Basic Mechanical Engineering (3110006)

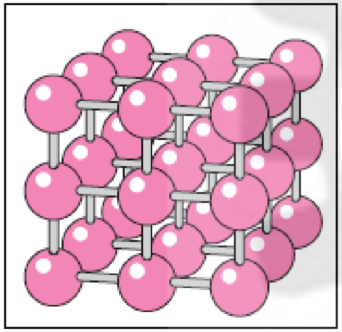
Chapter 4 Properties of Steam

Outline

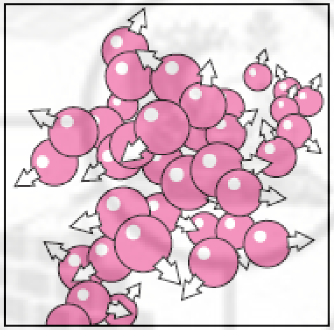
	Pure Substance and it’s phases	
4.1	Steam formation or **Phase-Change Process**	
4.2	Types of steam	
4.3	Properties of steam like Enthalpy, specific volume, Internal energy and dryness fraction	
4.4	Use of steam table	
4.5	Steam calorimeters	

Pure Substance and it’s phases

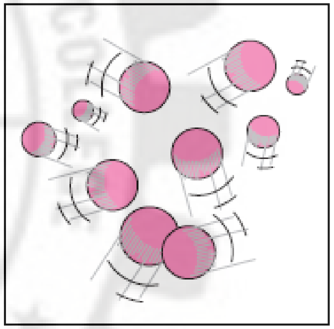
- Solid: strong intermolecular bond
- Liquid: intermediate intermolecular bonds
- Gas: weak intermolecular bond



Solid



Liquid



Gas

- There are many practical situations where *two phases* of a pure substances *coexist in equilibrium.*
- The homogeneous mixture of liquid in suspension with true gas of same substance is called *vapour.*
- *Most important vapour* is *steam* which is used in steam engines, steam turbines for power generation and as process steam in the industry.

Pure Substance and it’s phases

- **Pure Substance** :- A pure substance has a homogeneous and invariable chemical composition and may exist in more than one phase.
- **Examples:**
  1. Water (solid, liquid, and vapour phases)
  2. Mixture of liquid water and water vapour
  3. Carbon dioxide, CO_2
  4. Nitrogen, N_2
- ***Two independent properties*** are needed to define the ***state*** of a ***pure substance***.

- The variation or behavior of properties of a pure substance and their relationship to each other is most commonly and easily examined via ***property diagrams*** and ***property tables.***

Steam formation or Phase-Change Process

- Initially **1 kg** of ice at **-10°C** and **1 atm** pressure kept in **piston-cylinder arrangement,** which is **frictionless** and **weightless.**
- **Heating** the substance **at constant pressure** (1 atm.)

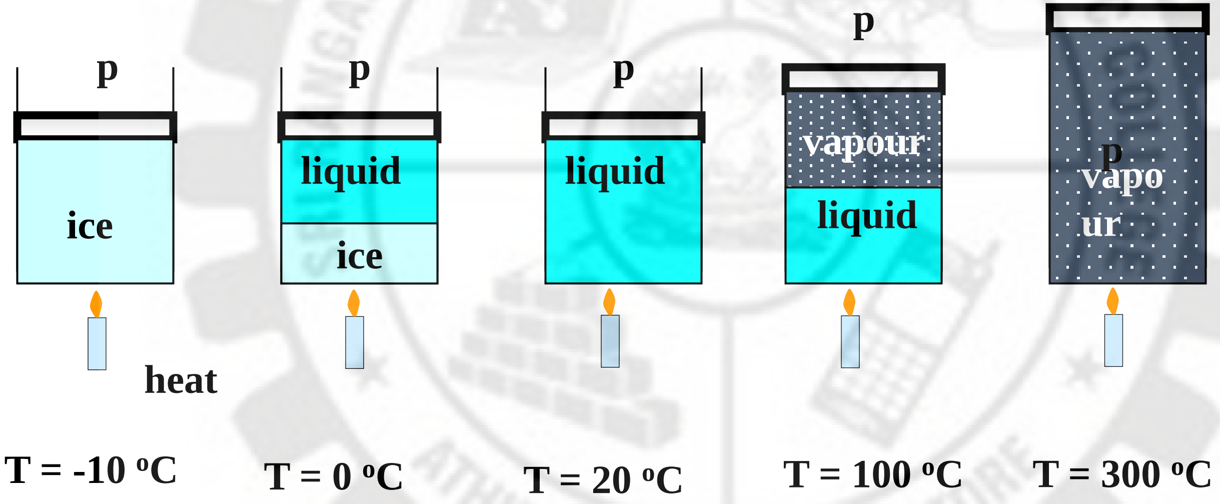


Fig. Heating of Ice at constant Pressure

Phase-Change Process

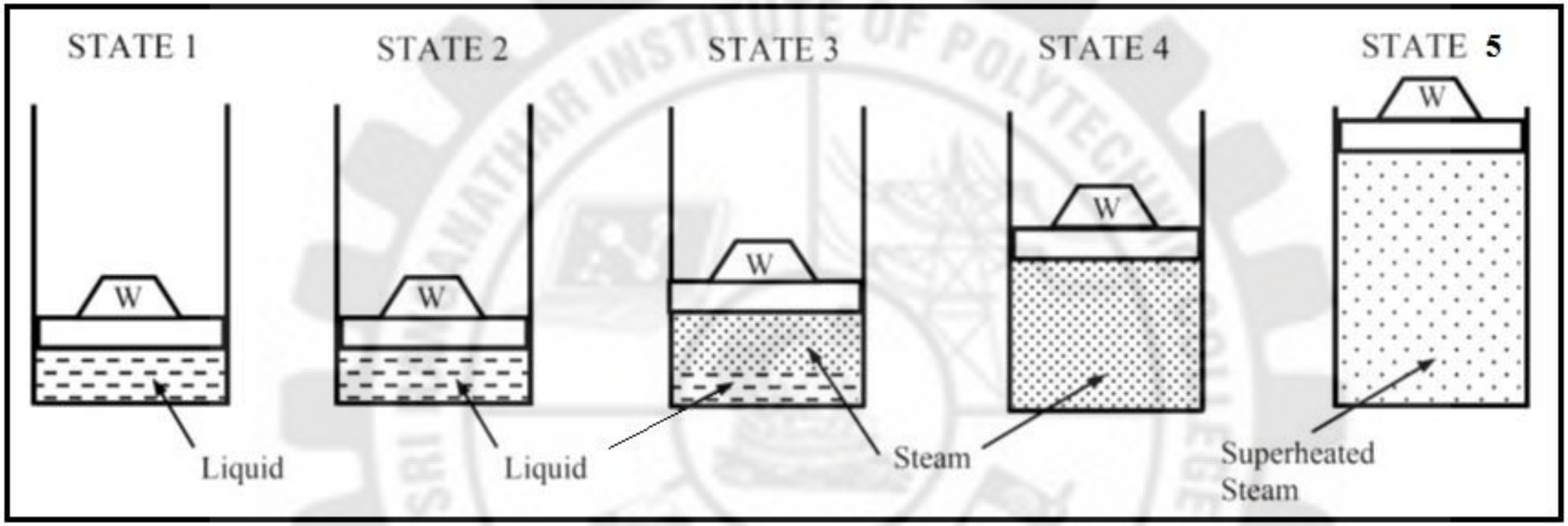


Fig. Heating water and steam at constant pressure (1 atm)

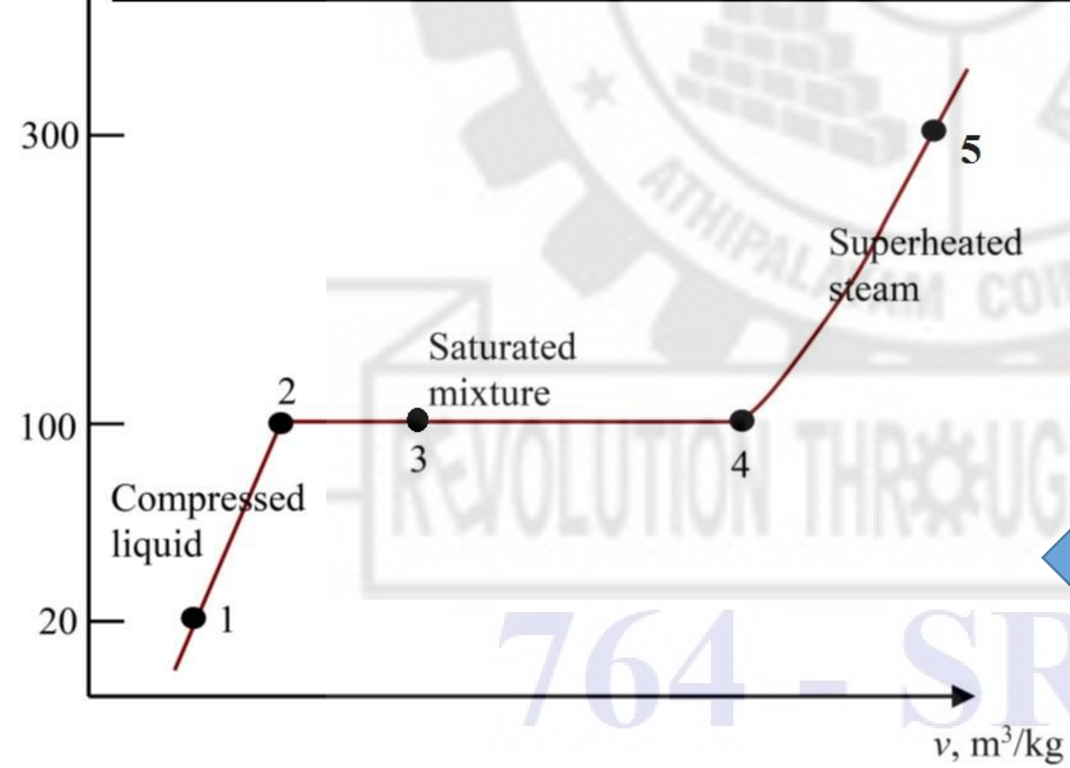


Fig. *T-v* diagram for the heating process of water at constant pressure (1 atm)

Phase-Change Process

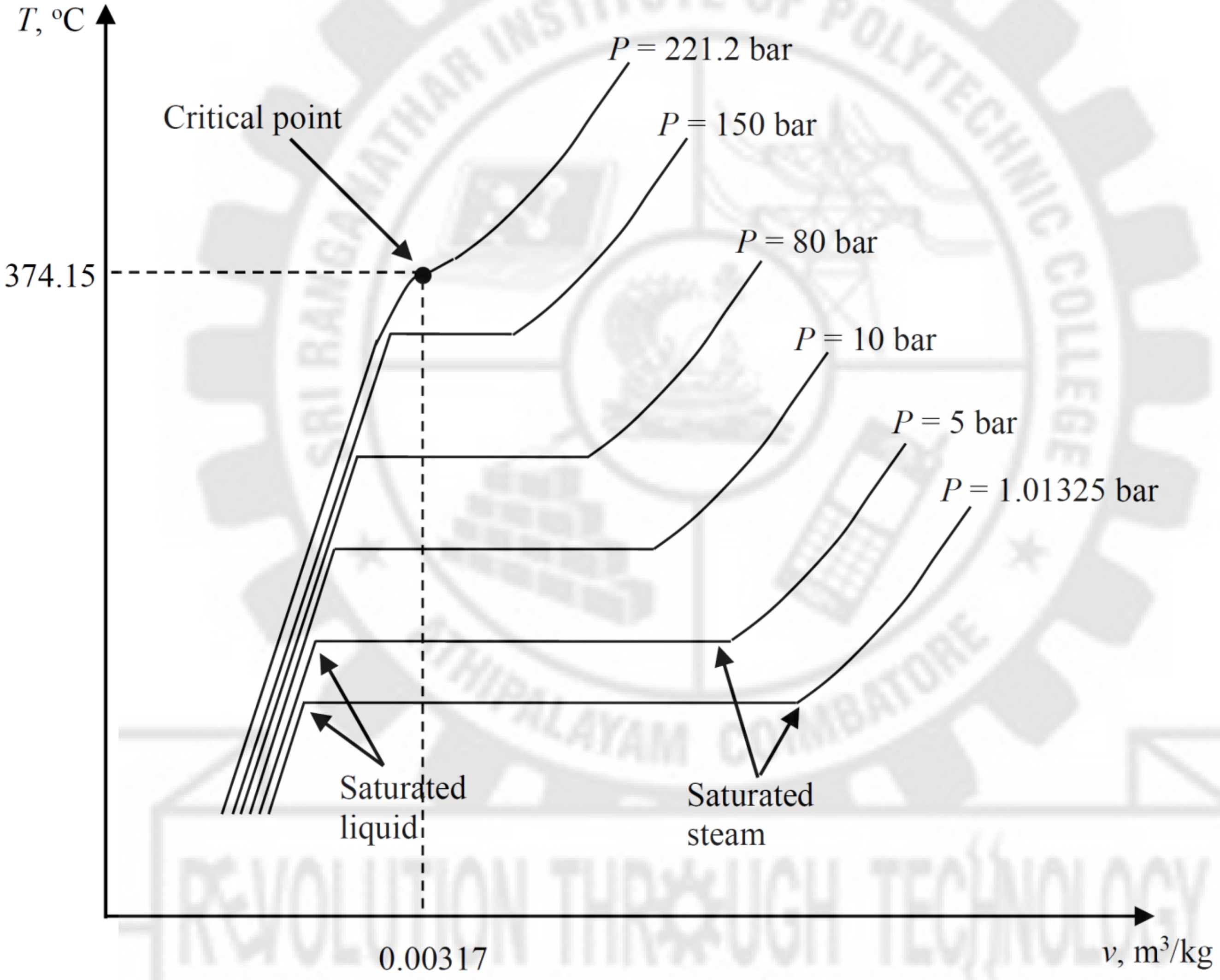
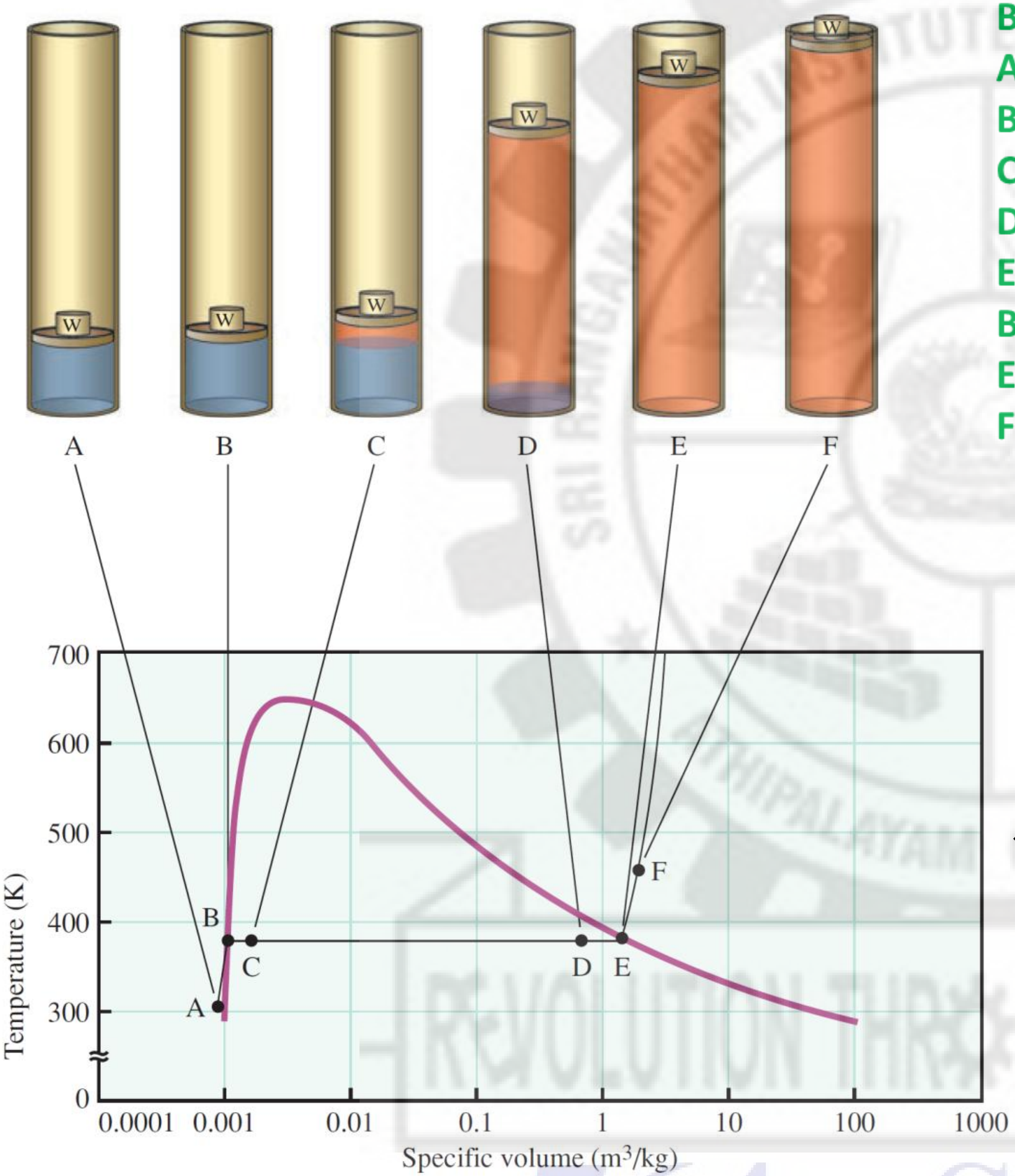


Fig. *T-v* diagram of constant pressure phase change processes of a pure substance at various pressures for water.

Phase-Change Process



A – water at 300 K (27 °C)
B – Saturated liquid
A to B – Sensible heating
B to A – Sensible cooling
C - Wet steam (x=0.1)
D – Wet steam (x=0.9)
E - Saturated vapour
B to E – Vapourisation
E to B – Condensation
F – Super heated steam

Sensible heating/cooling

$$H_{\text{sensible}} = mC_{p(\text{wat})}(T_B - T_A)$$

$$h_{\text{sensible}} = C_{p(\text{wat})}(T_B - T_A)$$

Latent heat is constant depending up on pressure/temperature

- *At 1 atm pressure, the latent heat of fusion of water is 333.7 kJ/kg and the latent heat of vapourization is 2256.5 kJ/kg.*

Fig. Heating water at constant pressure follows the path A–B–C–D–E–F on a temperature–specific volume diagram.

Phase-Change Process

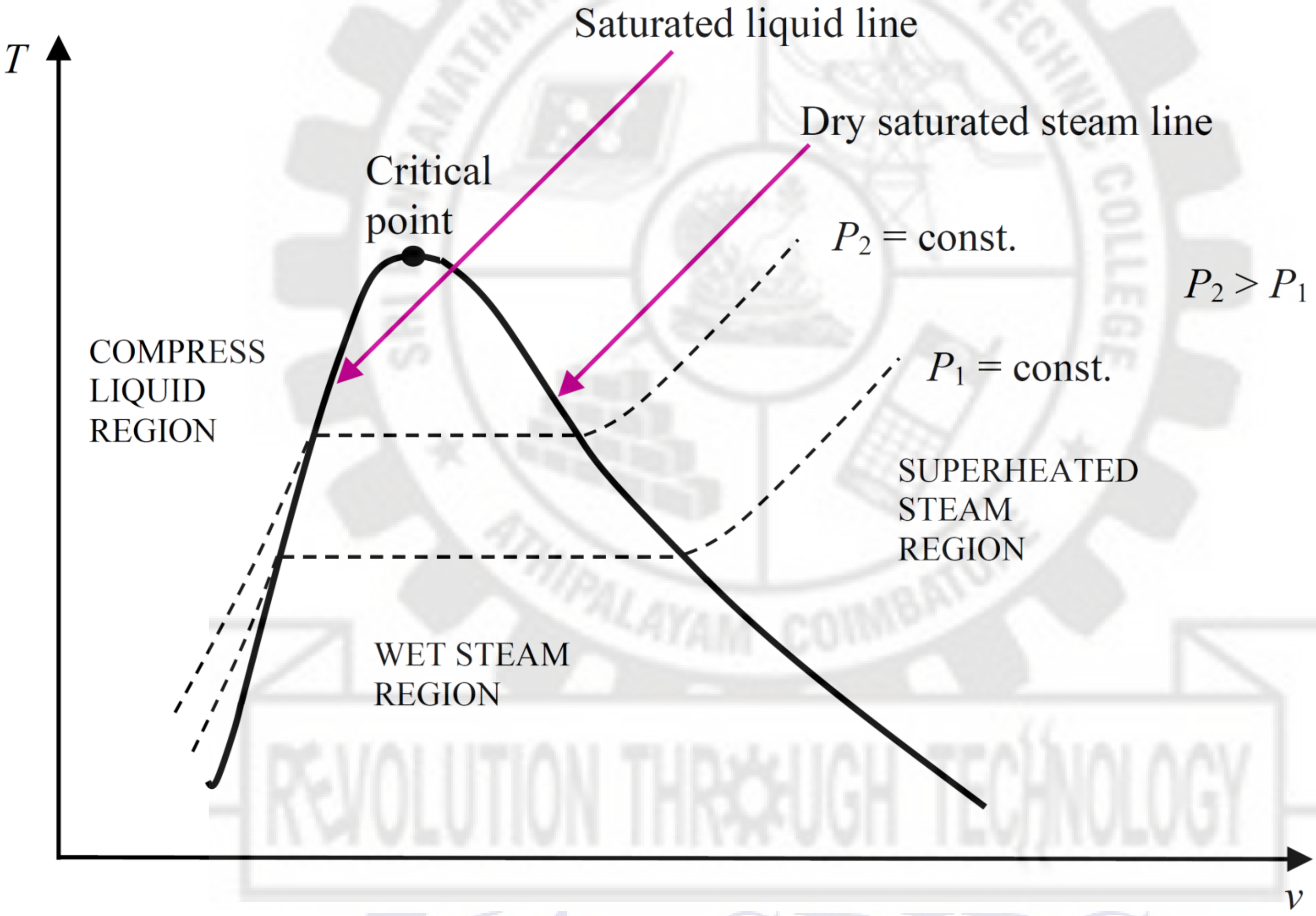


Fig. *T*-*v* diagram of a pure substance

vapour (Steam) Dome

- The dome-shaped region encompassing the two-phase, vapour-liquid equilibrium region.
- It is bordered by the saturated liquid line and the saturated vapour line, both of which end at the triple line and end at the critical point.
- The region below the vapour dome is also called: saturated liquid-vapour region or wet region

The steam during the steam generation process can exist in three types:

1) **Wet steam (saturated steam)**
    - Both the water molecules and steam coexist to form a two phase mixture, called wet steam.
2) **Dry steam (dry saturated steam)**
    - A steam at the saturation temperature corresponding to a given pressure and having no water molecules in it is known as dry saturated steam or dry steam.
3) **Superheated steam**
    - when a dry saturated steam is heated further at the given constant pressure, its temperature rise beyond its saturation vapour temperature. The steam in this state is said to be superheated.

Latent Heat

- ***Latent heat:*** The amount of energy absorbed or released during a phase-change process.
- ***Latent heat of fusion:*** The amount of energy absorbed during melting. It is equivalent to the amount of energy released during freezing.
- ***Latent heat of vapourization:*** The amount of energy absorbed during vapourization and it is equivalent to the energy released during condensation.
- ❑ *At 1 atm pressure, the latent heat of fusion of water is 333.7 kJ/kg and the latent heat of vapourization is 2256.5 kJ/kg.*

Saturation Temperature and Pressure

- T_{sat} -- Temperature at which a phase change takes place at a given pressure.
- P_{sat} -- Pressure at which a phase change takes place at a given temperature.

- **Critical point** -A limiting state above which there is no clear distinction between liquid and vapour phases. **OR** It is a Point at which the saturated vapour and saturated liquid lines coincide.
- Substances in this region are sometimes known as **“fluids”** rather than as vapours or liquids.

Saturated and Sub-cooled Liquids

- If a substance exists as a liquid at the saturation temperature and pressure, it is called a *saturated liquid*
- If the temperature of the liquid is lower than the saturation temperature for the existing pressure, it is called either a *subcooled liquid* or a *compressed liquid*
- **Degrees of Sub-Cooling**

Saturated and Superheated vapours

- If a substance exists entirely as vapour at saturation temperature, it is called *saturated vapour.*
- When the vapour is at a temperature greater than the saturation temperature, it is said to exist as *superheated vapour.*
- **Degrees of Superheat:-**
- The pressure and temperature of superheated vapour are independent properties, since the temperature may increase while the pressure remains constant

Difference between Gas and Vapour.

	Gas		**Vapour**
1	It is the state of substance in which the evapouration from the liquid state is complete	1	It is homogeneous mixture of liquid particles in suspension with true gas of the same substance.
2	Generally gas obey the gas law.	2	Vapour do not obey gas law.
3	Heat supply at constant pressure increases the temperature.	3	Heat supply at constant pressure does not increase the temperature up to saturation vapour state.

P-v diagram of a pure substance

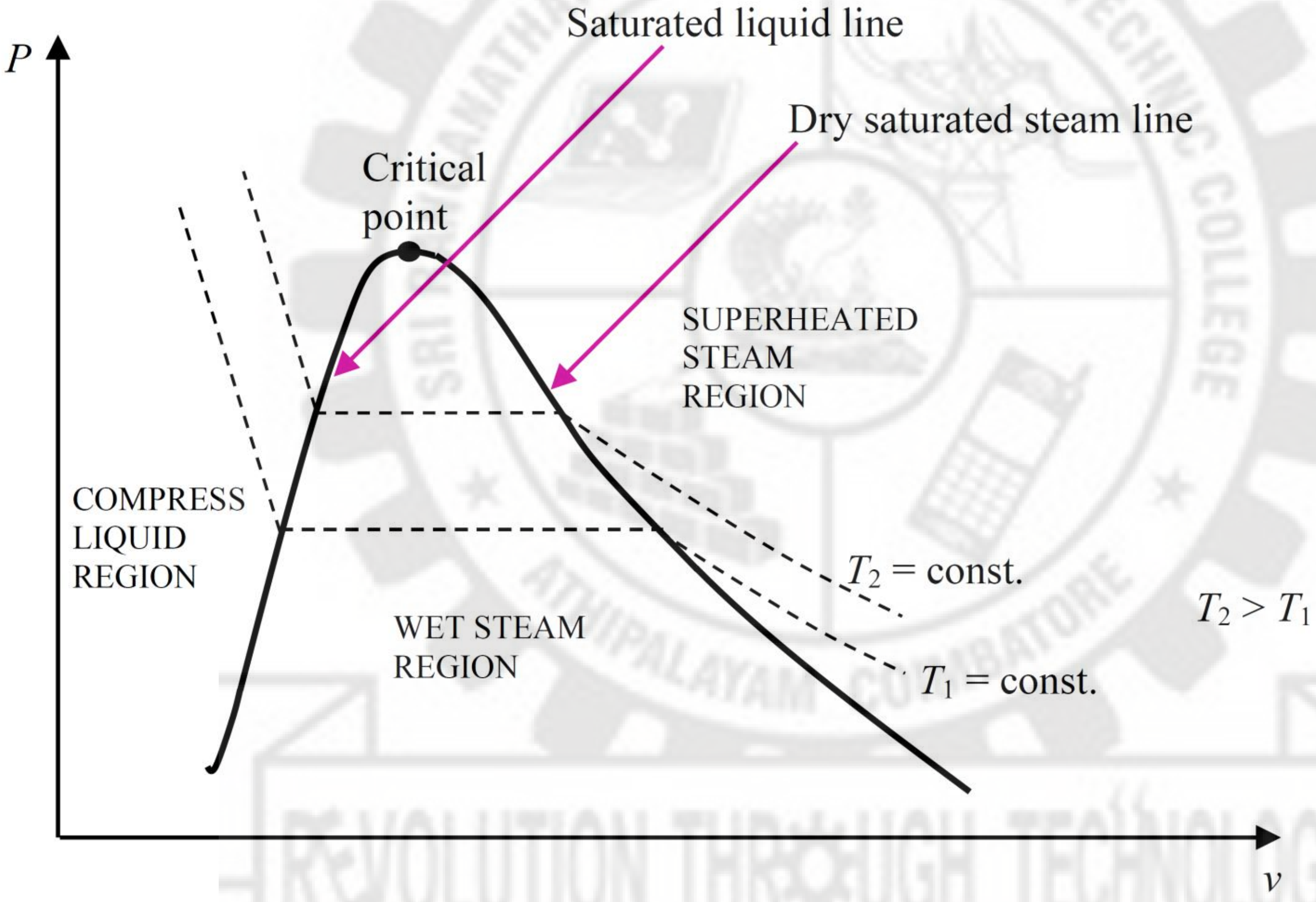
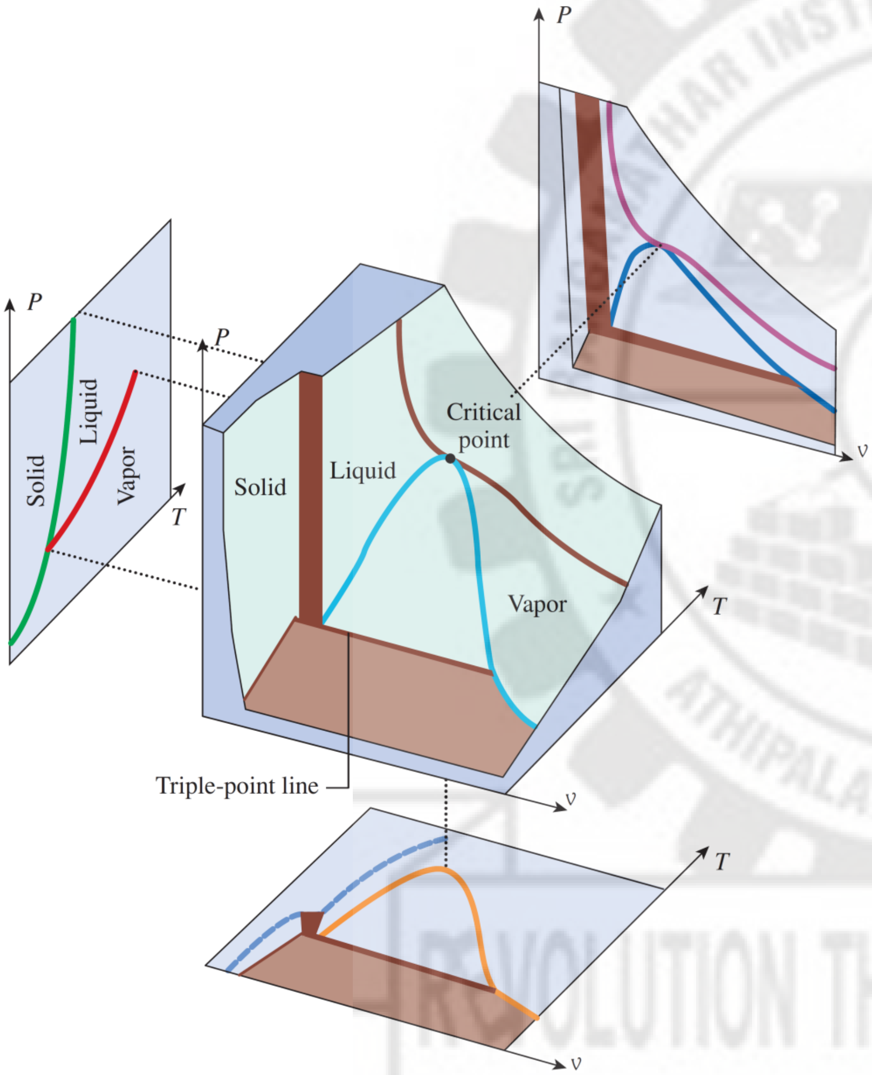
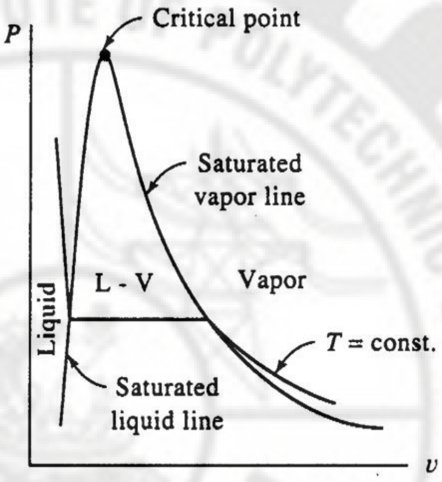
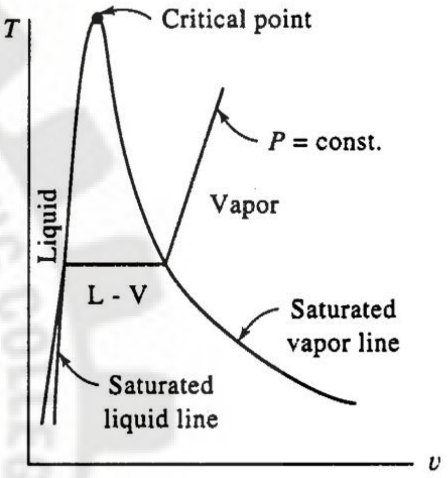


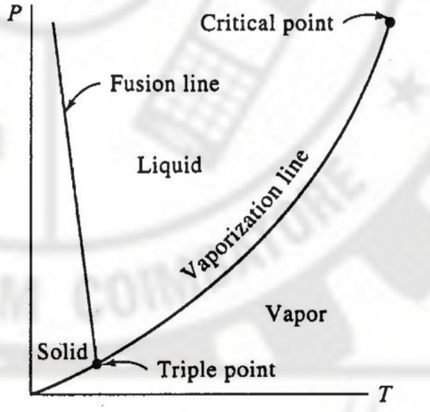
Fig. *P-v* diagram of a pure substance

P–v–*T* surface for a substance









Properties value at triple point for water

- $P_{triple} = 0.006112$ bar
- $T_{triple} = 273.16°C$

Properties value at critical point for water

- $P_c = 221\ bar$ (217.7 atm.)
- $T_c = 374\ °C$ (647 K)
- $v_c = 0.00317\ m^3/kg$

A P–v–T surface for a substance that contracts upon freezing.

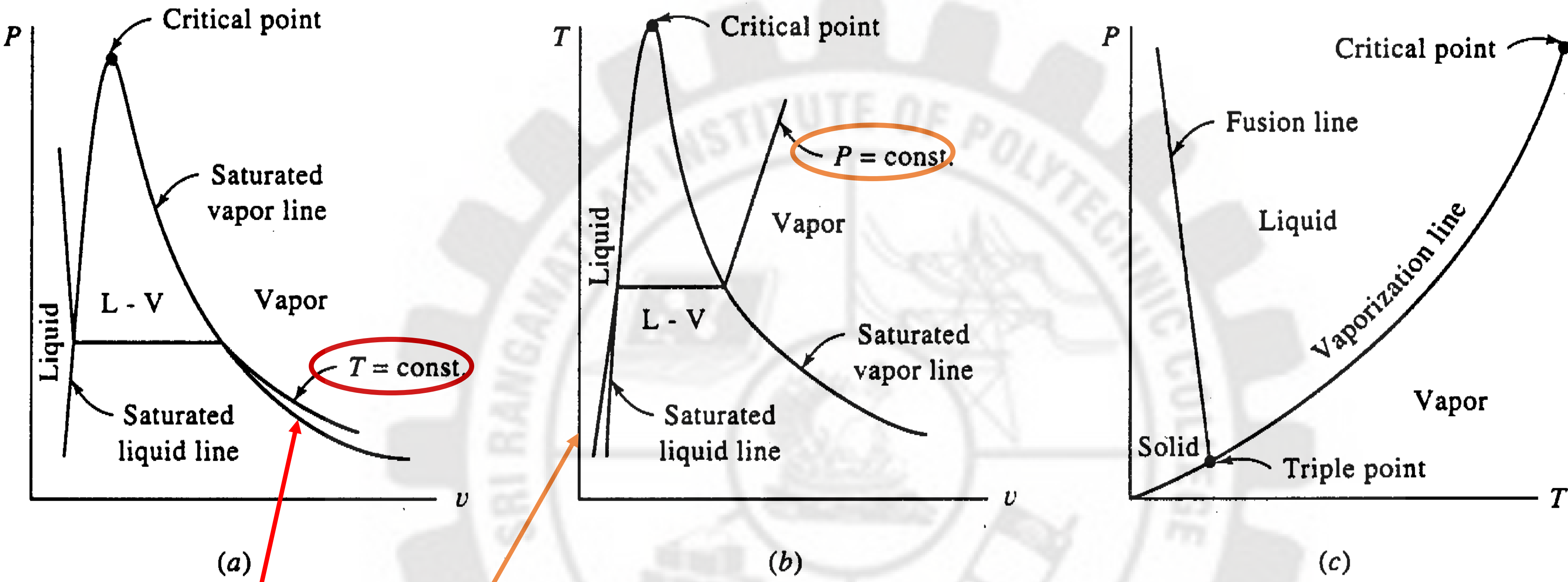


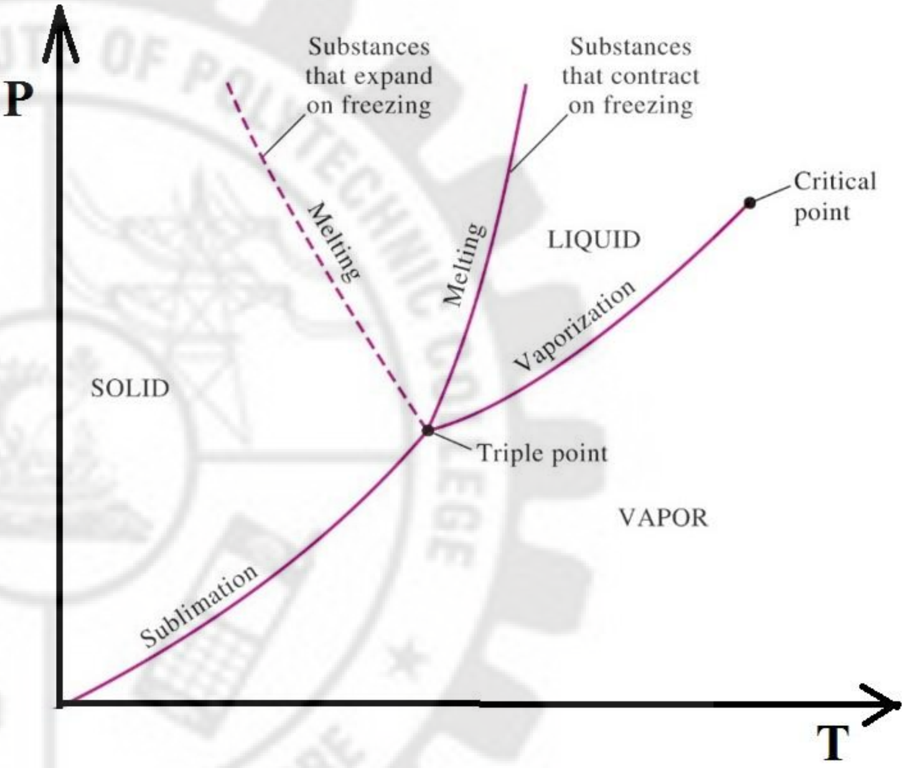
Fig. 2-4 The P-v, T-v, and P-T diagrams.

a) **P-v diagram**: Along the constant temperature line, increasing vapour pressure will lead to higher density (lower specific volume) due to compression. After it reaches the saturation pressure at that temperature, the vapour will condense into liquid while the pressure remains constant until all vapour condense into liquid.

b) **T-v diagram:** Along the constant pressure line, increasing liquid temperature will lead to lower density (higher specific volume) due to thermal expansion. At the saturation temperature, the liquid will vapourize into gaseous form at a constant pressure until all liquid vapourize.

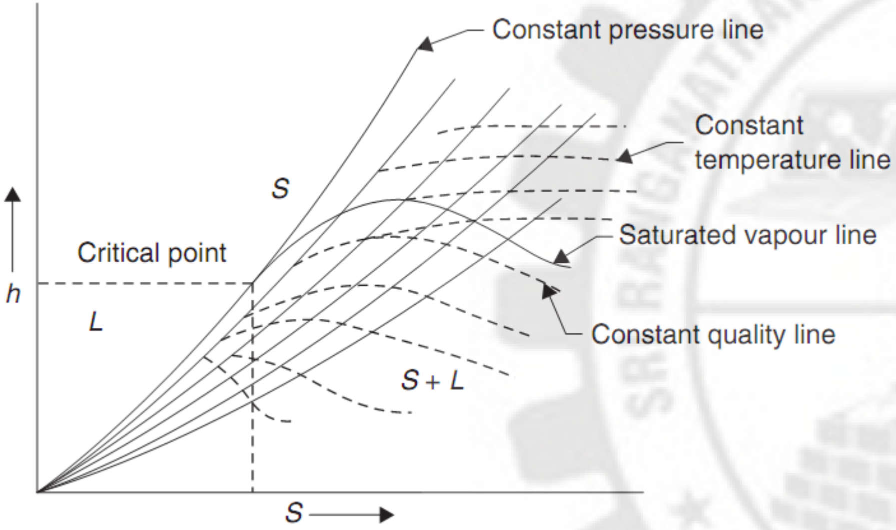
c) P-T phase diagram of pure substances

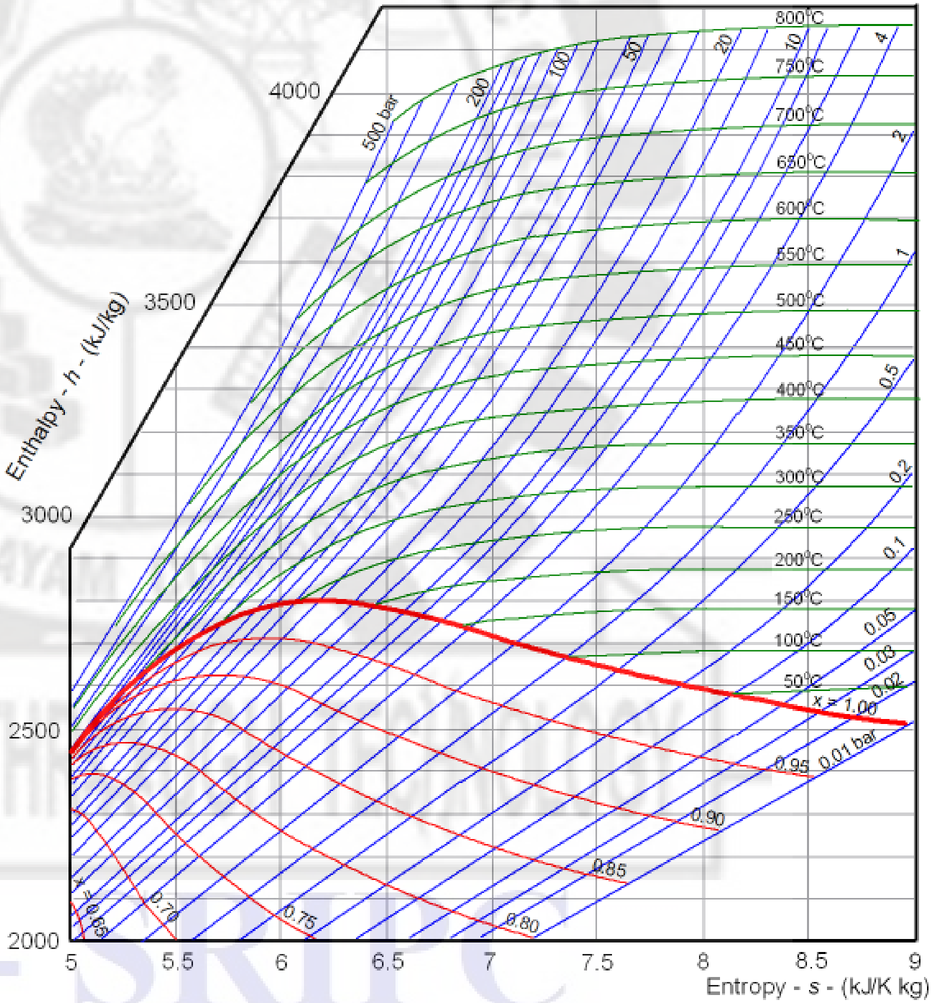
State 1	State 2	1 to 2	2 to 1
Solid	Liquid	Melting (Fusion)	Freezing
Liquid	Vapour	vapourization (Evapouration)	Condensation
Solid	Vapour	Sublimation	Desublimation (Deposition)



- **Melting** or **Fusion** - change of phase from solid to liquid.
- **Freezing** - change of phase from liquid to solid.
- **vapourization** or **Evapouration** - change of phase from liquid to vapour.
- **Condensation** - change of phase from vapour to liquid.
- **Sublimation** - change of phase from solid to vapour.
- **De-sublimation** or **Deposition** - change of phase from vapour to solid.
- **Triple point** - the temperature and pressure at which all three phases can exist in equilibrium.

Mollier Diagram OR **h–s Chart**





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- ***Enthalpy–entropy (h–s)* diagram for water showing liquid and vapour saturation lines.**

- ***Also showing isobars (p), isotherms (T) and quality of steam (x).***

Quality or Dryness fraction (x) of steam

- When a substance exists as part liquid and part vapour at saturation conditions, its *quality* or *dryness fraction (x) of steam* is **defined** as the ratio of the mass of the vapour to the total mass of both vapour and liquid.

$$\boxed{x = \frac{mass_{vap}}{mass_{total}} = \frac{m_g}{m_f + m_g} \qquad (0 \le x \le 1)}$$

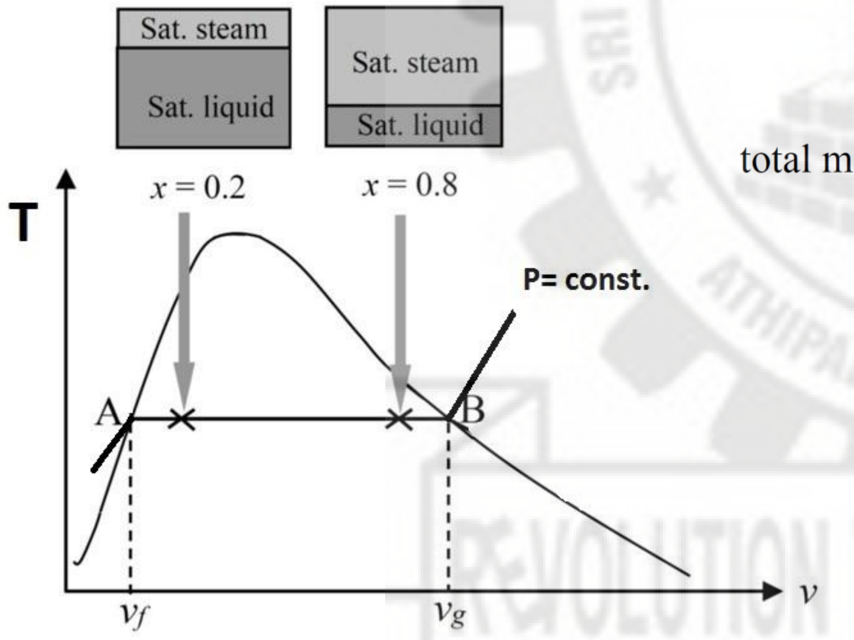
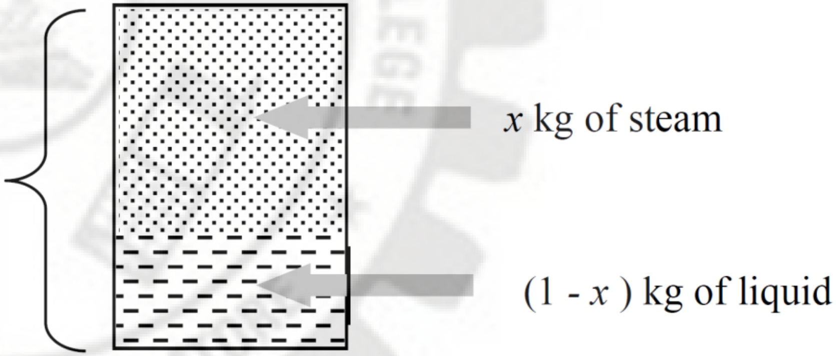


Fig. *P-v* diagram showing the dryness fraction of liquid-steam mixture



At point A, $x = 0$

At point B, $x = 1$

Between point A and B, $0 < x < 1.0$

Note that for a saturated liquid, $x = 0$; and that for dry saturated steam, $x = 1$.

Moisture Content

- The *moisture content* of a substance is the opposite of its quality. Moisture is defined as the ratio of the mass of the liquid to the total mass of both liquid and vapour

$$\text{moisture content} = \frac{mass_{water}}{mass_{total}} = \frac{m_f}{m_f + m_g} = \frac{(m_f + m_g) - m_g}{m_f + m_g} = 1 - x$$

We note

$$V = V_f + V_g$$

$$m = m_f + m_g$$

$$V = mv, \quad V_f = m_f v_f, \quad V_g = m_g v_g$$

$$mv = m_f v_f + m_g v_g$$

$$v = \frac{m_f v_f}{m} + \frac{m_g v_g}{m}$$

Recall the definition of quality *x*

$$x = \frac{m_g}{m} = \frac{m_g}{m_f + m_g}$$

Then

$$\frac{m_f}{m} = \frac{m - m_g}{m} = 1 - x$$

$$v = (1 - x)v_f + xv_g$$

$$v = v_f + x(v_g - v_f)$$

$$v = v_f + x\, v_{fg}$$

Generalised equation,

$$y = y_f + x\, y_{fg}$$

Where,
f : saturated liquid
g : saturated vapour
x : dryness fraction

The term y_{fg} is the difference between the saturated vapour and the saturated liquid values of the property y; y may be replaced by any of the variables v, u, h, or s.

$$\boxed{\begin{aligned} v &= v_f + x\, v_{fg} \\ u &= u_f + x\, u_{fg} \\ h &= h_f + x\, h_{fg} \\ s &= s_f + x\, s_{fg} \end{aligned}}$$

Where,

$$v_{fg} = v_g - v_f$$
$$u_{fg} = u_g - u_f$$
$$h_{fg} = h_g - h_f$$
$$s_{fg} = s_g - s_f$$

- The quantity ***h*** $_{fg}$ is called the **enthalpy of vapourization (or latent heat of vapourization).** It represents the amount of energy needed to vapourize a unit of mass of saturated liquid at a given temperature or pressure. It decreases as the temperature or pressure increases, and becomes zero at the critical point.

Enthalpy of Steam

- Enthalpy of Saturated liquid:

$$h_f = C_{pw}(T_f - 0)$$

- Enthalpy of Dry saturated steam:

$$h_g = h_f + h_{fg}$$

- Enthalpy of Wet steam:

$$h = h_f + x\,h_{fg}$$

- Enthalpy of Superheated steam:

$$h_{sup} = h_g + C_{ps}(T_{sup} - T_{sat})$$

Table The property of steam tables

Symbols	***Description***	***Units***
p	Absolute pressure of the fluid	bar
t_s	Saturation temperature corresponding to the pressure p bar	^oC
v_f	Specific volume of saturated liquid	m^3/kg
v_g	Specific volume of saturated steam	m^3/kg
u_f	Specific internal energy of saturated liquid	kJ/kg
u_g	Specific internal energy of saturated steam	kJ/kg
u_{fg}	Change of specific internal energy during evapouration	kJ/kg
h_f	Specific enthalpy of saturated liquid	kJ/kg
h_g	Specific enthalpy of saturated steam	kJ/kg
h_{fg}	Change of specific enthalpy during evapouration	kJ/kg
s_f	Specific entropy of saturated liquid	kJ/kg K
s_g	Specific entropy of saturated steam	kJ/kg K
s_{fg}	Change of specific entropy during evapouration	kJ/kg K

Properties tables for water

- Saturated ice-water table (A6)
- Compressed liquid water table (A5)
- Saturated water table (A2 & A3)
- Superheated water table (A4)

TABLE A–2

Saturated water—Temperature table

		Specific volume, m³/kg		*Internal energy, kJ/kg*			*Enthalpy, kJ/kg*			*Entropy, kJ/kg·K*		
Temp., T °C	Sat. press., P_{sat} kPa	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9	0.0000	9.1556	9.1556
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487	9.0249
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2	0.1511	8.7488	8.8999
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559	8.7803
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4	0.2965	8.3696	8.6661
25	3.1698	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5	0.3672	8.1895	8.5567
30	4.2469	0.001004	32.879	125.73	2290.2	2415.9	125.74	2429.8	2555.6	0.4368	8.0152	8.4520
35	5.6291	0.001006	25.205	146.63	2276.0	2422.7	146.64	2417.9	2564.6	0.5051	7.8466	8.3517
40	7.3851	0.001008	19.515	167.53	2261.9	2429.4	167.53	2406.0	2573.5	0.5724	7.6832	8.2556
45	9.5953	0.001010	15.251	188.43	2247.7	2436.1	188.44	2394.0	2582.4	0.6386	7.5247	8.1633
50	12.352	0.001012	12.026	209.33	2233.4	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748
55	15.763	0.001015	9.5639	230.24	2219.1	2449.3	230.26	2369.8	2600.1	0.7680	7.2218	7.9898
60	19.947	0.001017	7.6670	251.16	2204.7	2455.9	251.18	2357.7	2608.8	0.8313	7.0769	7.9082
65	25.043	0.001020	6.1935	272.09	2190.3	2462.4	272.12	2345.4	2617.5	0.8937	6.9360	7.8296
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
355	17,570	0.001808	0.007872	1682.2	706.4	2388.6	1714.0	812.9	2526.9	3.8442	1.2942	5.1384
360	18,666	0.001895	0.006950	1726.2	625.7	2351.9	1761.5	720.1	2481.6	3.9165	1.1373	5.0537
365	19,822	0.002015	0.006009	1777.2	526.4	2303.6	1817.2	605.5	2422.7	4.0004	0.9489	4.9493
370	21,044	0.002217	0.004953	1844.5	385.6	2230.1	1891.2	443.1	2334.3	4.1119	0.6890	4.8009
373.95	22,064	0.003106	0.003106	2015.7	0	2015.7	2084.3	0	2084.3	4.4070	0	4.4070

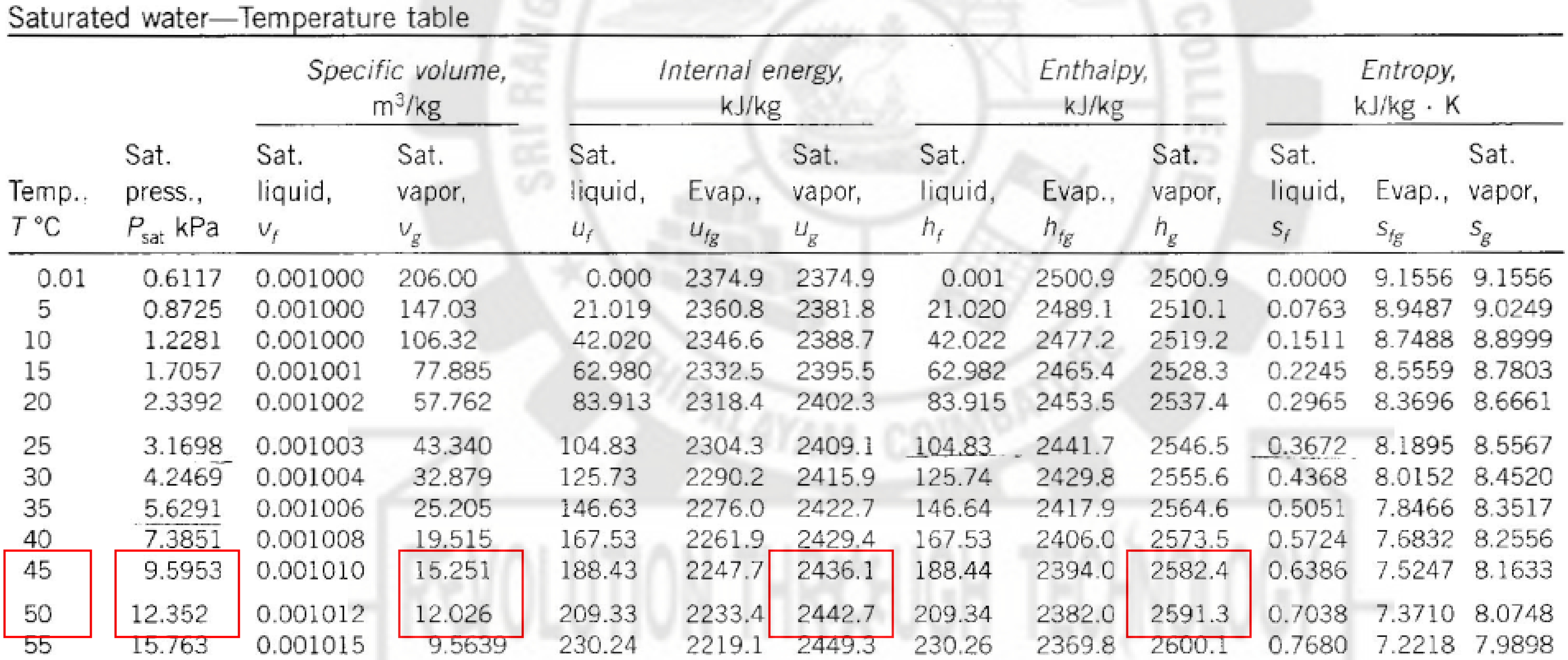
TABLE A–3

Saturated water—Pressure table

		Specific volume, m^3/kg		*Internal energy,* kJ/kg			*Enthalpy,* kJ/kg			*Entropy,* kJ/kg·K		
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765
4.0	28.96	0.001004	34.791	121.39	2293.1	2414.5	121.39	2432.3	2553.7	0.4224	8.0510	8.4734
5.0	32.87	0.001005	28.185	137.75	2282.1	2419.8	137.75	2423.0	2560.7	0.4762	7.9176	8.3938
7.5	40.29	0.001008	19.233	168.74	2261.1	2429.8	168.75	2405.3	2574.0	0.5763	7.6738	8.2501
10	45.81	0.001010	14.670	191.79	2245.4	2437.2	191.81	2392.1	2583.9	0.6492	7.4996	8.1488
15	53.97	0.001014	10.020	225.93	2222.1	2448.0	225.94	2372.3	2598.3	0.7549	7.2522	8.0071
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
18,000	356.99	0.001840	0.007504	1699.1	675.9	2375.0	1732.2	777.8	2510.0	3.8720	1.2343	5.1064
19,000	361.47	0.001926	0.006677	1740.3	598.9	2339.2	1776.8	689.2	2466.0	3.9396	1.0860	5.0256
20,000	365.75	0.002038	0.005862	1785.8	509.0	2294.8	1826.6	585.5	2412.1	4.0146	0.9164	4.9310
21,000	369.83	0.002207	0.004994	1841.6	391.9	2233.5	1888.0	450.4	2338.4	4.1071	0.7005	4.8076
22,000	373.71	0.002703	0.003644	1951.7	140.8	2092.4	2011.1	161.5	2172.6	4.2942	0.2496	4.5439
22,064	373.95	0.003106	0.003106	2015.7	$\boxed{0}$	2015.7	2084.3	$\boxed{0}$	2084.3	4.4070	$\boxed{0}$	4.4070

Example 2.1

Determine the saturated pressure, specific volume, internal energy and enthalpy for saturated water vapour at 45^{o}C and 50^{o}C.

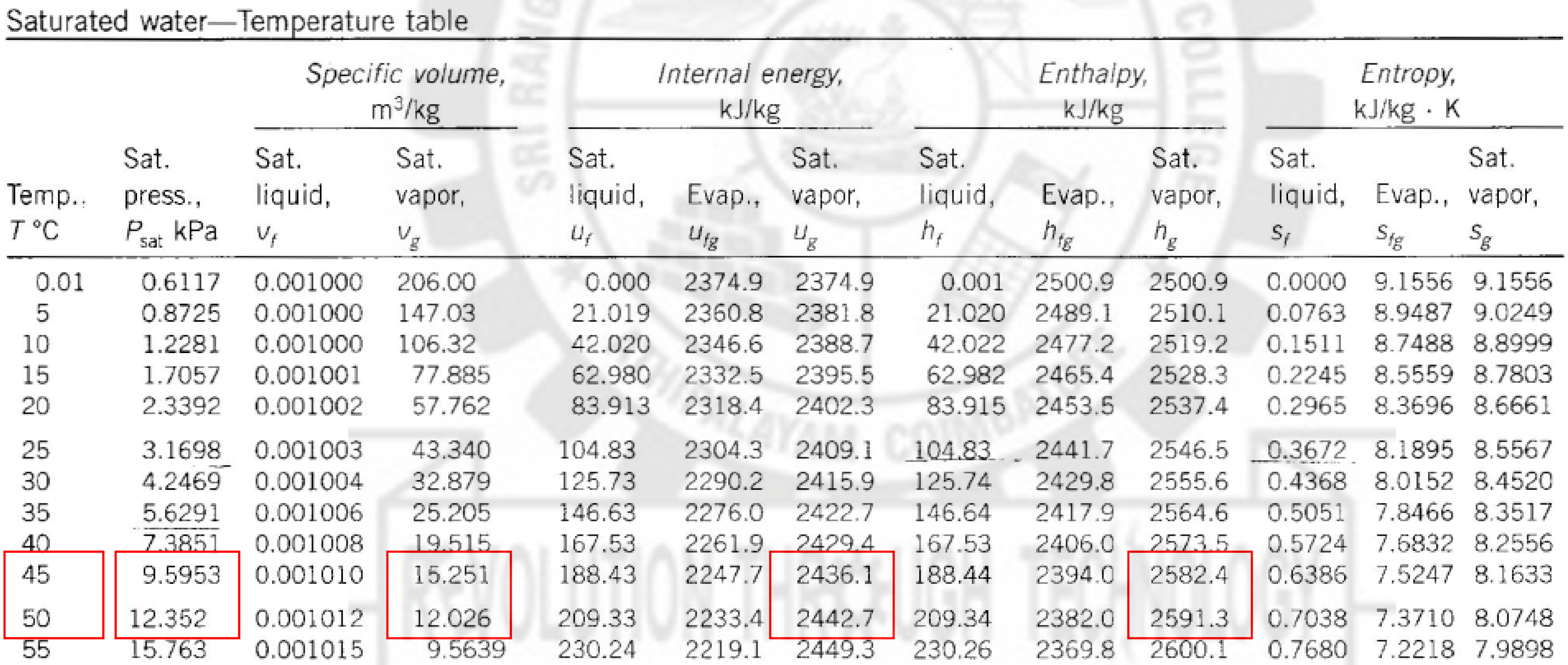


Saturated water—Temperature table

		Specific volume, m^3/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg · K		
Temp., T °C	Sat. press., P_{sat} kPa	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9	0.0000	9.1556	9.1556
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487	9.0249
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2	0.1511	8.7488	8.8999
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559	8.7803
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4	0.2965	8.3696	8.6661
25	3.1698	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5	0.3672	8.1895	8.5567
30	4.2469	0.001004	32.879	125.73	2290.2	2415.9	125.74	2429.8	2555.6	0.4368	8.0152	8.4520
35	5.6291	0.001006	25.205	146.63	2276.0	2422.7	146.64	2417.9	2564.6	0.5051	7.8466	8.3517
40	7.3851	0.001008	19.515	167.53	2261.9	2429.4	167.53	2406.0	2573.5	0.5724	7.6832	8.2556
45	9.5953	0.001010	15.251	188.43	2247.7	2436.1	188.44	2394.0	2582.4	0.6386	7.5247	8.1633
50	12.352	0.001012	12.026	209.33	2233.4	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748
55	15.763	0.001015	9.5639	230.24	2219.1	2449.3	230.26	2369.8	2600.1	0.7680	7.2218	7.9898

Example 2.2

Determine the saturated pressure, specific volume, internal energy and enthalpy for saturated water vapour at 47^0 C .



Saturated water—Temperature table

Temp., T °C	Sat. press., P_{sat} kPa	Specific volume, m³/kg Sat. liquid, v_f	Sat. vapor, v_g	Internal energy, kJ/kg Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Enthalpy, kJ/kg Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Entropy, kJ/kg · K Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9	0.0000	9.1556	9.1556
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487	9.0249
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2	0.1511	8.7488	8.8999
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559	8.7803
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4	0.2965	8.3696	8.6661
25	3.1698	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5	0.3672	8.1895	8.5567
30	4.2469	0.001004	32.879	125.73	2290.2	2415.9	125.74	2429.8	2555.6	0.4368	8.0152	8.4520
35	5.6291	0.001006	25.205	146.63	2276.0	2422.7	146.64	2417.9	2564.6	0.5051	7.8466	8.3517
40	7.3851	0.001008	19.515	167.53	2261.9	2429.4	167.53	2406.0	2573.5	0.5724	7.6832	8.2556
45	9.5953	0.001010	15.251	188.43	2247.7	2436.1	188.44	2394.0	2582.4	0.6386	7.5247	8.1633
50	12.352	0.001012	12.026	209.33	2233.4	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748
55	15.763	0.001015	9.5639	230.24	2219.1	2449.3	230.26	2369.8	2600.1	0.7680	7.2218	7.9898

Linear Interpolation

$$\left(\frac{x - x_1}{x_2 - x_1}\right) = \left(\frac{y - y_1}{y_2 - y_1}\right)$$

Solution:

- Extract data from steam table

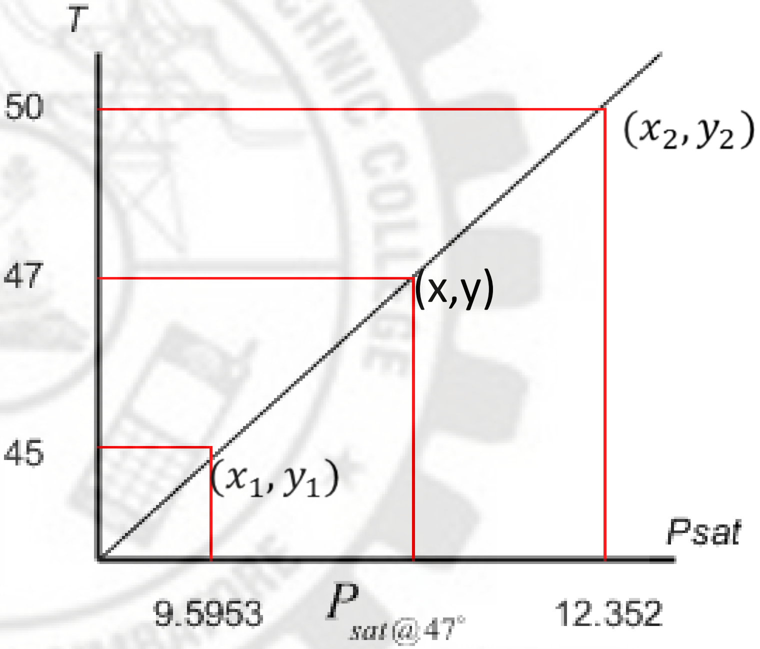
T	P_{sat}	v_g	u_g	h_g
45	9.5953	15.251	2436.1	2582.4
47	P_{sat}	v	u	h
50	12.352	12.026	2442.7	2591.3

- Interpolation for P_{sat}

$$\frac{P_{sat} - 9.5953}{12.352 - 9.5953} = \frac{47 - 45}{50 - 45}$$

$$P_{sat@47^\circ} = \underline{\underline{10.698\,kPa}}$$

- Do the same principal to others!!!!



Interpolation Scheme for P_{sat}

Example 2.3

Determine the enthalpy of 1.5 kg of water contained in a volume of 1.2 m^3 at 200 kPa.

Solution:

- Specific volume for water

$$v = \frac{Volume}{mass} = \frac{1.2\,m^3}{1.5\,kg} = 0.8\,\frac{m^3}{kg}$$

- From table A-5:

$$v_f = 0.001061\, {m^3}/{kg}$$

$$v_g = 0.8858\, {m^3}/{kg}$$

Is $v < v_f$? No

Is $v_f < v < v_g$? Yes

Is $v_g < v$? No

- Find the quality

$$v = v_f + x(v_g - v_f)$$

$$x = \frac{v - v_f}{v_g - v_f}$$

$$= \frac{0.8 - 0.001061}{0.8858 - 0.001061}$$

$= 0.903$ (What does this mean?)

- The enthalpy

$$h = h_f + x\,h_{fg}$$

$$= 504.7 + (0.903)(2201.6)$$

$$= 2492.7\,\frac{kJ}{kg}$$

TABLE A–3

Saturated water—Pressure table

		Specific volume, m^3/kg		*Internal energy,* kJ/kg			*Enthalpy,* kJ/kg			*Entropy,* kJ/kg·K		
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
175	116.04	0.001057	1.0037	486.82	2037.7	2524.5	487.01	2213.1	2700.2	1.4850	5.6865	7.1716
200	120.21	0.001061	0.88578	504.50	2024.6	2529.1	504.71	2201.6	2706.3	1.5302	5.5968	7.1270
225	123.97	0.001064	0.79329	520.47	2012.7	2533.2	520.71	2191.0	2711.7	1.5706	5.5171	7.0877
250	127.41	0.001067	0.71873	535.08	2001.8	2536.8	535.35	2181.2	2716.5	1.6072	5.4453	7.0525
275	130.58	0.001070	0.65732	548.57	1991.6	2540.1	548.86	2172.0	2720.9	1.6408	5.3800	7.0207

Superheated Water Table

A substance is said to be **superheated** if the given temperature is greater than the saturation temperature for the given pressure.

In the superheated water Table A-6, T and P are the independent properties. The value of temperature to the right of the pressure is the saturation temperature for the pressure.

The first entry in the table is the saturated vapour state at the pressure.

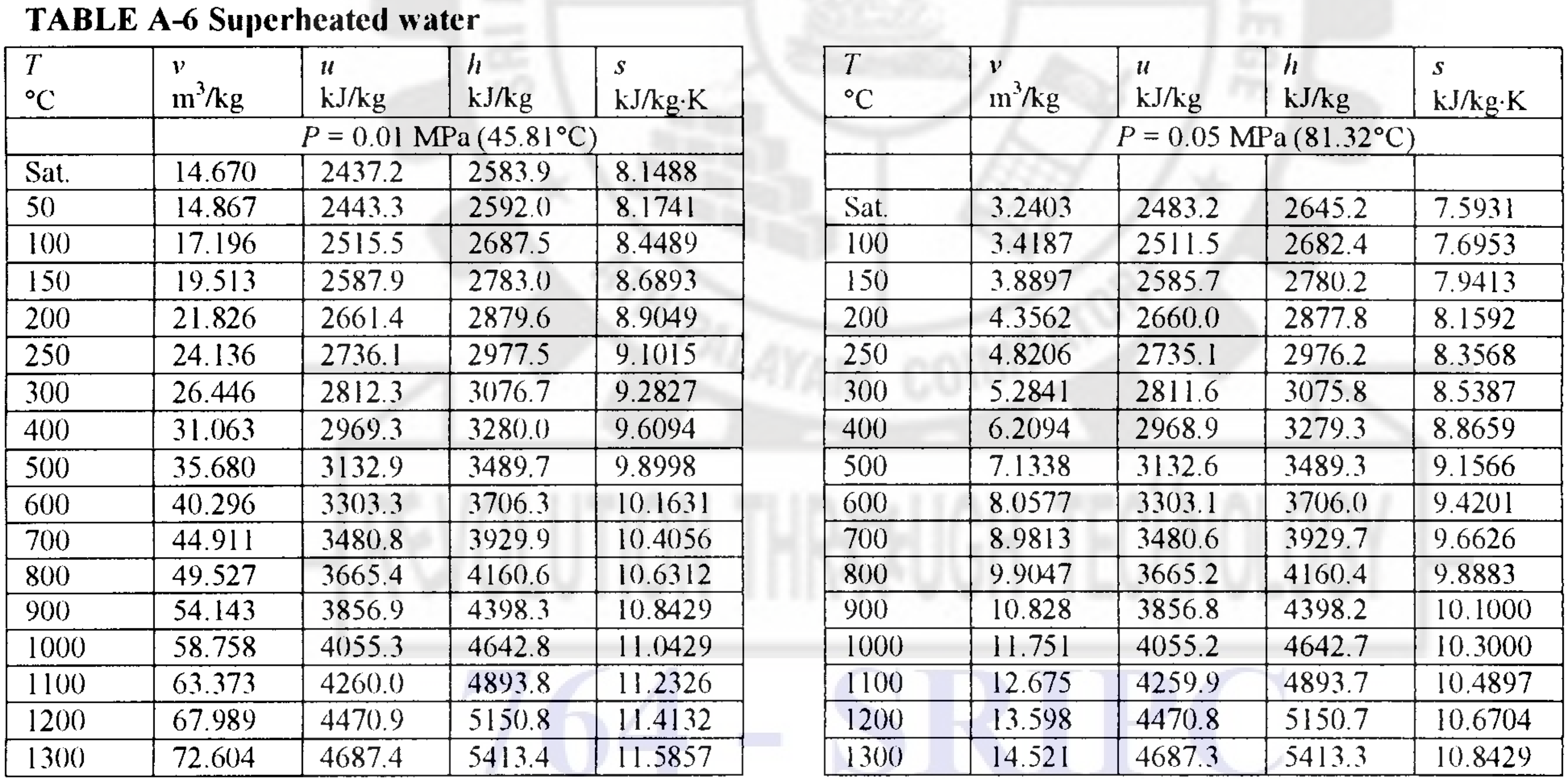


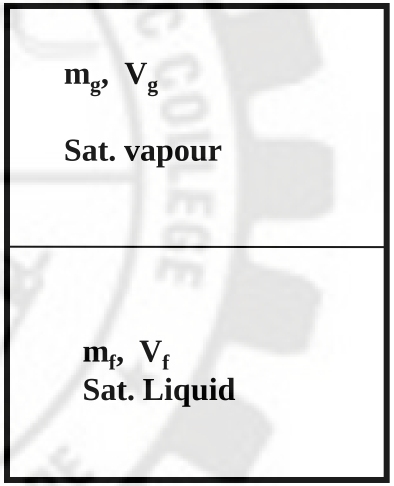
TABLE A-6 Superheated water

T °C	*v* m^3/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg·K
	P = 0.01 MPa (45.81°C)			
Sat.	14.670	2437.2	2583.9	8.1488
50	14.867	2443.3	2592.0	8.1741
100	17.196	2515.5	2687.5	8.4489
150	19.513	2587.9	2783.0	8.6893
200	21.826	2661.4	2879.6	8.9049
250	24.136	2736.1	2977.5	9.1015
300	26.446	2812.3	3076.7	9.2827
400	31.063	2969.3	3280.0	9.6094
500	35.680	3132.9	3489.7	9.8998
600	40.296	3303.3	3706.3	10.1631
700	44.911	3480.8	3929.9	10.4056
800	49.527	3665.4	4160.6	10.6312
900	54.143	3856.9	4398.3	10.8429
1000	58.758	4055.3	4642.8	11.0429
1100	63.373	4260.0	4893.8	11.2326
1200	67.989	4470.9	5150.8	11.4132
1300	72.604	4687.4	5413.4	11.5857

T °C	*v* m^3/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg·K
	P = 0.05 MPa (81.32°C)			
Sat.	3.2403	2483.2	2645.2	7.5931
100	3.4187	2511.5	2682.4	7.6953
150	3.8897	2585.7	2780.2	7.9413
200	4.3562	2660.0	2877.8	8.1592
250	4.8206	2735.1	2976.2	8.3568
300	5.2841	2811.6	3075.8	8.5387
400	6.2094	2968.9	3279.3	8.8659
500	7.1338	3132.6	3489.3	9.1566
600	8.0577	3303.1	3706.0	9.4201
700	8.9813	3480.6	3929.7	9.6626
800	9.9047	3665.2	4160.4	9.8883
900	10.828	3856.8	4398.2	10.1000
1000	11.751	4055.2	4642.7	10.3000
1100	12.675	4259.9	4893.7	10.4897
1200	13.598	4470.8	5150.7	10.6704
1300	14.521	4687.3	5413.3	10.8429

Example 2.4

Consider the closed, rigid container of water as shown. The pressure is 700 kPa, the mass of the saturated liquid is 1.78 kg, and the mass of the saturated vapour is 0.22 kg. Heat is added to the water until the pressure increases to 8 MPa. Find the final temperature, enthalpy, and internal energy of the water



Solution:

- Theoretically:

$$v_2 = v_1$$

- The quality before pressure increased (***state 1***).

$$x_1 = \frac{m_{g1}}{m_{f1} + m_{g1}}$$

$$= \frac{0.22\,kg}{(1.78 + 0.22)\,kg} = 0.11$$

- Specific volume at ***state 1***

$$v_1 = v_{f1} + x_1(v_{g1} - v_{f1})$$

$$= 0.001108 + (0.11)(0.2728 - 0.001108)$$

$$= 0.031\frac{m^3}{kg}$$

State 2:

- Information :

$$P_2 = 8\,MPa \quad v_2 = 0.031\tfrac{m^3}{kg}$$

- From table A-3:

$$v_{f,2} = 0.001384\frac{m^3}{kg}$$

$$v_{g,2} = 0.02352\frac{m^3}{kg}$$

$$v_{g2} < v_2$$

- Since that it is in superheated region, use table A-4:

$$T_2 = 361.8^o C$$

$$h_2 = 3024\tfrac{kJ}{kg}$$

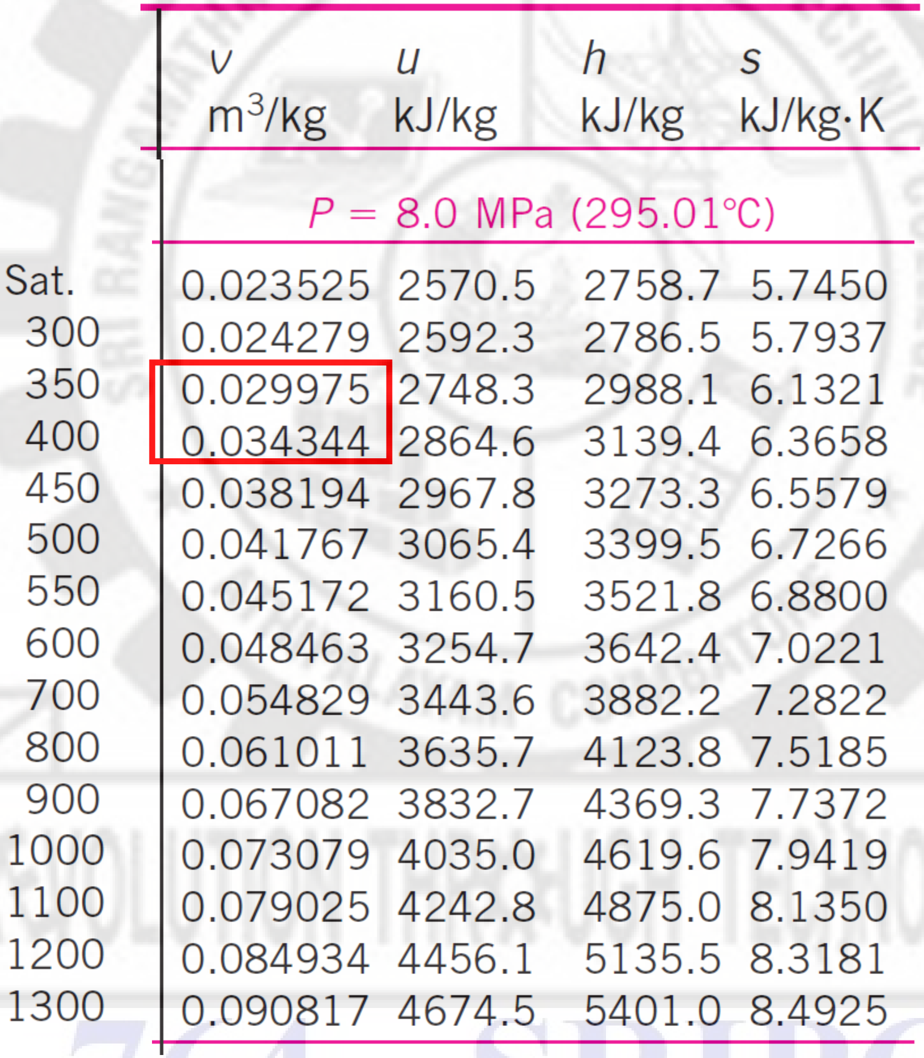
$$u_2 = 2776\tfrac{kJ}{kg}$$

TABLE A–3

Saturated water—Pressure table

		Specific volume, m^3/kg		*Internal energy,* kJ/kg			*Enthalpy,* kJ/kg			*Entropy,* kJ/kg·K		
Press., P kPa	Sat. temp., T_{sat} °C	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
1.0	6.97	0.001000	129.19	29.302	2355.2	2384.5	29.303	2484.4	2513.7	0.1059	8.8690	8.9749
1.5	13.02	0.001001	87.964	54.686	2338.1	2392.8	54.688	2470.1	2524.7	0.1956	8.6314	8.8270
2.0	17.50	0.001001	66.990	73.431	2325.5	2398.9	73.433	2459.5	2532.9	0.2606	8.4621	8.7227
2.5	21.08	0.001002	54.242	88.422	2315.4	2403.8	88.424	2451.0	2539.4	0.3118	8.3302	8.6421
3.0	24.08	0.001003	45.654	100.98	2306.9	2407.9	100.98	2443.9	2544.8	0.3543	8.2222	8.5765
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
650	161.98	0.001104	0.29260	683.37	1886.1	2569.4	684.08	2075.5	2759.6	1.9623	4.7699	6.7322
700	164.95	0.001108	0.27278	696.23	1875.6	2571.8	697.00	2065.8	2762.8	1.9918	4.7153	6.7071
750	167.75	0.001111	0.25552	708.40	1865.6	2574.0	709.24	2056.4	2765.7	2.0195	4.6642	6.6837
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
7000	285.83	0.001352	0.027378	1258.0	1323.0	2581.0	1267.5	1505.2	2772.6	3.1220	2.6927	5.8148
8000	295.01	0.001384	0.023525	1306.0	1264.5	2570.5	1317.1	1441.6	2758.7	3.2077	2.5373	5.7450
9000	303.35	0.001418	0.020489	1350.9	1207.6	2558.5	1363.7	1379.3	2742.9	3.2866	2.3925	5.6791

Superheated Water Table



	v m^3/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
	P = 8.0 MPa (295.01°C)			
Sat.	0.023525	2570.5	2758.7	5.7450
300	0.024279	2592.3	2786.5	5.7937
350	0.029975	2748.3	2988.1	6.1321
400	0.034344	2864.6	3139.4	6.3658
450	0.038194	2967.8	3273.3	6.5579
500	0.041767	3065.4	3399.5	6.7266
550	0.045172	3160.5	3521.8	6.8800
600	0.048463	3254.7	3642.4	7.0221
700	0.054829	3443.6	3882.2	7.2822
800	0.061011	3635.7	4123.8	7.5185
900	0.067082	3832.7	4369.3	7.7372
1000	0.073079	4035.0	4619.6	7.9419
1100	0.079025	4242.8	4875.0	8.1350
1200	0.084934	4456.1	5135.5	8.3181
1300	0.090817	4674.5	5401.0	8.4925

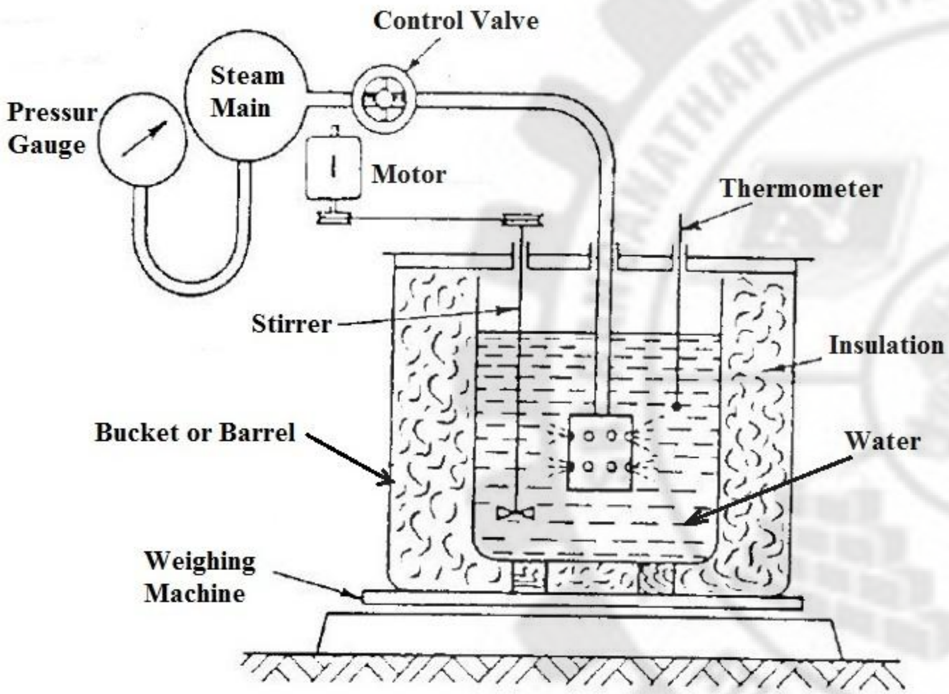
Calorimeters

Calorimeters are used for measurement of dryness fraction of steam.

The dryness fraction of steam can be measured experimentally with these <u>different types of calorimeters</u> :

1. Bucket or barrel calorimeter
2. Throttling calorimeter
3. Separating calorimeter
4. Combined separating & throttling calorimeter

Bucket or Barrel Calorimeter



- Inner vessel is usually made of copper.
- Insulating material is provided between inner and outer vessel.
- Here known amount of water (m_w) is filled in the calorimeter. Then certain quantity of steam (m_s) from

- The weight of calorimeter with water before mixing steam & after mixing the steam is measured by thermometer.
- Steam and water mixes together and so condensation of steam takes place and mass of water in the calorimeter increases.
- Latent and sensible heat of steam is given to water and its temperature will increase.
- Simultaneously the temperature of inner barrel will also increase.

Bucket or Barrel Calorimeter

Let

m_b =mass of the inner barrel (kg)

m_w =mass of the water before the steam goes in (kg)

m_s= mass of stem condensed (kg)

T_1= temperature of the water before the steam goes in (°C)

T_2 =temperature of the water after the steam goes in (°C)

T_s = saturated temperature of steam goes in (°C)

C_{pw}= Specific heat capacity of water at constant pressure (KJ/kg K)

C_b= Specific heat capacity of the metal of the barrel (KJ/kg K)

h_{fg} =specific enthalpy of the evapourar of steam(kJ/kg)

x =dryness fraction

- Amount of heat lost by steam = Heat gain by water + Heat gain by barrel

$$m_s(x \cdot h_{fg}) + m_s C_{pw}(T_s - T_2) = m_w C_{pw}(T_2 - T_1) + m_b C_b(T_2 - T_1)$$

$$\boxed{x = \frac{(m_w C_{pw} + m_b C_b)\,(T_2 - T_1) - m_s C_{pw}(T_s - T_2)}{m_s h_{fg}}}$$

Limitation

1) Method is not accurate as heat losses would always take place.

2) Losses are more at higher temperature difference.

3) Due to heat losses, measured 'x' will always less than actual.

Separating Calorimeter

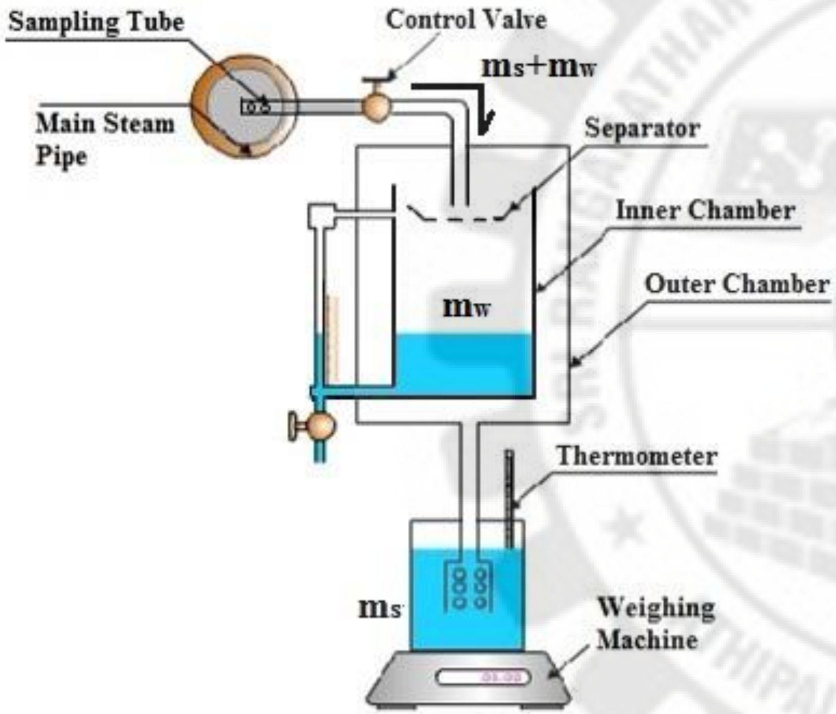


Fig. Separating Calorimeter

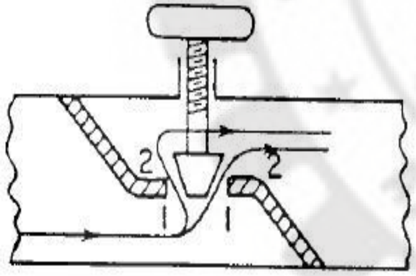
- This calorimeter is used to measure dryness fraction of very wet steam. The steam is passed through sampling tube. The moisture is separated mechanically from steam passing through the separator .
- The water partials are separated due to inertia of water partials as steam is passed through the perforated trays.
- The out going steams is then condensed in the bucket calorimeter.

- Mass of the dry steam m_s can be calculated from the difference in mass of water of barrel calorimeter.
- So dryness fraction x = $\frac{m_s}{m_f + m_s}$
- **Limitation:** The value of x would approximate value & always higher than actual as total separation of water particles from the steam is not possible by mechanical means.

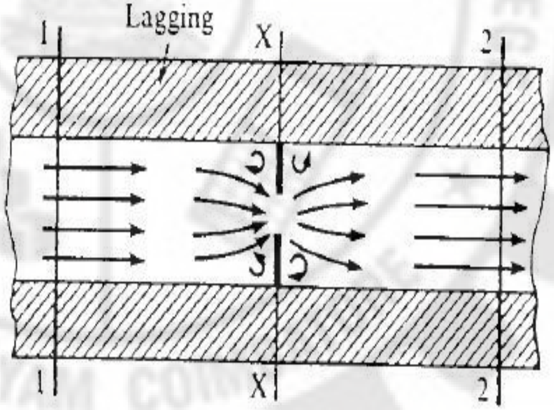
Throttling Calorimeter

Throttling

- A throttling process is one in which the fluid is made to flow through a restriction,
- **Enthalpy in throttling process remain constant.**
- e.g. a partially opened valve or an orifice plate, causing a considerable loss in the pressure of the fluid.



Valve



Orifice Plate

Throttling Calorimeter

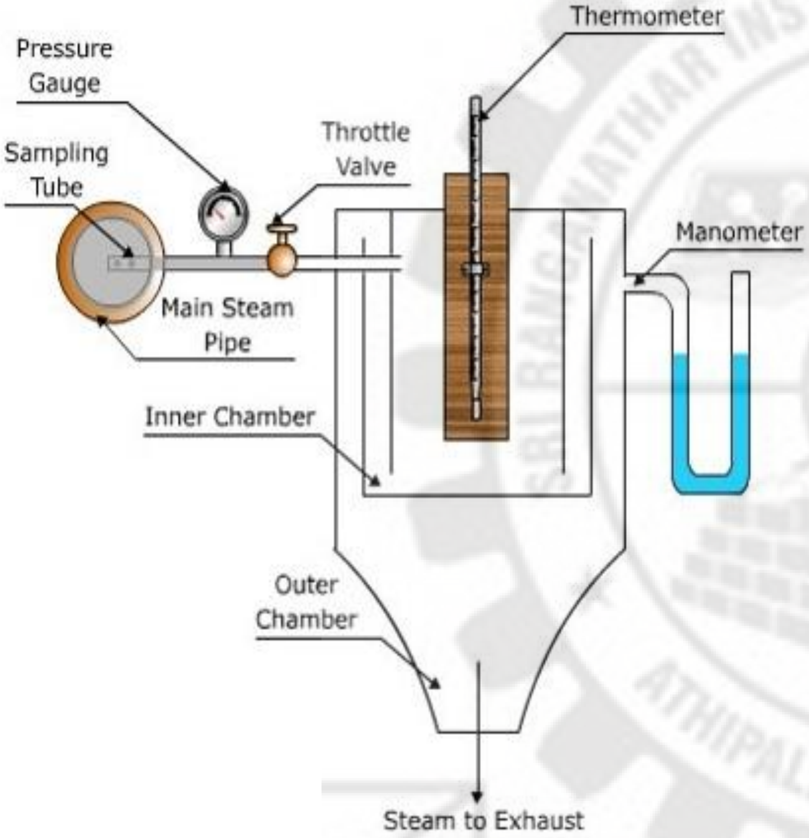


Fig. Throttling Calorimeter

- In this calorimeter a throttling valve is used to throttle the steam.
- This types of calorimeter is used to measure dryness fraction of steam whose dryness fraction is considerably high.
- The steam sample is passed through a throttle valve & is allowed to throttle down to pressure unit until it comes out in dry saturated or super heated condition.
- The pressure of steam reduces after throttling. Pressure and temperature of steam before and after throttling is measured.
- Enthalpy of steam before and after throttling remains constant.
- The pressure & temperature of steam coming out of throttling calorimeter is measured with water manometer & thermometer respectively.

Throttling Calorimeter

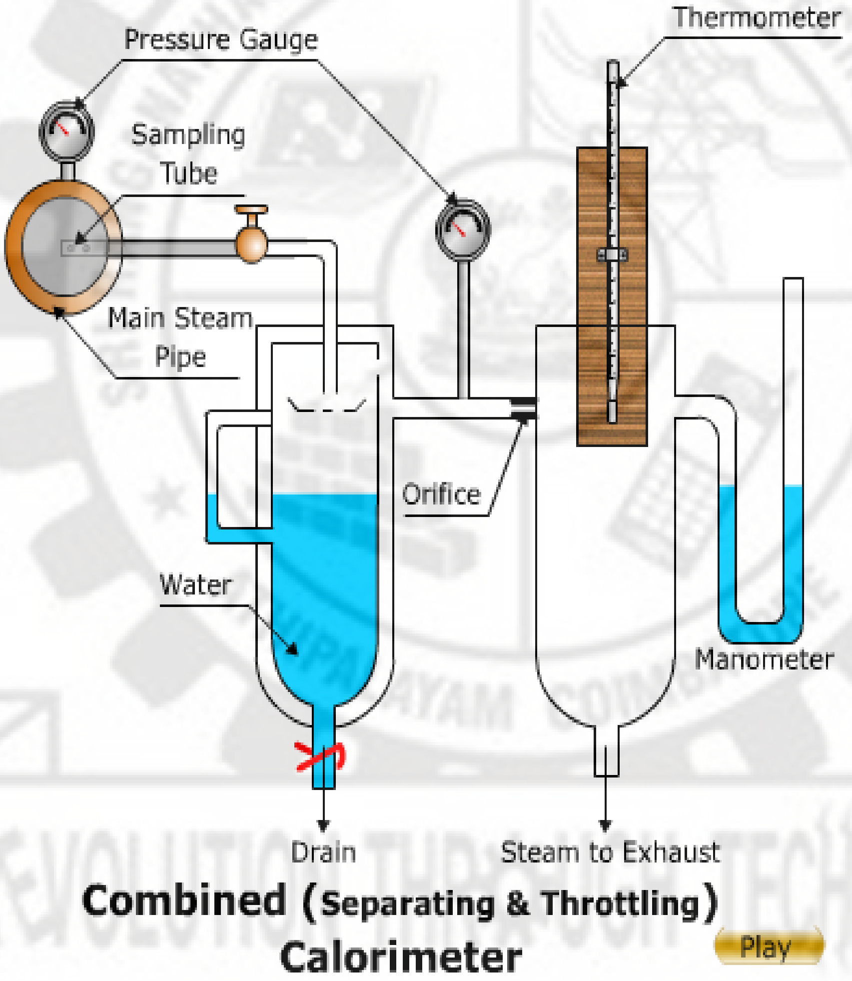
- Enthalpy of steam before throttling = Enthalpy of steam after throttling

$$h_{f1} + x h_{fg1} = h_{g2} + C_{ps}\left(T_{sup2} - T_{sat2}\right)$$

$$x = \frac{h_{g2} + C_{ps}\left(T_{sup2} - T_{sat2}\right) - h_{f1}}{h_{fg1}}$$

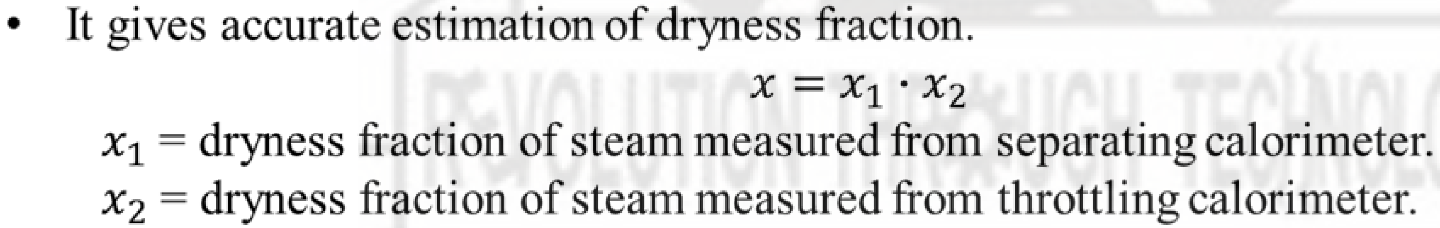
- **Limitation:** The throttling calorimeter cannot be used if the steam after throttling does not become superheated.

Combined Separating & Throttling Calorimeter



Combined Separating & Throttling Calorimeter

- The combined separating & throttling calorimeter gives the dryness fraction of wide quality steam very accurately.
- The limitations of separating and throttling calorimeters can be overcome if they are used in series as in this type of calorimeter.
- In this calorimeter, the stream from sampling tube is first passed through the separating calorimeter where most of the moisture is removed & steam partly dried.
- This steam is further passed to throttling calorimeter where it comes out as dry saturated or in superheated form.
- The steam coming out from throttling calorimeter is condensed in condenser coming out of condenser is recorded.
- The weight of water separated In separating calorimeter & the pressure & temperature of steam coming out from throttling valve are also recorded.



- It gives accurate estimation of dryness fraction.

$$x = x_1 \cdot x_2$$

x_1 = dryness fraction of steam measured from separating calorimeter.
x_2 = dryness fraction of steam measured from throttling calorimeter.

Properties of Water

- Cpi = 2.06 kJ/kg K
- Cpw= 4.184 kJ/kg K
- Cps=2.02 kJ/kg K

- Lvap =2259 kJ/kg
- Lmelt = 334 kJ/kg

- **Critical Point** – P=221.2 bar, T=374.15 °C

- **Triple Point** – P=611.2 Pa, T=0.01 °C

Thank You…

Performance Improvement of Boilers

Performance Improvement of Boilers

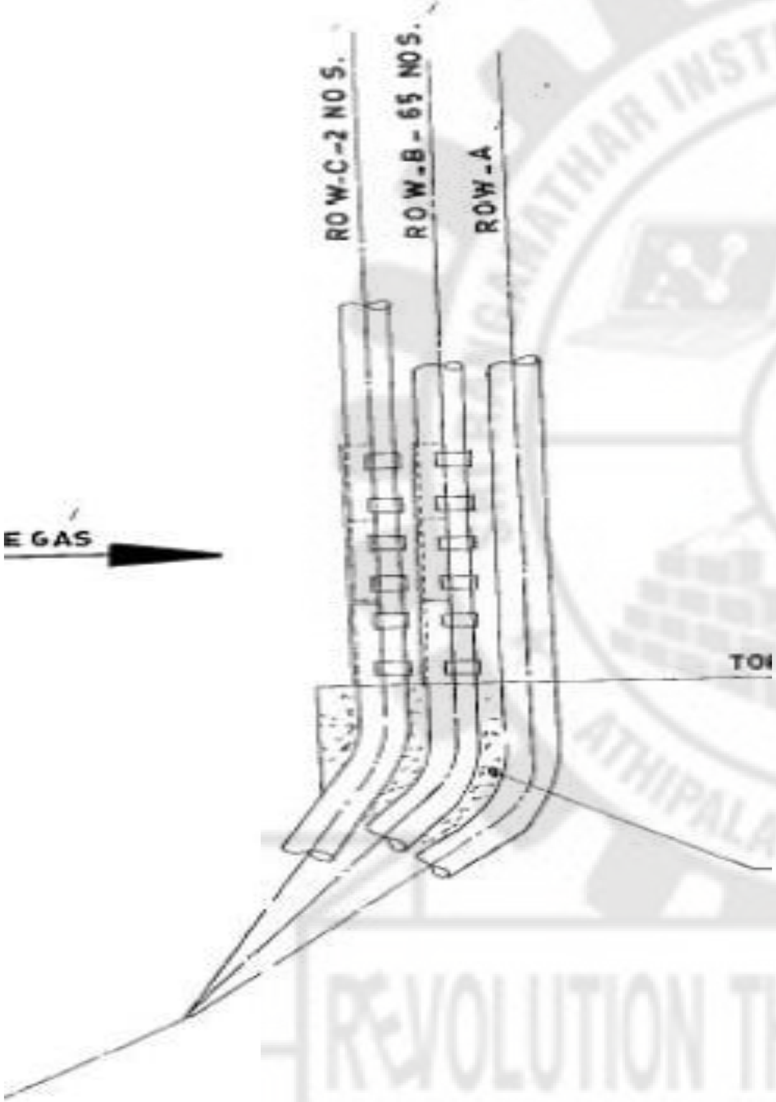
1. **Higher Availability & Reliability**
2. **Highest Plant efficiency**
3. **Lower Heat Rate**
4. **Minimum Auxiliary Power Consumption**
5. **Minimum Emission of Pollutants**

1. To increase Boiler Availability ….

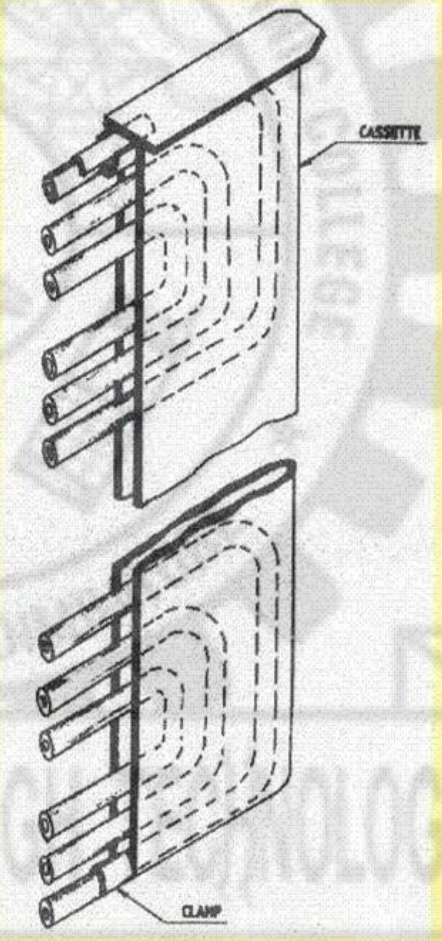
Maintain the auxiliaries

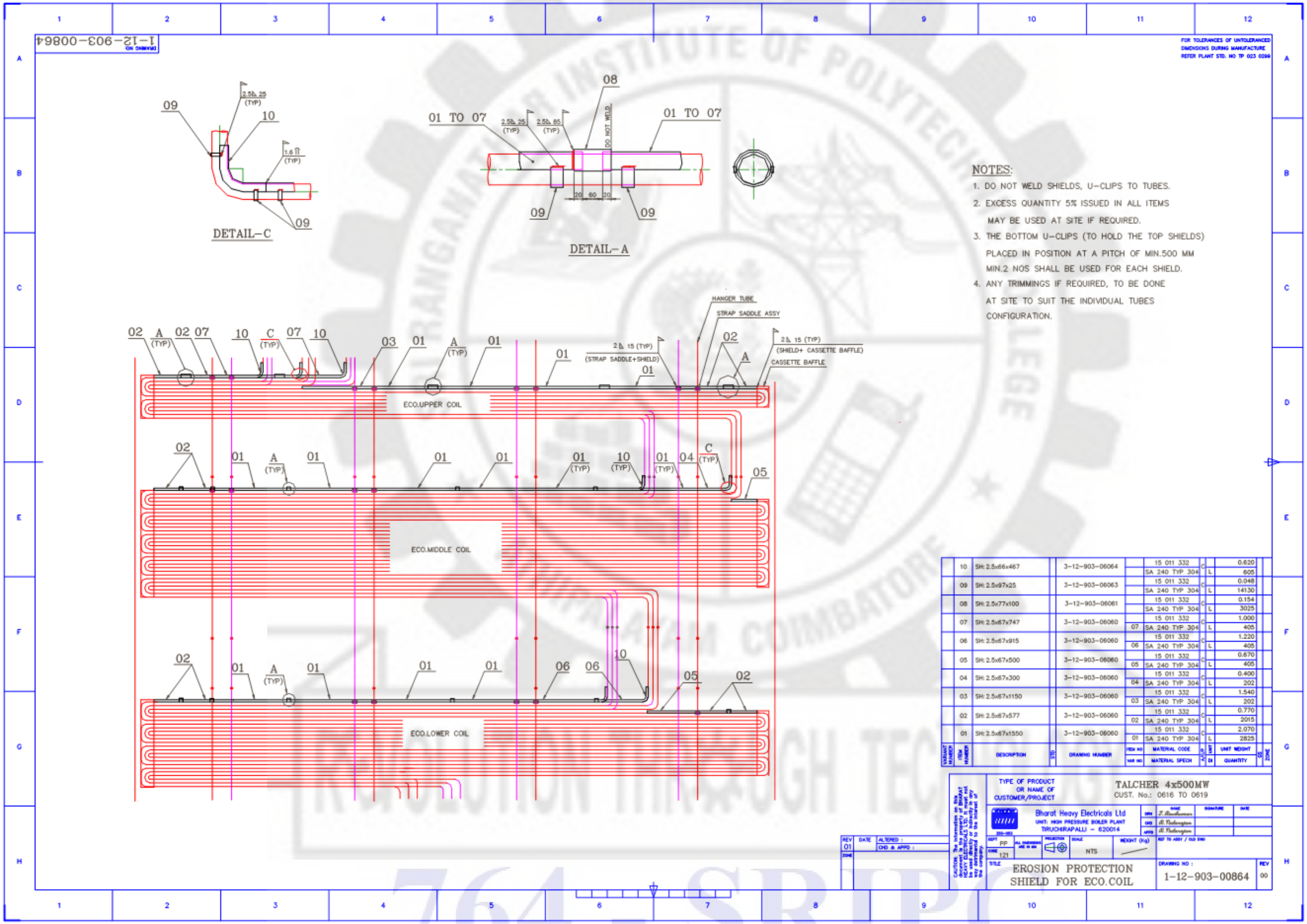
Reduce boiler tube failure

- **Fatigue failure – expansion restriction / differential**
- **Erosion failures**
- **Water chemistry related problems**
- **Overheating failures**
- **Clinkering (related to coal and operating condition)**



CASSETTE BAFFLE





NOTES:

1. DO NOT WELD SHIELDS, U-CLIPS TO TUBES.
2. EXCESS QUANTITY 5% ISSUED IN ALL ITEMS MAY BE USED AT SITE IF REQUIRED.
3. THE BOTTOM U-CLIPS (TO HOLD THE TOP SHIELDS) PLACED IN POSITION AT A PITCH OF MIN.500 MM MIN.2 NOS SHALL BE USED FOR EACH SHIELD.
4. ANY TRIMMINGS IF REQUIRED, TO BE DONE AT SITE TO SUIT THE INDIVIDUAL TUBES CONFIGURATION.

VARIANT NUMBER	ITEM NUMBER	DESCRIPTION	STD	DRAWING NUMBER	ITEM NO VAR NO	MATERIAL CODE MATERIAL SPECN	A/C/P	UNIT DI	UNIT WEIGHT QUANTITY	SS	ZONE
	10	SH: 2.5x66x467		3-12-903-06064		15 011 332 SA 240 TYP 304	C	L	0.620 605		
	09	SH: 2.5x97x25		3-12-903-06063		15 011 332 SA 240 TYP 304	C	L	0.048 14130		
	08	SH: 2.5x77x100		3-12-903-06061		15 011 332 SA 240 TYP 304	C	L	0.154 3025		
	07	SH: 2.5x67x747		3-12-903-06060	07	15 011 332 SA 240 TYP 304	C	L	1.000 405		
	06	SH: 2.5x67x915		3-12-903-06060	06	15 011 332 SA 240 TYP 304	C	L	1.220 405		
	05	SH: 2.5x67x500		3-12-903-06060	05	15 011 332 SA 240 TYP 304	C	L	0.670 405		
	04	SH: 2.5x67x300		3-12-903-06060	04	15 011 332 SA 240 TYP 304	C	L	0.400 202		
	03	SH: 2.5x67x1150		3-12-903-06060	03	15 011 332 SA 240 TYP 304	C	L	1.540 202		
	02	SH: 2.5x67x577		3-12-903-06060	02	15 011 332 SA 240 TYP 304	C	L	0.770 2015		
	01	SH: 2.5x67x1550		3-12-903-06060	01	15 011 332 SA 240 TYP 304	C	L	2.070 2825		

TYPE OF PRODUCT OR NAME OF CUSTOMER/PROJECT: TALCHER 4x500MW
CUST. No.: 0616 TO 0619

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Bharat Heavy Electricals Ltd
UNIT: HIGH PRESSURE BOILER PLANT
TIRUCHIRAPALLI - 620014

	NAME	SIGNATURE	DATE
DRN	T. Ravikumar		
CHD	R. Natarajan		
APPD	R. Natarajan		

DEPT PP
CODE 121
ALL DIMENSIONS ARE IN MM
PROJECTION
SCALE NTS
WEIGHT (Kg)
REF TO ASSY / OLD DWG

REV 01 | DATE | ALTERED : | CHD & APPD :
ZONE

TITLE: EROSION PROTECTION SHIELD FOR ECO.COIL
DRAWING NO : 1-12-903-00864
REV 00

2. To improve Plant Efficiency ….

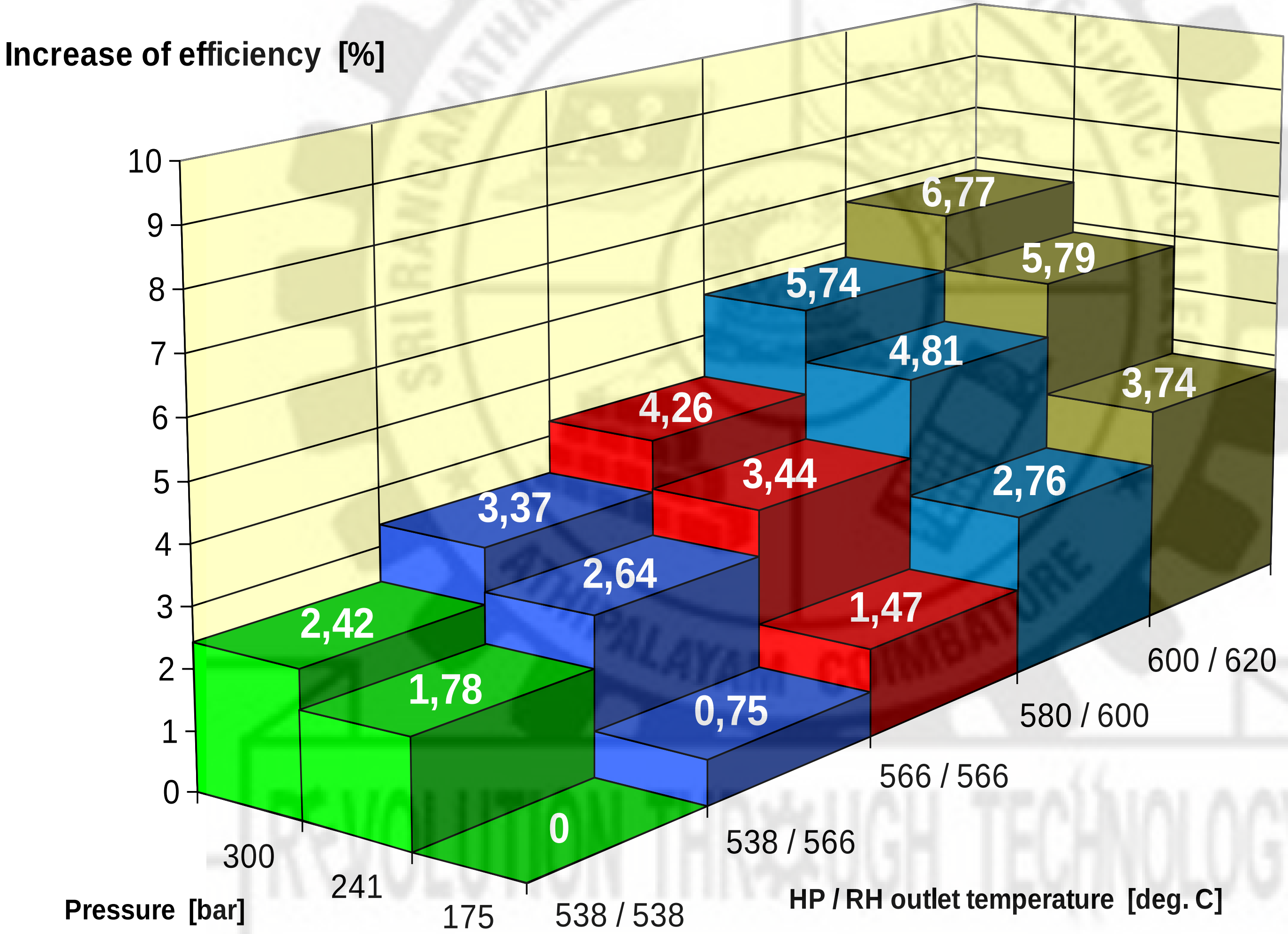
Boiler side Measures

1. Minimum flue gas temperature at AH outlet
2. Minimum excess air at AH outlet
3. Minimum un-burnt Carbon loss
4. Minimum RH spray
5. Minimum SH spray (if tapped off before feed heaters)
6. Reduced Auxiliary Power Consumption

Turbine side Measures

1. Higher steam parameters (MS Pressure & SHO/RHO Steam Temp)
2. Adoption of double Reheat cycle
3. Increasing feed water temperature with Enhanced Regenerative feed heating
4. Increase in condenser vacuum

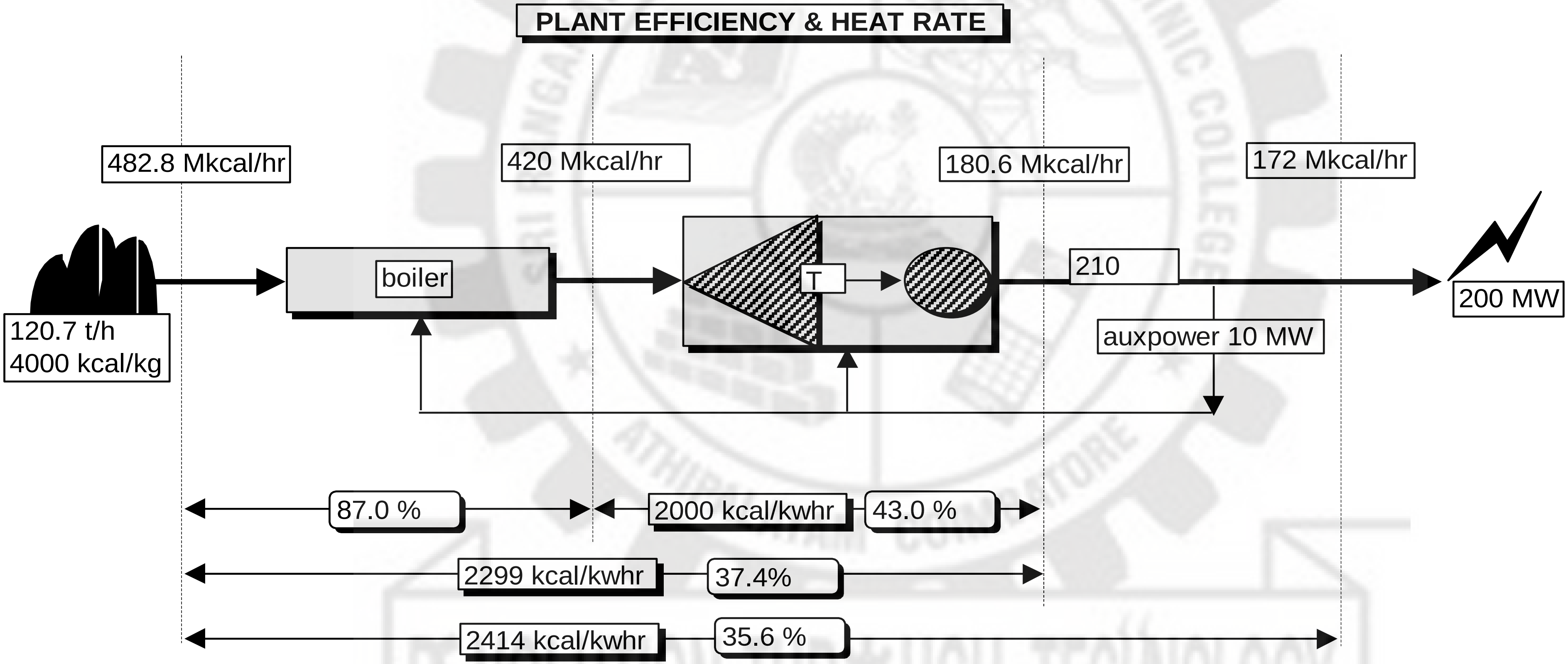
Increase of Cycle Efficiency due to Steam Parameters



3. Turbine Heat Rate ….

UNIT CAPACITY	TURBINE INLET PARAMETER	TURBINE HEAT RATE (kcal / kW hr)	STATION HEAT RATE (kcal / kW hr)
60/100MW	90 ata 535 ^{0}C	2315	2784
110/120 MW	130 ata 535/535 ^{0}C	2180	2551
200/210 MW	130 ata 535/535 ^{0}C	2025	2424
210/250 MW	150 ata 535/535 ^{0}C	1975	2335
500 MW	170 ata 535/535 ^{0}C	1950	2294
800 MW	240 ata 538/565 ^{0}C	1820	2140

Heat Rate & Efficiency



4. Reduce Auxiliary Power Consumption ….

Major reasons for increase in APC

- Operation of unit with higher excess air
- Air preheater choking & leakage
- Higher PA fan outlet pressure
- High mill fineness, more no. of mills
- Air ingress into boiler
- Plugging in line / ducting

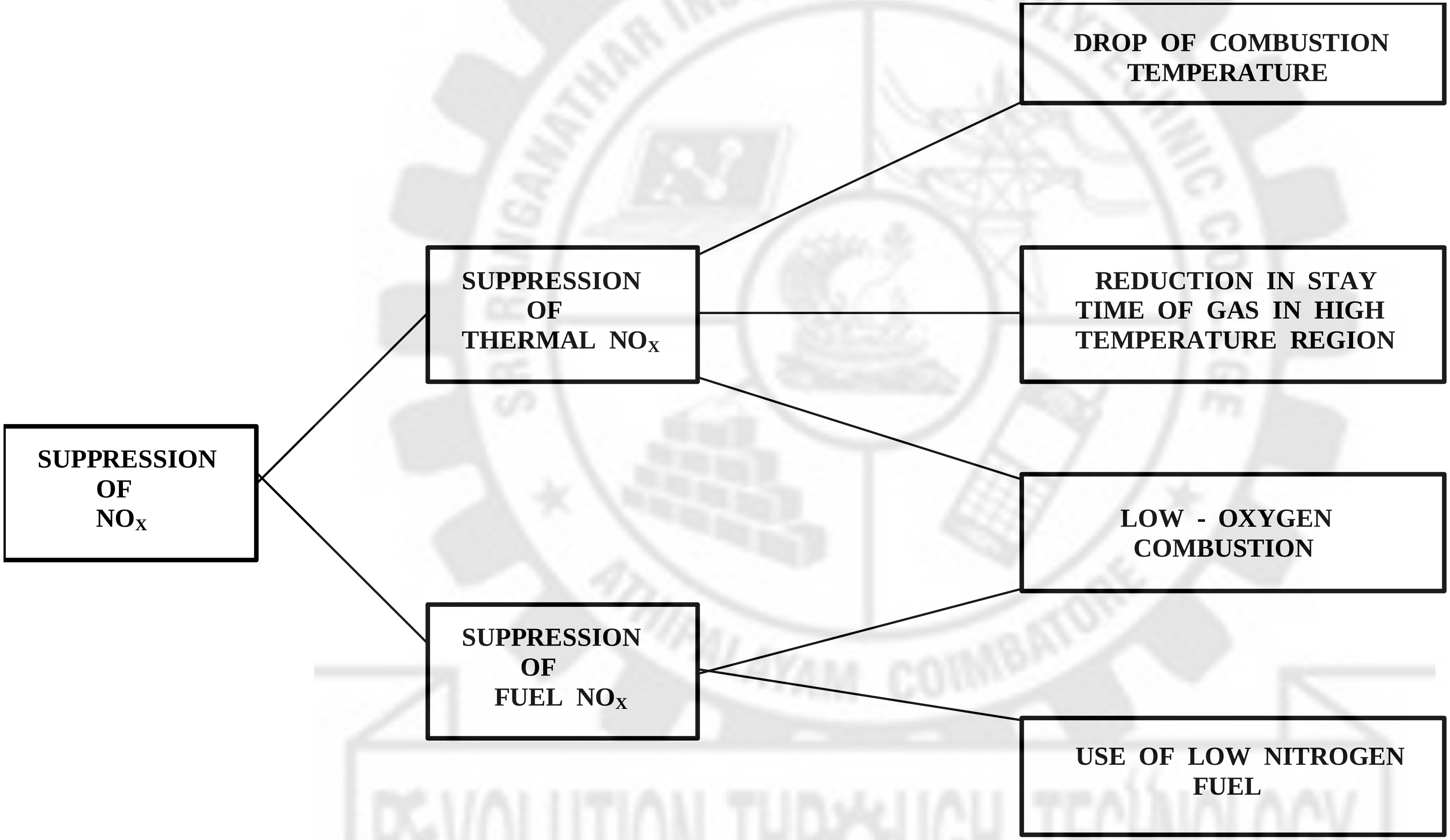
5. Minimization of Emission Levels

CEA Norms

Capacity	Pollutant	Emission
Below 210 MW	Particulate matter (PM)	350 mg/Nm3
210 MW & above		150 mg/Nm3
500 MW & above		50 mg/Nm3

NO_X Formation Mechanism

- Prompt NO_X
- Thermal NO_X
- Fuel NO_X



SUPPRESSION OF NO_X

SUPPRESSION OF THERMAL NO_X

SUPPRESSION OF FUEL NO_X

DROP OF COMBUSTION TEMPERATURE

REDUCTION IN STAY TIME OF GAS IN HIGH TEMPERATURE REGION

LOW - OXYGEN COMBUSTION

USE OF LOW NITROGEN FUEL

PRINCIPLE OF NO_X SUPPRESSION

NO_X Suppression - Combustion Based Technology

- Burner out of service (BOOS)
- Fuel biasing
- Over fire air
- Reburning
- Low excess air operation
- Flue gas recirculation (FGR)
- Low NO_X burners
- Water / steam injection

NO$_X$ Suppression - Post Combustion Based Technology

- Urea injection
- Ammonia injection (Thermal de-NO$_X$)
- Conventional SCR
- Duct SCR
- Activated SCR

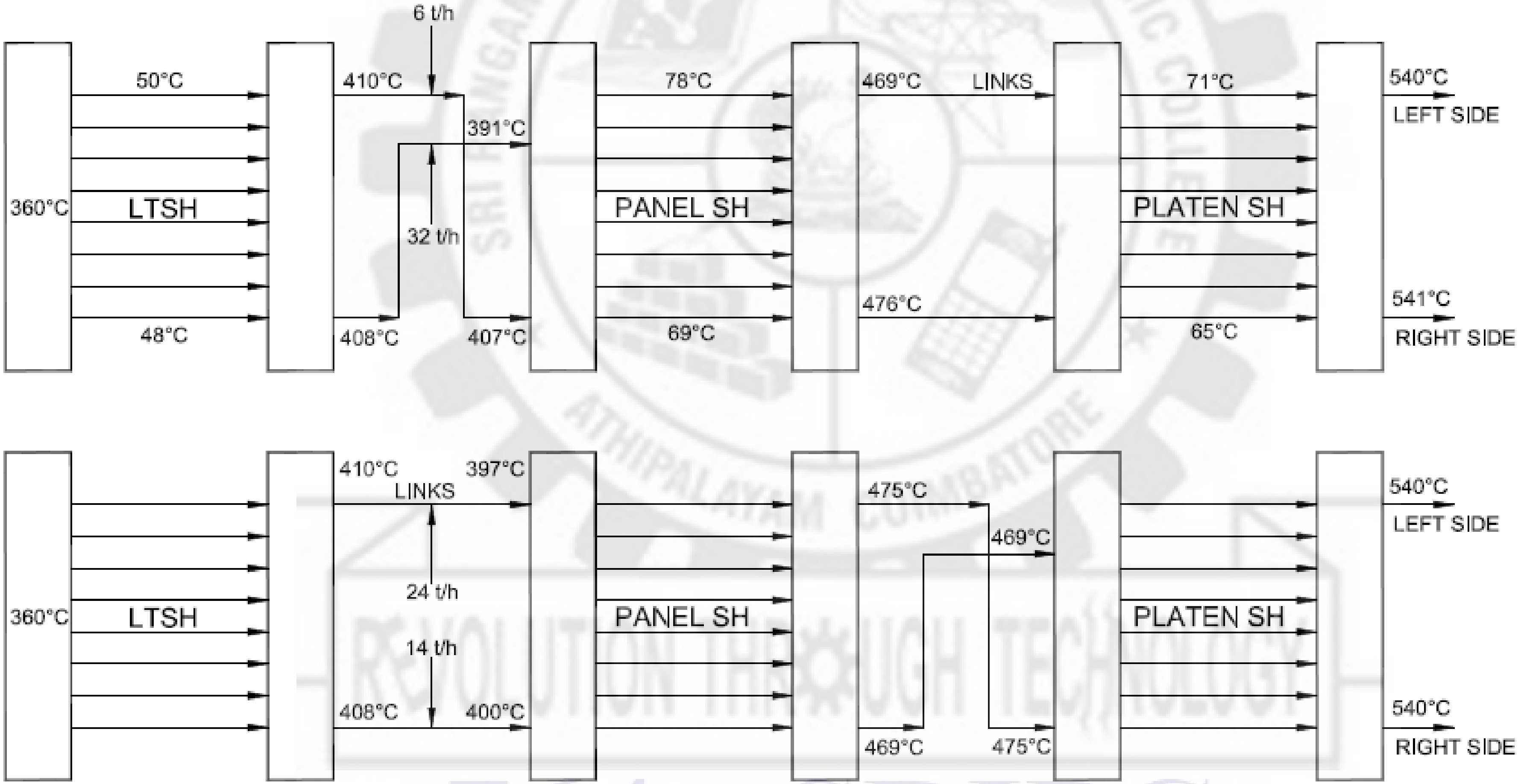
SCR : Selective Catalytic Reduction

Problems faced in 500 MW units

- Achieving the rated steam temperature in SH/RH with zero spray in RH
- Unbalance in SH/RH outlet temperature within +/-10°C
- High Metal Temperature (especially in RH)
- RH leading SH resulting in RH spray

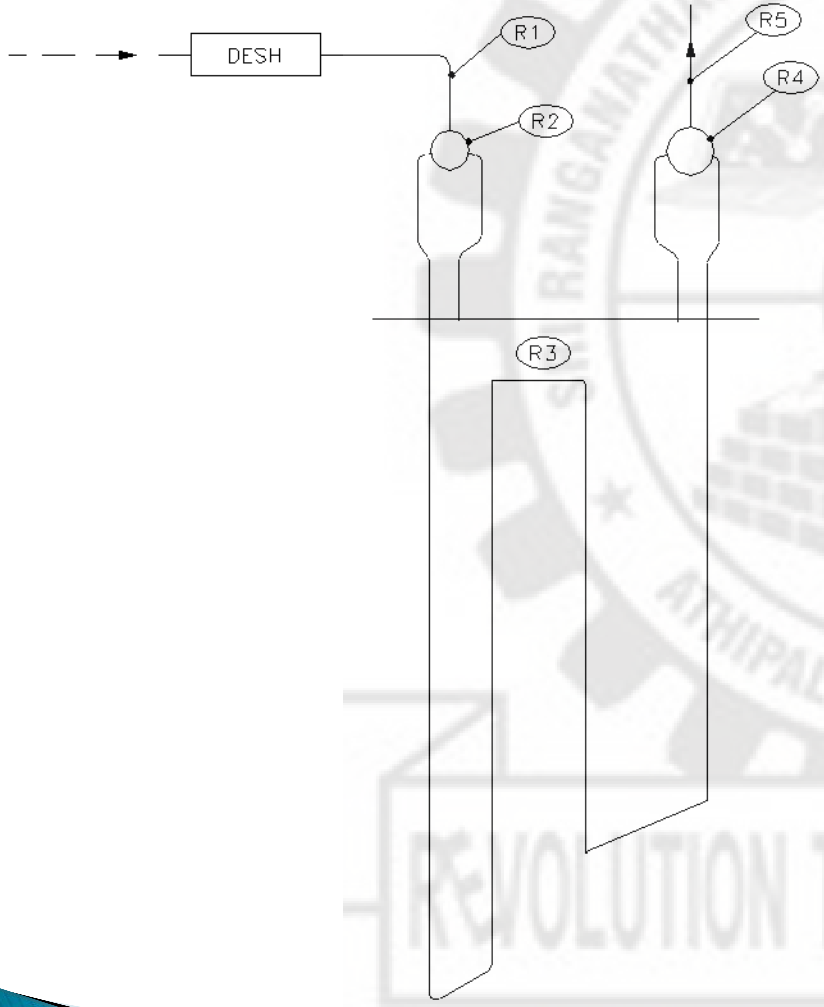
Main Steam Temperature Unbalance

Shifting of cross over links from LTSH outlet to Panel outlet to reduce the SH unbalance

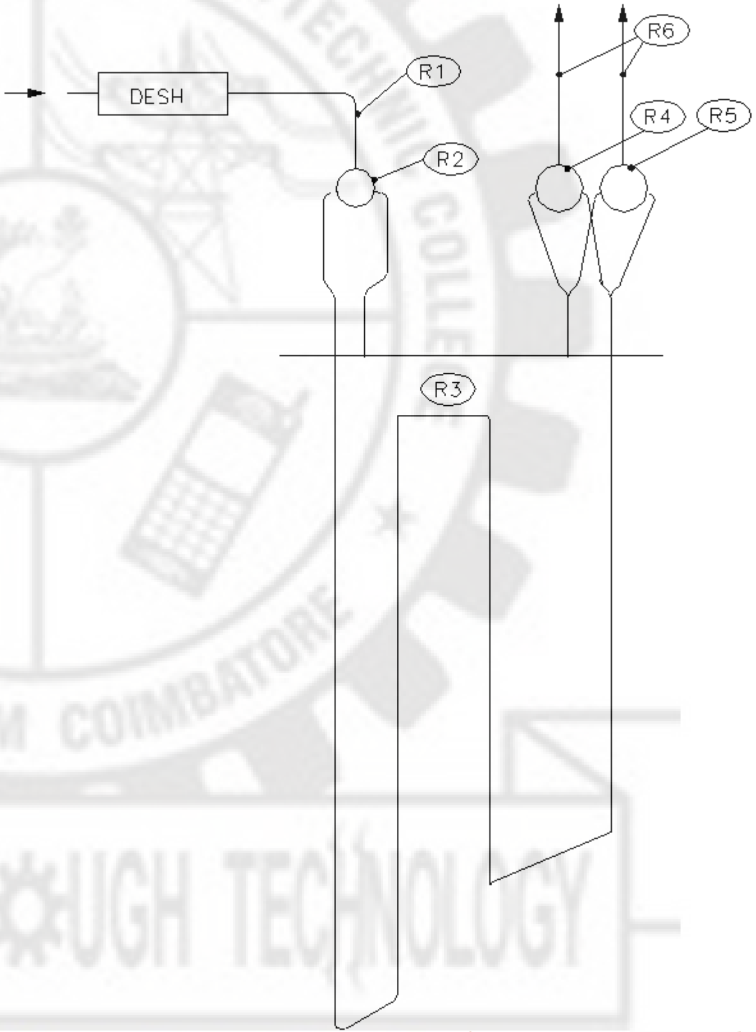


RH Temperature unbalance

Siamese header for RHO to solve the RH unbalance



RH Arrangement - Earlier



RH Arrangement - Siamese Headers

High Metal Temperature in RH

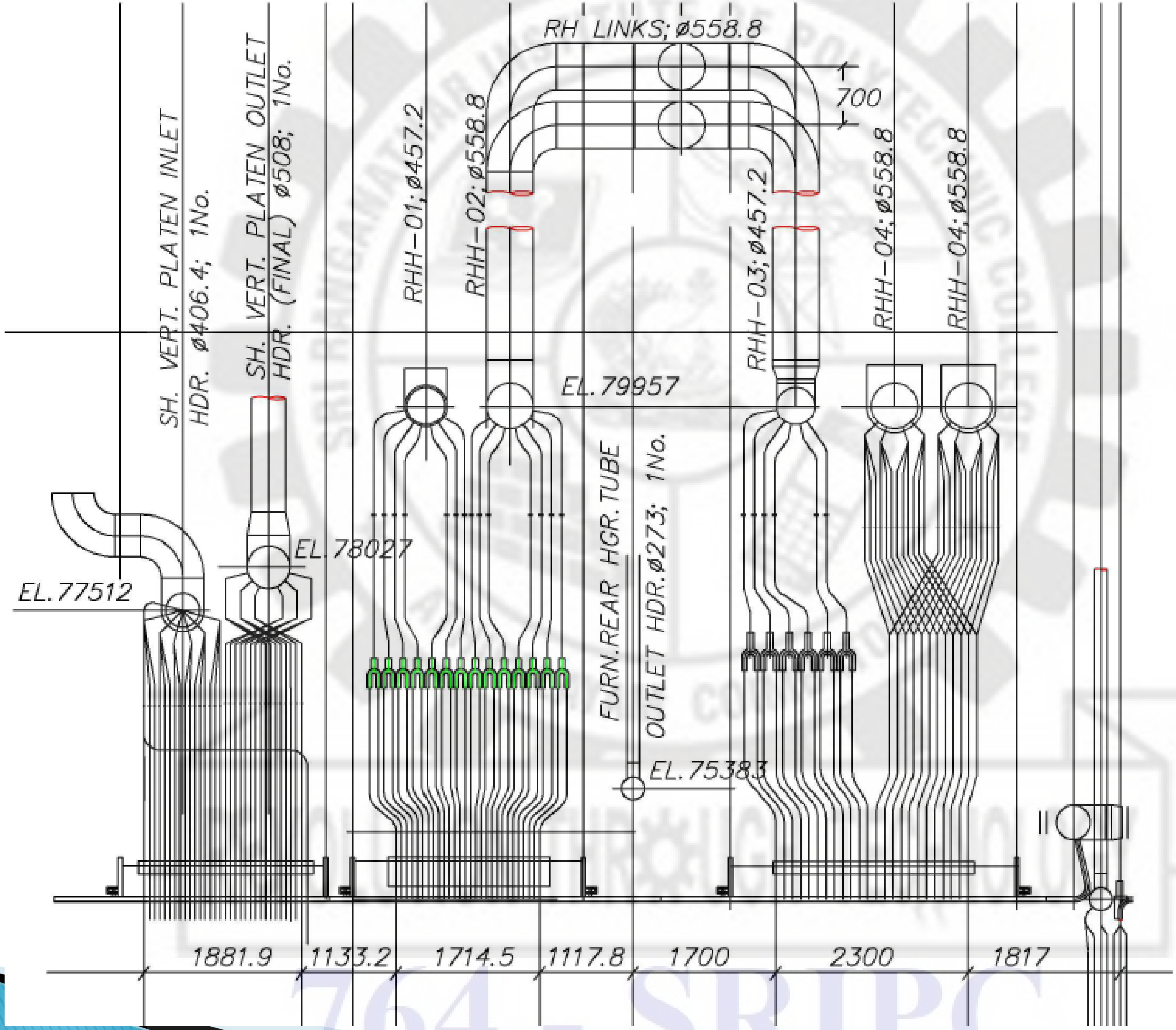
1) Upgrading the material with Stainless steel in RH rear

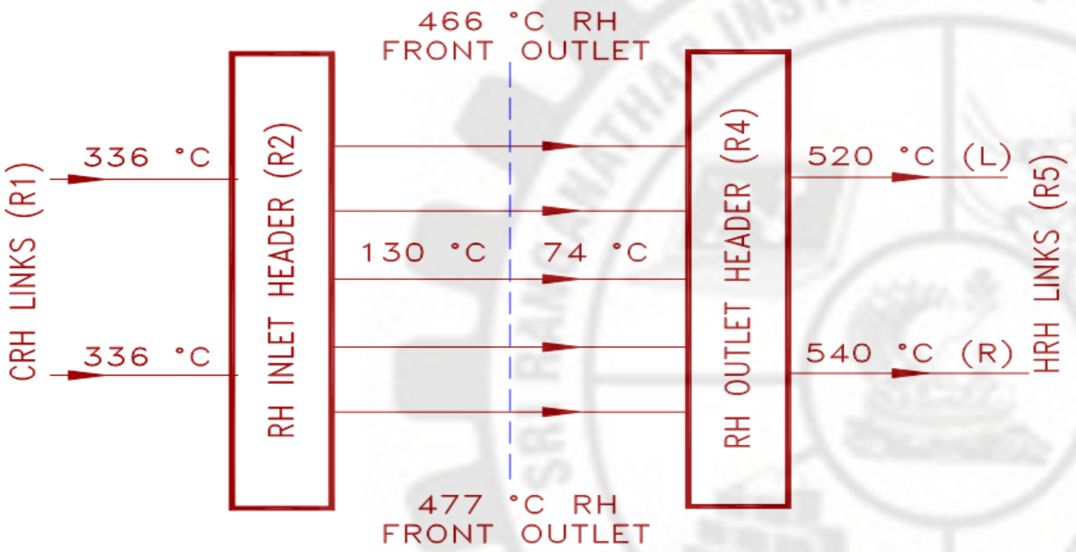
Recommended for units with 540°C RHOT

2)Splitting the existing RH into two sections with criss cross to reduce the unbalance

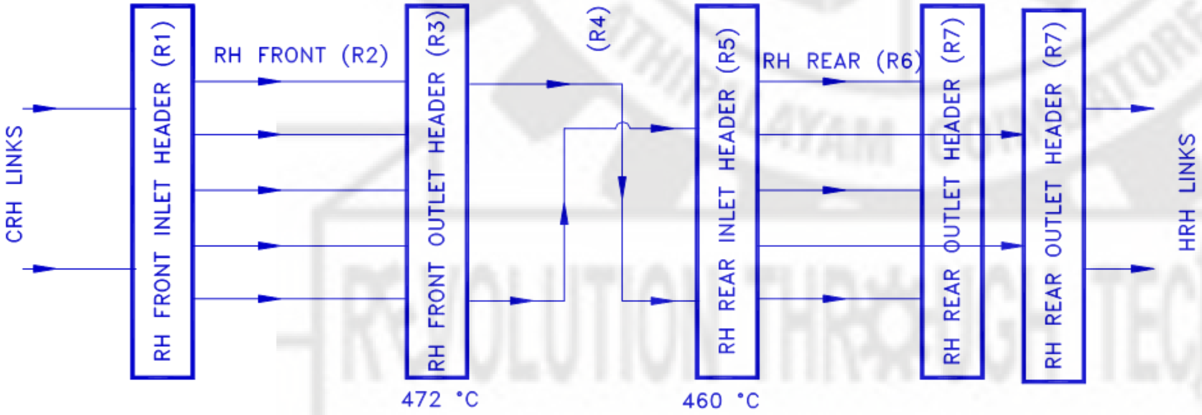
(By splitting sections, heat pickup & unbalance in each section is reduced and by crisscrossing the links overall unbalance is reduced. Pressure drop will exceed by 0.5 Kg/Sq.cm)

Recommended for units with 568°C RHOT


RH LINKS; ø558.8
700
SH. VERT. PLATEN INLET HDR. ø406.4; 1No.
SH. VERT. PLATEN OUTLET HDR. (FINAL) ø508; 1No.
RHH-01; ø457.2
RHH-02; ø558.8
RHH-03; ø457.2
RHH-04; ø558.8
RHH-04; ø558.8
EL.79957
EL.78027
EL.77512
FURN.REAR HGR.TUBE OUTLET HDR.ø273; 1No.
EL.75383
1881.9
1133.2
1714.5
1117.8
1700
2300
1817



500 MW
RH PICKUP



Expected
RH Pickup pattern
With split section

POWER PLANT ENGINEERING (R17A0326)

4th Year B. Tech I- sem, Mechanical Engineering

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COURSE OBJECTIVES

UNIT - 1	**CO1:To create awareness about various sources of energy, working of thermal power plants and combustion process**
UNIT - 2	CO2: To understand how Diesel and gas power plants are functioning
UNIT - 3	CO3: To understand how power is achieved from renewable sources of energy and functions of hydro-electric power plants
UNIT - 4	CO4: Able to learn about Nuclear power plants
UNIT - 5	CO5: To apply the concepts of economics in power plants

UNIT 1

COALBASED THERMAL POWER PLANTS

CO1: To create awareness about various sources of energy, working of thermal power plants and combustion process

UNIT – I (SYLLABUS)

Rankine Cycle:

- Improvisations, Layout of modern coal power plant
- Super Critical Boilers
- FBC Boilers, Turbines, Condensers
- Steam & Heat rate
- Subsystems of thermal power plants

Fuel and Ash Handling Systems:

- Fuel and ash handling
- Draught system
- Feed water treatment.
- Binary Cycles and Cogeneration systems

COURSE OUTINE – UNIT I

LECTURE	LECTURE TOPIC	KEY ELEMENTS	Learning Objectives
1	Introduction of Power Plant Engineering, Various power plants, Introduction of Thermal Power	Introduction about the power plants, various energy sources	• Understanding various power generation systems • Thermal power plant
2	Plant Rankine cycle , Thermodynamic processes Layout of Modern thermal power plant, Four Circuits, working	Thermodynamic cycle and processes of Rankine cycle and thermal power plant	• Understanding the basic concept behind thermal power plant and the actual process
3	Super critical boilers, FBC boilers Classification and working	Classification of both super critical boilers and FBC boilers with working principles	• Understand the working and applications of all the boilers
4	Condensers, classification, working, Steam and Heat rate	Classification of condensers, working, steam and heat calculations	• Understanding the numerical calculations
5	Sub systems of thermal power plant, Coal and Ash handling	Different components of thermal power plants	• Knowing about Working of various components
6	Draught System and Feed water treatment	Draught systems classification and calculations	• Understanding types of Draught systems and solving problems
7	Binary Cycles and Cogeneration systems	Binary cycles and cogeneration with other power cycles	• Various cycles and combined power cycles for cogeneration

LECTURE 1

Introduction of Power Plant Engineering, Various power plants, Introduction of Thermal Power

LIVE TO LEARN & LEARN TO SHARE

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TOPICS TO BE COVERED

- Introduction to Power Plant Engineering
- Various Power Plants
- Introduction to Thermal Power

LECTURE 1

Introduction to Power Plant Engineering, Various power plants, Introduction to Thermal Power

INTRODUCTION TO POWER PLANT ENGINEERING

- A power plant is an industrial facility used to generate electric power with the help of one or more generators which converts different energy sources into electric power.
- A power plant or a power generating station, is basically an industrial location that is utilized for the generation and distribution of electric power in mass scale, usually in the order of several 1000 Watts. These are generally located at the sub-urban regions or several kilometers away from the cities or the load centers, because of its requisites like huge land and water demand, along with several operating constraints like the waste disposal etc.

INTRODUCTION TO POWER PLANT ENGINEERING

- Electricity is produced at a an electric power plant. Some fuel source, such as coal, oil, natural gas, or nuclear energy produces heat. The heat is used to boil water to create steam. The steam under high pressure is used to spin a turbine.
- For this reason, a power generating station has to not only take care of efficient generation but also the fact that the power is transmitted efficiently over the entire distance and that’s why, the transformer switch yard to regulate transmission voltage also becomes an integral part of the power plant.

INTRODUCTION TO POWER PLANT ENGINEERING

- At the center of it, however, nearly all power generating stations has an AC generator or an alternator, which is basically a rotating machine that is equipped to convert energy from the mechanical domain (rotating turbine) into electrical domain by creating relative motion between a magnetic field and the conductors.

INTRODUCTION TO POWER PLANT ENGINEERING

The energy source harnessed to turn the generator shaft varies widely, and is chiefly dependent on the type of fuel used.

Types of Power Plants

A power plant can be of several types depending mainly on the type of fuel used. A power generating station can be broadly classified in to 5 types mentioned below.

- **Thermal Power Plants**
- **Diesel Engine Power Plants**
- **Gas Turbine Power Plants**
- **Nuclear Power Plants**
- **Hydro Electric Power Plants**

INTRODUCTION TO POWER PLANT ENGINEERING

Introduction to Thermal Power and Thermal Power Station:

Thermal Power Station

A thermal power station or a coal fired thermal power plant is the most conventional method of generating electric power with reasonably high efficiency. It uses coal as the primary fuel to boil the water available to superheated steam for driving the steam turbine.

The steam turbine is then mechanically coupled to an alternator rotor, the rotation of which results in the generation of electric power. Generally in India, bituminous coal or brown coal are used as fuel of boiler which has volatile content ranging from 8 to 33% and ash content 5 to 16 %. To enhance the thermal efficiency of the plant, the coal is used in the boiler in its pulverized form.

INTRODUCTION TO POWER PLANT ENGINEERING

In coal fired thermal power plant, steam is obtained in very high pressure inside the steam boiler by burning the pulverized coal. This steam is then super heated in the super heater to extreme high temperature. This super heated steam is then allowed to enter into the turbine, as the turbine blades are rotated by the pressure of the steam.

The turbine is mechanically coupled with alternator in a way that its rotor will rotate with the rotation of turbine blades. After entering into the turbine, the steam pressure suddenly falls leading to corresponding increase in the steam volume. After having imparted energy into the turbine rotors, the steam is made to pass out of the turbine blades into the steam condenser of turbine. In the condenser, cold water at ambient temperature is circulated with the help of pump which leads to the condensation of the low pressure wet steam.

INTRODUCTION TO POWER PLANT ENGINEERING

In thermal power plants, the heat energy obtained from combustion of solid fuel (mostly coal) is used to convert water into steam, this steam is at high pressure and temperature. This steam is used to rotate the turbine blade turbine shaft is connected to the generator.

INTRODUCTION TO POWER PLANT ENGINEERING

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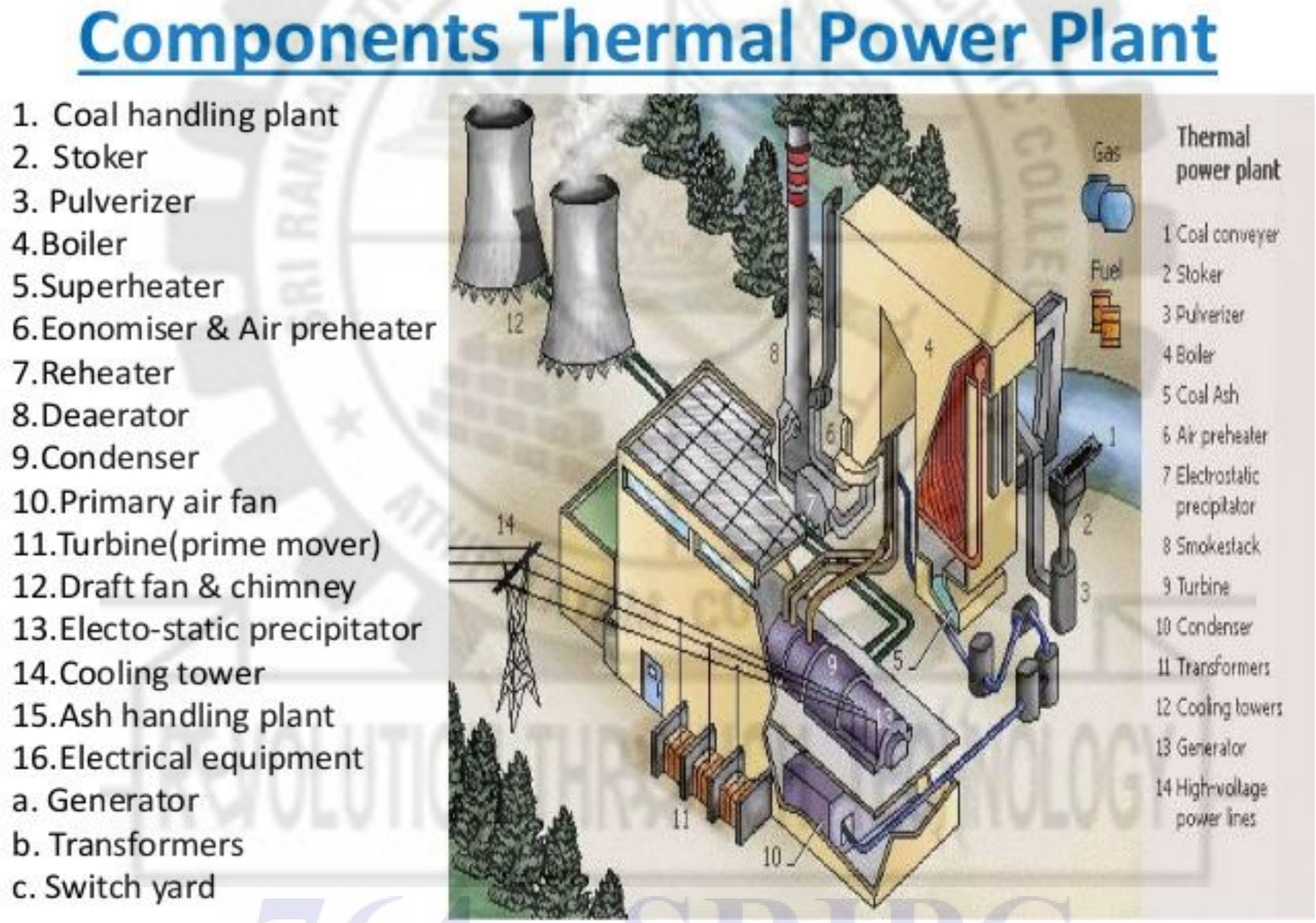
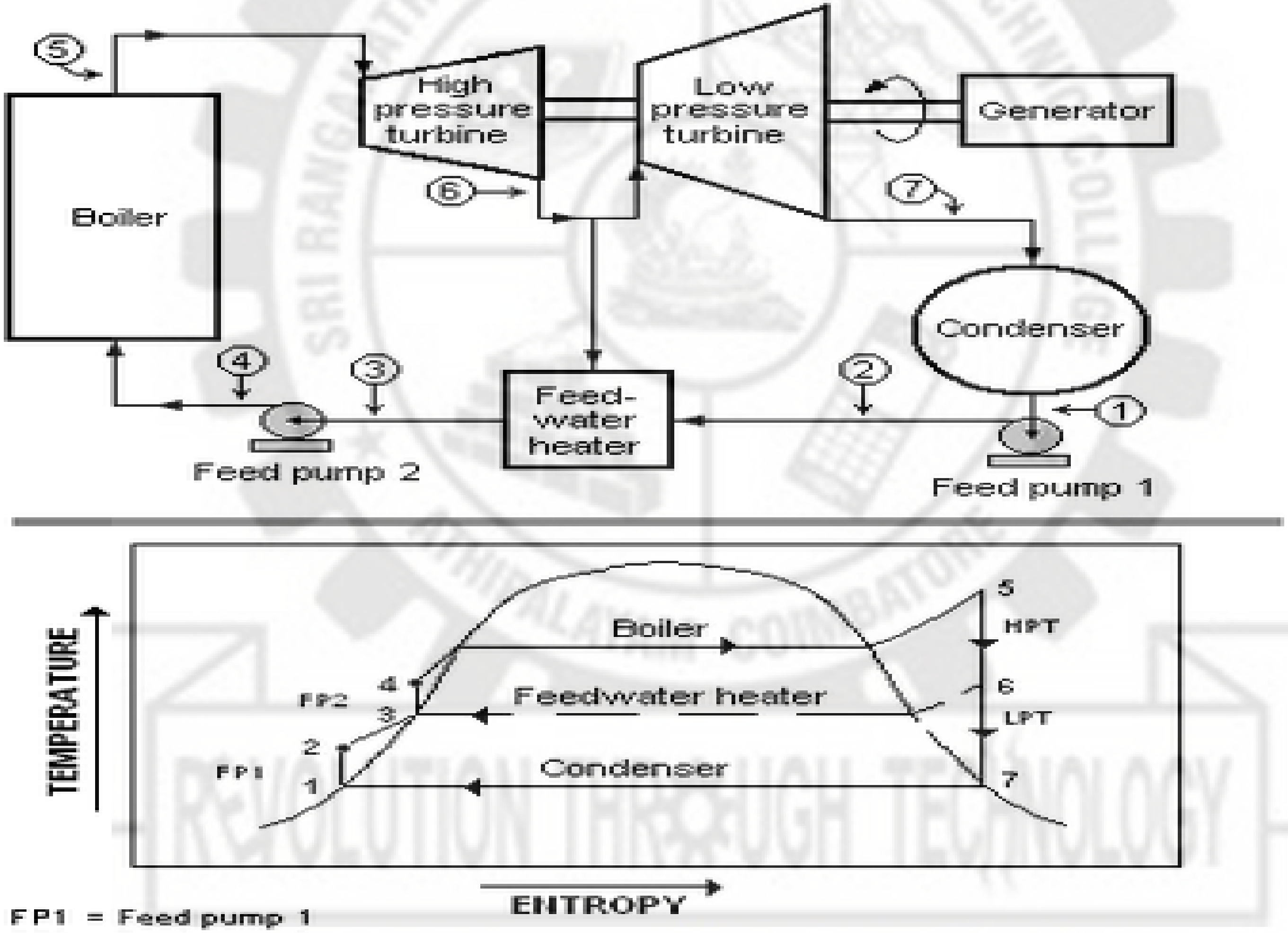
INTRODUCTION TO POWER PLANT ENGINEERING



Components Thermal Power Plant

1. Coal handling plant
2. Stoker
3. Pulverizer
4. Boiler
5. Superheater
6. Eonomiser & Air preheater
7. Reheater
8. Deaerator
9. Condenser
10. Primary air fan
11. Turbine(prime mover)
12. Draft fan & chimney
13. Electo-static precipitator
14. Cooling tower
15. Ash handling plant
16. Electrical equipment
   a. Generator
   b. Transformers
   c. Switch yard

INTRODUCTION TO POWER PLANT ENGINEERING



FP1 = Feed pump 1
FP2 = Feed pump 2
HPT = High pressure turbine
LPT = Low pressure turbine

THANK YOU

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LECTURE 2

TOPICS TO BE COVERED

- Rankine Cycle
- Thermodynamic processes
- Layout of Modern thermal power plant
- Four Circuits
- Working

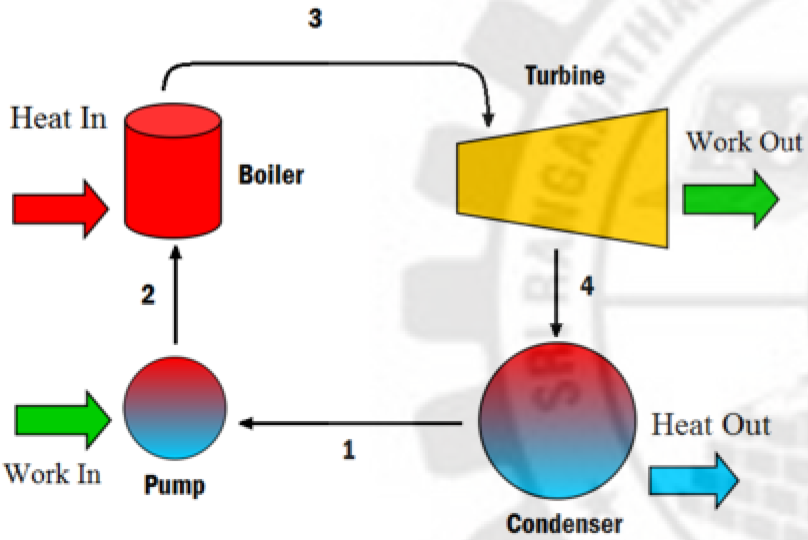
LECTURE 2

Introduction to Rankine Cycle

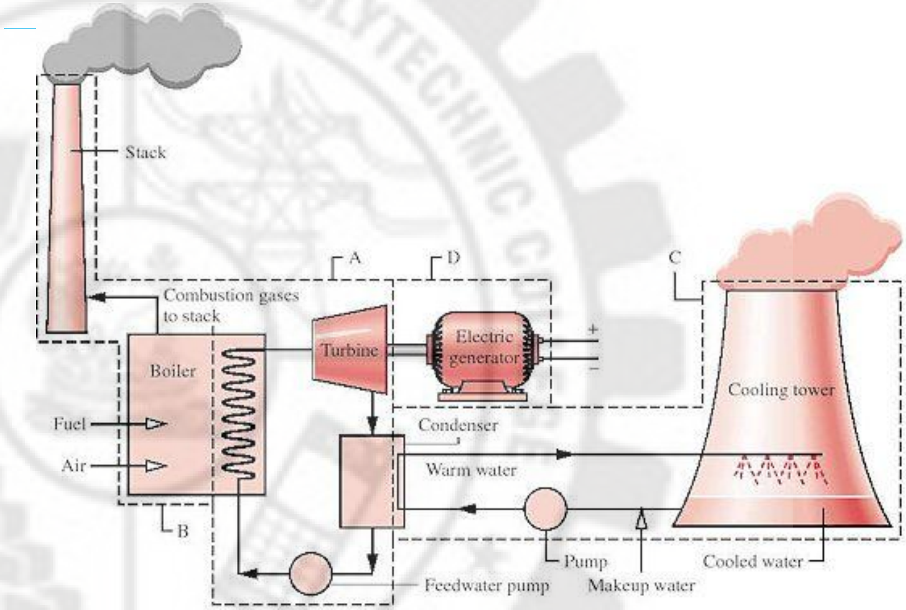
RANKINE CYCLE

- Introduction
    - Rankine cycle
- Thermodynamic Processes
- Layout of Modern Thermal Power Plant
- Four Circuits
- Working

RANKINE CYCLE



Rankine Cycle



- The Rankine cycle or Rankine Vapor Cycle is the process widely used by power plants such as coal-fired power plants or nuclear reactors. In this mechanism, a fuel is used to produce heat within a boiler, converting water into steam which then expands through a turbine producing useful work.
- The Rankine cycle is a model used to predict the performance of steam turbine systems. It was also used to study the performance of reciprocating steam engines. The Rankine cycle is an idealized thermodynamic cycle of a heat engine that converts heat into mechanical work while undergoing phase change.

There are four processes in the Rankine cycle. The states are identified by numbers (in brown) in the T–s diagram.

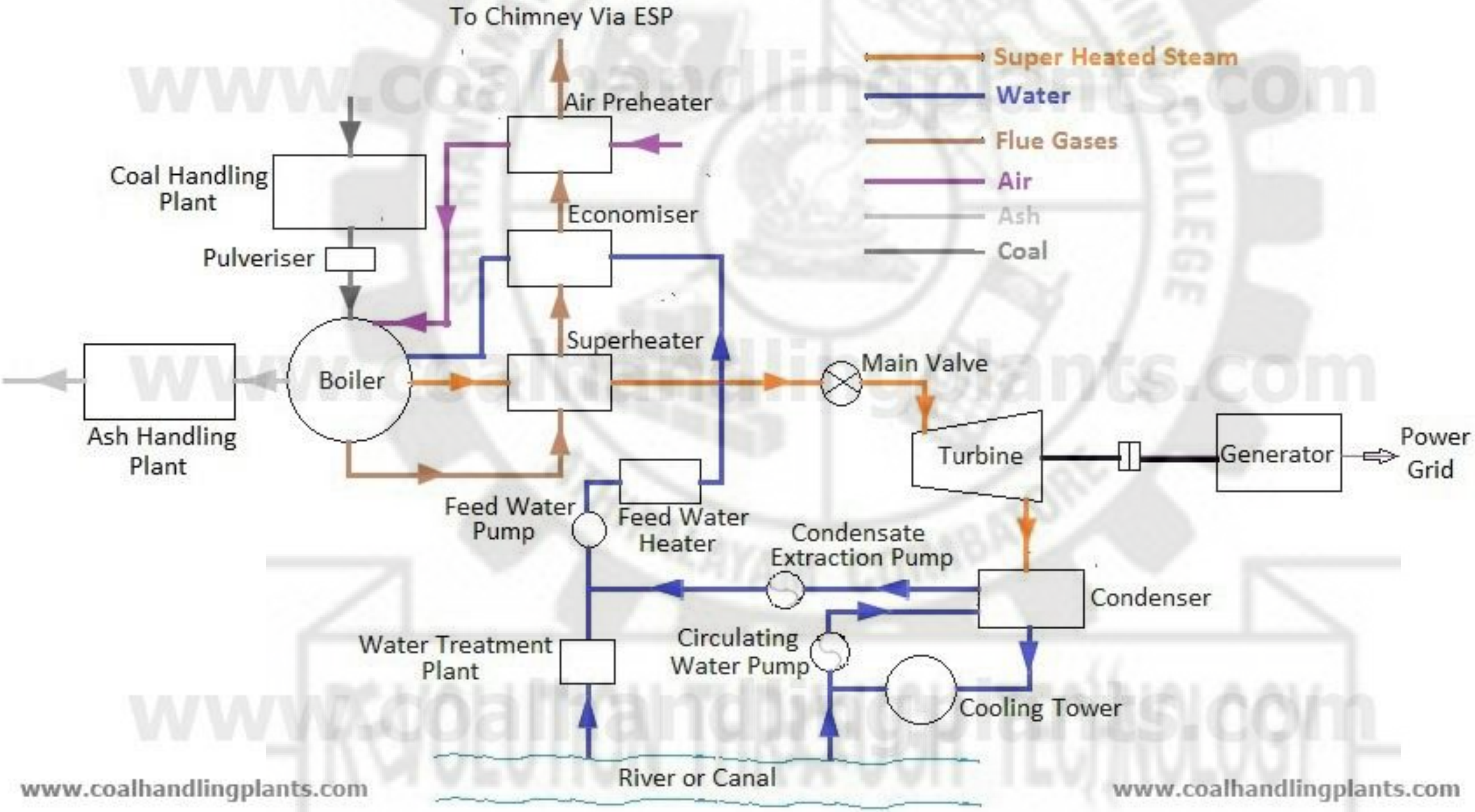
- Process 1–2: The working fluid is pumped from low to high pressure. As the fluid is a liquid at this stage, the pump requires little input energy.
- In other words Process 1-2 is [Isentropic compression]

- Process 2–3: The high-pressure liquid enters a boiler, where it is heated at constant pressure by an external heat source to become a dry saturated vapour. The input energy required can be easily calculated graphically, using an enthalpy–entropy chart (h–s chart, or Mollier diagram), or numerically, using steam tables.
- In other words Process 2-3 is [Constant pressure heat addition in boiler]

- Process 3–4: The dry saturated vapour expands through a turbine, generating power. This decreases the temperature and pressure of the vapour, and some condensation may occur. The output in this process can be easily calculated using the chart or tables noted above.
- In other words Process 3-4 is [Isentropic expansion]

- Process 4–1: The wet vapour then enters a condenser, where it is condensed at a constant pressure to become a saturated liquid.

MODERN THERMAL POWER PLANT



FOUR CIRCUITS

- Coal and Ash circuit
- Water and steam circuit
- Air and flue gas circuit
- Cooling water circuit

(PDF)

THANK YOU

LECTURE 3

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TOPICS TO BE COVERED

- Super critical boilers
- FBC boilers
- Classification and working

LECTURE 3

Super critical boilers, FBC boilers Classification and working

SUPER CRITICAL BOILERS

Supercritical Boilers

- B&W's supercritical and **ultra-supercritical boiler** designs offer the flexibility and reliability to meet the most demanding steam generation needs of our customers.
- At supercritical pressures, steam turbine efficiency improves significantly compared to the typical subcritical cycle. Ultra-supercritical steam conditions provide even greater efficiency improvements. The combination of utilizing supercritical throttle pressures along with an increase in throttle temperatures results in cost reductions in fuel usage and handling, flue gas treatment and ash disposal. B&W's supercritical and ultra-supercritical boilers are designed to take full advantage of variable pressure turbine operation.

SUPER CRITICAL BOILERS

Specific advantages include:

- For a given output, lower fuel consumption, and thus lower carbon emissions, than other less efficient systems
- The load change rate capability of the system is not restricted by the turbine
- Steam temperature at the inlet and outlet of the reheater is nearly constant over a wide load range
- The boiler feed water pump power is significantly reduced at lower loads
- Short startup times
- Higher plant efficiency over the entire load range (PDF attachment)

FBC BOILERS

Fluidized bed combustion (FBC) is a combustion technology used to burn solid fuels. ... Limestone is used to precipitate out sulfate during combustion, which also allows more efficient heat transfer from the boiler to the apparatus used to capture the heat energy (usually water tubes).

Fluidized Bed Combustion takes place when the forced draught fan supplies air to the Furnace of the Boiler. In the furnace, sand is (used for Bubbling phenomenon) placed on the Bed and is heated before fluidization, the air enters the bed from the nozzles fitted on the Furnace Bed. (PDF ATTACHMENT)

THANK YOU

LECTURE 4

TOPICS TO BE COVERED

- Condensers
- Classification, working
- Steam and Heat rate

LECTURE 4

Condensers, classification, working, Steam and Heat rate

CONDENSERS

- A condenser is designed to transfer heat from a working fluid (e.g. water in a steam power plant) to a secondary fluid or the surrounding air. The condenser relies on the efficient heat transfer that occurs during phase changes, in this case during the condensation of a vapor into a liquid.
- Inside the condenser, the refrigerant vapor is compressed and forced through a heat exchange coil, condensing it into a liquid and rejecting the heat previously absorbed from the cool indoor area. The condenser's heat exchanger is generally cooled by a fan blowing outside air through it.

- The function of the condenser is to condense exhaust steam from the steam turbine by rejecting the heat of vaporisation to the cooling water passing through the condenser. The temperature of the condensate determines the pressure in the steam/condensate side of the condenser
- The main difference between the compressor and condenser is indicated by their names, respectively. In a nutshell, the compressor compresses and the condenser condenses. ... Keep in mind, the refrigerant is a gas as it travels through the compressor – still a gas, yet slightly altered in order to be made into liquid vapor.

- The evaporator coil contains cold refrigerant that absorbs heat from your air. The condenser coil is where the refrigerant goes to get rid of this heat so it can come back to absorb more. The evaporator coil is located indoors, inside or near your air handler.

- A/C condenser is a radiator positioned between the car's grille and the radiator for the motor. In the condenser, the gaseous refrigerant sheds heat and returns to a liquid state. In other words, the condenser condenses the refrigerant from a gas to a liquid.

- Initially the refrigerant is sent to compressor where its pressure is raised. Next the refrigerant flows through the condenser(The black wire casing you see on back of your refrigerator), where it condenses from vapor form to liquid form(by convection), giving off heat in the process.

Classification

- Water cooled
- Air cooled and
- Evaporative (PDF)

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LECTURE 5

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TOPICS TO BE COVERED

- Sub systems of thermal power plant
- Coal and Ash handling

LECTURE 5

Sub systems of thermal power plant, Coal and Ash handling

SUB SYSTEMS OF THERMAL POWER PLANT

- Boiler make-up water treatment **plant** and storage.
- Fuel preparation system.
- Barring gear.
- Oil system.
- Generator cooling.
- Generator high-voltage system.
- Monitoring and alarm system.
- Battery-supplied emergency lighting and communication.

COAL AND ASH HANDLING

- **Ash handling** refers to the method of collection, **conveying**, interim storage and load out of various types of **ash** residue left over from solid fuel combustion processes. The most common types of **ash** resulting from the combustion of coal, wood and other solid fuels. bottom **ash**.
- INPLANT **COAL HANDLING** The In-Plant **coal handling system** deals with feeding of **coal** from live storage to the furnace. It includes various **equipment's** for transfer of **coal** like belt conveyor, screw conveyor etc. & the **equipment** needed to weigh the quantity of **coal** for feed.

COAL AND ASH HANDLING

- When burning solid fuel, typically coal, which contains a significant amount of ash, an ash handling system is essential to keep the boiler in service. ... This ash is collected in hoppers in the flue gas path and removed from the gases leaving the boiler by electrostatic precipitators or bag houses.

- PDF Attachment

THANK YOU

LECTURE 6

TOPICS TO BE COVERED

- Draught System
- Feed water treatment

LECTURE 6

Draught System and Feed water treatment

DRAUGHT SYSTEM

- Boiler draught is the pressure difference required to maintain constant flow of air into the furnace and to discharge the flue gases to the atmosphere through a chimney. Thus, boiler draught is one of the most essential system.
- Boiler draught may be defined as the small difference between the pressure of outside air and that of gases within a furnace or chimney at the grate level, which causes the flow of air/hot flue gases to take place through the boiler. Draught is maintained inside boilers using fans.

DRAUGHT SYSTEM

- PDF ATTACHMENT

FEED WATER TREATMENT

- Boiler Feed Water Treatment for Industrial Boilers and Power Plants. In the steam boiler industry, high purity feed water is required to ensure proper operation of steam generation systems. When a boiler is used to run a steam turbine, turbine blade erosion is reduced due to higher purity steam generated.
- Boiler water is treated to prevent scaling, corrosion, foaming, and priming. Chemicals are put into boiler water through the chemical feed tank to keep the water within chemical range. These chemicals are mostly oxygen scavengers and phosphates.

FEED WATER TREATMENT

Coagulation and chemical precipitation

- After all the large objects are removed from the original water source, various chemicals are added to a reaction tank to remove the bulk suspended solids and other various contaminants
- A boiler feed water treatment system is a system made up of several individual technologies that address your specific boiler feed water treatment needs.

FEED WATER TREATMENT

Treating boiler feed water is essential for both high- and low-pressure boilers. Ensuring the correct treatment is implemented before problems such as fouling, scaling, and corrosion occur, will go a long way in avoiding costly replacements/upgrades down the line.

An efficient and well-designed boiler feed water treatment system should be able to:

- Efficiently treat boiler feed water and remove harmful impurities prior to entering the boiler
- Promote internal boiler chemistry control
- Maximize use of steam condensate
- Control return-line corrosion
- Avoid plant downtime and boiler failure
- Prolong equipment service life

FEED WATER TREATMENT

- A boiler feed water treatment system might be made up of the technologies necessary to remove problematic **dissolved solids, suspended solids, and organic material**, including any number of the following:
- **Iron:** either soluble or insoluble, iron can deposit on boiler parts and tubes, damage downstream equipment, and affect the quality of certain manufacturing processes
- **Copper:** can cause deposits to settle in high-pressure turbines, decreasing their efficiency and requiring costly cleaning or equipment change-outs
- **Silica:** if not removed to low levels, especially in high-pressure boilers, silica can cause extremely hard scaling

FEED WATER TREATMENT

- **Calcium:** can cause scaling in several forms depending on the chemistry of the boiler feed water (e.g. calcium silicate, calcium phosphate, etc.)
- **Magnesium:** if combined with phosphate, magnesium can stick to the interior of the boiler and coat tubes, attracting more solids and contributing to scale
- **Aluminum:** deposits as scale on the boiler interior and can react with silica to increase the likelihood of scaling
- **Hardness:** also causes deposits and scale on boiler parts and piping
- **Dissolved gasses:** chemical reactions due to the presence of dissolved gases such as oxygen and carbon dioxide can cause severe corrosion on boiler pipes and parts

THANK YOU

LECTURE 7

TOPICS TO BE COVERED

- Binary Cycles
- Cogeneration systems

LECTURE 7

Binary Cycles and Cogeneration systems

BINARY CYCLES

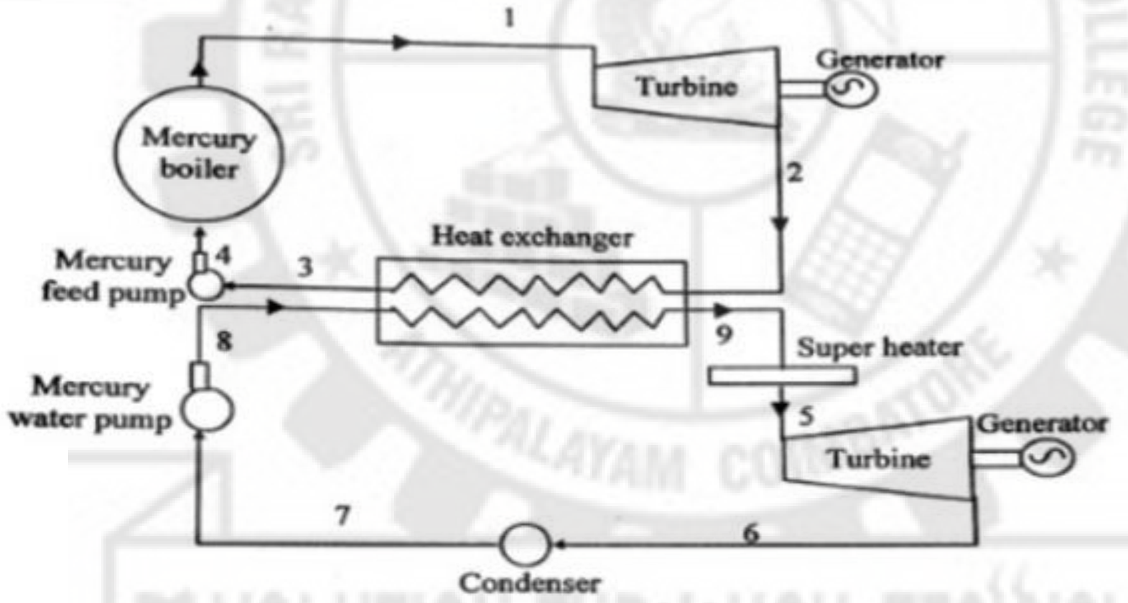
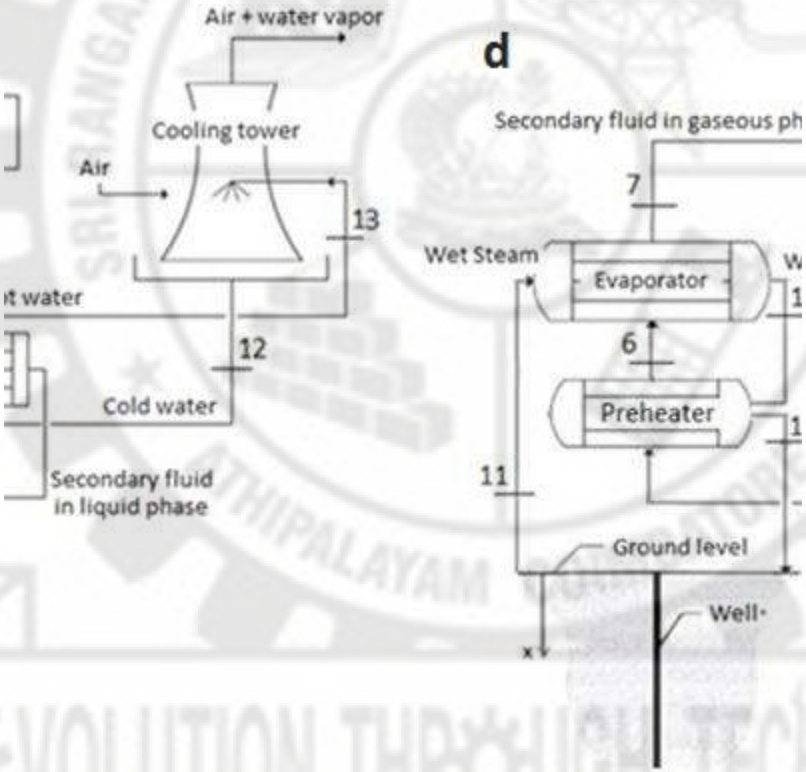


Figure 1.113 Layout of binary vapour cycle

BINARY CYCLES



BINARY CYCLES

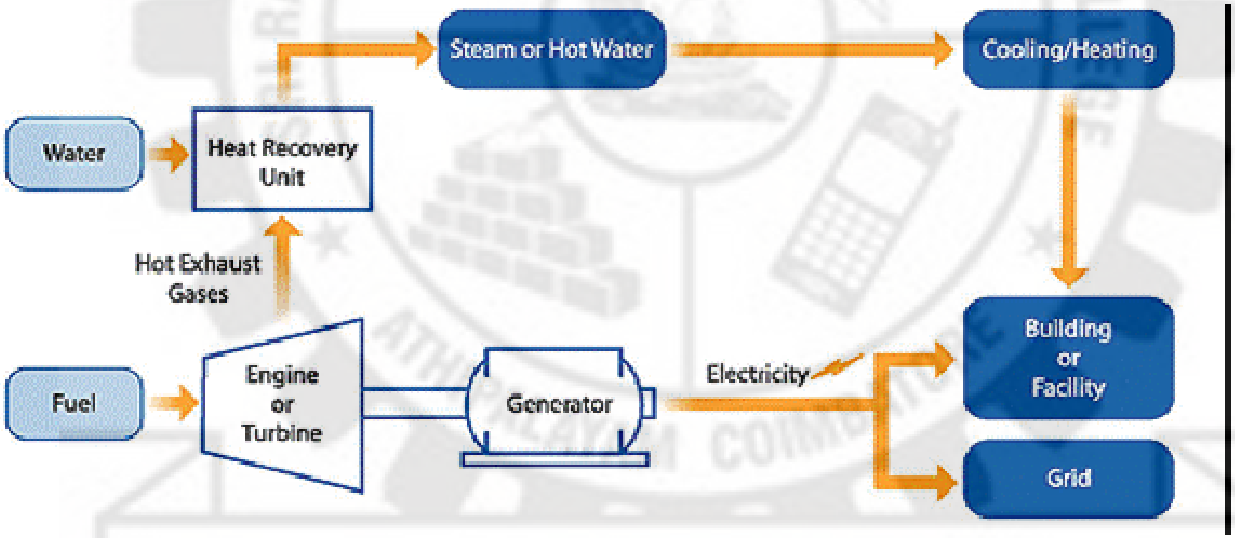
Binary Cycle Power Plant

- Low to moderately heated (below 400°F) geothermal fluid and a secondary (hence, "binary") fluid with a much lower boiling point that water pass through a heat exchanger. Binary cycle power plants are closed-loop systems, and virtually nothing (except water vapor) is emitted to the atmosphere.
- A binary cycle power plant is a type of geothermal power plant that allows cooler geothermal reservoirs to be used than is necessary for dry steam and flash steam plants

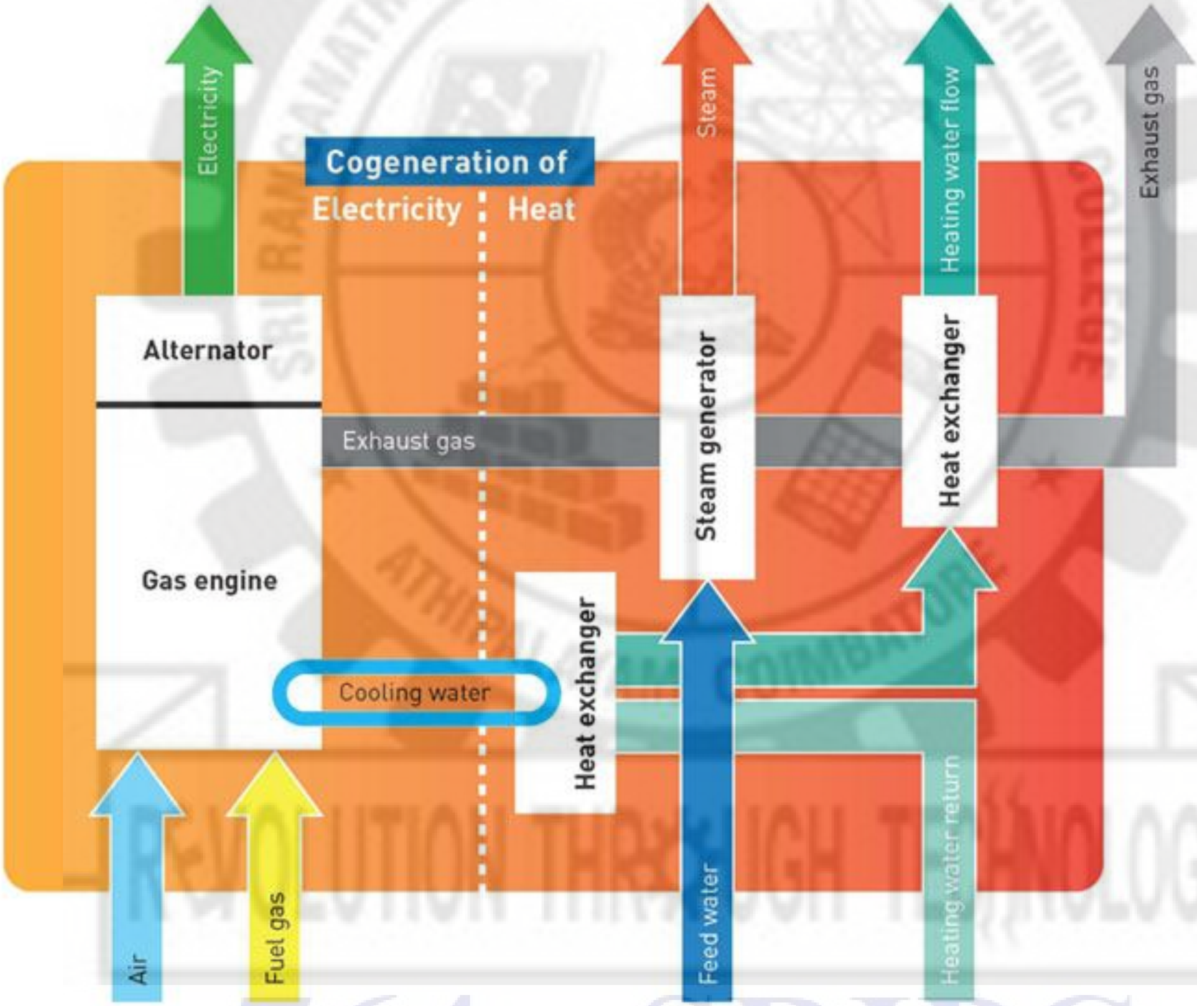
BINARY CYCLES

- Binary Power Plants. Binary plants, like dry-steam and flash-steam plants, make use of naturally sourced hot steam generated by activity from within the Earth's core. All geothermal plants convert thermal energy to mechanical energy, then finally to electrical energy.
- The vapor exiting the turbine is then condensed by cold air radiators or cold water and cycled back through the heat exchanger. A binary vapor cycle is defined in thermodynamics as a power cycle that is a combination of two cycles, one in a high temperature region and the other in a lower temperature region.

COGENERATION SYSTEMS



COGENERATION SYSTEMS



COGENERATION SYSTEMS

- Cogeneration—also known as combined heat and power, distributed generation, or recycled energy—is the simultaneous production of two or more forms of energy from a single fuel source. Cogeneration power plants often operate at 50 to 70 percent higher efficiency rates than single-generation facilities
- A conventional power plant makes electricity by a fairly inefficient process. A fossil fuel such as oil, coal, or natural gas is burned in a giant furnace to release heat energy. ... Cogeneration (the alternative name for CHP) simply means that the electricity and heat are made at the same time.

COGENERATION SYSTEMS

- Cogeneration is a more efficient use of fuel because otherwise-wasted heat from electricity generation is put to some productive use.This is also called combined heat and power district heating. Small CHP plants are an example of decentralized energy.
- Cogeneration is the process of producing electricity from steam (or other hot gases) and using the waste heat as steam in chemical processes. In contrast, a stand-alone power-producing plant typically converts less than 40% of the heat energy of fuel (coal, natural gas, nuclear, etc.) into electricity.

ASSIGNMENT QUESTIONS

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POWER PLANT ENGINEERING (R17A0326)

4th Year B. Tech I- sem, Mechanical Engineering

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COURSE OBJECTIVES

UNIT - 1	**CO1:To create awareness about various sources of energy, working of thermal power plants and combustion process**
UNIT - 2	CO2: To understand how Diesel and gas power plants are functioning
UNIT - 3	CO3: To understand how power is achieved from renewable sources of energy and functions of hydro-electric power plants
UNIT - 4	CO4: Able to learn about Nuclear power plants
UNIT - 5	CO5: To apply the concepts of economics in power plants

UNIT 2

DIESEL, GAS TURBINE AND COMBINED CYCLE POWER PLANTS

CO2: To understand how Diesel and gas power plants are functioning

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UNIT – II (SYLLABUS)

DIESEL AND GAS TURBINE POWER PLANTS

- Otto, Diesel, Dual & Brayton Cycle
- Analysis & Optimization.
- Components of Diesel and Gas Turbine power plants

COMBINED CYCLE POWER PLANTS:

- Combined Cycle Power Plants.
- Integrated Gasifier based Combined Cycle systems.

COURSE OUTLINE- UNIT II

LECTURE	LECTURE TOPIC	KEY ELEMENTS	Learning Objectives
1	Analysis of Otto, Diesel , Dual and Brayton cycles	Various cycles of Otto, Diesel,Dual and Brayton	• Learning the working of all the thermodynamic cycles for producing power
2	Components of diesel engine power plants ,working	Different diesel engine power plant components and their working	• Understanding the working of diesel engine power plant
3	Components of Gas turbine power plants ,working	Different gas turbine power plant components and their working	• Understanding the working of gas turbine power plant •
4	Combined cycle power plants	Combined cycle plant operations	• Understand the process of combined cycle plants
5	Integrated Gasifier based Combined Cycle systems.	Components in combined cycle plants	• Various Operations of combined cycle plants
6	Combined cycle systems	Applications combined cycle plants	• Applications where the combined cycles can be used to increase the efficiency

LECTURE 1

Analysis of Otto, Diesel , Dual and Brayton cycles

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TOPICS TO BE COVERED

- Analysis of Otto, Diesel , Dual and Brayton cycles

LECTURE 1

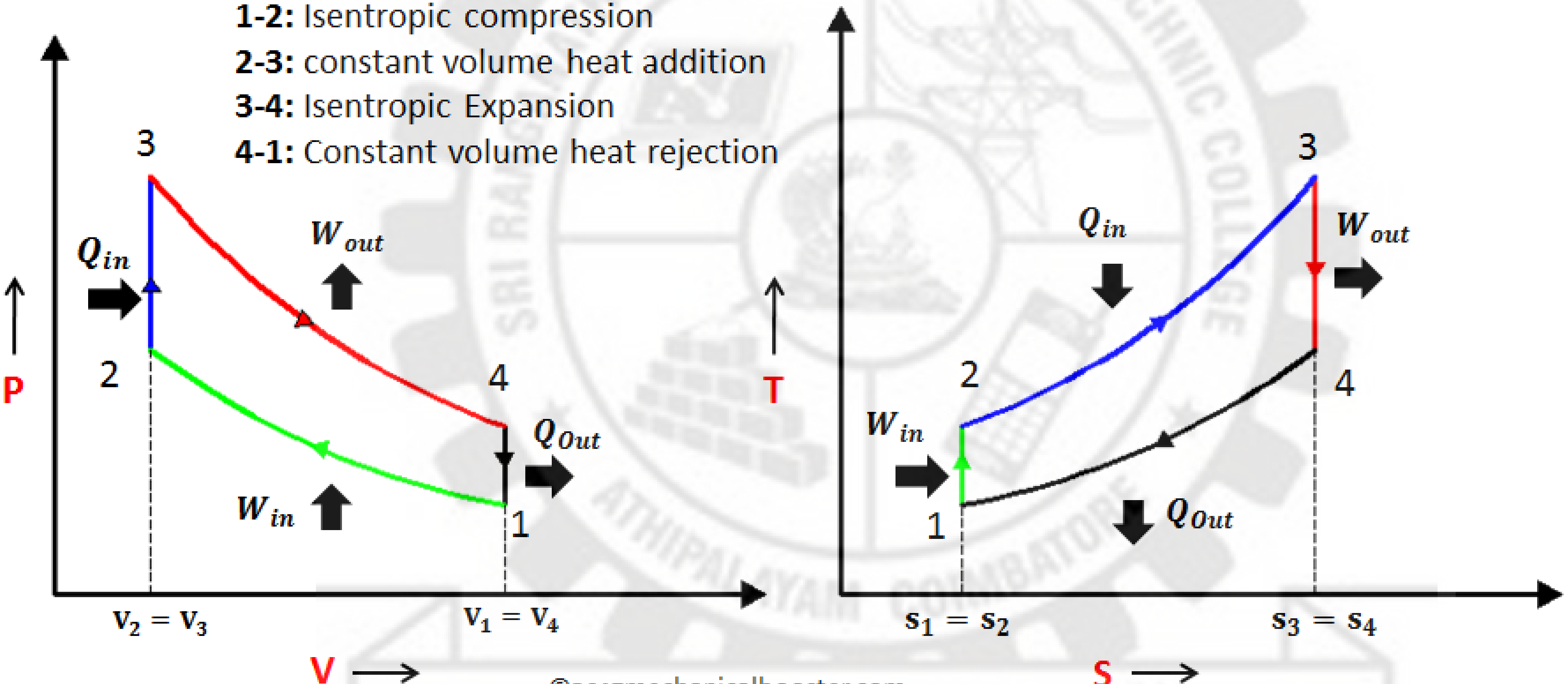
Analysis of Otto, Diesel , Dual and Brayton cycles

OTTO CYCLE

- An Otto cycle is an idealized thermodynamic cycle that describes the functioning of a typical spark ignition piston engine. It is the thermodynamic cycle most commonly found in automobile engines.

An Otto cycle is an idealized thermodynamic cycle that describes the functioning of a typical spark ignition piston engine. It is the thermodynamic cycle most commonly found in automobile engines.

OTTO CYCLE



1-2: Isentropic compression
2-3: constant volume heat addition
3-4: Isentropic Expansion
4-1: Constant volume heat rejection

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P-V and T-S Diagram of Otto Cycle

DIESEL CYCLE

- The Diesel cycle is a combustion process of a reciprocating internal combustion engine. In it, fuel is ignited by heat generated during the compression of air in the combustion chamber, into which fuel is then injected.

The Diesel cycle is a combustion process of a reciprocating internal combustion engine. In it, fuel is ignited by heat generated during the compression of air in the combustion chamber, into which fuel is then injected. This is in contrast to igniting the fuel-air mixture with a spark plug as in the Otto cycle engine.

DIESEL CYCLE

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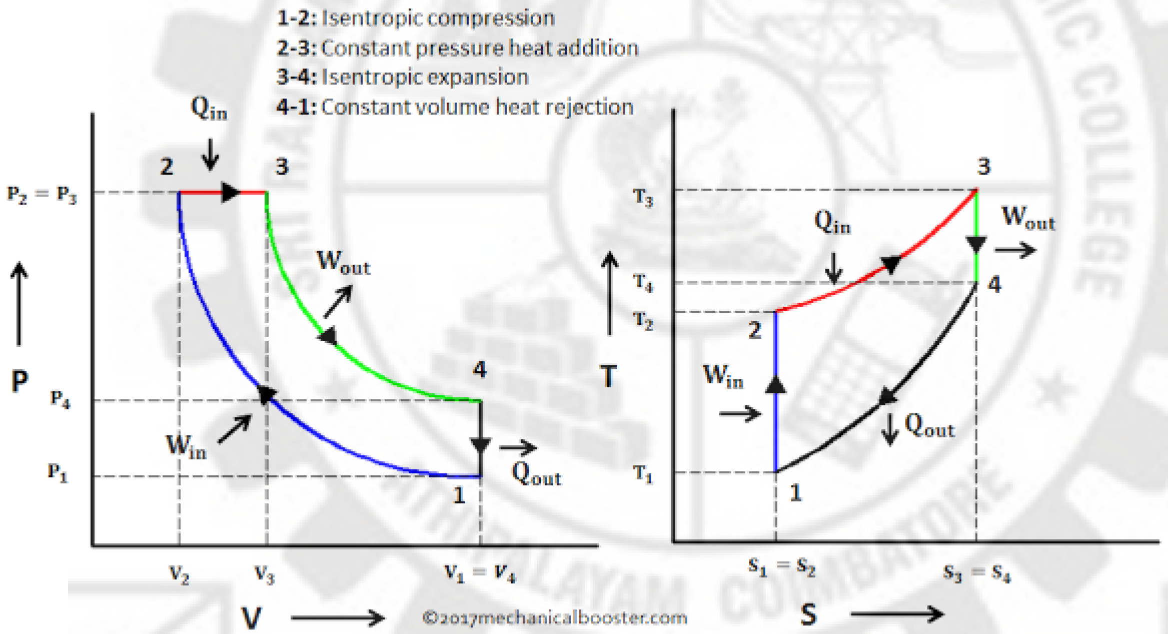

1-2: Isentropic compression
2-3: Constant pressure heat addition
3-4: Isentropic expansion
4-1: Constant volume heat rejection

P-V and T-S Diagram of Diesel Cycle

DUAL CYCLE

- The dual combustion cycle is a thermal cycle that is a combination of the Otto cycle and the Diesel cycle.
- Because of lagging characteristics of fuel this cycle is invariably used for Diesel and hot spot ignition engines. It consists of two adiabatic and two constant volume and one constant pressure processes.
- Dual cycle, or limited pressure cycle, is a thermodynamic cycle that combines the Otto cycle and the Diesel cycle. In the dual cycle, combustion occurs partly at constant volume and partly at constant pressure. It can be used to describe internal combustion engines.

DUAL CYCLE

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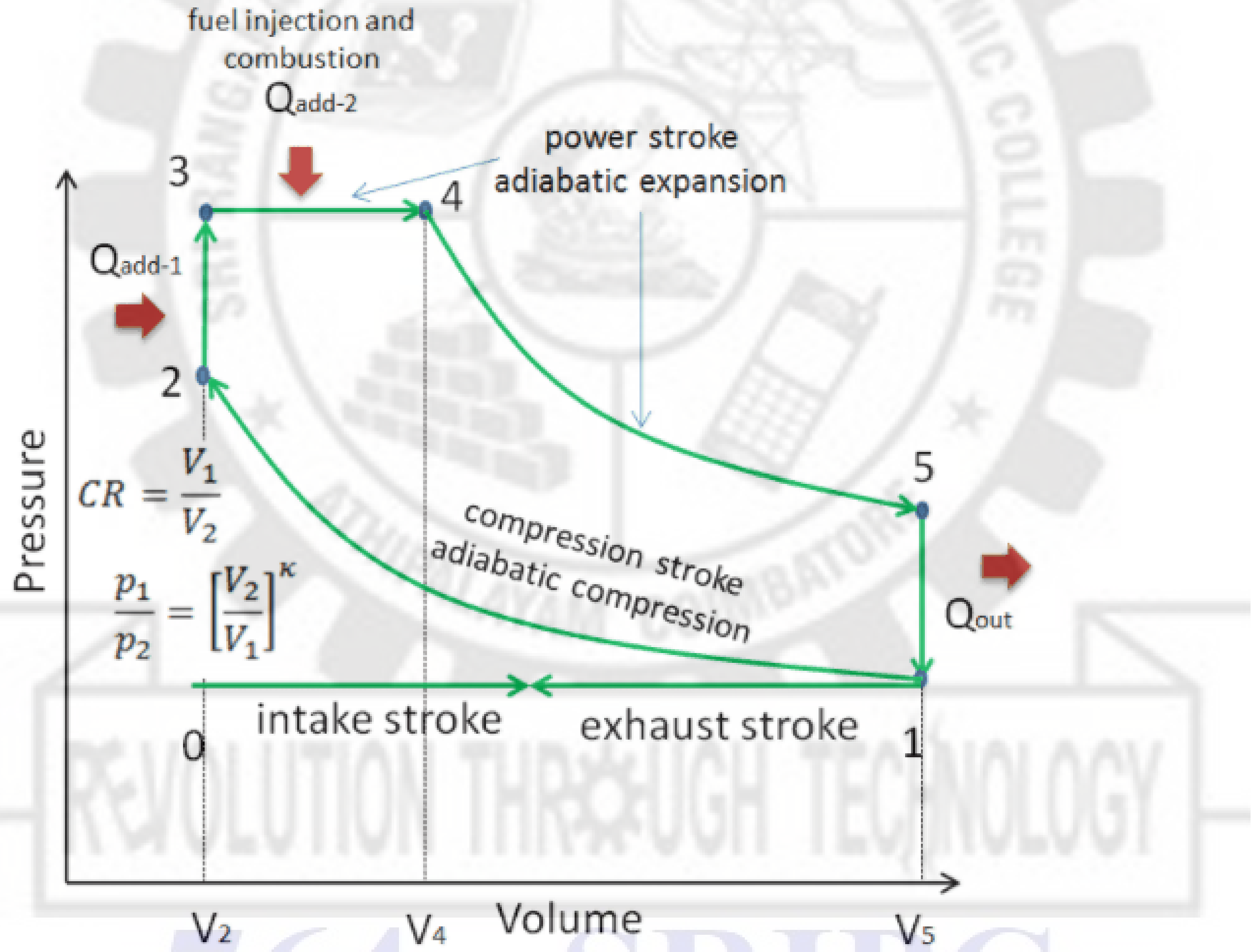
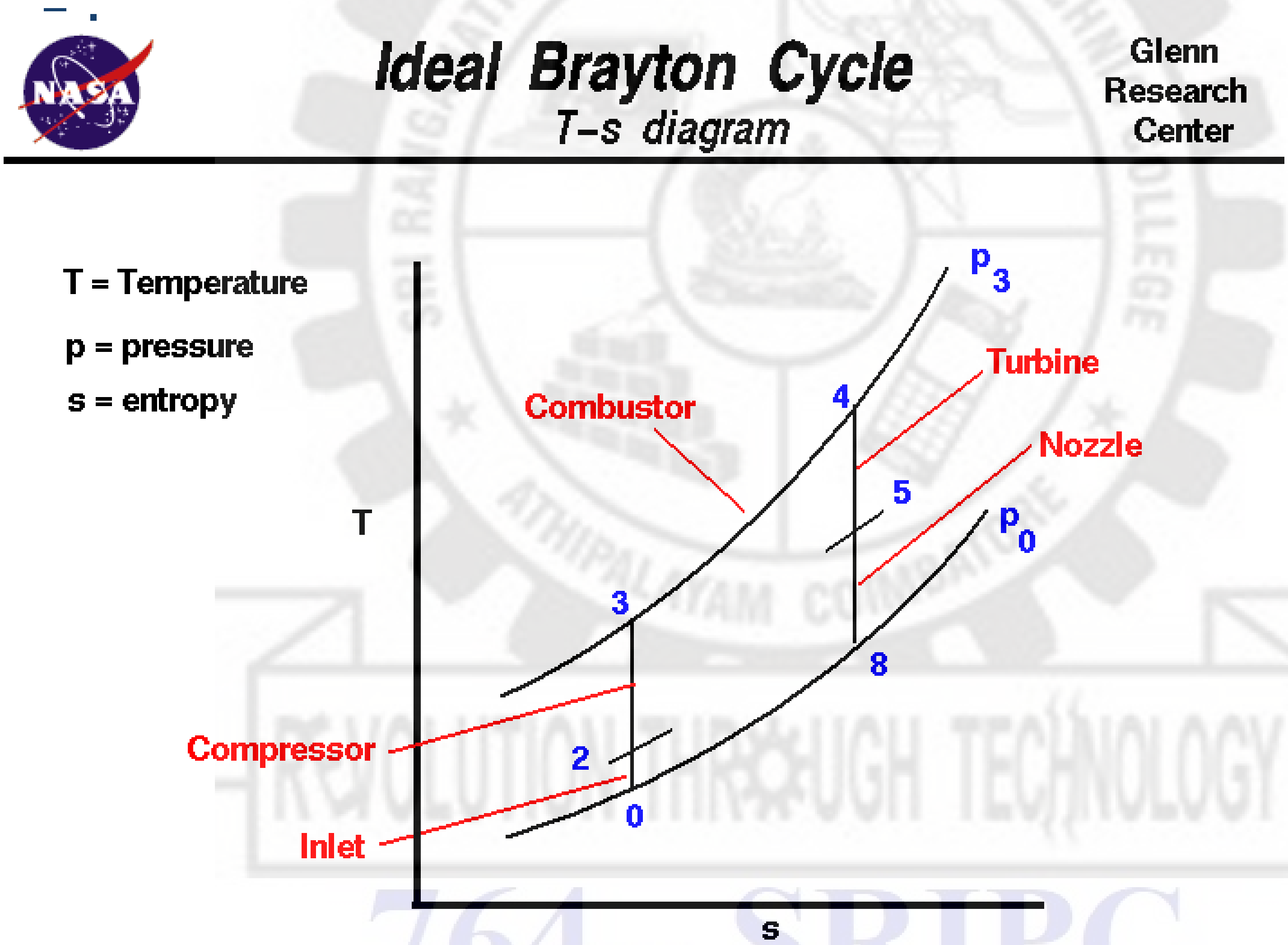


fuel injection and combustion
Q_{add-2}
3
4
power stroke
adiabatic expansion
Q_{add-1}
2
Pressure
$CR = \frac{V_1}{V_2}$
$\frac{p_1}{p_2} = \left[\frac{V_2}{V_1}\right]^{\kappa}$
5
compression stroke
adiabatic compression
Q_{out}
intake stroke
exhaust stroke
0
1
V_2
V_4
Volume
V_5

BRAYTON CYCLE

- The Brayton cycle is a thermodynamic cycle named after George Brayton that describes the workings of a constant-pressure heat engine. The original Brayton engines used a piston compressor and piston expander, but more modern gas turbine engines and air breathing jet engines also follow the Brayton cycle.
- Brayton cycle. A thermodynamic cycle using constant pressure, heat addition and rejection. Fuel and a compressor are used to heat and increase the pressure of a gas; the gas expands and spins the blades of a turbine, which, when connected to a generator, generates electricity.

BRAYTON CYCLE



Ideal Brayton Cycle

T–s diagram

Glenn Research Center

T = Temperature

p = pressure

s = entropy

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LECTURE 2

TOPICS TO BE COVERED

- Components of diesel engine power plants
- working

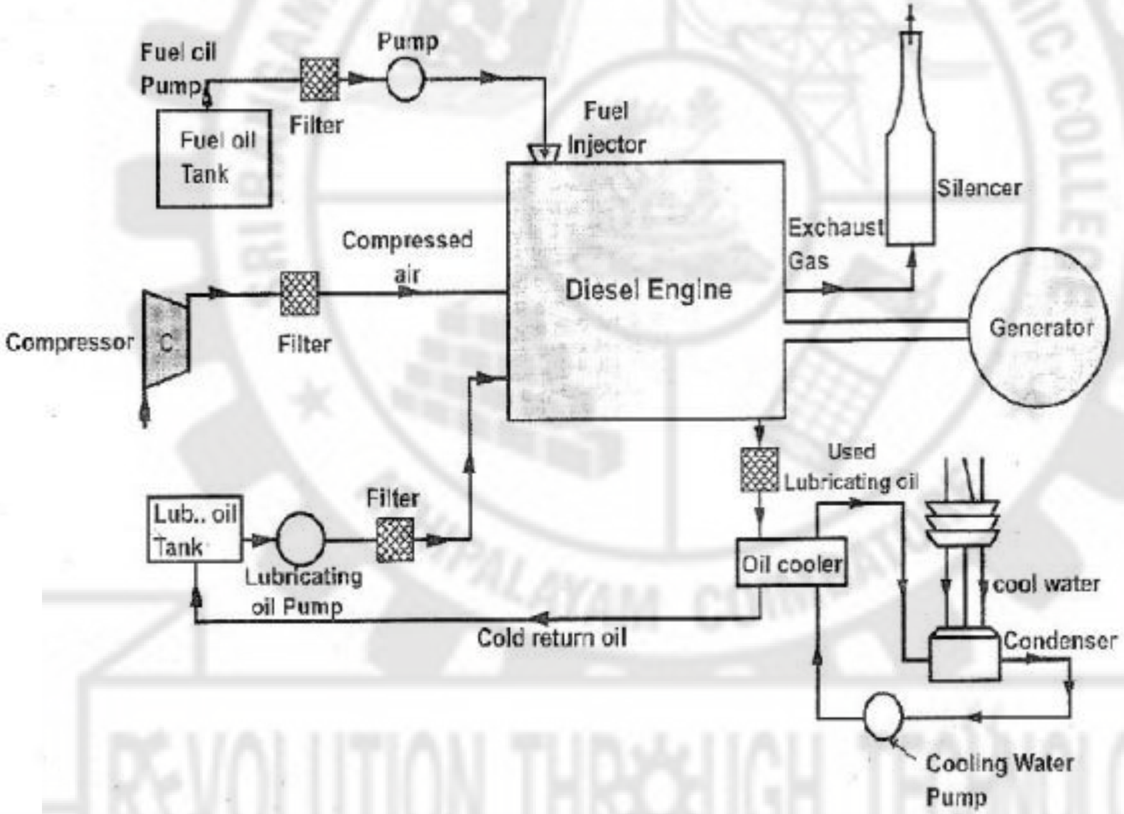
LECTURE 2

Components of diesel engine power plants ,working

DIESEL ENGINE POWER PLANT

- A Diesel Power Plant is wherein the prime mover of an alternator is a diesel engine. Using a diesel engine has its own pros and cons. Installation and operation are easier as compared to other power plants.
- In a diesel power station, diesel engine is used as the prime mover. The diesel burns inside the engine and the products of this combustion act as the working fluid to produce mechanical energy. The diesel engine drives alternator which converts mechanical energy into electrical energy.

DIESEL ENGINE POWER PLANT



DIESEL ENGINE POWER PLANT

Component s of Diesel Power Plants–Lecture Notes

– Engine.

– Air Intake System.

– Engine Starting system.

– Fuel System.

– Exhaust System.

– Cooling System.

– Lubricating System.

PDF attachment

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LECTURE 3

TOPICS TO BE COVERED

- Components of Gas turbine power plants
- working

LECTURE 3

Components of Gas turbine power plants ,working

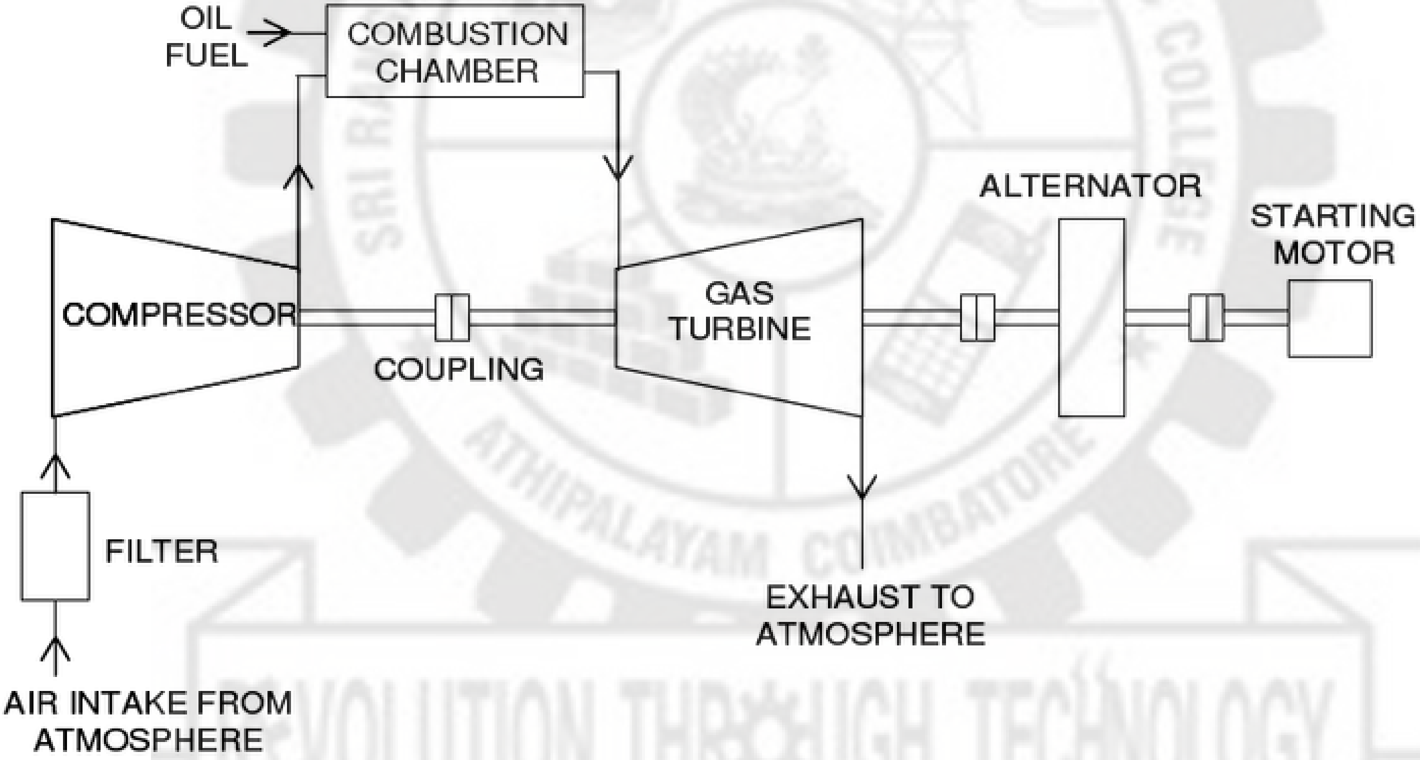
GAS TURBINE POWER PLANT

Gas turbine power plant

The combustion (gas) turbines being installed in many of today's natural-gas-fueled power plants are complex machines, but they basically involve three main sections: The compressor, which draws air into the engine, pressurizes it, and feeds it to the combustion chamber at speeds of hundreds of miles per hour.

Gas turbines are used to power aircraft, trains, ships, electrical generators, pumps, gas compressors, and tanks.

GAS TURBINE POWER PLANT LAYOUT



GAS TURBINE POWER PLANT

The gas turbine is made up of the following components:

- An air compressor.
- A combustor.
- A power turbine, which produces the power to drive the air compressor and the output shaft.

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LECTURE 4

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TOPICS TO BE COVERED

- **Combined cycle power plants**

LECTURE 4

Combined cycle power plants

COMBINED CYCLE POWER PLANTS

- A combined cycle power plant is an assembly of heat engines that work in tandem from the same source of heat, converting it into mechanical energy. On land, when used to make electricity the most common type is called a combined cycle gas turbine plant.

- A combined-cycle power plant uses both a gas and a steam turbine together to produce up to 50 percent more electricity from the same fuel than a traditional simple-cycle plant. The waste heat from the gas turbine is routed to the nearby steam turbine, which generates extra power.

COMBINED CYCLE POWER PLANTS

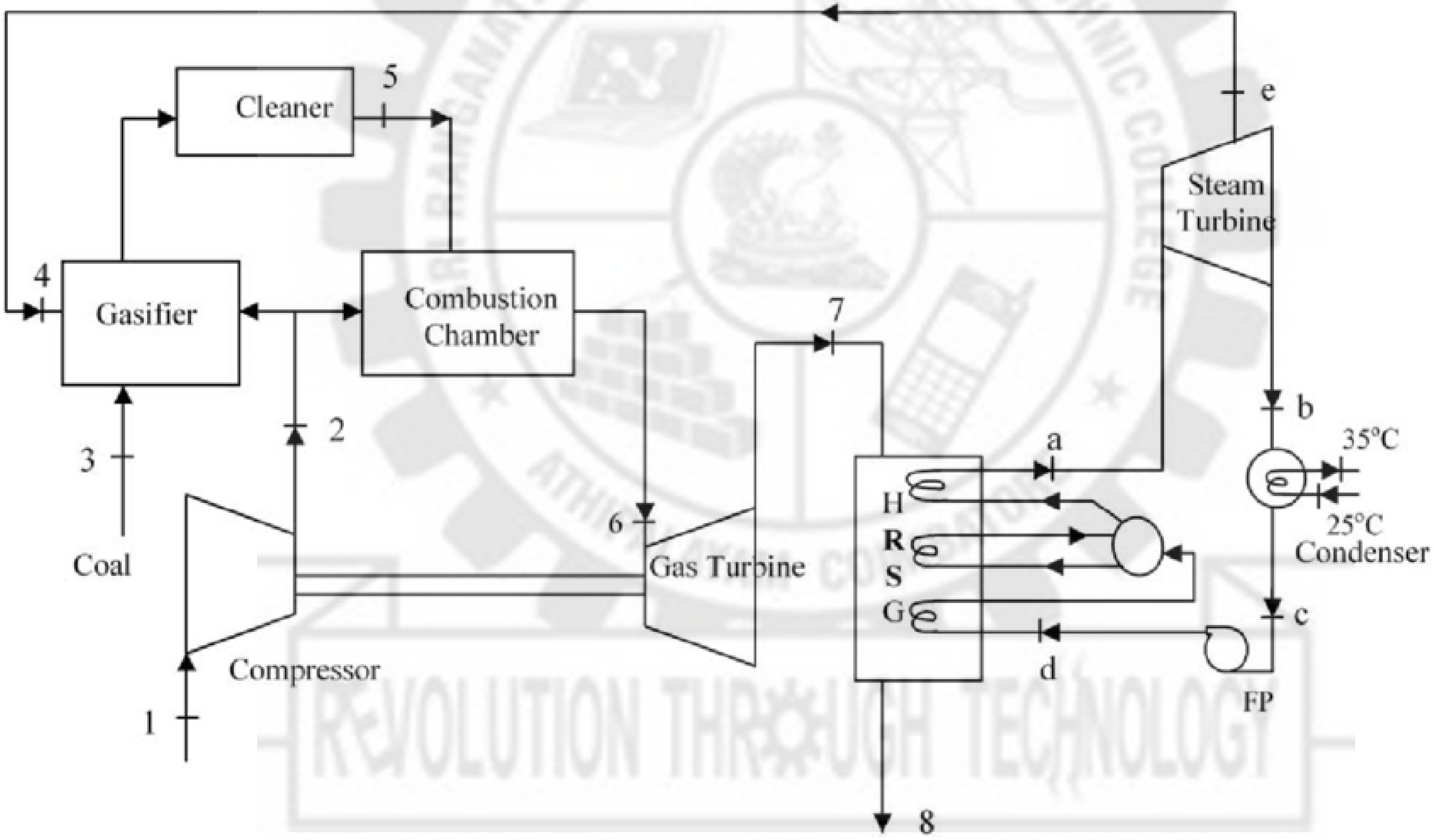
- A Combined Cycle Power Plant produces high power outputs at high efficiencies (up to 55%) and with low emissions. In a Conventional power plant we are getting 33% electricity only and remaining 67% as waste.

- The major components of a combined cycle plant are a gas turbine, a heat recovery steam generator, a steam turbine, and balance of plant systems.

COMBINED CYCLE POWER PLANTS

- A combined-cycle power plant uses both a gas and a steam turbine together to produce up to 50 percent more electricity from the same fuel than a traditional simple-cycle plant. The waste heat from the gas turbine is routed to the nearby steam turbine, which generates extra power.
- Co-generations uses waste heat for many different processes, such as space heating or drying. Combined-cycle power generation is a two-cycle electricity generation process that uses the heat from the first cycle to run a second cycle.
- PDF attachment

COMBINED CYCLE POWER PLANTS



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LECTURE 5

TOPICS TO BE COVERED

- **Integrated Gasifier based Combined Cycle systems**

LECTURE 5

Integrated Gasifier based Combined Cycle systems

INTEGRATED GASIFIER BASED COMBINED CYCLE SYSTEMS

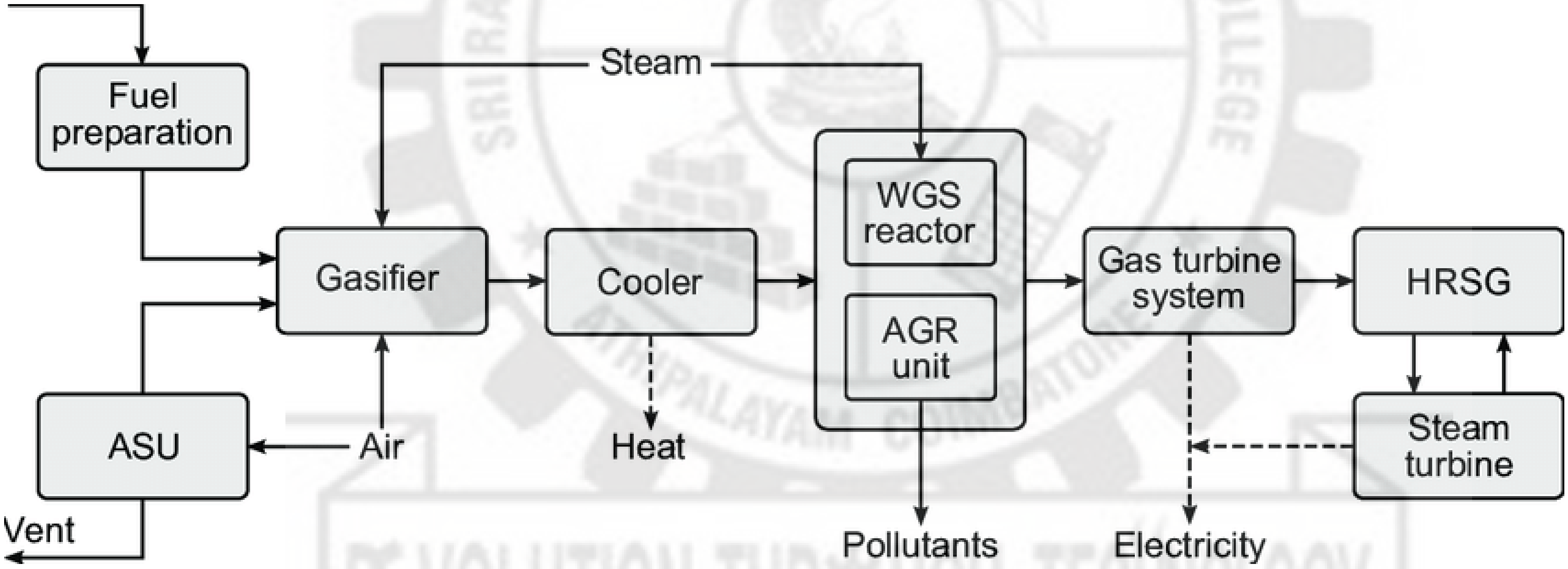
- An integrated gasification combined cycle is a technology that uses a high pressure gasifier to turn coal and other carbon based fuels into pressurized gas—synthesis gas. It can then remove impurities from the syngas prior to the power generation cycle.
- Integrated coal gasification combined cycle (IGCC) power plants are a next-generation thermal power system with significantly enhanced power generation efficiency and environmental performance due to its combination with coal gasification and the Gas Turbine Combined Cycle (GTCC) system.

INTEGRATED GASIFIER BASED COMBINED CYCLE SYSTEMS

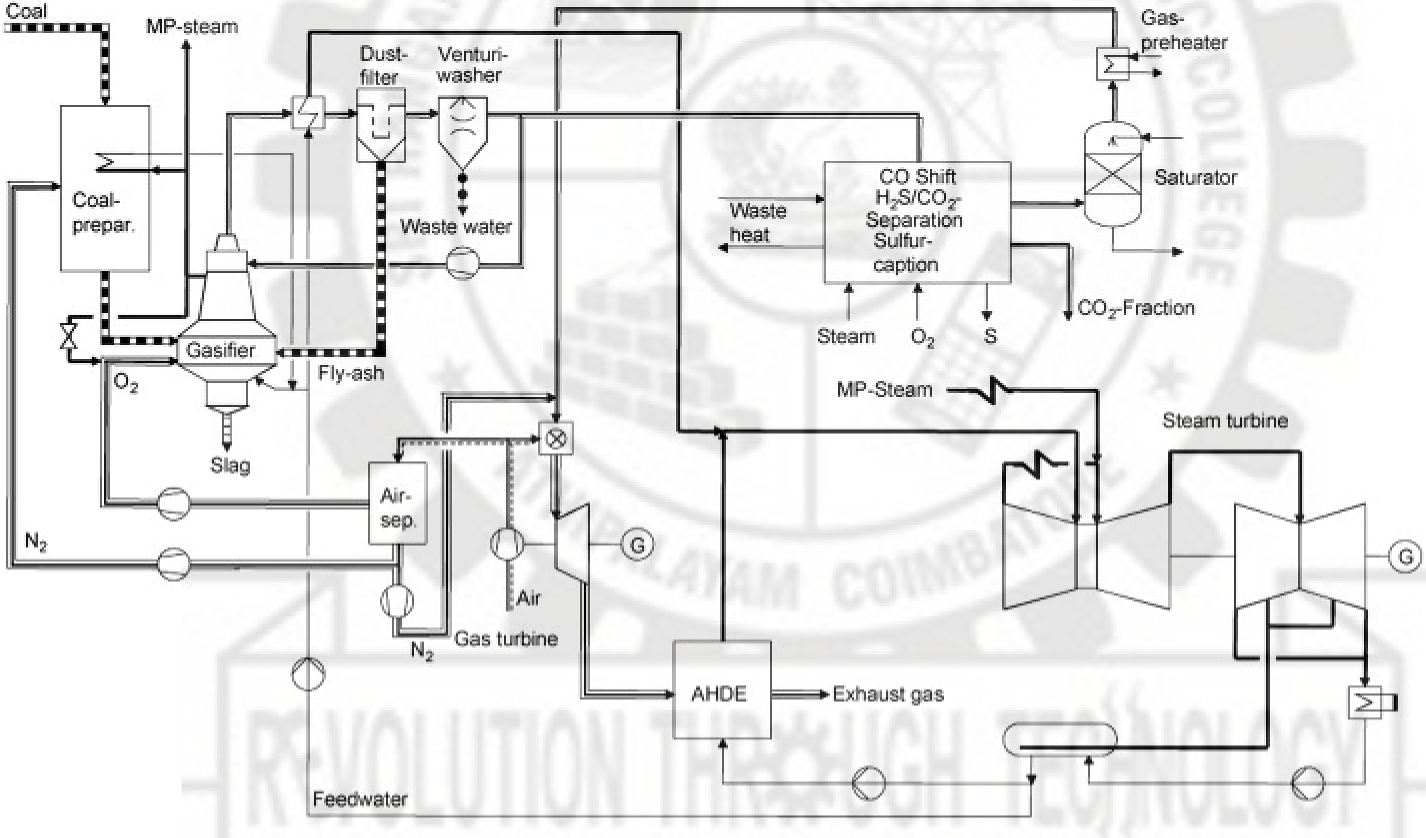
- A combined-cycle power plant uses both a gas and a steam turbine together to produce up to 50 percent more electricity from the same fuel than a traditional simple-cycle plant. The waste heat from the gas turbine is routed to the nearby steam turbine, which generates extra power.

- Combined Cycle Gas Turbines (CCGT)are a form of highly efficient energy generation technology that combines a gas-fired turbine with a steam turbine.

INTEGRATED GASIFIER BASED COMBINED CYCLE SYSTEMS



INTEGRATED GASIFIER BASED COMBINED CYCLE SYSTEMS



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LECTURE 6

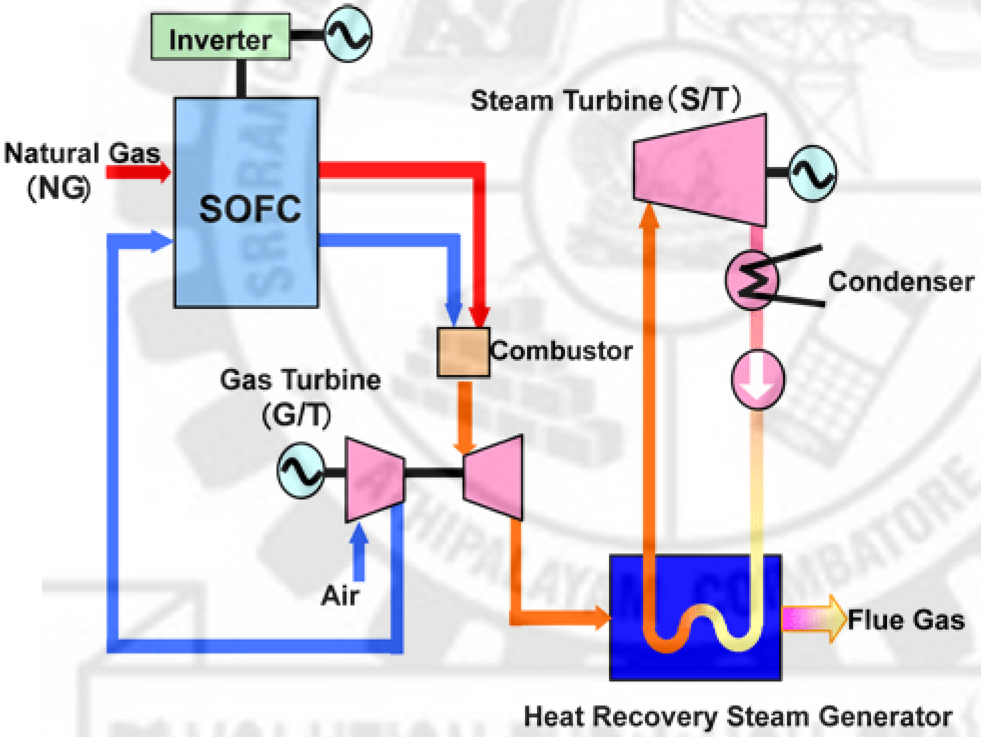
TOPICS TO BE COVERED

○ **Combined cycle systems**

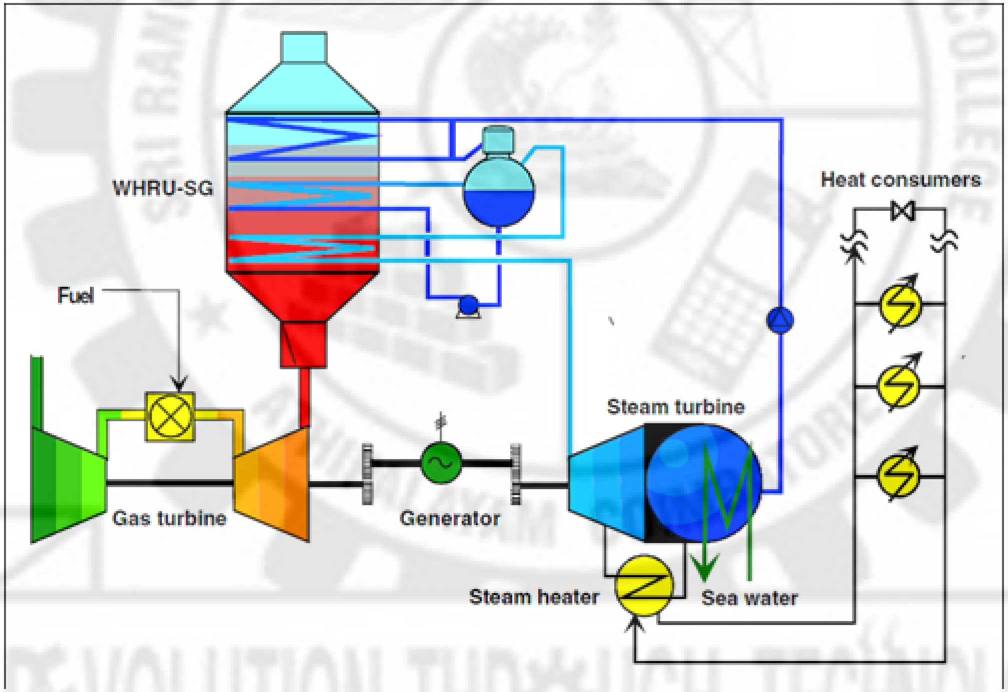
LECTURE 6

Combined cycle systems

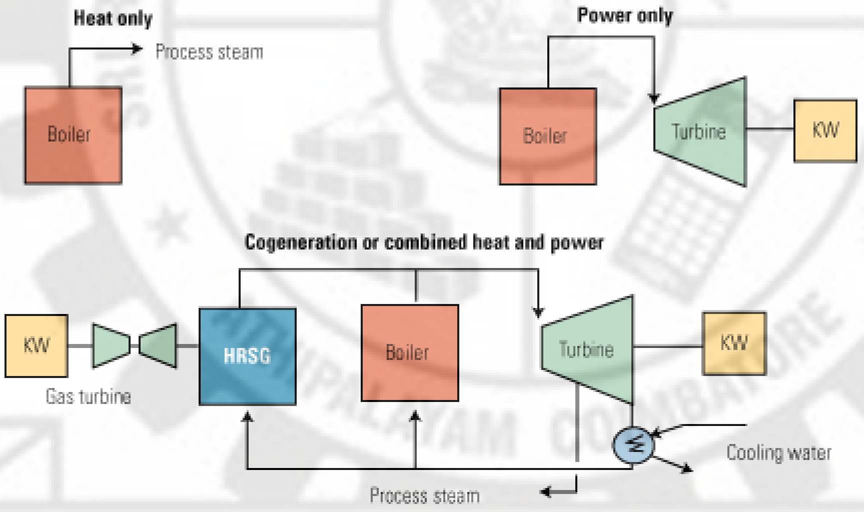
COMBINED CYCLE SYSTEMS



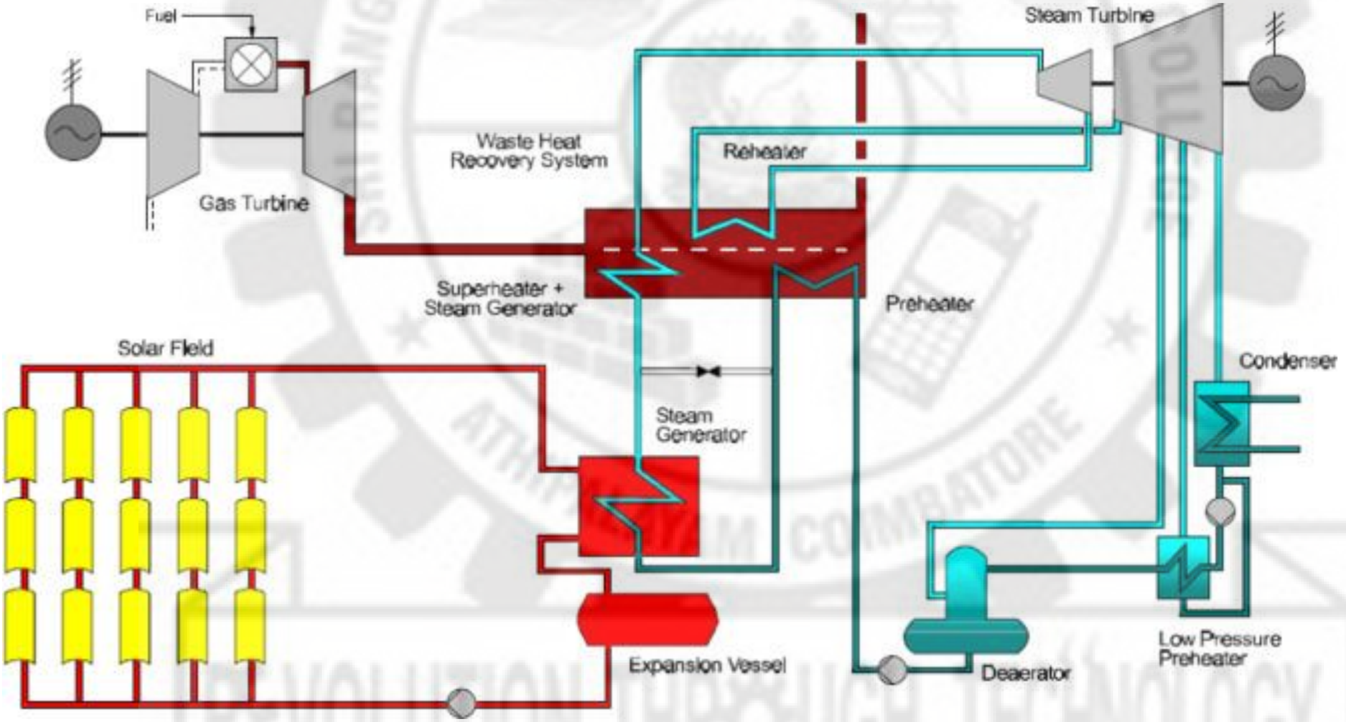
COMBINED CYCLE SYSTEMS



COMBINED CYCLE SYSTEMS



COMBINED CYCLE SYSTEMS



ASSIGNMENT QUESTIONS

ASSIGNMENT QUESTIONS

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COURSE OBJECTIVES

UNIT - 1	**CO1:To create awareness about various sources of energy, working of thermal power plants and combustion process**
UNIT - 2	CO2: To understand how Diesel and gas power plants are functioning
UNIT - 3	CO3: Able to learn about Nuclear power plants
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UNIT - 5	CO5: To apply the concepts of economics in power plants

UNIT 3

NUCLEAR POWER PLANTS

CO3: To Able to learn about Nuclear power plants

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UNIT-III (SYLLABUS)

NUCLEAR POWER PLANTS

NUCLEAR POWER PLANTS

- Basics of Nuclear Engineering, Layout and subsystems of Nuclear Power Plants
- Working of Nuclear Reactors : Boiling Water Reactor (BWR), Pressurized Water Reactor (PWR), Canada Deuterium- Uranium reactor (CANDU), Breeder, Gas Cooled and Liquid Metal Cooled Reactors.
- Safety measures for Nuclear Power plants.

COURSE OUTLINE-UNIT III

LECTURE	LECTURE TOPIC	KEY ELEMENTS	Learning Objectives
1	Basics of nuclear engineering	Basics of nuclear physics	• Understanding the energy generation using nuclear engineering
2	Layout and subsystems of nuclear power plants	Complete introduction about nuclear reactor and nuclear power plant	• Understanding the working and resources of nuclear power plant
3	Working and classification of various nuclear power plants	Different types of nuclear power plants	• Understanding various types of power plants their working
4	Different components and applications of nuclear power plants	Functioning of each component of plant and their classifications etc	• Understanding various functions of plant working
5	Safety measures for nuclear power plants	The precautions to be taken in nuclear power plants	• Understanding the types of radiations release and what measures to be taken to be safe

LECTURE 1

Basics of Nuclear Engineering

TOPICS TO BE COVERED

- Basics of Nuclear Engineering

LECTURE 1

Basics of Nuclear Engineering

BASICS OF NUCLEAR ENGINEERING

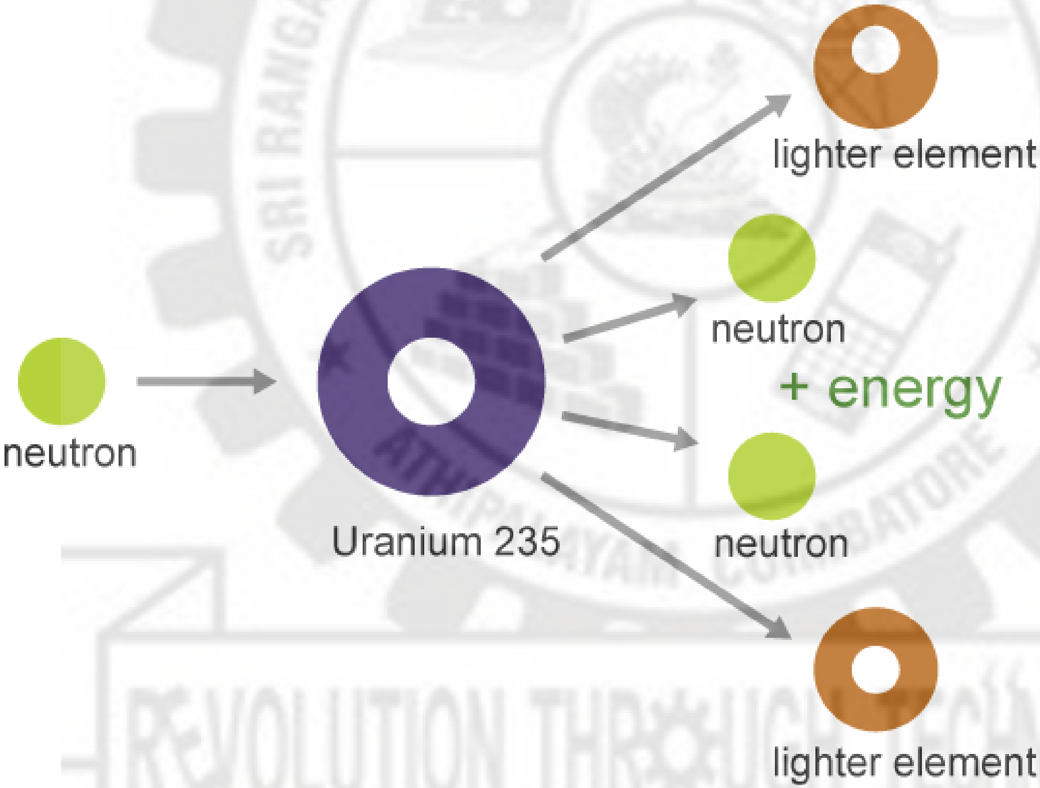
Nuclear power is a clean and efficient way of boiling water to make steam, which turns turbines to produce electricity. Nuclear power plants use low-enriched uranium fuel to produce electricity through a process called fission—the splitting of uranium atoms in a nuclear reactor.

The process in which nuclear energy is produced in the result of a series of steps:

- Splitting of Atoms. Uranium atoms, in the form of ceramic-coated pellets, are placed in a reactor core.
- Absorption. Control rods are used to absorb the free floating neurons released during the fission process.
- Heat.
- Water and Piping.

BASICS OF NUCLEAR ENGINEERING

How fission splits the uranium atom



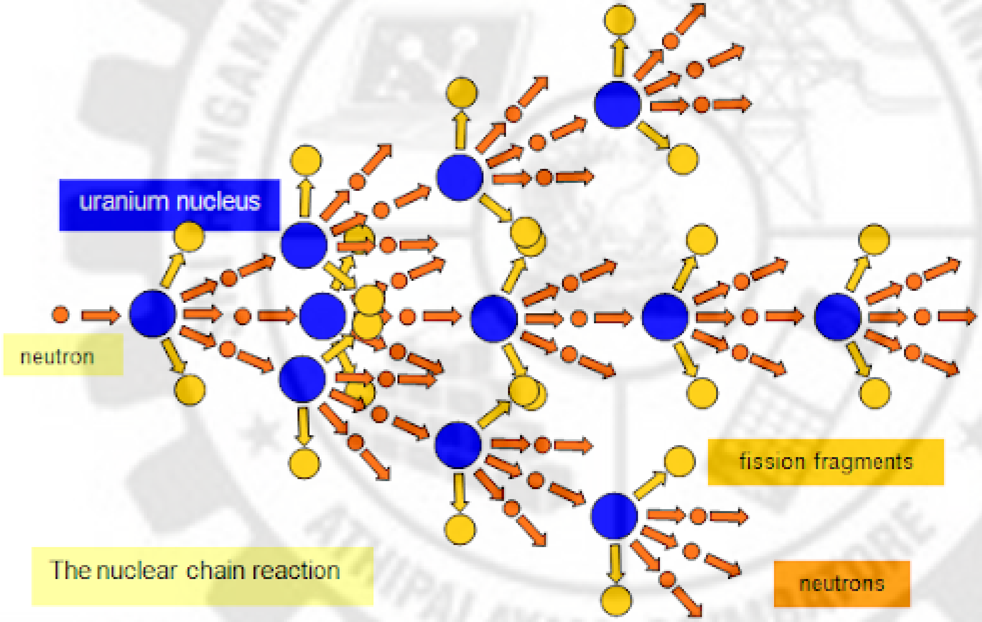
Source: Adapted from National Energy Education Development Project (public domain)

BASICS OF NUCLEAR ENGINEERING

Nuclear fission products are the atomic fragments left after a large atomic nucleus undergoes nuclear fission. Typically, a large nucleus like that of uranium fissions by splitting into two smaller nuclei, along with a few neutrons, the release of heat energy (kinetic energy of the nuclei), and gamma rays.

Fusion only produces more energy than it consumes in small nuclei (in stars, Hydrogen & its isotopes fusing into Helium). The energy released when 4 Hydrogen nuclei (= protons) fuse (there are some decays involved as well) into a Helium nucleus is around 27 Million Electron Volts (MeV), or about 7 MeV per nucleon.

BASICS OF NUCLEAR ENGINEERING



BASICS OF NUCLEAR ENGINEERING

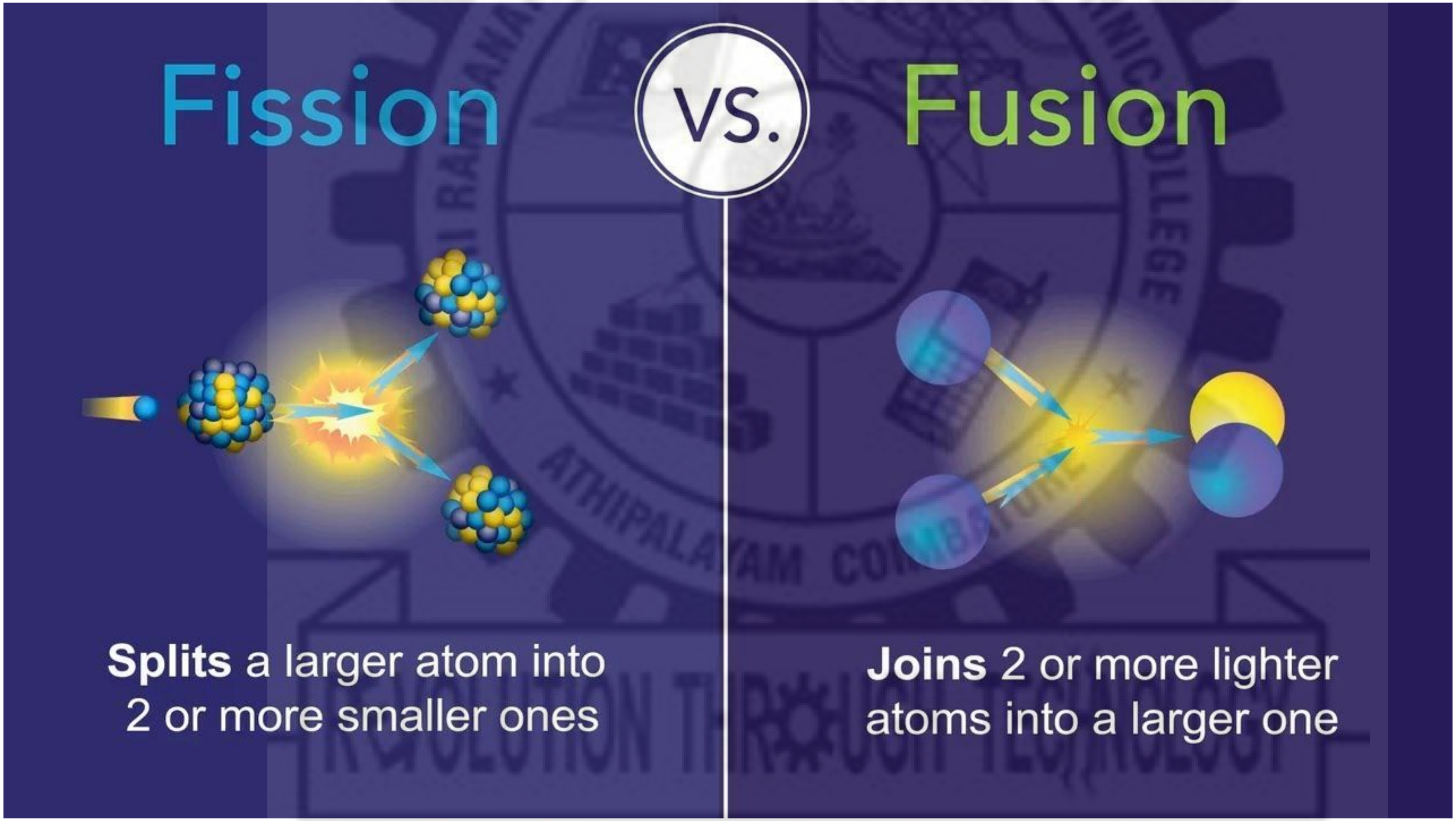
Fission and fusion are two physical processes that produce massive amounts of energy from atoms.

They yield millions of times more energy than other sources through nuclear reactions.

Fission

Fission occurs when a neutron slams into a larger atom, forcing it to excite and spilt into two smaller atoms—also known as fission products. Additional neutrons are also released that can initiate a chain reaction.

BASICS OF NUCLEAR ENGINEERING



Splits a larger atom into 2 or more smaller ones

Joins 2 or more lighter atoms into a larger one

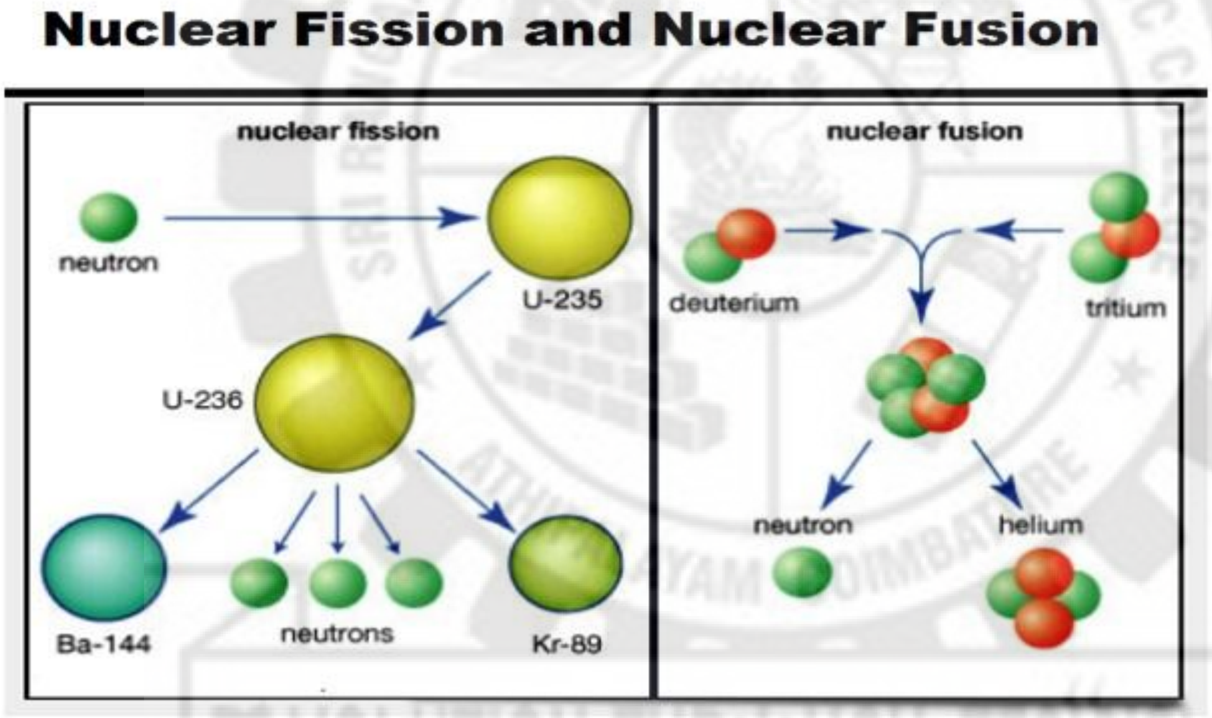
BASICS OF NUCLEAR ENGINEERING

When each atom splits, a tremendous amount of energy is released.

Uranium and plutonium are most commonly used for fission reactions in nuclear power reactors because they are easy to initiate and control

The energy released by fission in these reactors heats water into steam. The steam is used to spin a turbine to produce carbon-free electricity.

BASICS OF NUCLEAR ENGINEERING



BASICS OF NUCLEAR ENGINEERING

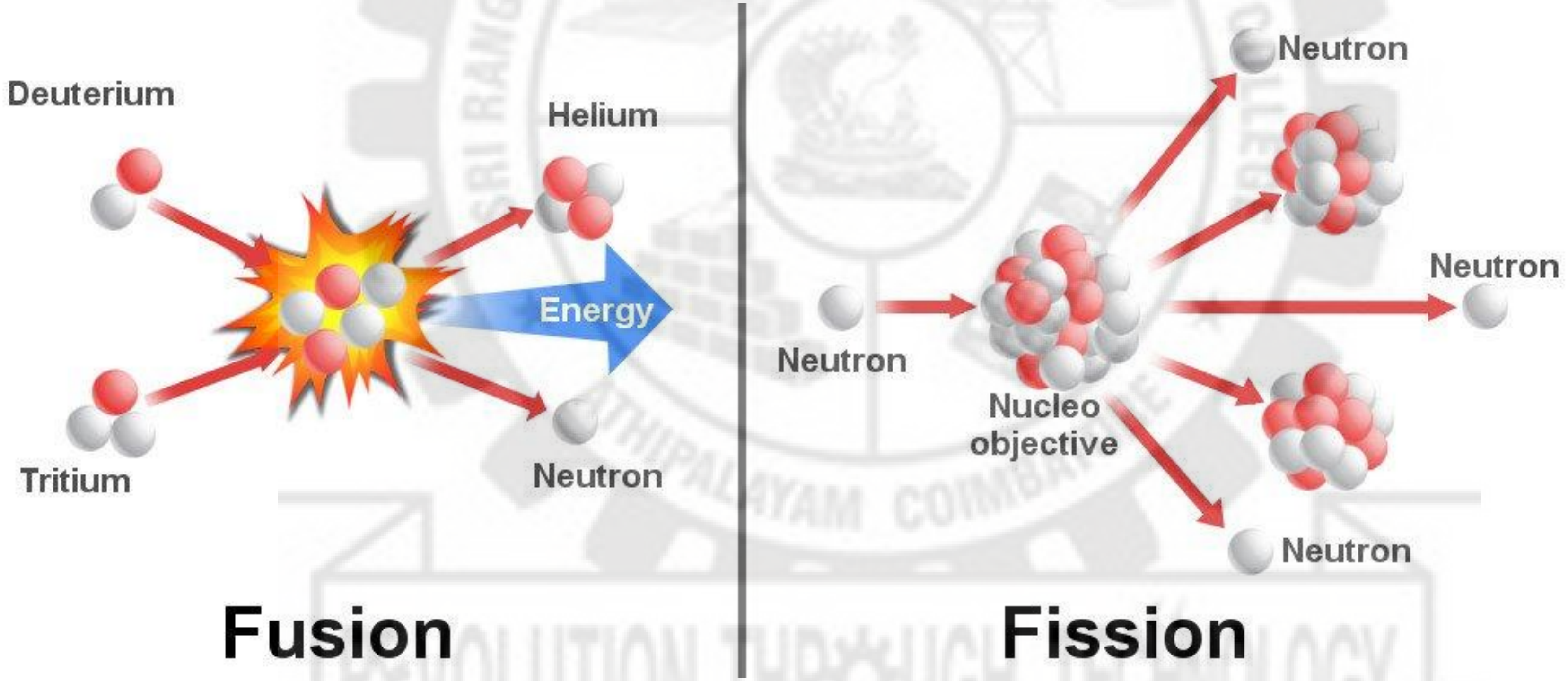
Fusion

Fusion occurs when two atoms slam together to form a heavier atom, like when two hydrogen atoms fuse to form one helium atom.

This is the same process that powers the sun and creates huge amounts of energy—several times greater than fission. It also doesn’t produce highly radioactive fission products.

Fusion reactions are being studied by scientists, but are difficult to sustain for long periods of time because of the tremendous amount of pressure and temperature needed to join the nuclei together.

BASICS OF NUCLEAR ENGINEERING



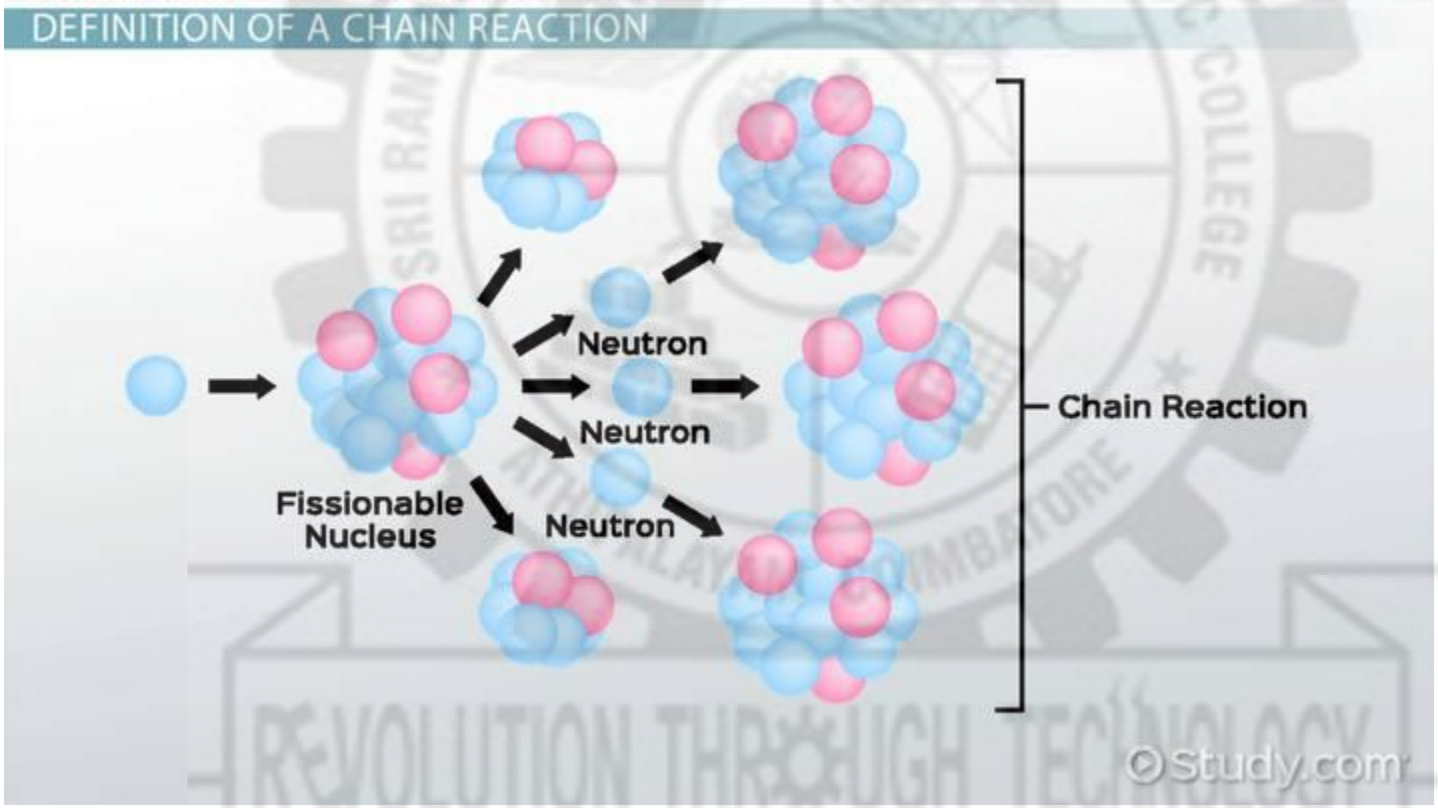
BASICS OF NUCLEAR ENGINEERING

Chain Reaction

A self-sustaining reaction in which the fission of nuclei of one generation of nuclei produces particles that cause the fission of at least an equal number of nuclei of the succeeding generation.

For example, a single neutron causes the nucleus of a uranium atom to undergo fission. In the process, two or three more neutrons are released.

BASICS OF NUCLEAR ENGINEERING



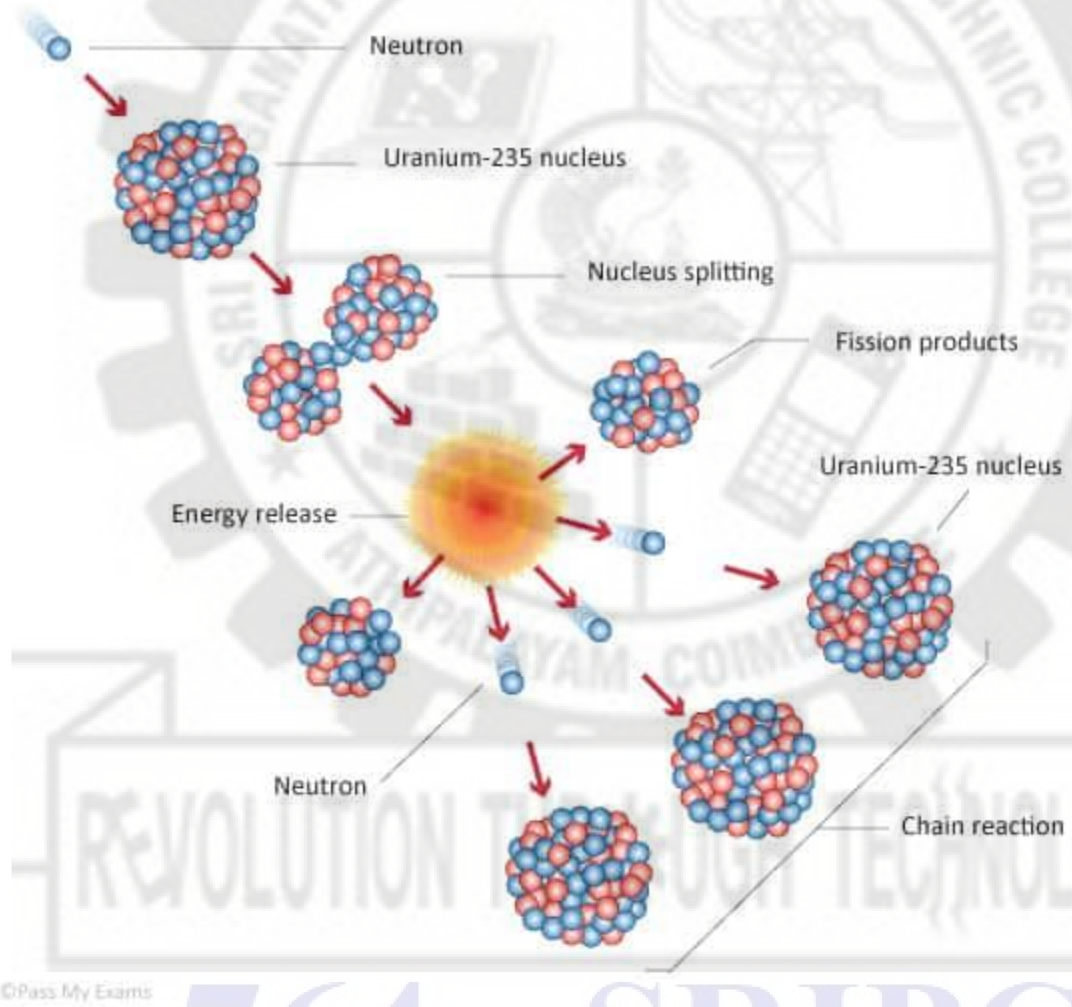
BASICS OF NUCLEAR ENGINEERING

In the operation of a nuclear reactor, fuel assemblies are put into place and then the control rods are slowly lifted until a chain reaction can just be sustained. As the reaction proceeds, the number of uranium-235 nuclei decreases and fission by-products which absorb neutrons build up.

Uncontrolled Chain Reactions

Each time a nucleus splits and releases a neutron, a large amount of energy is released. ... However, because of Chain Reactions, a controlled nuclear reaction will increase in speed each time another nucleus splits (this is known as an 'Uncontrolled Chain Reaction').

BASICS OF NUCLEAR ENGINEERING



BASICS OF NUCLEAR ENGINEERING

Water, heavy water, and graphite are good materials for slowing down neutrons, and atoms with heavy nuclei have good neutron capture cross-sections and can absorb neutrons quickly. These materials are used in control rods.

Nuclear Chain Reactions. A chain reaction refers to a process in which neutrons released in fission produce an additional fission in at least one further nucleus. This nucleus in turn produces neutrons, and the process repeats. The process may be controlled (nuclear power) or uncontrolled (nuclear weapons).

BASICS OF NUCLEAR ENGINEERING

The only way to control or stop a nuclear chain reaction is to stop the neutrons from splitting more atoms. Control rods made of a neutron-absorbing element such as boron reduce the number of free neutrons and take them out of the reaction.

THANK YOU

LECTURE 2

TOPICS TO BE COVERED

- Layout and subsystems of nuclear power plants

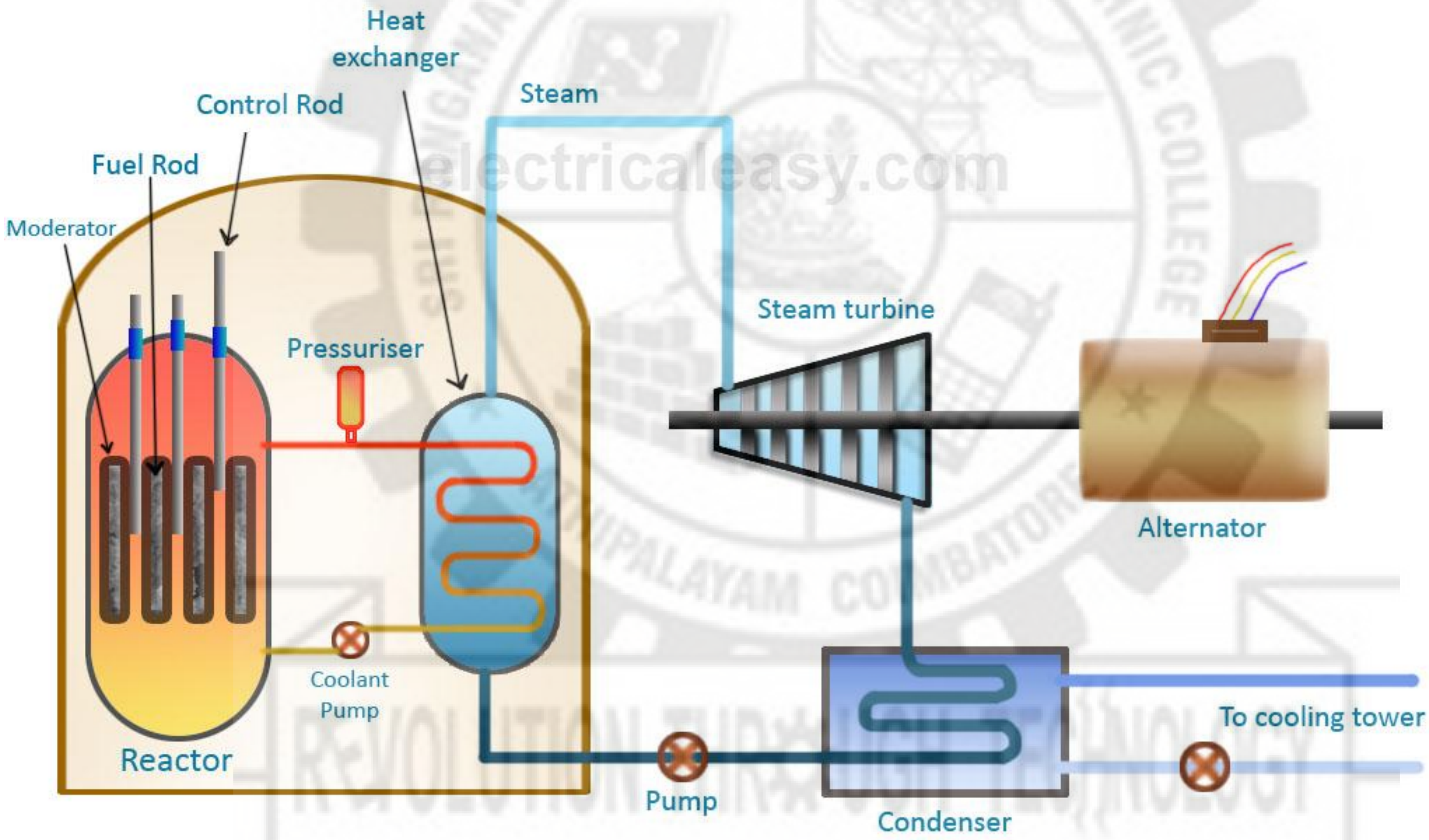
LECTURE 2

Layout and subsystems of nuclear power plants

LAYOUT AND SUBSYSTEMS OF NUCLEAR POWER PLANTS

– A **nuclear power plant** is a thermal power station in which the heat source is a nuclear reactor. As is typical of thermal power stations, heat is used to generate steam that drives a steam turbine connected to a generator that produces electricity.

LAYOUT AND SUBSYSTEMS OF NUCLEAR POWER PLANTS

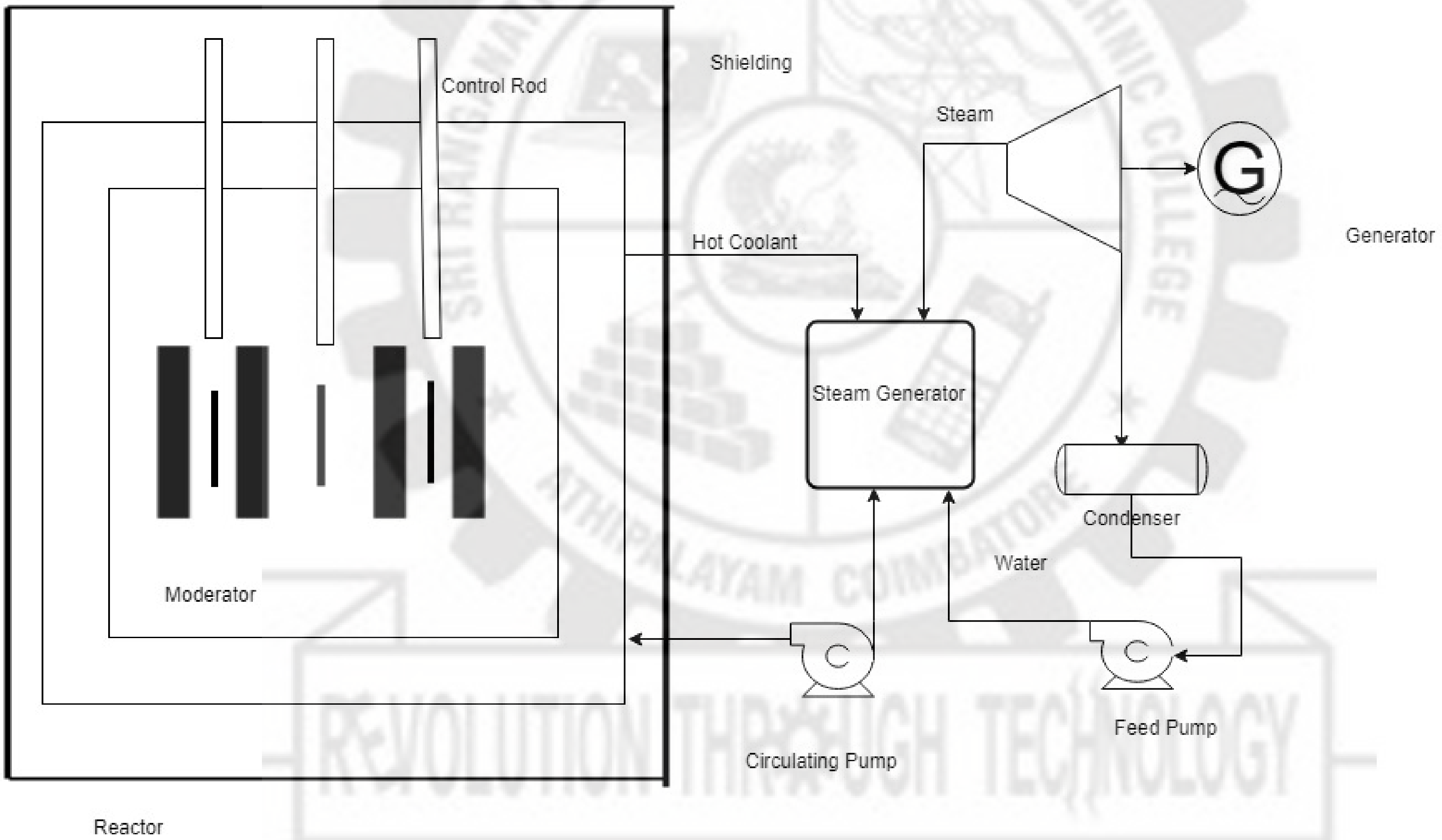


LAYOUT AND SUBSYSTEMS OF NUCLEAR POWER PLANTS

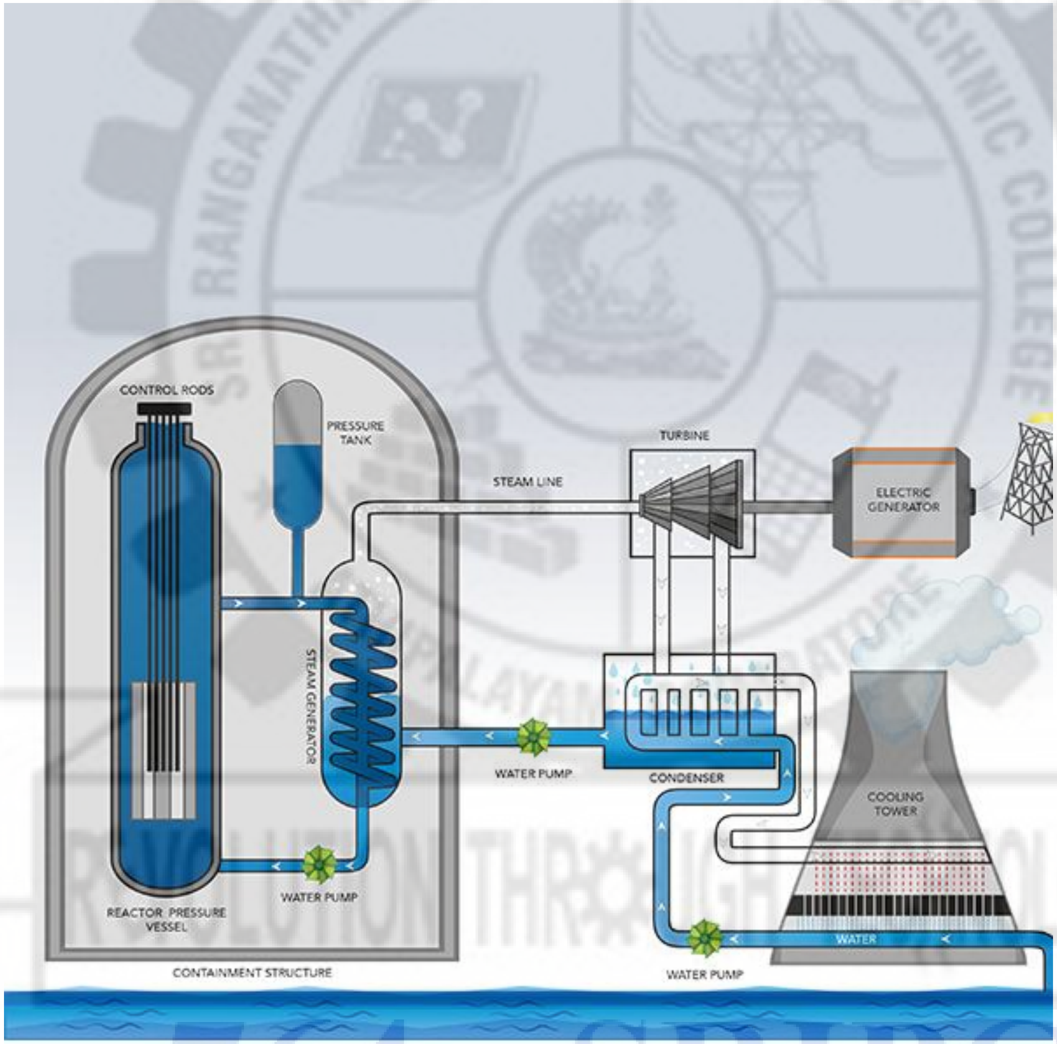
Nuclear Power

Nuclear energy originates from the splitting of uranium atoms – a process called fission. This generates heat to produce steam, which is used by a turbine generator to generate electricity. Because nuclear power plants do not burn fuel, they do not produce greenhouse gas emissions.

LAYOUT AND SUBSYSTEMS OF NUCLEAR POWER PLANTS



LAYOUT AND SUBSYSTEMS OF NUCLEAR POWER PLANTS



LAYOUT AND SUBSYSTEMS OF NUCLEAR POWER PLANTS

- **A nuclear reactor,** formerly known as an atomic pile, is a device used to initiate and control a self-sustained nuclear chain reaction. Nuclear reactors are used at nuclear power plants for electricity generation and in nuclear marine propulsion.

THANK YOU

LECTURE 3

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TOPICS TO BE COVERED

- ○ **Working and classification of various nuclear power plants**

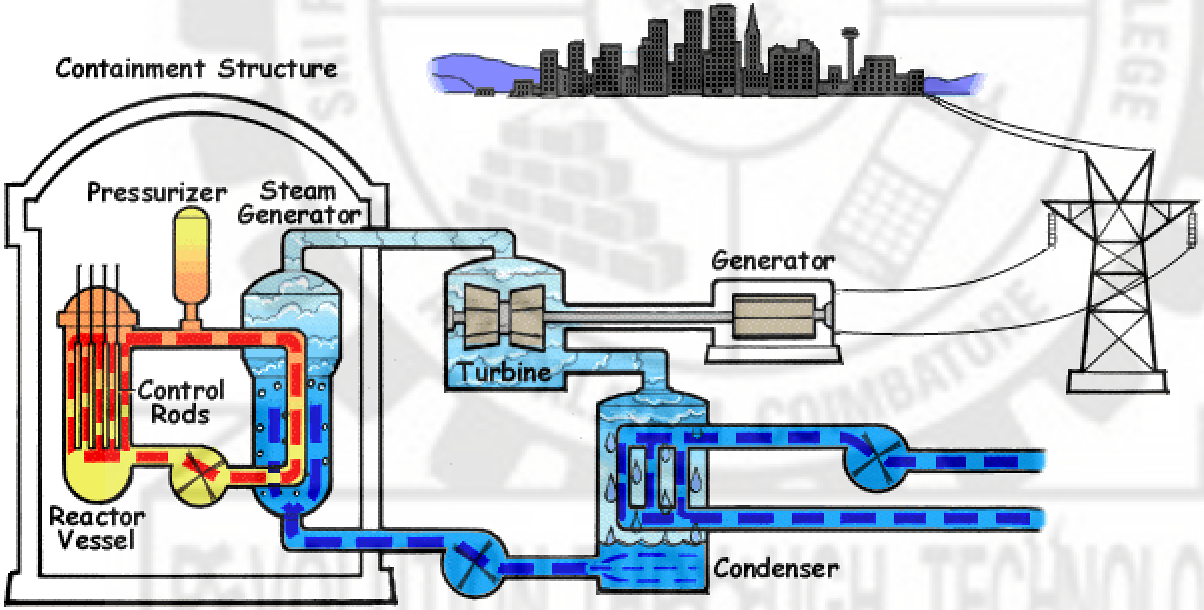
LECTURE 3

Working and classification of various nuclear power plants

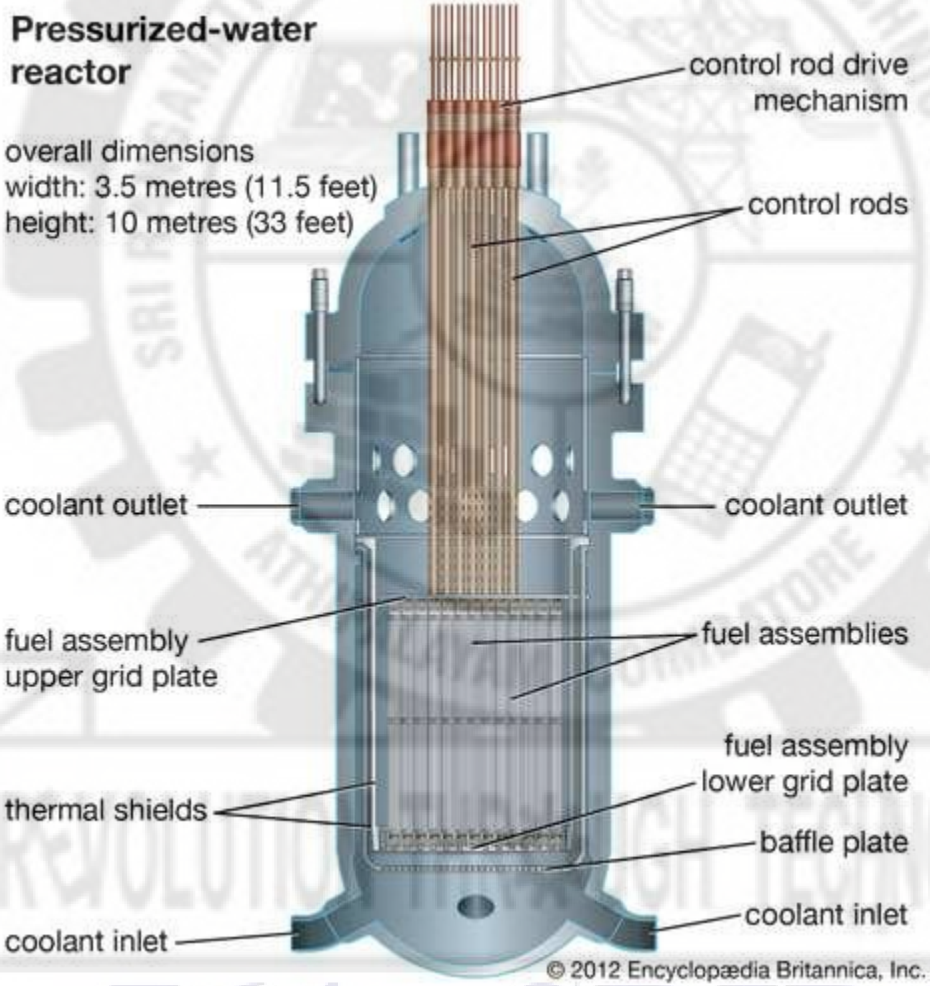
CLASSIFICATION OF VARIOUS NUCLEAR POWER PLANTS

– **Classification of Nuclear power plants**

PWR

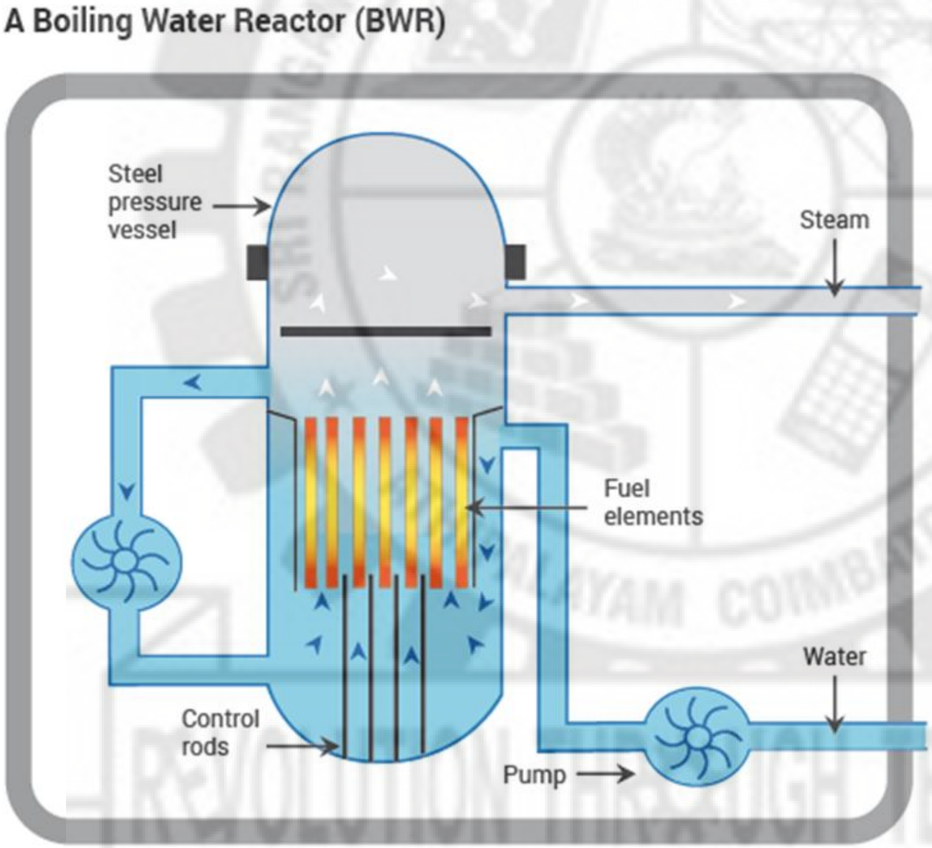


CLASSIFICATION OF VARIOUS NUCLEAR POWER PLANTS

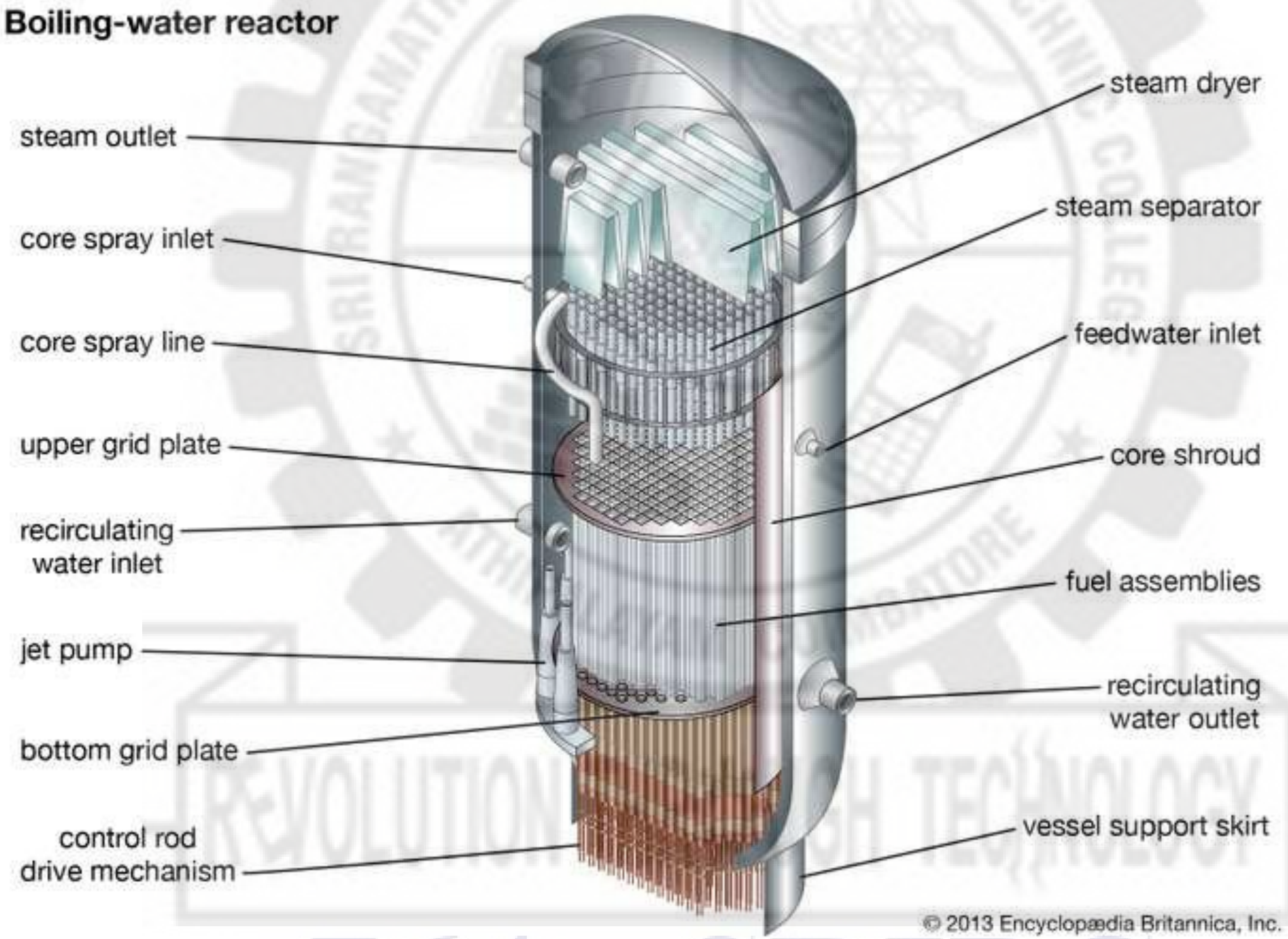


CLASSIFICATION OF VARIOUS NUCLEAR POWER PLANTS

- BWR



CLASSIFICATION OF VARIOUS NUCLEAR POWER PLANTS



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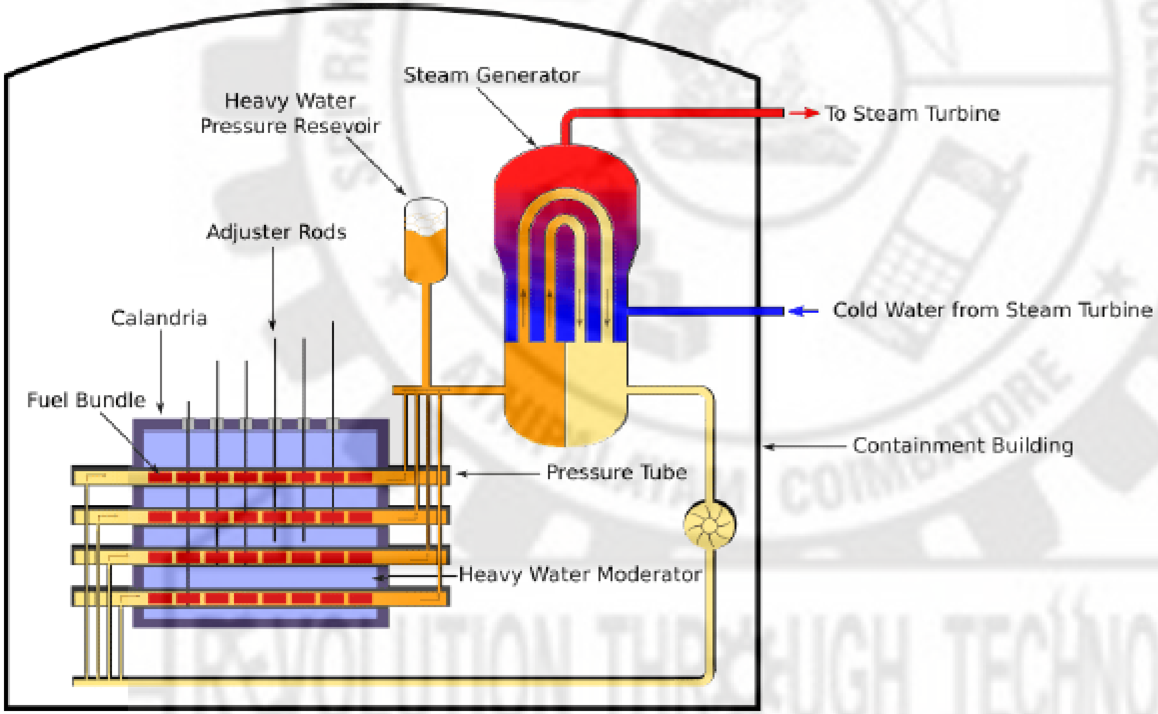
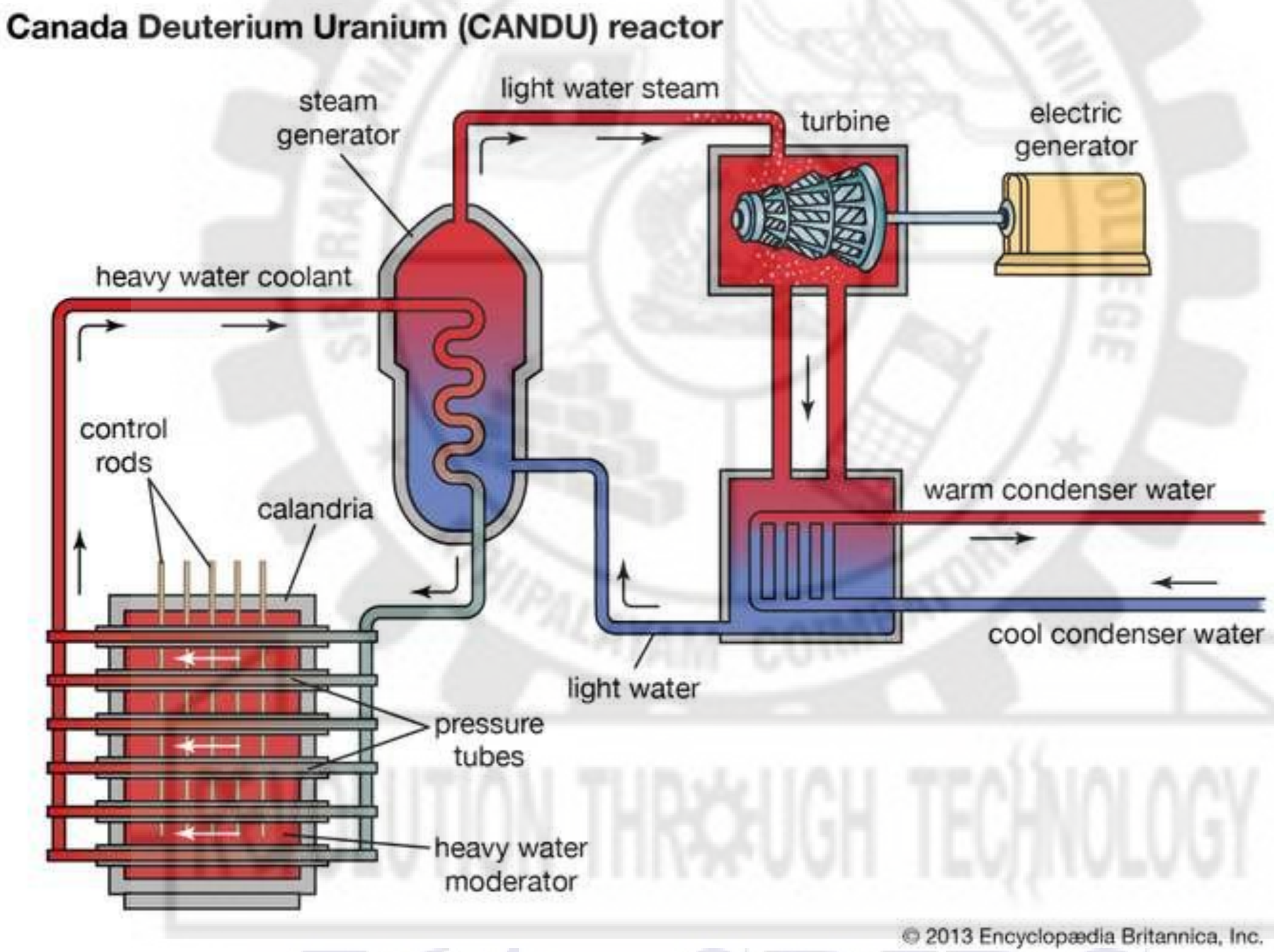
CLASSIFICATION OF VARIOUS NUCLEAR POWER PLANTS

– **CANDU Reactor**



CLASSIFICATION OF VARIOUS NUCLEAR POWER PLANTS



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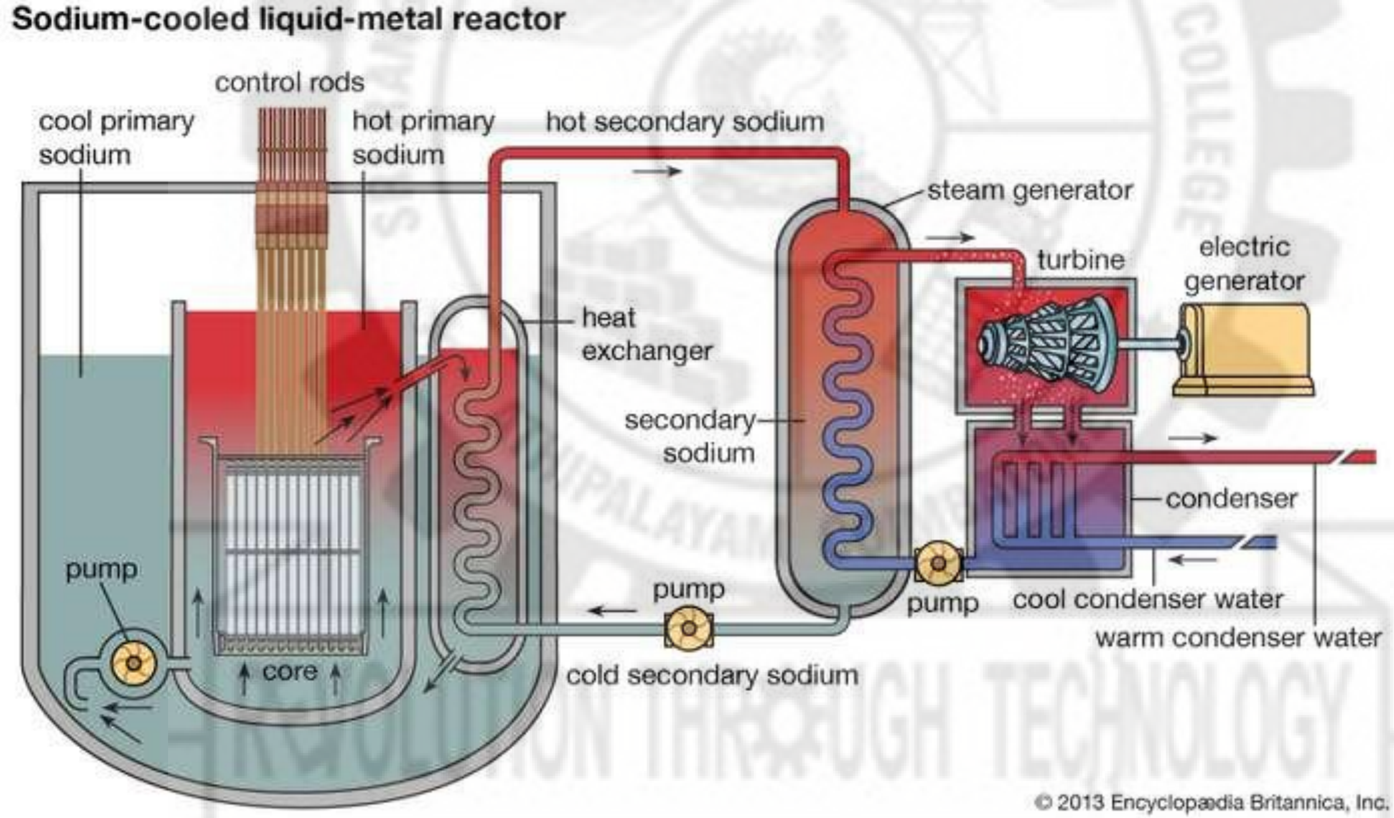
CLASSIFICATION OF VARIOUS NUCLEAR POWER PLANTS

- Liquid metal cooled reactor



Sodium-cooled liquid-metal reactor

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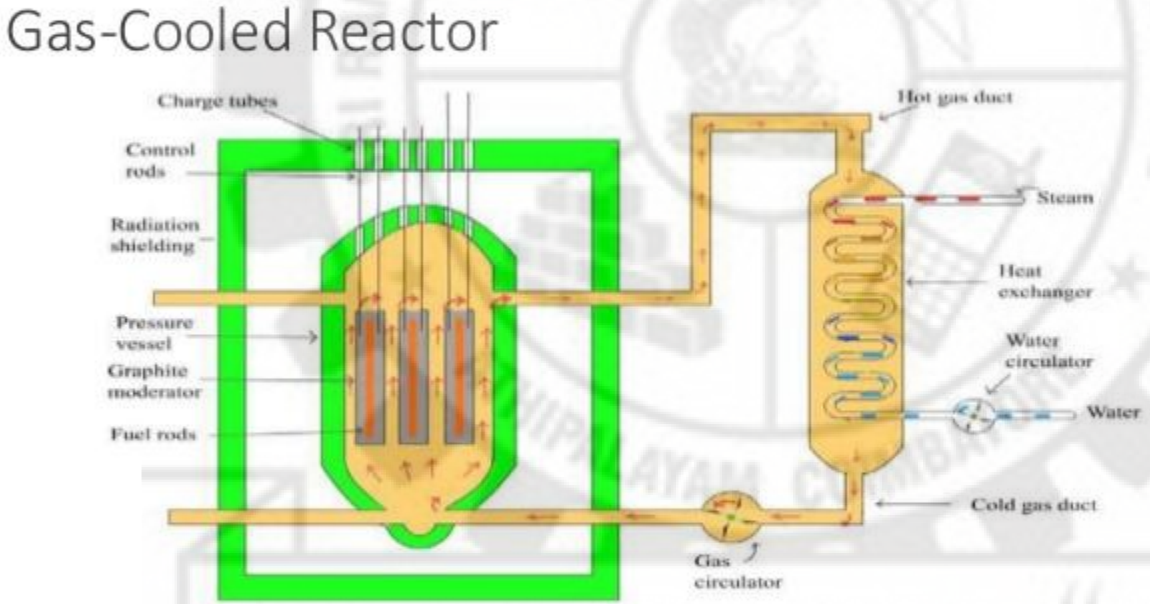
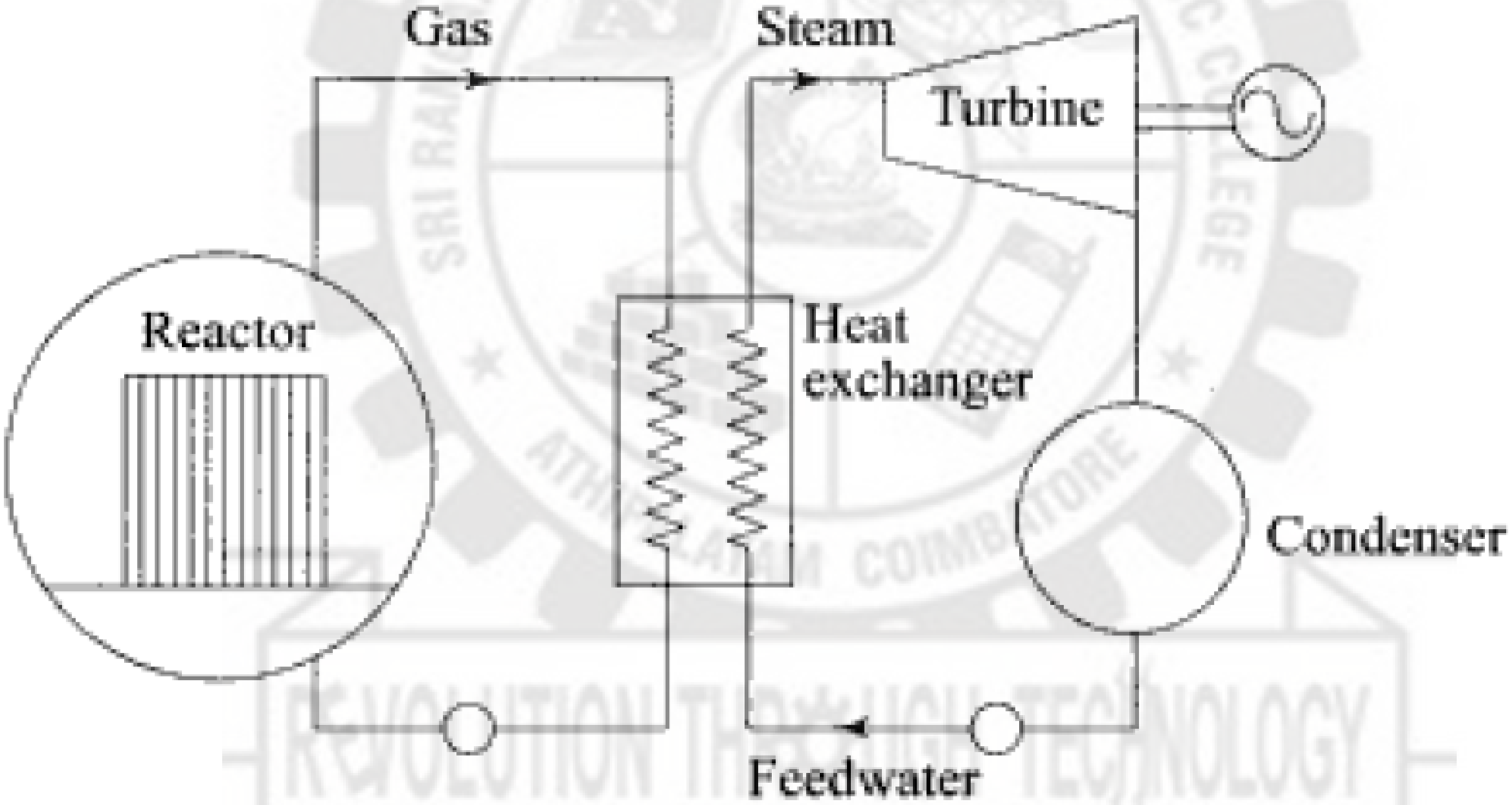
CLASSIFICATION OF VARIOUS NUCLEAR POWER PLANTS

– **Gas cooled reactor**


Gas-Cooled Reactor

CLASSIFICATION OF VARIOUS NUCLEAR POWER PLANTS



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LECTURE 4

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TOPICS TO BE COVERED

○ **Different components and applications of nuclear power plants**

LECTURE 4

Different components and applications of nuclear power plants

DIFFERENT COMPONENTS AND APPLICATIONS OF NUCLEAR POWER PLANTS

Main components of nuclear power plants:

i) **Moderators**

In any chain reaction, the neutrons produced are fast moving neutrons. These are less effective in causing fission of U235 and they try to escape from the reactor. It is thus implicit that speed of these neutrons must be reduced if their effectiveness is carrying out fission is to be increased. This is done by making these neutrons collide with lighter nuclei of other materials, which does not absorb these neutrons but simply scatter them. Each collision causes loss of energy and thus the speed of neutrons is reduced. Such a material is called a ‘Moderator’.The neutrons thus slowed down are easily captured by the fuel element at the chain reaction proceeds slowly.

DIFFERENT COMPONENTS AND APPLICATIONS OF NUCLEAR POWER PLANTS

ii) Reflectors

Some of the neutrons produced during fission will be partly absorbed by the fuel elements, moderator, coolant and other materials. The remaining neutrons will try to escape from the reactor and will be lost. Such losses are minimized by surrounding (lining) the reactor core with a material called a reflector which will reflect the neutrons back to the core. They improve the neutron economy. Economy: Graphite, Beryllium.

DIFFERENT COMPONENTS AND APPLICATIONS OF NUCLEAR POWER PLANTS

iii) Shielding

During Nuclear fission ¥, b, g particles and neutrons are also produced. They are harmful to human life. Therefore it is necessary to shield the reactor with thick layers of lead, or concrete to protect both the operating personnel as well as environment from radiation hazards.

iv) Cladding

In order to prevent the contamination of the coolant by fission products, the fuel element is covered with a protective coating. This is known as cladding. Control rods are used to control the reaction to prevent it from becoming violent. They control the reaction by absorbing neutrons. These rods are made of boron or cadmium. Whenever the reaction needs to be stopped, the rods are fully inserted and placed against their seats and when the reaction is to be started the rods are pulled out.

DIFFERENT COMPONENTS AND APPLICATIONS OF NUCLEAR POWER PLANTS

v) Coolant

The main purpose of the coolant in the reactor is to transfer the heat produced inside the reactor. The same heat carried by the coolant is used in the heat exchanger for further utilization in the power generation.

Some of the desirable properties of good coolant are listed below

1. It must not absorb the neutrons.
2. It must have high chemical and radiation stability
3. It must be non-corrosive.
4. It must have high boiling point (if liquid) and low melting point (if solid)
5. It must be non-oxidising and non-toxic.

DIFFERENT COMPONENTS AND APPLICATIONS OF NUCLEAR POWER PLANTS

The above-mentioned properties are essential to keep the reactor core in safe condition as well as for the better functioning of the content.

6. It must also have high density, low viscosity, high conductivity and high specific heat. These properties are essential for better heat transfer and low pumping power.

The water, heavy water, gas (He, CO2), a metal in liquid form (Na) and an organic liquid are used as coolants.

The coolant not only carries large amounts of heat from the core but also keeps the fuel assemblies at a safe temperature to avoid their melting and destruction.

DIFFERENT COMPONENTS AND APPLICATIONS OF NUCLEAR POWER PLANTS

vi) Nuclear reactor

A nuclear reactor may be regarded as a substitute for the boiler fire box of a steam power plant. Heat is produced in the reactor due to nuclear fission of the fuel U235 The heat liberated in the reactor is taken up by the coolant circulating through the core. Hot coolant leaves the reactor at top and flows into the steam generator (boiler).

Radiation hazards and Shielding

The reactor is a source of intense radioactivity. These radiations are very harmful to human life. It requires strong control to ensure that this radioactivity is not released into the atmosphere to avoid atmospheric pollution. A thick concrete shielding and a pressure vessel are provided to prevent the escape of these radiations to atmosphere

DIFFERENT COMPONENTS AND APPLICATIONS OF NUCLEAR POWER PLANTS

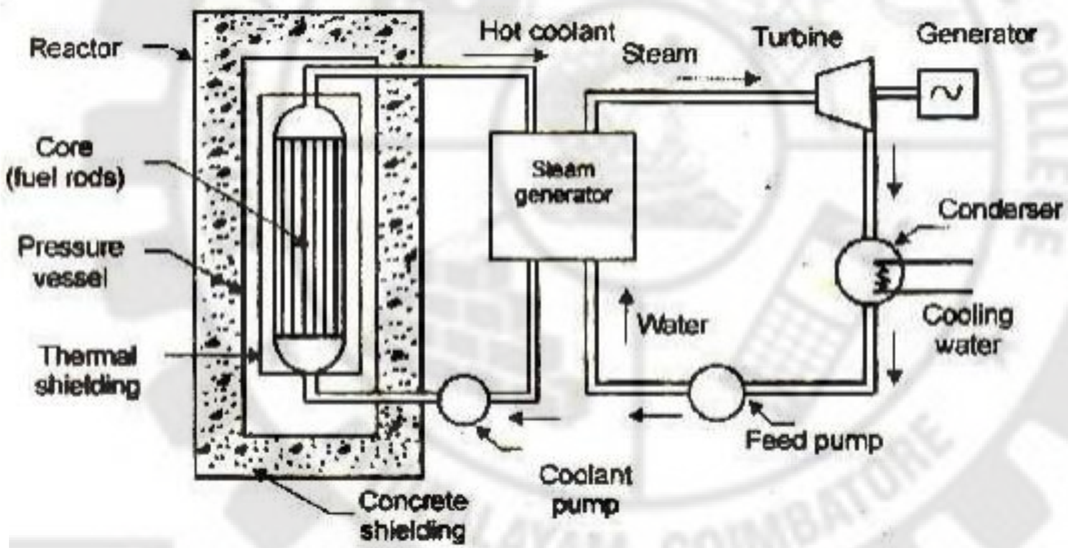

Figure : Nuclear Power Plant (PWR)

DIFFERENT COMPONENTS AND APPLICATIONS OF NUCLEAR POWER PLANTS

vii) Steam generator

The steam generator is fed with feed water which is converted into steam by the heat of the hot coolant. The purpose of the coolant is to transfer the heat generated in the reactor core and use it for steam generation. Ordinary water or heavy water is a common coolant.

viii) Turbine

The steam produced in the steam generator is passed to the turbine and work is done by the expansion of steam in the turbine.

ix) Coolant pump and Feed pump

The steam from the turbine flows to the condenser where cooling water is circulated. Coolant pump and feed pump are provided to maintain the flow of coolant and feed water respectively.

DIFFERENT COMPONENTS AND APPLICATIONS OF NUCLEAR POWER PLANTS

Advantages of nuclear power plant

1. It can be easily adopted where water and coal resources are not available.

2. The nuclear power plant requires very small quantity of fuel. Hence fuel transportation cost is less.

3. Space requirement is less compared to other power plants of equal capacity.

4. It is not affected by adverse weather conditions.

5. Fuel storage facilities are not needed as in the case of the thermal power plant.

6. Nuclear power plants will converse the fossils fuels (coal, petroleum) for other energy needs.

7. Number of workmen required at nuclear plant is far less than thermal plant.

8. It does not require large quantity of water.

DIFFERENT COMPONENTS AND APPLICATIONS OF NUCLEAR POWER PLANTS

Disadvantages

1. Radioactive wastes, if not disposed of carefully, have adverse effect on the health of workmen and the population surrounding the plant.

2. It is not suitable for varying load condition.

3. It requires well-trained personnel.

4. It requires high initial cost compared to hydro or thermal power plants.

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LECTURE 5

TOPICS TO BE COVERED

- Safety measures for nuclear power plants

LECTURE 5

Safety measures for nuclear power plants

SAFETY MEASURES FOR NUCLEAR POWER PLANTS

- The biggest concern associated with a nuclear power accident is the negative effects that exposure to radiation can have on the human body. It is interesting to note that we are exposed to radiation naturally just by living our lives. Natural background radiation comes from outer space, and even radiates up from the ground below us. You may also have been exposed to a medical procedure, such as a CT scan, X-ray or nuclear medicine, such as an MRI, that utilized different types of radiation to diagnose problems or treat a disease.

SAFETY MEASURES FOR NUCLEAR POWER PLANTS

The design considerations that have a bearing on radiation protection in NPPs include:

- Proper design, plant layout and adequate shielding:
- Limits of air contamination levels in different zones of the plant:
- Source control by proper selection of materials/components:
- Design limit for collective dose:

Health Concerns

- The biggest concern associated with a nuclear power accident is the negative effects that exposure to radiation can have on the human body. ... However, if a person were exposed to significant amounts of radiation over a period of time, this exposure could damage body cells and lead to cancer.

SAFETY MEASURES FOR NUCLEAR POWER PLANTS

- If a person were to be exposed to an acute dose of high-levels of radiation, the result would be radiation sickness. Radiation sickness is defined as illness caused by exposure to a large dose of radiation over a short period of time. Symptoms may include skin burns, nausea, vomiting, diarrhea, hair loss, general weakness and possibly death.
- In addition to personal health concerns, there are also environmental health concerns associated with nuclear power generation. Nuclear power plants use water from local lakes and rivers for cooling. Local water sources are used to dissipate this heat, and the excess water used to cool the reactor is often released back into the waterway at very hot temperatures. This water can also be polluted with salts and heavy metals, and these high temperatures, along with water pollutants, can disrupt the life of fish and plants within the waterway.

SAFETY MEASURES FOR NUCLEAR POWER PLANTS

- PDF attachement

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