Thermal Power Plant, Steam Generator & Turbines

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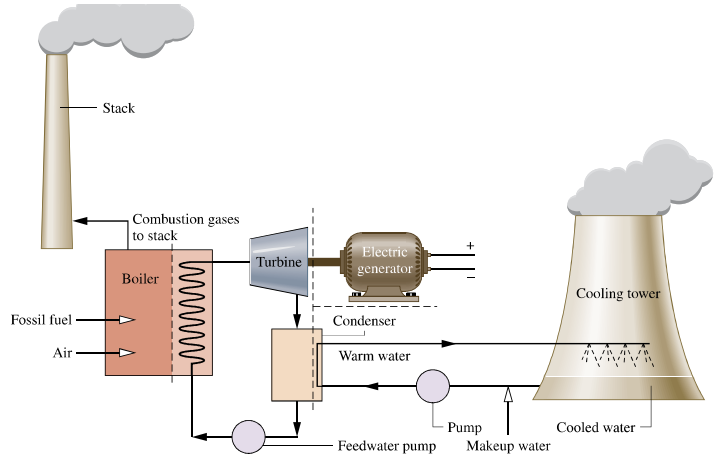
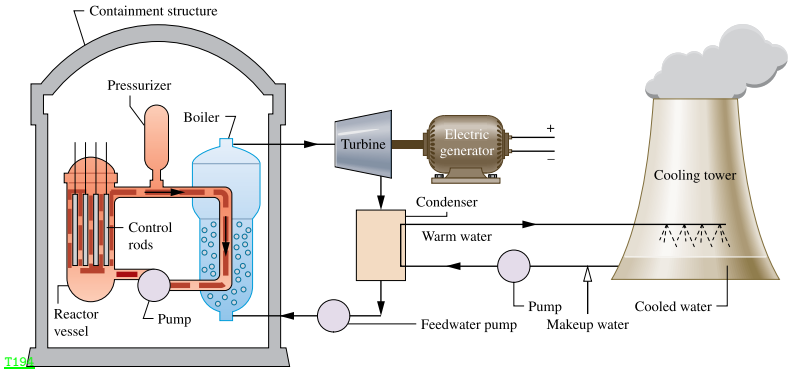
ME 101 : Introduction to Mechanical Engineering
`http://zahurul.buet.ac.bd/ME101/`

Components of a Simple Vapour Power Plant



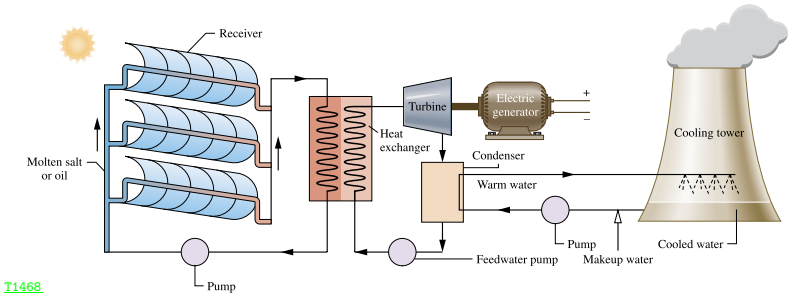
T193

Fossil-fuelled vapour power plant



T194

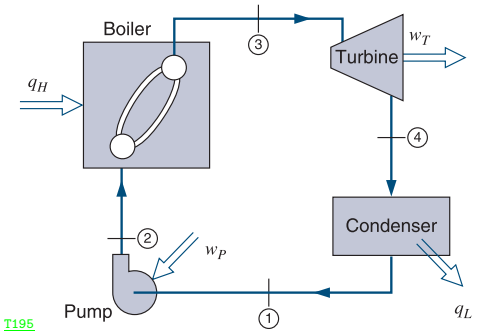
Pressurized-water reactor nuclear vapour power plant



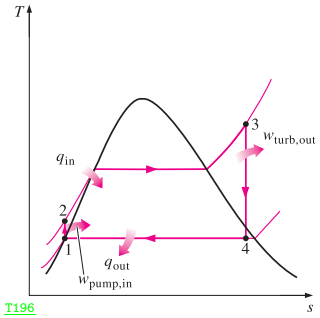
T1468

Concentrating solar thermal vapour power plant

Rankine Cycle for Thermal Power Plant



T195



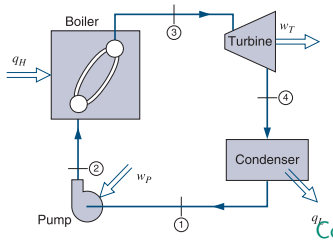
T196

1 → 2 : Isentropic (constant entropy) compression (in a pump)

2 → 3 : Constant pressure (isobaric) heat addition (in a boiler)

3 → 4 : Isentropic expansion (in a turbine)

4 → 1 : Constant pressure heat rejection (in a condenser)



T195

First-Law of Thermodynamics:

$$q + h_{in} = w + h_{out}$$

h is enthalpy of working fluid.

Turbine: $q = 0,\ w = w_T = h_3 - h_4$

Pump: $q = 0,\ w = -w_P \rightarrow w_p = h_2 - h_1$

Boiler: $w = 0,\ q = q_H = h_3 - h_2$

Condenser: $w = 0,\ q = -q_L \rightarrow q_L = h_4 - h_1$

- h_2 is in sub-cooled (compressed) state & difficult to estimate.

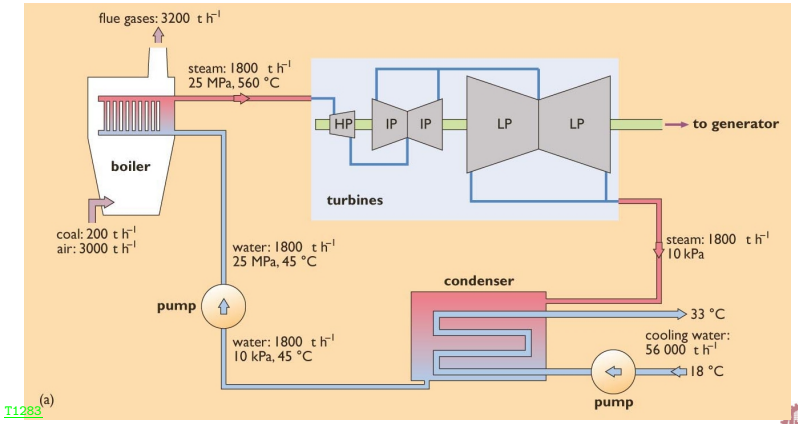
$\Rightarrow w_P = h_2 - h_1 \simeq 0$ as $h_1 \simeq h_2$

$\Rightarrow w_{net} = w_T - w_P$

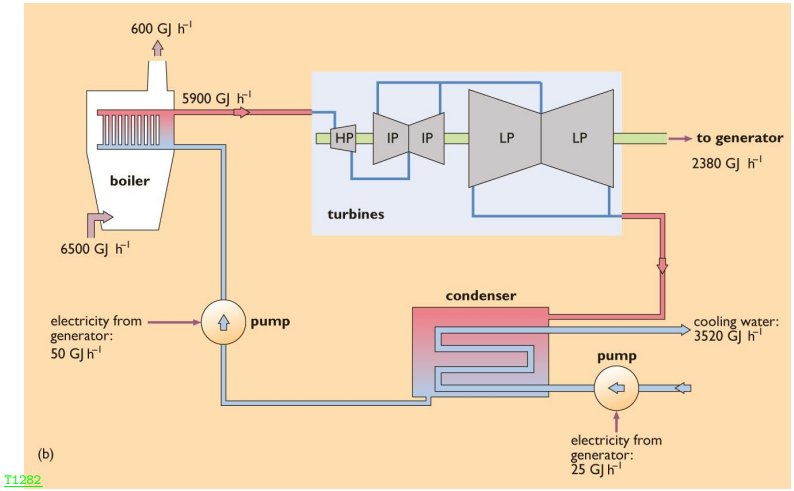
$\Rightarrow q_{in} = q_H = h_3 - h_2$

$\Rightarrow$ Thermal efficiency, $\eta_{th} \equiv \frac{w_{net}}{q_{in}} = \frac{(h_3 - h_4) - (h_2 - h_1)}{h_3 - h_2} \simeq \frac{h_3 - h_4}{h_3 - h_1}$

Flows in a 660 MW Power Station Steam Turbine System

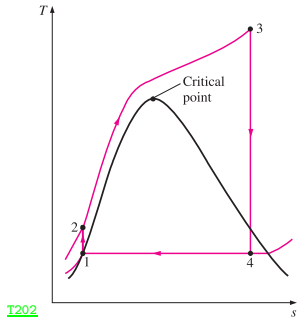


T1283



T1282

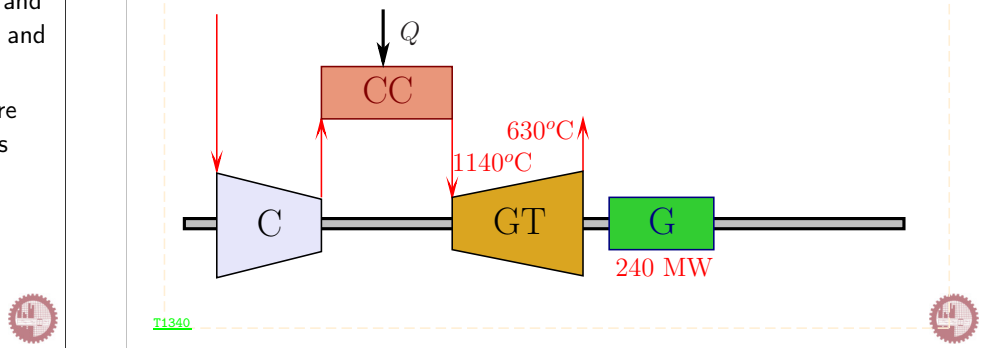
1 $GJ\ hr^{-1} = 0.278\ MW$



T202

A super-critical Rankine cycle

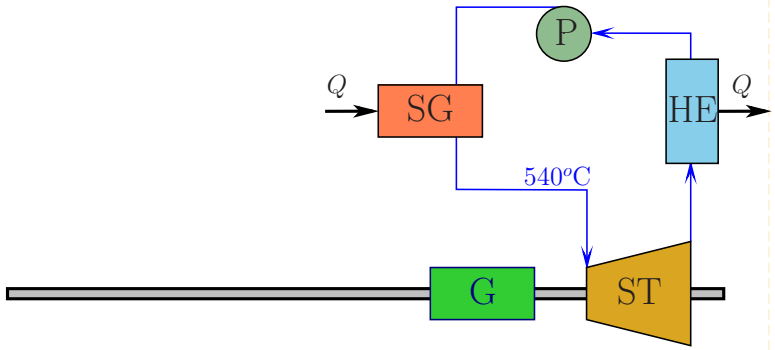
- Some modern power plants operate at super-critical pressure ($P \approx 30$ MPa $> P_C = 22.06$ MPa) and have $\eta_{th} \sim 40\%$ for fossil-fuel plants and $\eta_{th} \sim 34\%$ for nuclear power plants.
- Lower η_{th} of nuclear power plants are due to lower maximum temperatures used due to safety reasons.



Gas Turbine Cycle

T1340

Rankine Cycle



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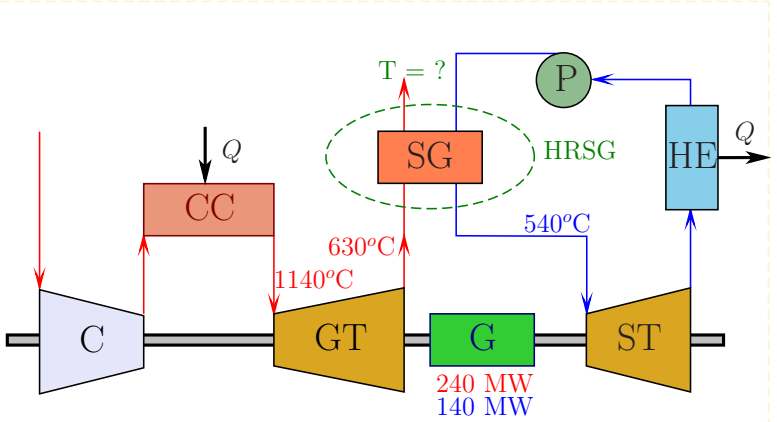
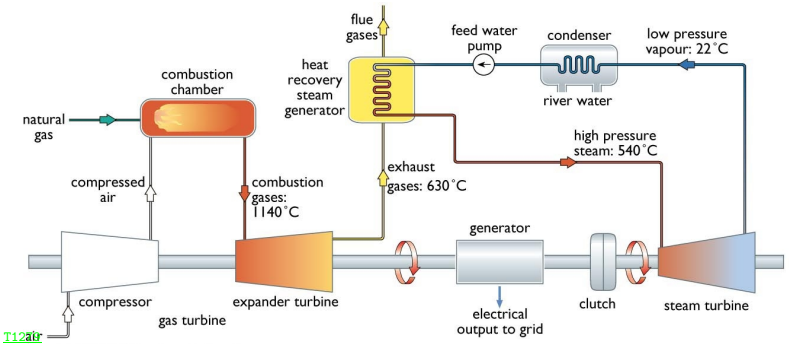
Combined Gas Turbine + Rankine Cycle



T1342

HRSG ≡ Heat Recovery Steam Generator

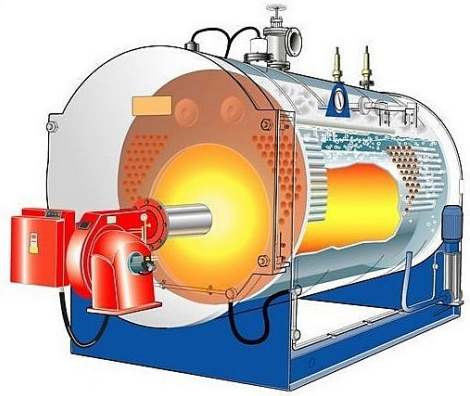


T1287

- Power produced by the GT = 240 MW
- Power produced by the ST = 140 MW (using the hot exhaust)
- Net output power = 380 MW
- RPCL power plant, Mymensingh: 4 GT produce 140 MW and 2 ST produce additional 70 MW using the hot exhaust from GT.

Boiler

A steam generator or boiler is a closed vessel in which steam is produced from water by the application of heat.

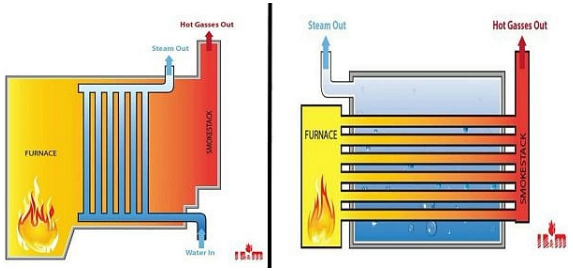


T1286

Purpose of Steam Generation

- **Power Generation**: mechanical or electric power is produced by expanding the steam to low pressure in the turbine.
- **Industrial Processes**: in textile, sugar and chemical industries etc.
- **Heating**: for heating residential and commercial buildings, supply of hot water etc.

Boiler Classifications: Water Tube & Fire Tube



T1297

Water tube boiler *Fire tube boiler*

1. **Water Tube Boiler**: water is inside the tubes and hot gases surround the tubes.
2. **Fire Tube Boiler**: hot gases are inside the tube and water surrounds the tubes.

Boiler Capacity & Performance Parameters

- **Boiler Efficiency**:

$$\eta_{boiler} \equiv \frac{Heat\ absorbed\ by\ feed\ water}{Energy\ released\ by\ fuel} \equiv \frac{\dot{m}_w(h_s - h_w)}{\dot{m}_f\ HV}$$

- **Equivalent Evaporation**: Evaporation which would be obtained if feed water were supplied at 100°C and converted into dry saturated steam at 100°C at standard atmospheric pressure.

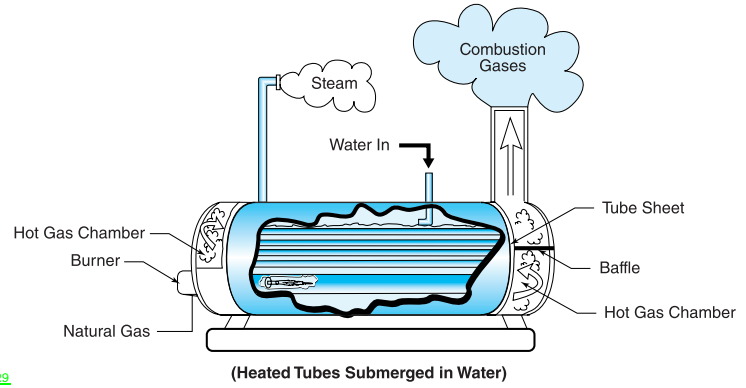
$$W_e = \frac{\dot{m}_w\ (h_s - h_w)}{L}$$

- **Boiler HP**:

$$Boiler\ HP = \frac{equivalent\ evaporation\ per\ hr}{15.653}$$

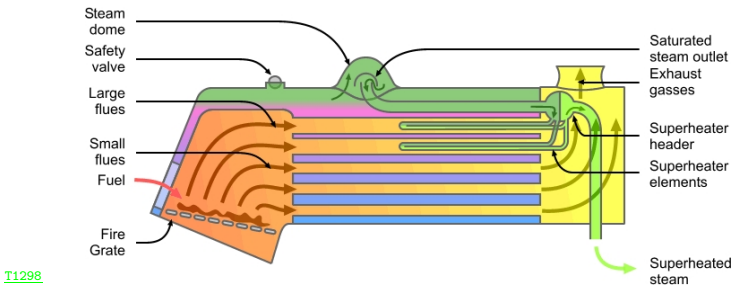
- $L \equiv$ Latent heat of evaporation of water at 100°C (2256 kJ/kg)
- $\dot{m}_w \equiv$ actually generated steam (kg/hr), $\dot{m}_f \equiv$ fuel consumption rate (kg/hr)
- $h_s \equiv$ enthalpy of dry/saturated steam, $h_w \equiv$ enthalpy of feed water (kJ/kg)
- $HV \equiv$ Heating value of fuel (kJ/kg)

Fire Tube Boiler



T1129

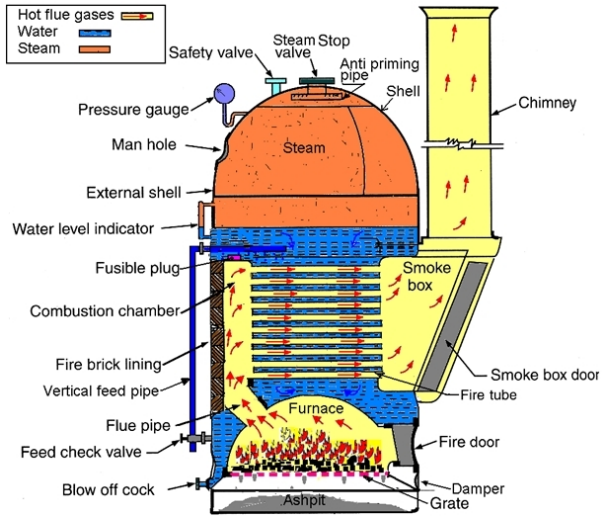
In fire tube boiler, the hot gases passes inside the tubes and boiler feed water in the shell side is converted into steam.



T1298

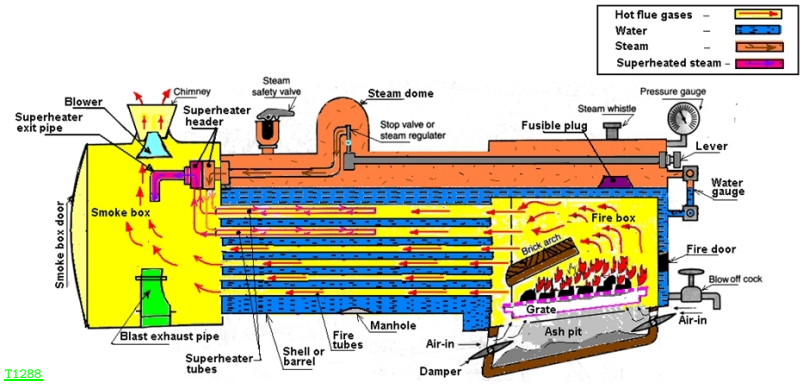
- Fire tube boilers are generally used for relatively small steam capacities and low to medium steam pressure.
- Fire tube boilers are competitive for steam generation rated up to 12,000 Kg/hr and pressures up to 10 atm.
- It may cause serious accident, if leakage of a large amount of hot water and steam occurs.

Fire Tube Boiler: Cochran Boiler



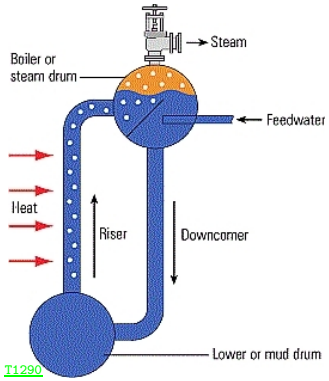
T1287

Fire Tube Boiler: Locomotive Boiler



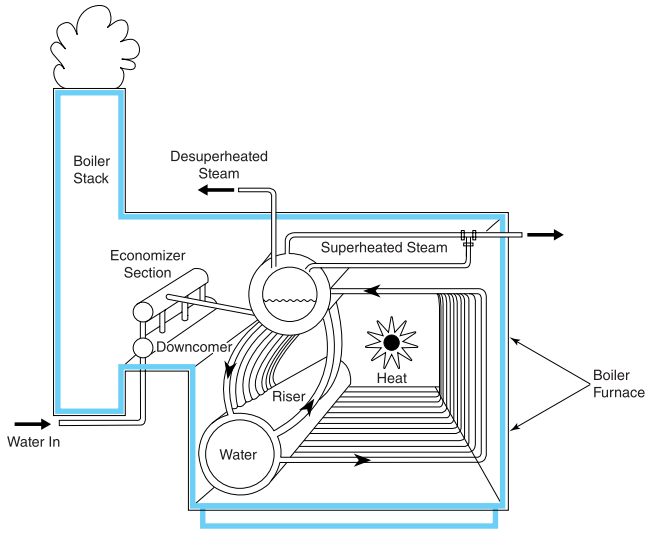
T1288

Water Tube Boiler



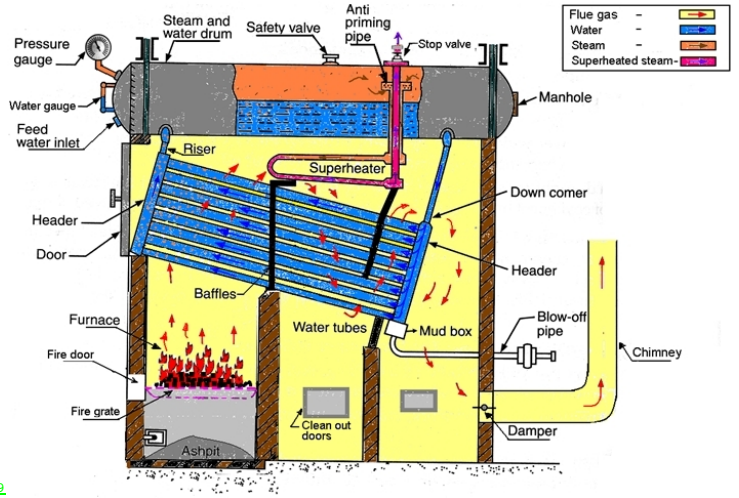
T1290

- In a water tube boiler, water is heated inside the tubes and the hot gases surround the tubes.
- Larger heating surface can be achieved by using more numbers of tubes.
- Due to convectional flow, movement of water is much faster than that of fire tube boiler, hence rate of heat transfer is high which results into higher efficiency.
- Very high pressure in order of 140 atm can be obtained smoothly.



T1130

Water Tube Boiler: Babcock & Wilcox Boiler



T1289

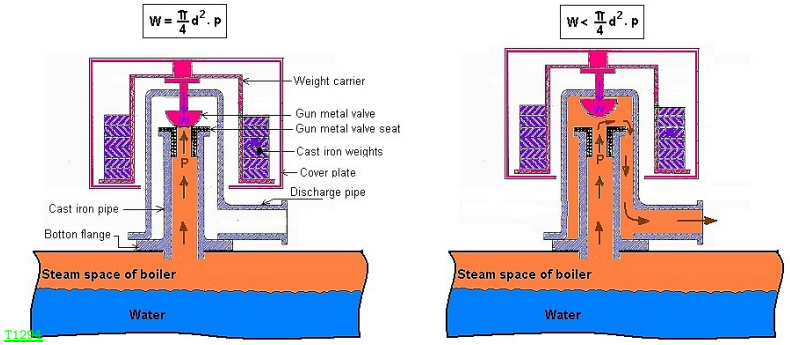
Fire Tube vs. Water Tube Boiler

Mention the characteristics of both types.

Boiler Components

1. **Boiler Mountings**: primarily intended for the safety of the boiler and for complete control of the steam generation process.
   - Two safety valves (pressure relief valves)
   - Two water level indicators (water gauges)
   - Two pressure gauge
   - Fusible plug
   - Steam stop valve
   - Blow-down valve ...
2. **Boiler Accessories**: components installed to increase the efficiency and help proper working of the boiler unit.
   - Air pre-heater
   - Economiser
   - Super-heater
   - Feed pump
   - ...

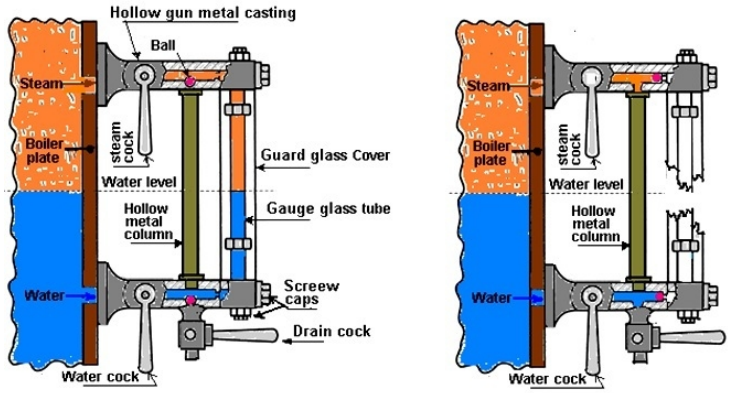
Boiler Mountings: Safety Valve



T1290

Safety valves are used to relieve steam pressure if the pressure exceeds a pre-set value.

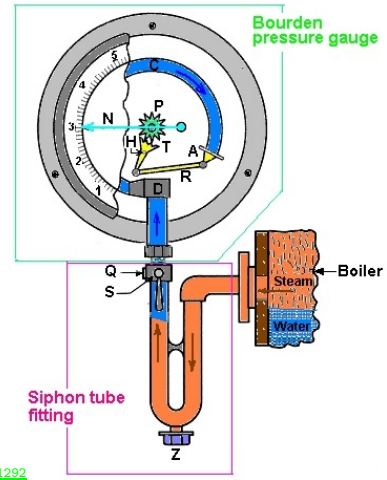
Boiler Mountings: Water Level Indicator



T1291

Water gauges are used to ascertain the water level of the boiler.

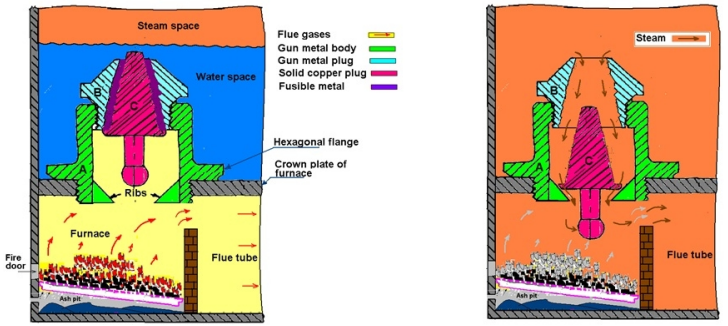
Boiler Mountings: Pressure Gauge



T1292

- Steam pressure is indicated by a pointer which rotates over a circular graduated dial.
- Indicated pressure is known as gauge pressure which is measured above the atmospheric pressure.

Boiler Mountings: Fusible Plug

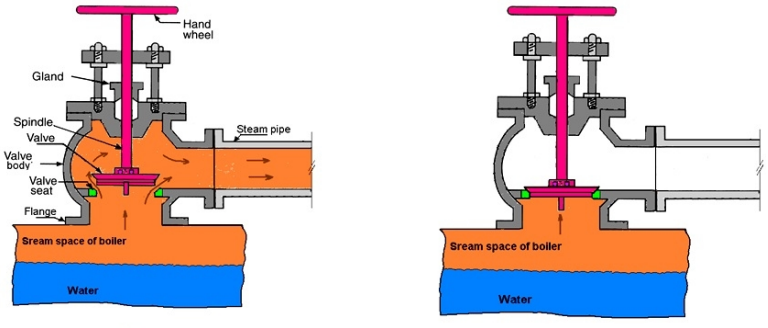


T1293

(a) (b)

Fusible plug is used to protect the boiler against the damage due to overheating for low water level.

Boiler Mountings: Steam Stop Valve



T1295

(a) (b)

Steam stop valve or junction valve is used to regulate the steam flow rate from the boiler.

Boiler Mountings: Blow-down Valve

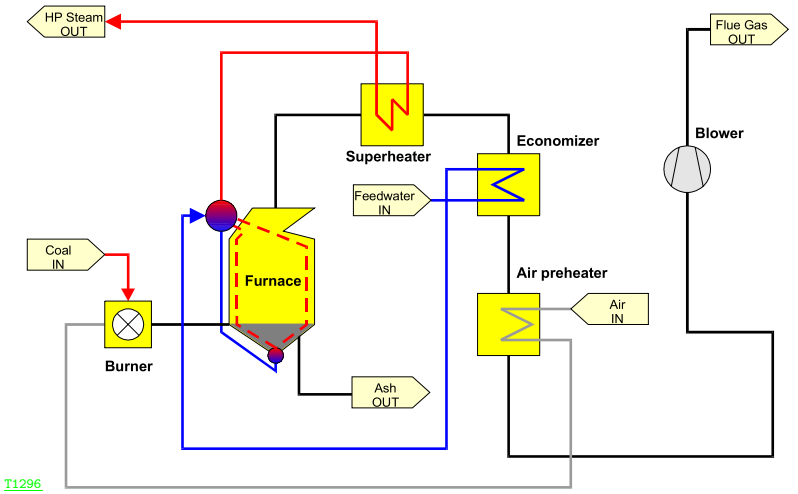
T1471

Blow down valves have two functions:

- It may empty the boiler when needed for cleaning, inspection and repair.
- It may discharge a portion of the water to blow out mud, scale or sediment periodically.

Boiler Accessories

- **Air-Preheater**: air supplied to the boiler is heated using the hot flue gases in the chimney.
  - Some waste heat is recovered, so system efficiency improves.
  - Better combustion and low-grade fuels can be burnt.
- **Economiser**: feed-water is heated using the hot flue gases.
  - Recovers energy leaving with flue gases, so system efficiency improves.
  - Hot feed water is supplied to the boiler drum, so thermal shock is minimized.
- **Super-heater**: steam is superheated to increase system efficiency.

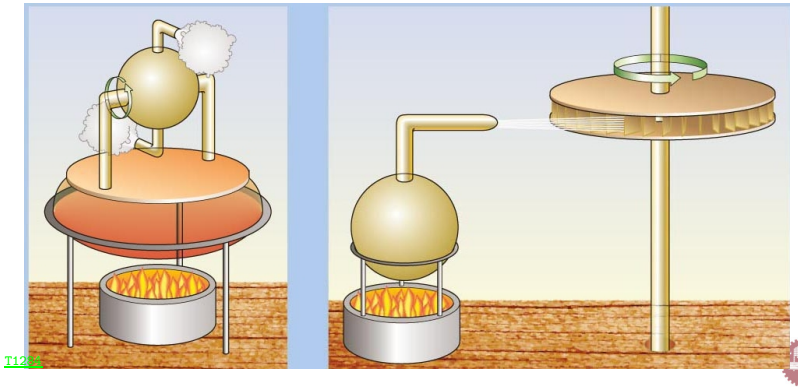


T1296

Typical steam and gas circuit showing the locations of some boiler accessories.

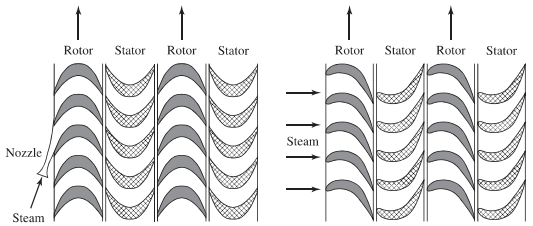
Impulse & Reaction Turbines

Steam from the boiler expands to very low pressure in the turbine and the thermal energy is converted into mechanical power.



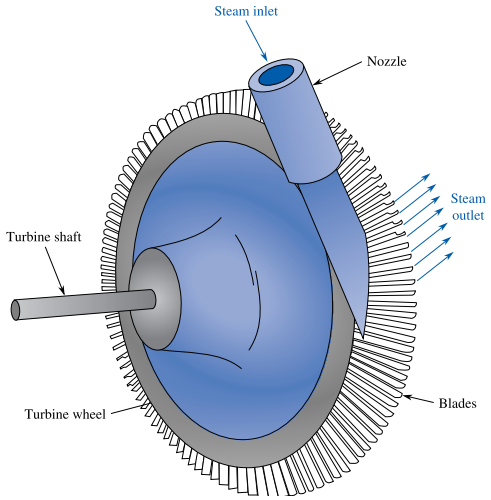
T1294

1. **Impulse Turbine**: In an impulse turbine, thermal energy of superheated steam is converted to very high speed steam jet in the fixed set of nozzles. High speed steam jets are directed to a set of moving blades to transfer the momentum.
2. **Reaction Turbine**: A reaction turbine consists of rows of fixed (stator) and moving (rotor) blades. The blades are shaped to form a converging nozzle. Within the converging blades the steam pressure, density and temperature decline while converting its enthalpy to kinetic energy.



T1472

Staging at: (a) impulse turbine (b) reaction turbine

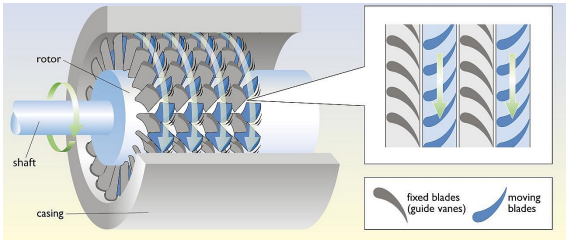


T1470

Impulse turbine

Turbine Staging

- If superheated steam is expanded in the single-stage-turbine, conversion of huge thermal energy results in a very high steam velocity.
- The high velocity steam will impinge the turbine blades and the turbines should have very high rotational speed.
- In practice, steam is expanded in several stages to keep a reasonable steam velocity to achieve overall thermal and economic efficiency.



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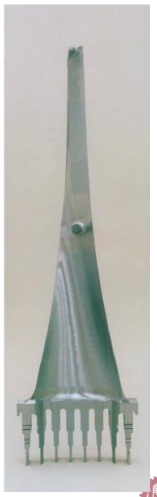

T1385