	51.05
6.70	52.36
6.80	53.68
6.90	55.02
7.00	56.38

From ‘Pipeline Capacity’

F = 0.030

Capacity = 501.1 kg/h

Size = 50mm

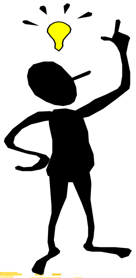
Factor F	Pipe size (mm)							
	15	20	25	32	40	50	65	80
	Capacity (kg/h)							
0.0250	10.99	33.48	70.73	127.3	209.8	459.7	834.6	1 367
0.0300	12.00	36.78	77.23	137.9	229.9	501.1	919.4	1 480
0.0400	14.46	44.16	93.17	169.2	279.5	600.7	1 093	1 790

- After sizing the pipe, the flow velocity has to be calculated
- Steam = 286kg/h at 7 bar (specific volume = 0.24 m^3/kg)
- Thus volume flow = 68.64 m^3/h = 0.019 m^3/s

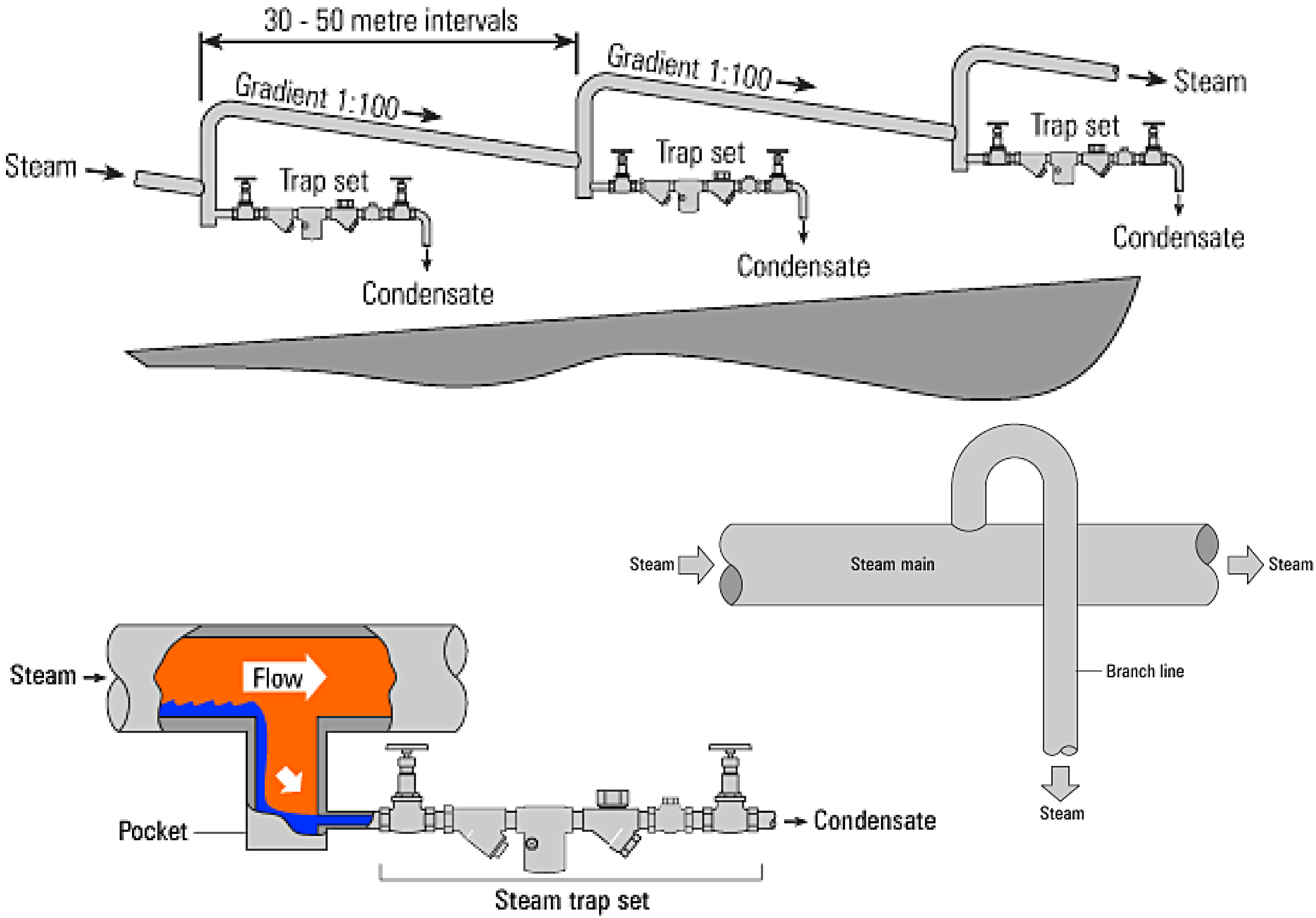
- 50mm pipe area = 0.00196 m^2

- Thus pipe velocity = 0.019 m^3/s ÷ 0.00196 m^2 = 9.7 m/s
- This pipe size is well below the normal design velocity range (24 – 36 m/s)

Design considerations



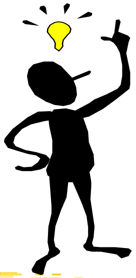
- Permissible pressure drop & flow velocity are affected by several factors:
  - Relative direction of steam & condensate flow within the same pipe
  - Whether the pipe is vertical, horizontal or sloping down in the direction of steam flow or against it
  - Steam quality & erosive action of wet steam on valve seats
  - Possibility of carry-over of water droplets from boiler steam spaces & flash steam vessels
  - Permissible noise level



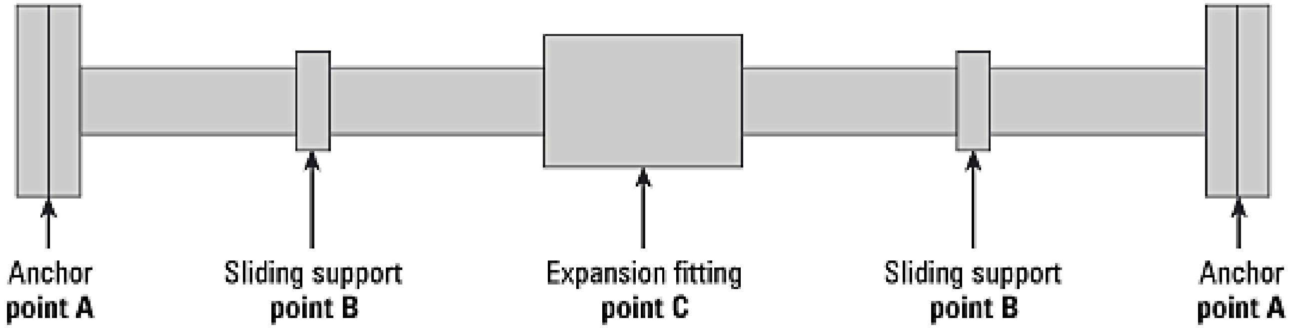
Typical steam main & branch line installation

(Source: www.spiraxsarco.com/learn)

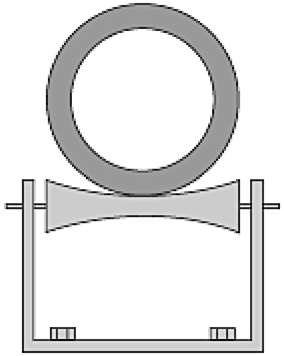
Design considerations



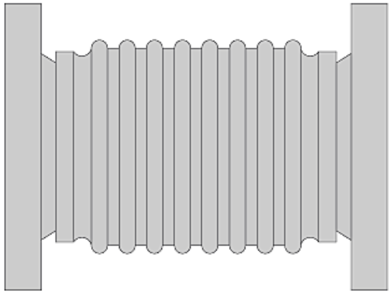
- Steam and condensate pipes
  - Analyze most economic thickness for pipe thermal insulation
  - Expansion joints or loops to relieve stresses due to expansion and contraction
  - Provided with a fall of about 1 in 100
  - Provided with drainage outlet at low points



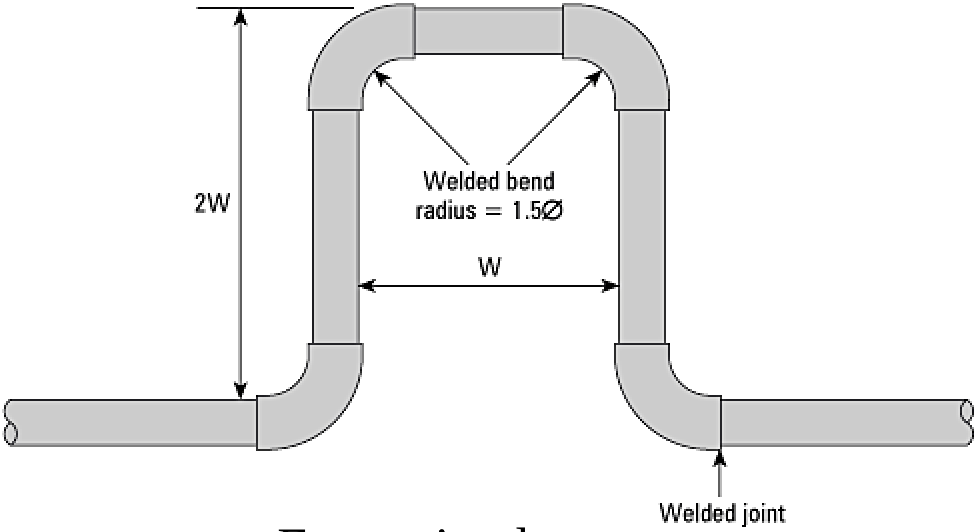
Pipeline with fixed point, variable anchor point and expansion fitting



Chair and roller



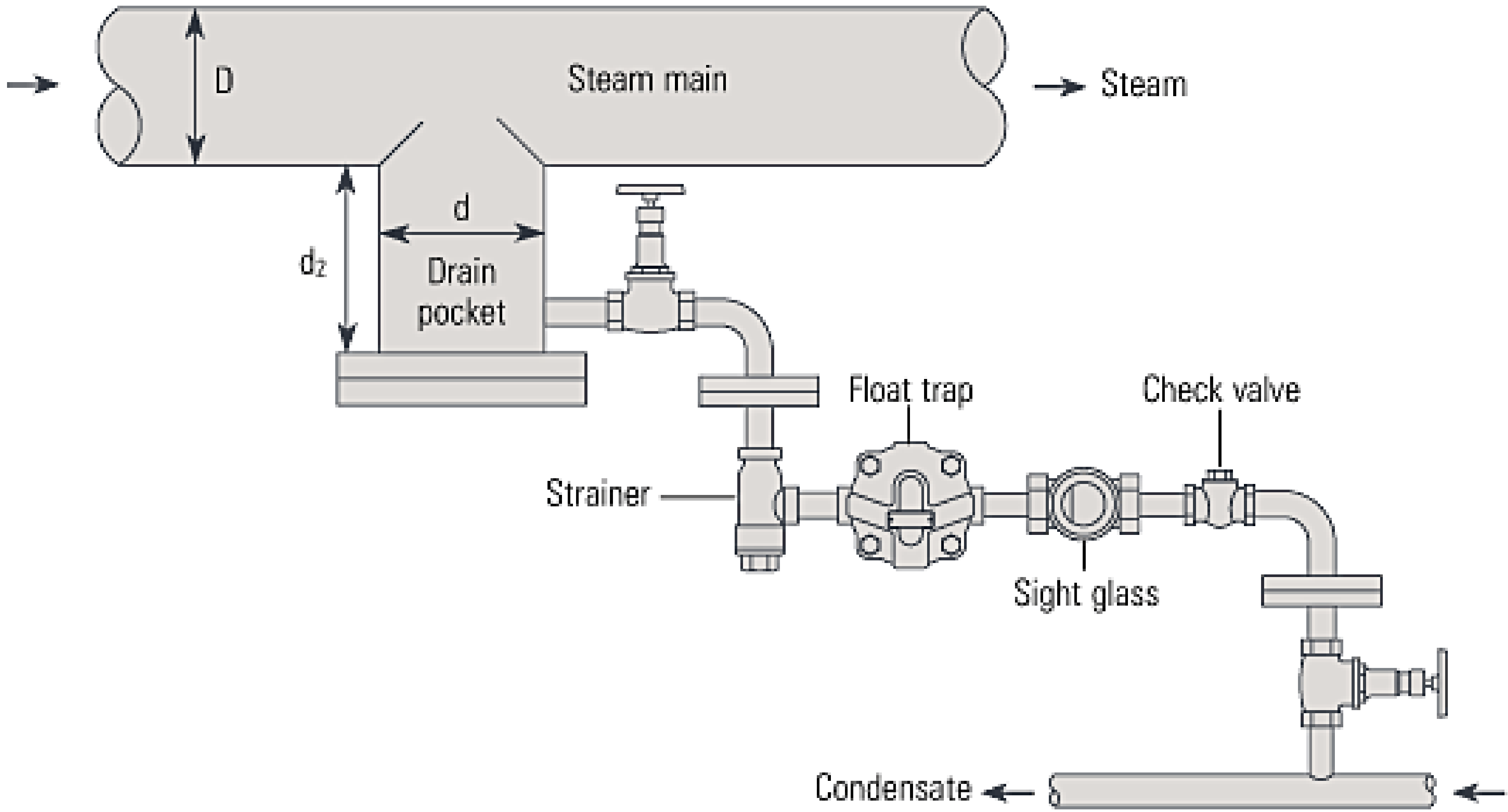
Expansion bellow



Expansion loop

Pipe expansion and support

(Source: www.spiraxsarco.com/learn)



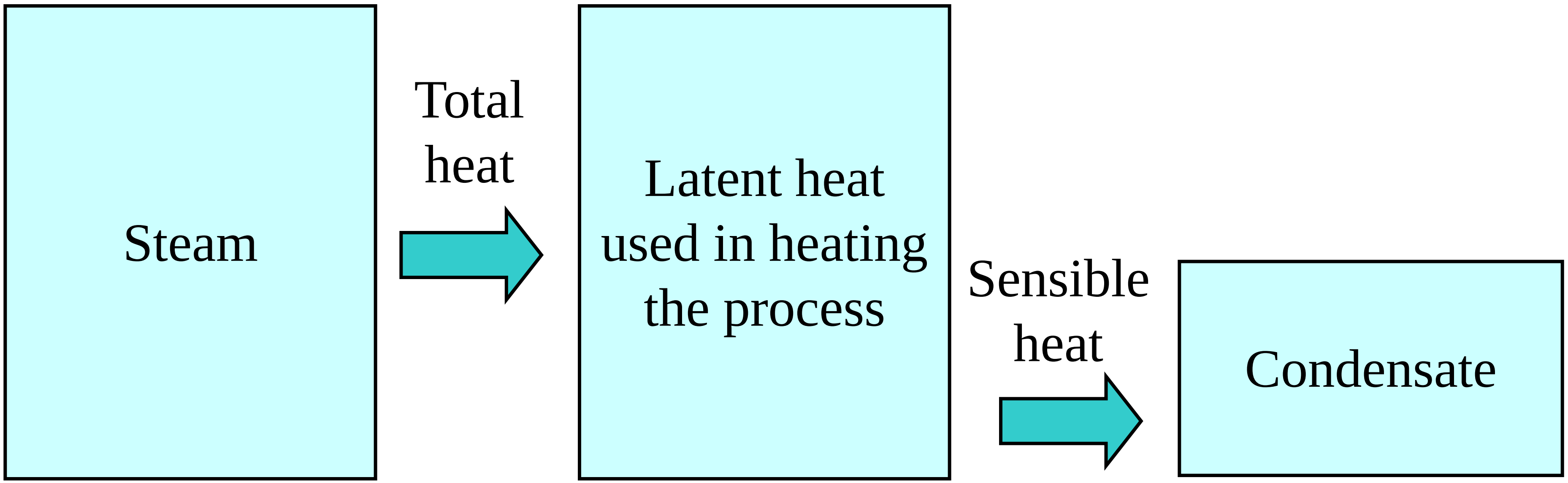
Main diameter D	Pocket diameter d_1	Pocket depth d_2
Up to 100 mm	d_1 = D	Minimum d_2 = 100 mm
125 mm - 200 mm	d_1 = 100 mm	Minimum d_2 = 150 mm
250 mm and above	d_1 = D/2	Minimum d_2 = D

Ideal arrangement when draining a steam main

(Source: www.spiraxsarco.com/learn)

Design considerations

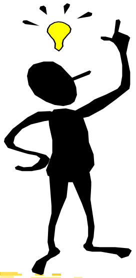
- Condensate recovery
  - Returned to the boiler for reuse as feed-water
    - Can increase heat efficiency of the cycle
    - Can reduce make-up water charges
    - Can reduce effluent charges and possible cooling costs
    - Can keep water-treatment problems to a minimum
    - Can reduce boiler blowdown (less energy is lost)
- Start-up load: initial warm up of components
  - Highest steam consumption
- Running load: fairly stable condition

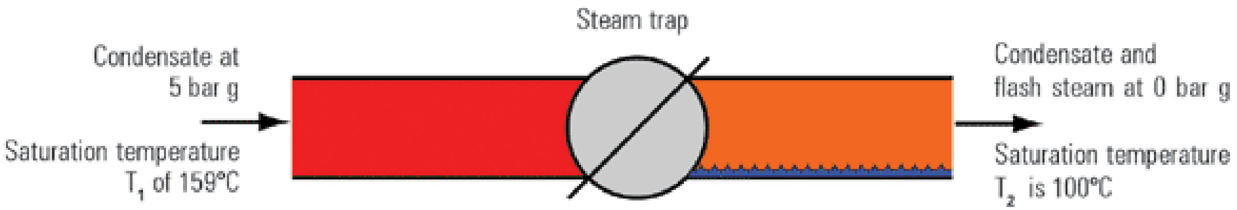


After giving up its latent heat to heat the process, steam turns to water containing only sensible heat

(Source: www.spiraxsarco.com/learn)

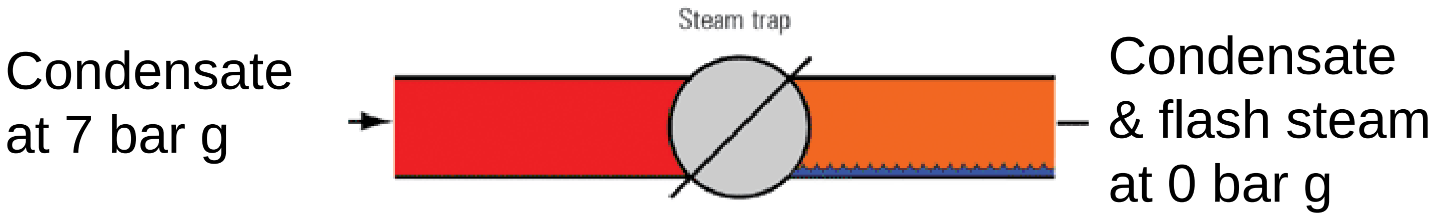
Design considerations





- Flash steam
  - Formed when high pressure condensate is discharged to a lower pressure
  - Should be collected and led to a flash vessel
- Other important issues:
  - Suitable collecting legs or reservoirs for condensate
  - Minimum pressure differential across the steam trap
  - Choice of steam trap type and size
  - Proper trap installation

Example: Calculate the amount of flash steam from condensate.



Hot condensate at 7 bar g has a heat content of 721 kJ/kg. When it is released to atmospheric pressure (0 bar g), each kilogram of water can only retain 419 kJ of heat.

The excess energy in each kg of the condensate is 721 - 419 = 302 kJ
This excess energy is available to evaporate some of the condensate into steam.

If the enthalpy of evaporation at atmospheric pressure is 2258 kJ/kg, then the percentage of flash steam evaporated is = 302 / 2258 x 100%

Thus, flash steam evaporated = **13.4%**

Further reading

- Spirax Sarco Learning Centre
  - www.spiraxsarco.com/learn/
  - Steam Engineering Tutorials
    - 1. Introduction
    - 2. Steam Engineering Principles and Heat Transfer
    - 3. The Boiler House
    - 10. Steam Distribution
    - 11. Steam Traps and Steam Trapping
    - 14. Condensate Recovery
  - Reference: The Steam and Condensate Loop

Further reading

- Steam and Condensate [Engineering ToolBox] (web sites)
- www.engineeringtoolbox.com/steam-condensate-properties-t_28.html
  - Classification of Steam Heating Systems
  - Design of Steam Heating Systems
  - Entropy of Superheated Steam
  - Flash Steam
  - Properties of Saturated Steam - SI Units
  - Sizing Steam and Condensate Pipes
  - Steam Pipes – Sizing
  - Steam Thermodynamics
  - Steam Trap Selection Guide