

University of Anbar

College of Engineering

Mechanical Eng. Department



Power Plants

Chapter one

Steam Power Plant

by

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Power Plants

A Power Plant may be defined as a machine or assembly of equipment that generates and delivers a flow of mechanical or electrical energy.

Classification of Power Plants

1. Conventional Power Plants

- Steam Turbine Power Plant
- Gas Turbine Power Plant
- Diesel Power Plant
- Nuclear Power Plant

2. Non-conventional Power Plants

- Wind Energy Power System
- Solar Thermal Power Plant
- Ocean Thermal Energy Conversion
- Biomass Energy Power System
- Geothermal Energy

Energy sources

1. Renewable energy sources

- Solar energy
- Wind energy

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- Tidal energy
- Flowing of stream of water

2. Non-renewable energy Sources

- Coal
- Petroleum
- Natural gas
- Nuclear power

Fuels

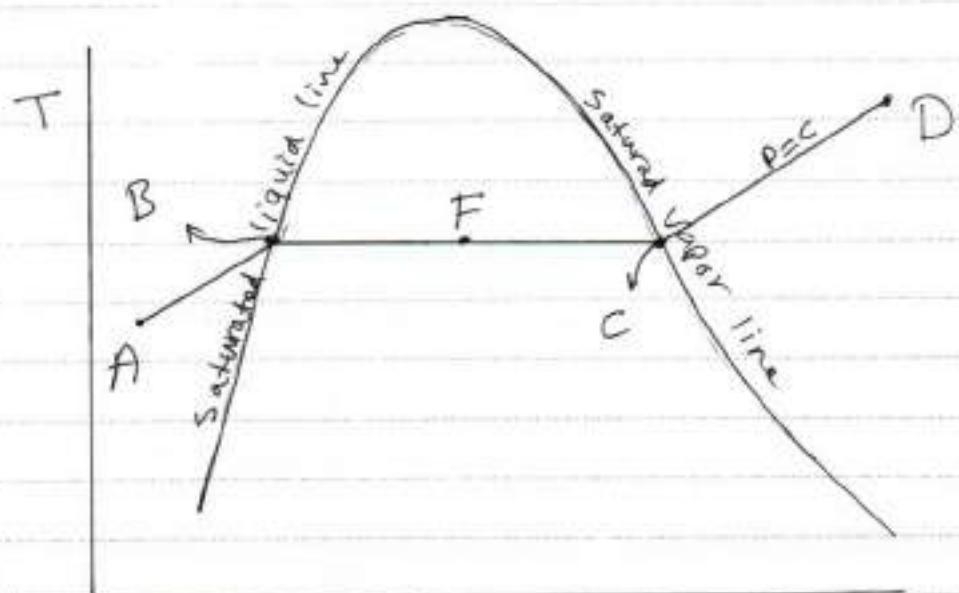
It is defined as any material which when burn will produce heat. Various fuels commonly used are as follows:-

- Solid fuels (Wood, lignite, coal)
- Liquid fuels (Petroleum)
- Gaseous fuels (Natural gas)

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Definitions ↗

- Subcooled water (A) ↗ It refers to water existing below its normal saturation temp.
- Saturated liquid (B) ↗ a liquid that exists at the saturation temperature or boiling point that corresponds to the existing pressure. If any energy is added to the liquid and the pressure remain constant, some of the liquid would boil. During boiling, temp. will remain constant.



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- Saturated Vapor (C) ~

A vapor that exists at the saturation temperature that corresponding to the existing pressure. If any energy was removed while the pressure is constant, some the vapour would condense and the temp. remains constant.

- Superheated Steam (D) ~

Steam existing at a temp. above the saturation temperature that corresponding to the existing pressure. The removal of a small amount of energy will not cause the vapor to condense, its temperature will just decrease.

- Wet Steam (F) ~

It is a mixture of ~~water~~^{liquid} and vapor. If additional heat is added to the wet steam at constant pressure, the temperature remains constant until all liquid is evaporated (saturated steam)

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- Dryness Fraction or

It is a ratio of vapor mass to the total mass.

$$x = \frac{m_v}{m_v + m_L}$$

Where m_v : vapor mass
 m_L : liquid mass

- Moisture Content:-

It is the ratio of liquid mass to the total mass

$$y = \frac{m_L}{m_L + m_v}$$

$$\therefore x + y = 1$$

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h_f : Enthalpy of Water (KJ/Kg.°C)

h_g : Enthalpy of dry steam (KJ/Kg.°C)

h_x : Enthalpy of wet steam (KJ/Kg.°C)

$$h_x = h_f + x h_{fg}$$

Where $h_{fg} = h_g - h_f$

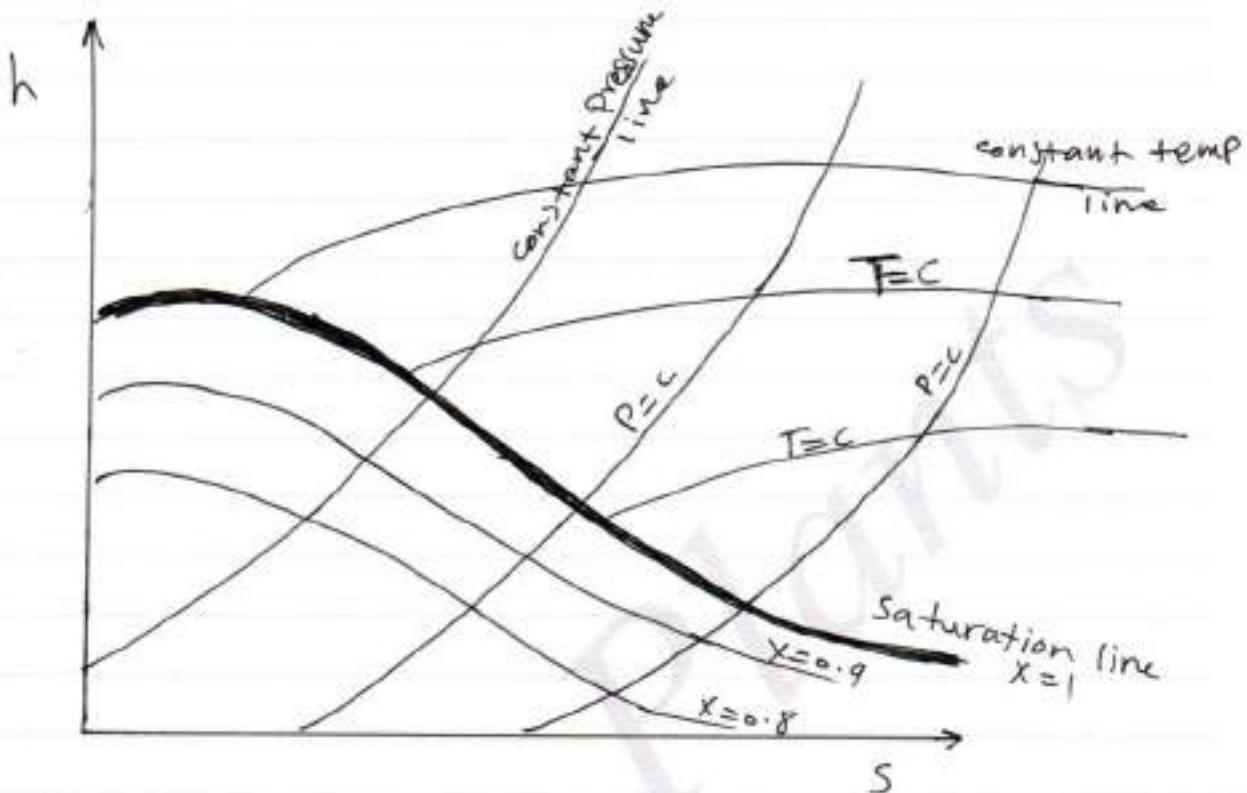
So, $x = \frac{h_x - h_f}{h_g}$

* h-S diagram (Mollier Chart)

The Mollier Chart is a chart on which enthalpy (h) versus entropy (s) is plotted. The chart contains a series of constant temperature lines, a series of constant pressure, a series of constant quality lines.

The Mollier chart is used when quality (x) is greater than 50% and for ~~saturated~~ superheated steam

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Ex/ Find the enthalpy drop when steam expand from 5 bar, 300 °C to 0.1 bar Using Mollier chart

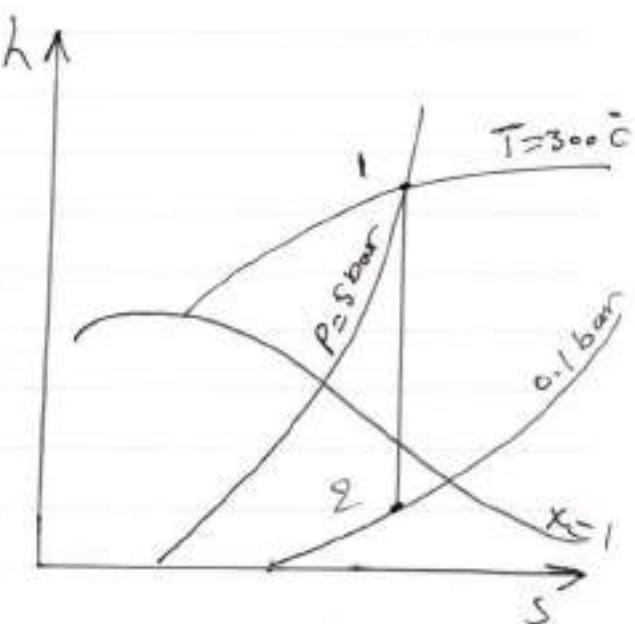
$$h_1 = 3070 \text{ kJ/kg}$$

$$h_2 = 2370 \text{ kJ/kg}$$

$$\Delta h = h_1 - h_2$$

$$= 3070 - 2370$$

$$= 700 \text{ kJ/kg}$$



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Steam Power Plant Cycles

Steam is most common Working fluid used in Vapor power plant cycles because of its many desirable characteristics such as :-

- low cost
- availability
- high enthalpy of vaporization

Steam power plant are commonly referred to as coal plant, nuclear plant, or natural gas plant depending on type of fuel used to apply heat to the steam.

- Vapor Power Cycles Classifications :-

- Carnot Vapour Power Plant
- Rankine Cycle
- Reheat Cycle
- Regenerative Cycle

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- Performance Parameters:

- Thermal efficiency.

Thermal efficiency is the parameter which gauges the extent to which the energy input to the device is converted to net work output from it.

$$\text{Thermal efficiency } \eta = \frac{\text{Net Work in cycle}}{\text{Heat added in cycle}}$$

- Work ratio

It refers to the ratio of net work to the positive work.

$$\text{Work ratio} = \frac{W_{\text{net}}}{W_{\text{turbine}}}$$

- Specific Steam Consumption (SSC):

It indicates the steam requirement per unit power output, and it is given in kg/kW.h

$$SSC = \frac{3600}{W_{\text{net}}} , \text{kg / kW.h}$$

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* Carnot Vapour Power Cycle

Carnot cycle can be defined as an ideal cycle having highest thermodynamic efficiency.

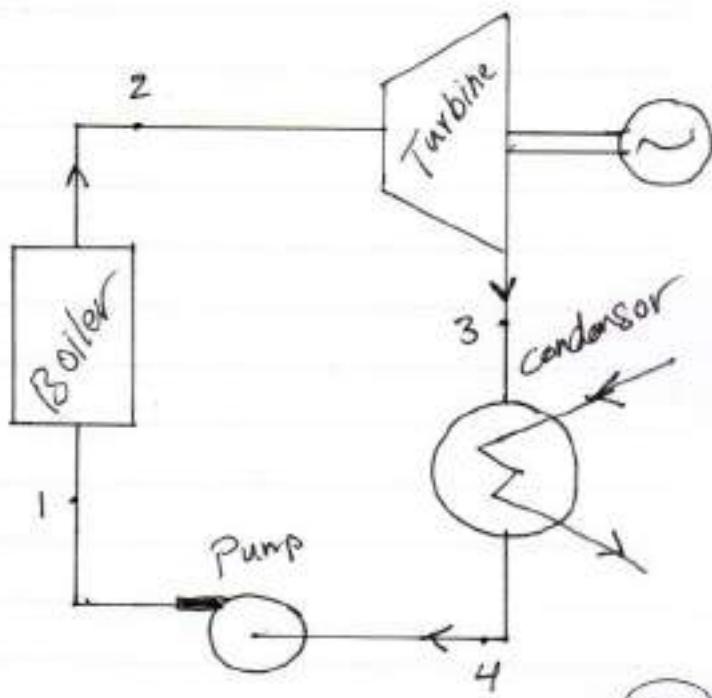
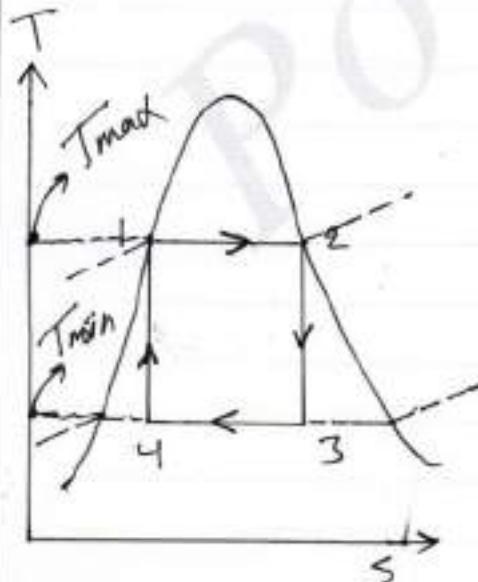
Arrangement proposed for using Carnot Vapour Power cycle is as follows :-

1-2 = Reversible isothermal heat addition in the boiler

2-3 = Reversible adiabatic expansion in steam turbine

3-4 = Reversible isothermal heat rejection in the condenser.

4-1 = Reversible adiabatic compression or pumping in feed water pump.



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Assuming steady-state flow processes in the cycle and neglecting changes in kinetic and potential energy:

$$\text{Thermal efficiency} = \frac{\text{Net work}}{\text{Head added}}$$

$$\begin{aligned}\text{Net work} &= \text{Turbine work} - \text{Pumping work} \\ &= (h_2 - h_3) - (h_1 - h_4)\end{aligned}$$

$$\text{Head added} = h_2 - h_1$$

$$\begin{aligned}\eta_{\text{Carnot}} &= \frac{(h_2 - h_3) - (h_1 - h_4)}{(h_2 - h_1)} \\ &= 1 - \frac{h_3 - h_4}{h_2 - h_1}\end{aligned}$$

$$Q_{\text{Rejected}} = h_3 - h_4$$

$$\eta_{\text{Carnot}} = 1 - \frac{Q_{\text{Rejected}}}{Q_{\text{Added}}}$$

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Also, heat added and rejected may be given as function of temp. and entropy as follows -

$$Q_{\text{add}} = T_1 \times (S_2 - S_1)$$

$$Q_{\text{rej}} = T_3 \times (S_3 - S_4)$$

$$S_1 = S_4, \quad S_2 = S_3$$

Therefore, Substituting values,

$$\eta_{\text{Carnot}} = 1 - \frac{T_3}{T_1}$$

$$T_1 = T_2, \quad T_3 = T_4$$

* Limitations of Carnot cycle

Although Carnot cycle is simple thermodynamically and has the highest thermal efficiency, it is difficult to operate in practice because of the following reasons -

1. It is difficult to compress a wet vapour isentropically to the saturated state as required by the process 4-1

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2. It is difficult to control the quality of the condensate coming out of the condenser, so that the state (4) is hard to obtain.
3. It is difficult for a pump to handle wet mixture ~~steam~~ which undergoes simultaneous change in its phase as its pressure increases.

Ex / In a steam power plant, the steam supply is at 15 bar and dry saturated. The condenser pressure is 0.4 bar. Calculate the Carnot efficiency

Solutions~

From Steam table:

$$\text{At } 15 \text{ bar: } t_s = 198.3^\circ\text{C} = T_1 = T_2, T_1 = 198.3 + 273 = 471.3 \text{ K}$$

$$\text{At } 0.4 \text{ bar: } t_s = 75.9^\circ\text{C} = T_3 = T_4, T_3 = 75.9 + 273 = 348.9 \text{ K}$$

$$\eta_{\text{Carnot}} = 1 - \frac{T_{\min}}{T_{\max}}$$
$$= 1 - \frac{348.9}{471.3} = 25.9\%$$

