EN 410
Energy Management

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Problem 2 (Indirect method) – Furnace Oil Burner

Boiler data

- Fuel firing: 2650 kg/hr
- Surface temperature of boiler: 80 °C
- Surface area of boiler: 90 m^2

Fuel analysis (in %)

- Carbon: 84
- Moisture:0.5
- Hydrogen: 12
- Nitrogen: 0.5
- Sulphur:1.5
- Oxygen: 1.5
- GCV of Coal: 10000 kcal/kg

Flue gas analysis

- V%CO_2 in flue gas: 10.8
- V%O_2 in flue gas: 7.4
- Flue gas temperature: 190 °C

Ambient data

- Ambient temperature: 30 °C
- Humidity: 0.025 kg / kg dry air
- Wind velocity: 3.8 m/s

Flue Gas Heat Loss

$$L_1 = \frac{m \, x \, C_p \, x (T_f - T_a)}{GCV \; of \; fuel} \; x \, 100$$

Where,

L_1 = % Heat loss due to dry flue gas

m = Mass of dry flue gas in kg/kg of fuel

= Combustion products from fuel: $CO_2 + SO_2$ + Nitrogen in fuel + Nitrogen in the actual mass of air supplied + O_2 in flue gas. (H_2O/Water vapour in the flue gas should not be considered)

C_p = Specific heat of flue gas in kcal/kg

T_f = Flue gas temperature in ^oC

T_a = Ambient temperature in ^oC

m = Total mass of flue gas – Mass of water vapor

= Mass of air flow rate + Mass of fuel rate – (9*Hydrogen content in fuel)- Moisture content in fuel (and air)

Cp = 0.24 kcal/kg

Mass flow rate of air

- Theoretical air
- Excess air
- Actual mass of supplied air

$C + O_2 \rightarrow CO_2$ + 8084 kcal/kg of carbon burnt

$H_2 + 1/2\ O_2 \rightarrow H_2O$ + 28922 kcal/kg of H_2

$S + O_2 \rightarrow SO_2$ + 2224 kcal/kg of S

b) % Excess Air supplied (EA)	=	$\frac{O_2\%}{21 - O_{2\%}} x100$ [from flue gas analysis]
		Normally O_2 measurement is recommended. If O_2 measurement is not available, use CO_2 measurement
		$\frac{7900\,x[(CO_2\%)_t - (CO_2\%)_a]}{(CO_2)_a\%\ x\,[100 - (CO_2\%)_t]}$ [from flue gas analysis]

Heat Loss due to the formation of water

The combustion of hydrogen causes a heat loss because the product of combustion is water. This water is converted to steam and this carries away heat in the form of its latent heat.

$$L_2 = \frac{9 \times H_2 \times \{584 + C_p\ (T_f - T_a)\}}{\text{GCV of fuel}} \times 100$$

Where

H_2 = kg of hydrogen present in fuel on 1 kg basis
C_p = Specific heat of superheated steam in kcal/kg °C
T_f = Flue gas temperature in °C
T_a = Ambient temperature in °C
584 = Latent heat corresponding to partial pressure of water vapour in kcal/kg

Cp = 0.45 kcal/kg

Heat Loss due to Moisture in Fuel

$$L_3 = \frac{M \times \{584 + C_p (T_f - T_a)\}}{\text{GCV of fuel}} \times 100$$

where

M	=	kg of moisture in fuel in 1 kg basis
C_p	=	Specific heat of superheated steam in kcal/kg °C
T_f	=	Flue gas temperature in °C
T_a	=	Ambient temperature in °C
584	=	Latent heat corresponding to partial pressure of water vapour in kcal/kg

Cp = 0.45 kcal/kg

Heat Loss due to Moisture in Air

$$L_4 = \frac{AAS\ x\ humidity\ factor\ x\ C_p\ x\ (T_f - T_a)}{\text{GCV of fuel}}\ x\ 100$$

where

AAS	=	Actual mass of air supplied per kg of fuel
Humidity factor	=	kg of water/kg of dry air
C_p	=	Specific heat of superheated steam in kcal/kg°C
T_f	=	Flue gas temperature in °C
T_a	=	Ambient temperature in °C (dry bulb)

Cp = 0.45 kcal/kg

Surface heat loss

- Difficult to estimate
- Assumed based on type and size of boiler

➢ Industrial fire tube boiler – 1.5 to 2.5 %

➢ Industrial water tube boiler – 2 to 3 %

➢ Power station boiler – 0.4 to 1%

$$L_6 = 0.548 \times \left[(T_s / 55.55)^4 - (T_a / 55.55)^4 \right] + 1.957 \times (T_s - T_a)^{1.25} \times \text{sq.rt of } \left[(196.85\, V_m + 68.9) / 68.9 \right]$$

where

L_6 = Radiation loss in W/m^2

V_m = Wind velocity in m/s

T_s = Surface temperature (K)

T_a = Ambient temperature (K)

W = 0.86 kcal/hr

Heat Loss due to Incomplete Combustion

$$L_5 = \frac{\%CO \ x \ C}{\%CO + \%CO_2} \ x \ \frac{5654^*}{GCV \ of \ fuel} \ x \ 100$$

L_5	=	% Heat loss due to partial conversion of C to CO
CO	=	Volume of CO in flue gas (%) (1% = 10000 ppm)
CO_2	=	Actual Volume of CO_2 in flue gas (%)
C	=	Carbon content kg / kg of fuel

* Heat loss due to partial combustion of carbon, kcal/kg of Carbon.

$C + O_2 \rightarrow CO_2$ + 8084 kcal/kg of Carbon
$2C + O_2 \rightarrow 2\,CO$ + 2430 kcal/kg of Carbon
$2H_2 + O_2 \rightarrow 2H_2O$ + 28,922 kcal/kg of Hydrogen
$S + O_2 \rightarrow SO_2$ + 2,224 kcal/kg of Sulphur

Heat Loss due to unburnt fuel

7. Heat loss due to unburnt in fly ash (%):

$$L_7 = \frac{\text{Total ash collected / kg of fuel burnt x G.C.V of fly ash}}{\text{GCV of fuel}} \; x\, 100$$

8. Heat loss due to unburnt in bottom ash (%)

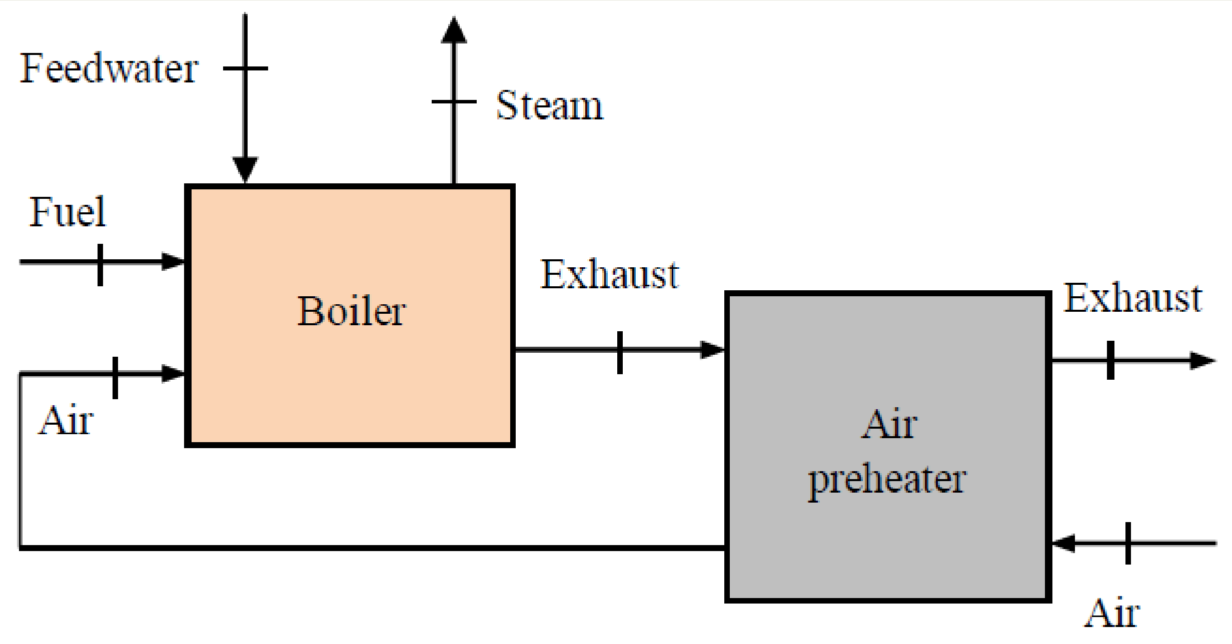
$$L_8 = \frac{\text{Total ash collected / kg of fuel burnt x G.C.V of bottom ash}}{\text{GCV of fuel}} \; x\, 100$$

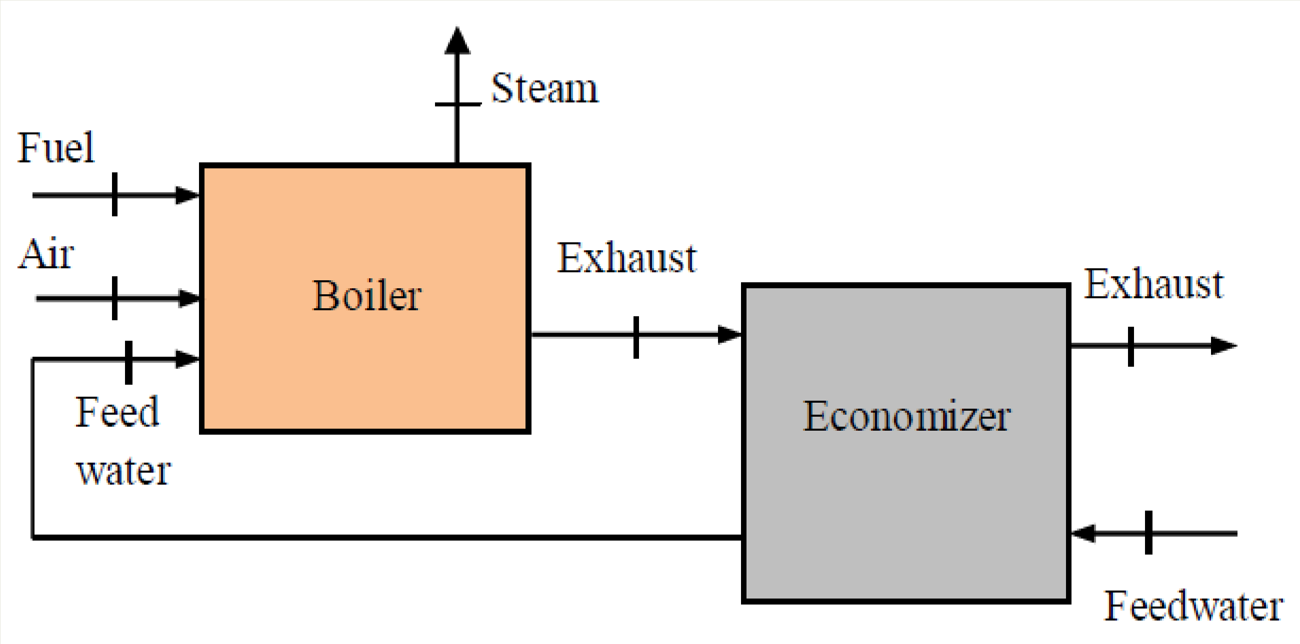
Boiler efficiency

Indirect efficiency = 100 – Losses

Energy Conservation - Air preheater and economizer

- Air preheater: A heat exchanger that transfers heat from the exhaust gases to the inlet air.
- Economizer: A heat exchanger that transfer heat from exhaust gases to feedwater.
- Economizers are preferred over air preheaters for boilers of less than about 25 TPH capacity.





Minimum Exhaust Temperature

- A main method of improving boiler efficiency is to recover heat of stack gases.
- However, temperature of stack gases should not be lowered below certain limits to avoid corrosion problems.
- For boilers generating steam, the exhaust gas temperature should not be lower than the temperature of steam.
- For effective heat transfer and reasonable boiler size, the exhaust temperature should be about 80°C greater than the steam temperature.
- *It is more economical to recover heat of exhaust gases by using air preheaters and economizers rather than adding more heat transfer surfaces in the boiler to decrease exhaust temperature.*

Fuel used in the boiler	Gas temperature, °C
Fuel oil (> 2.5% S)	200
Fuel oil (< 1.0% S)	165
Bituminous coal (> 3.5% S)	145
Bituminous coal (< 1.5% S)	110
Pulverized anthracite	105
Natural gas	105

Energy Conservation - optımizing air-fuel ratio

- One of the easiest and most effective methods to increase the efficiency of a boiler is to optimize air-fuel ratio.
- Excess air: Most boilers operating at high temperatures use 10 to 20% excess air.
- The recommended value is often about 10% excess air for natural gas boilers and 20% excess air for boilers using liquid or solid fuels.
- Any air-fuel ratio below and above the optimum value would decrease the boiler efficiency.
- Deficiency of air: If the air-fuel ratio is less than the stoichiometric (theoretical), some fuel will leave the boiler unburned as there is not sufficient air to burn all the fuel.
- Liquid and solid fuels require more excess air than gaseous fuels.

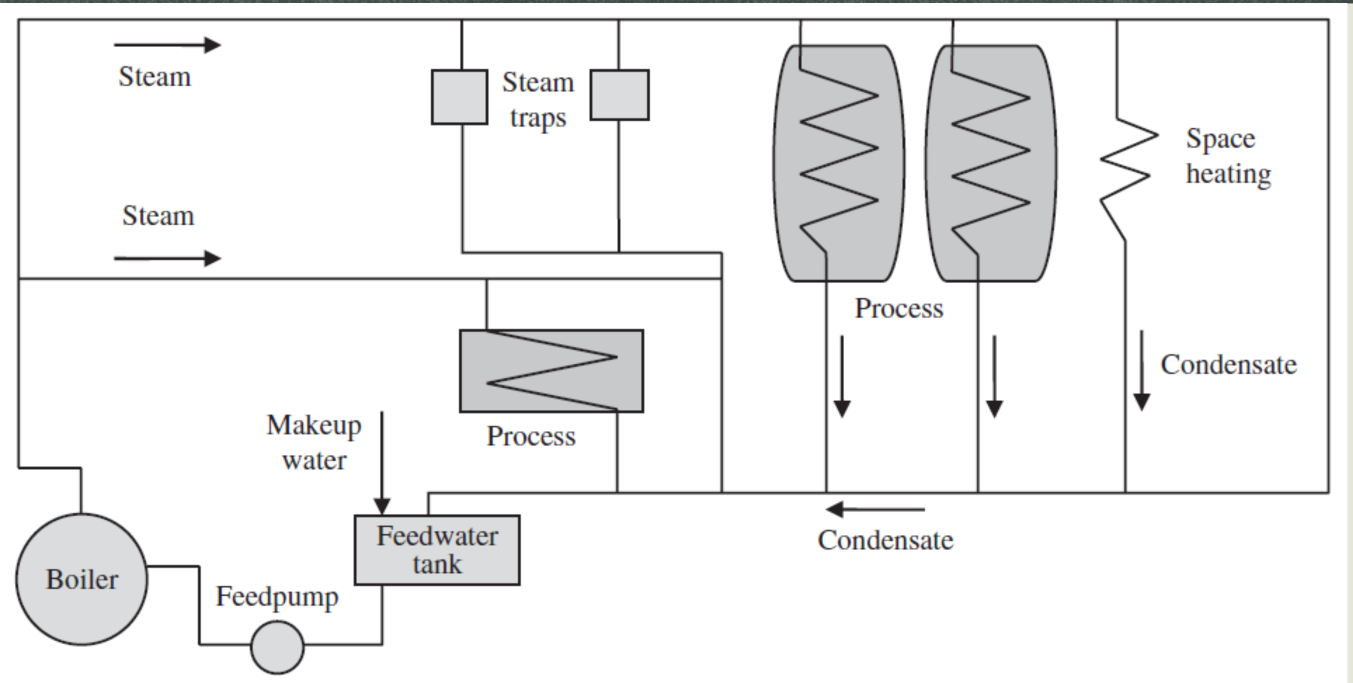
Using multiple boilers

- In some industrial facilities, two or more boilers are installed for process steam or hot water requirements.
- Usually one or more boilers operate simultaneously to meet the base demand, and an additional one is put in operation when there is extra demand.
- This scheme of using multiple boilers is usually preferred over using a large boiler with a sufficient rating to meet the entire demand.
- This is because the large boiler operates at part load (and low efficiency) most of the time.
- Boilers are generally designed to have maximum efficiency at the rated full power. At part load, the boiler efficiency decreases.
- One major reason for this is that heat losses remain essentially the same when the load is decreased.

Other Opportunities

- Condensate recovery : The maximum possible amount of condensate water should be returned to boiler to reduce heat transfer requirement for a given hot water or steam output.
- Blowdown heat recovery
- Sufficient insulation
- Energy efficient fans, blowers and pumps
- Soot blowers: They can be used to remove boiler tube deposits that hurt heat transfer.
- Fuel additives: Combustion catalysts, Soot eliminators, Ash modifiers
- Appropriate boiler water treatment

Steam Distribution Network



- Optimum pressure and diameter
  - Superheated ~ 50-70 m/s
  - Saturated ~ 30-40 m/s
  - Wet ~ 20-30 m/s

- Falling slope > 125 mm for every 30 m in the direction of steam flow
- Drain points @ every 30-45 m, elevation changes, equal tee connections
- Branch lines from top

Steam traps

Steam traps are an essential part of a steam distribution network.

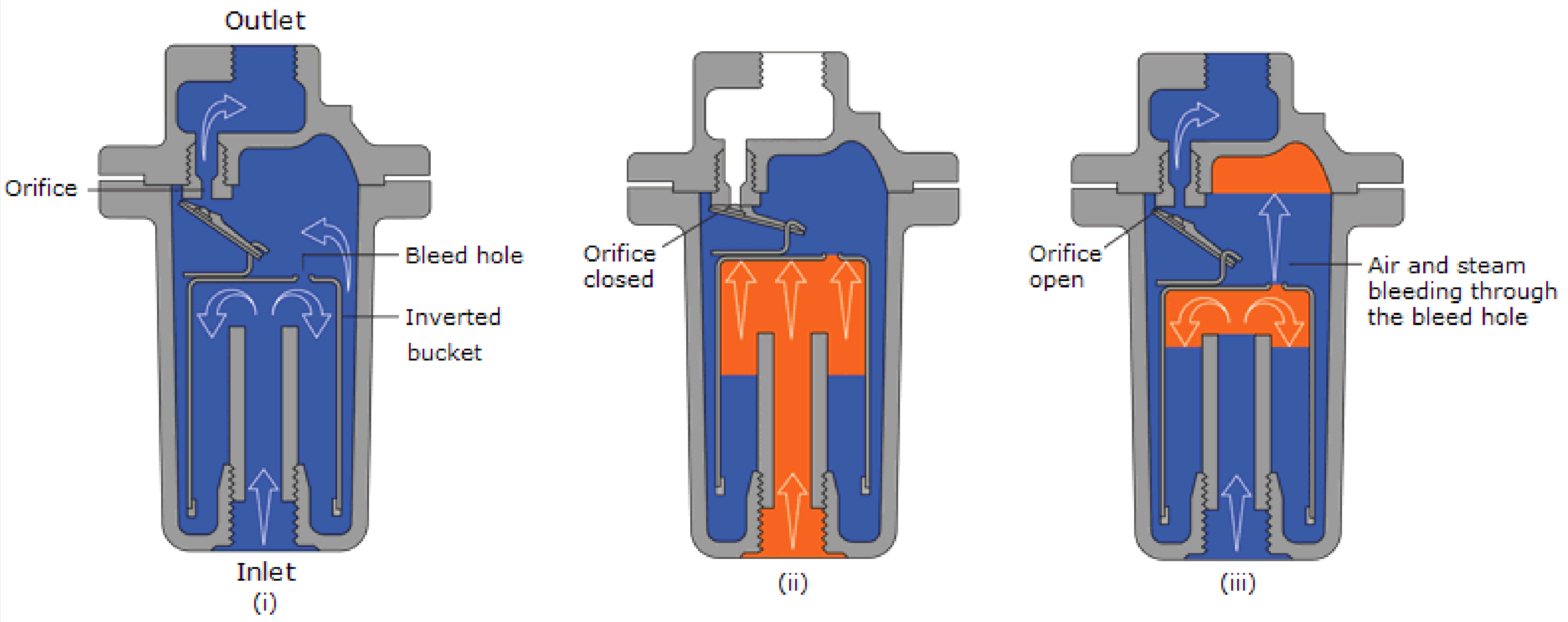
The functions of steam traps are:

- To discharge condensate as soon as it is formed (which also prevents water hammer) without steam loss
- To be capable of discharging air and other non-condensable gases

Steam traps

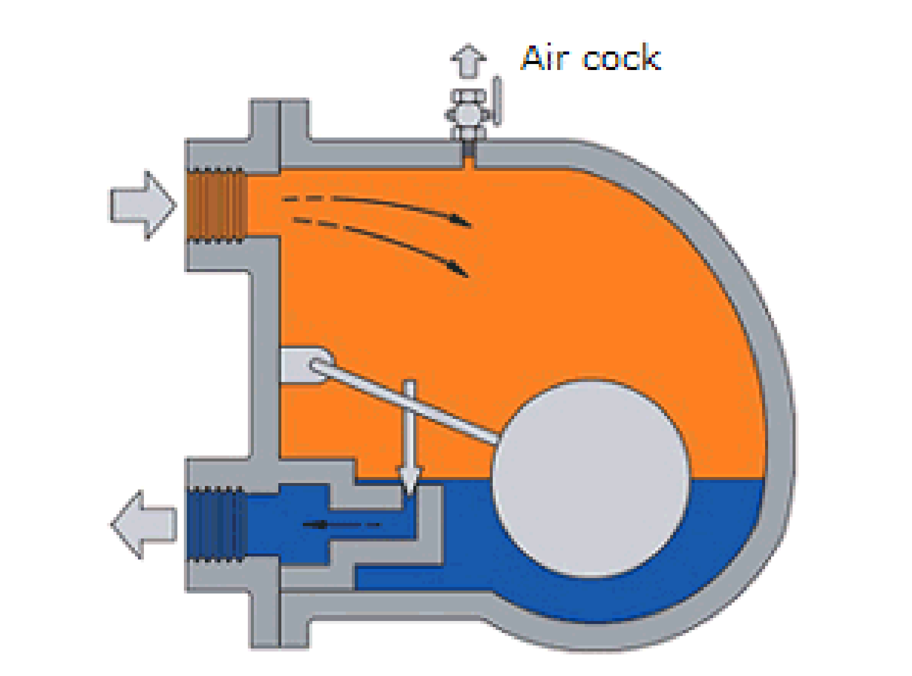
- Mechanical steam trap is operated by sensing the density difference between the steam and condensate. It only allows high density condensate to pass into trap. Two types in this category are ball float traps and inverted bucket traps.
- Thermostatic steam trap is operated by changes in water temperature. Steam is condensed at the saturation temperature corresponding to its pressure. Thermostatic steam trap senses this lower temperature subcooled liquid and responds by passing the condensate.
- Thermodynamic steam trap is operated by changes in fluid dynamics. The formation of flash steam from condensate is used in its operation. Disc, impulse, and labyrinth steam traps are included in this group.

Inverted bucket trap



https://www.youtube.com/watch?v=VA1csDl1Mfw
https://www.youtube.com/watch?v=eWS6pN8-zDs

Float trap



Float trap with air cock

https://www.youtube.com/watch?v=HP2epe-8FtA
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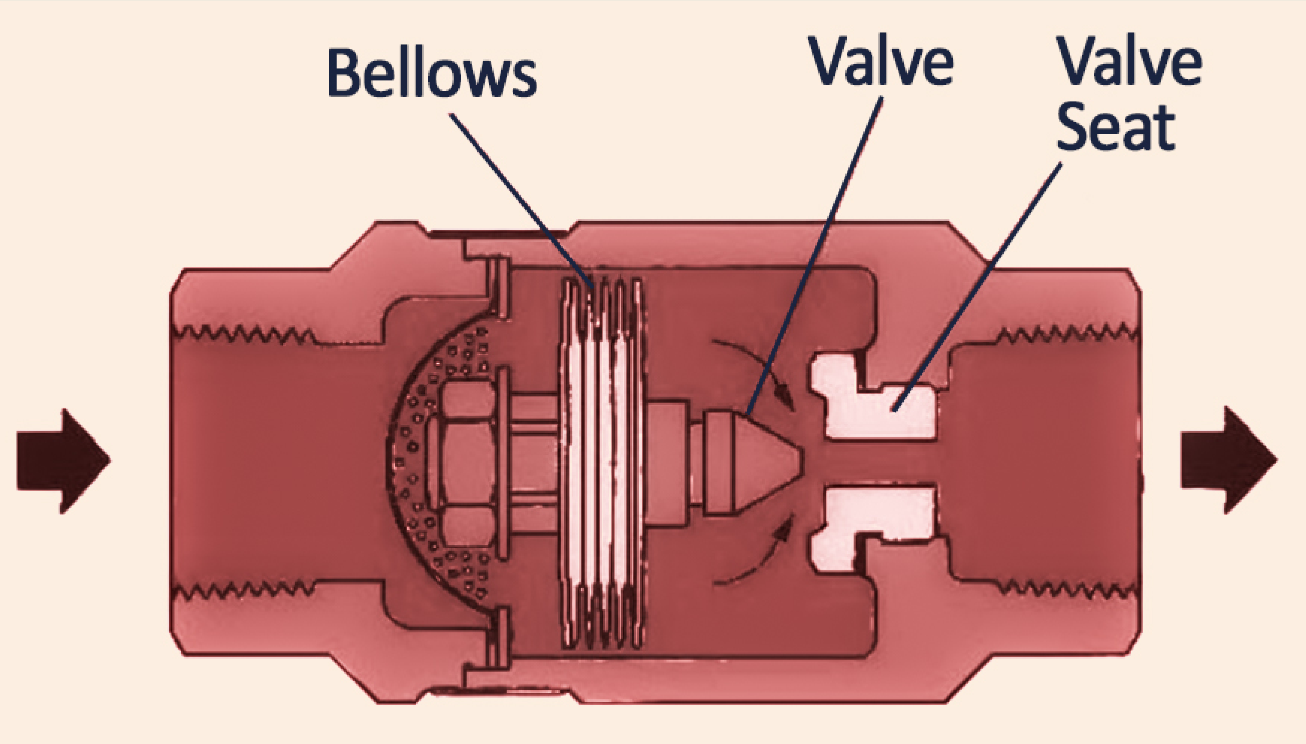
Thermostatic trap



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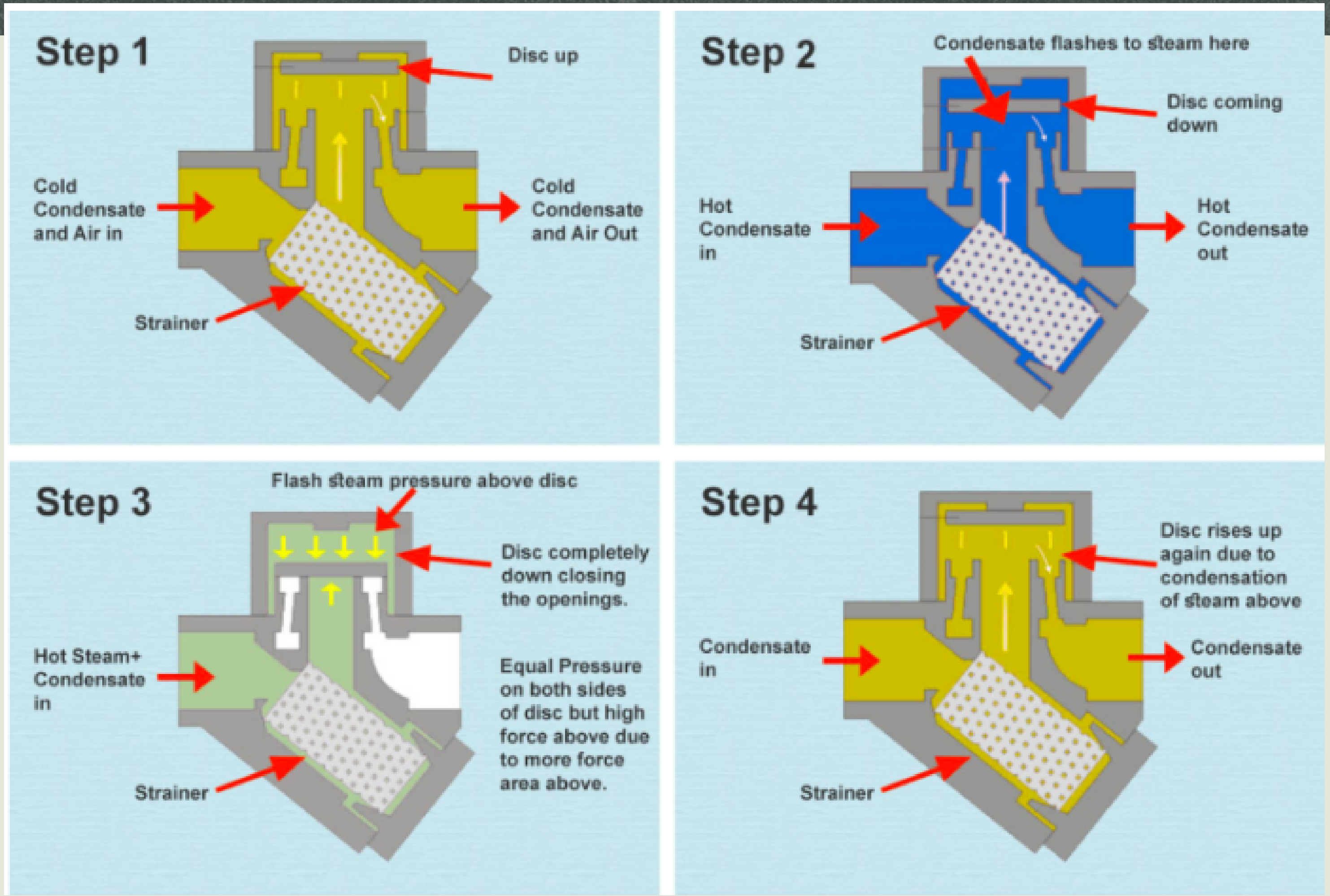
Thermodynamic trap



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