UNIT-1 STEAM POWER PLANT

Cycle

A cycle is a series of two or more processes in which the final state is the same as the initial state.

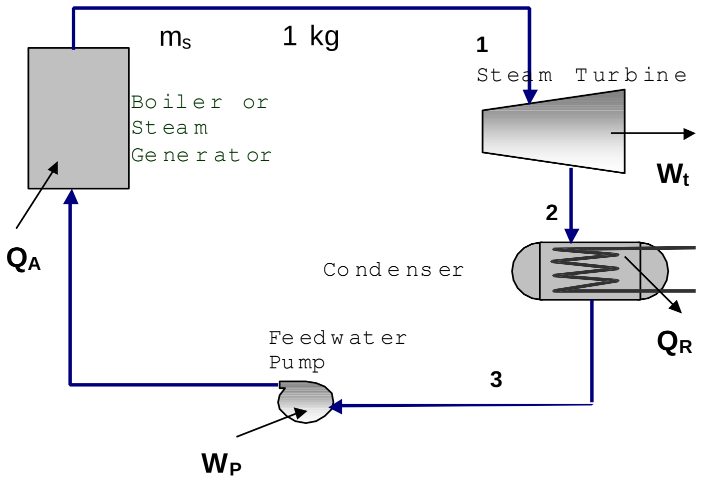
Steam Power Cycle: A power generating cycle that uses steam or water vapor as the working substance. This cycle differ with an internal combustion engine cycle because the combustion occurs in the boiler, unlike that of an IC engine that combustion occurs inside the working cylinders.

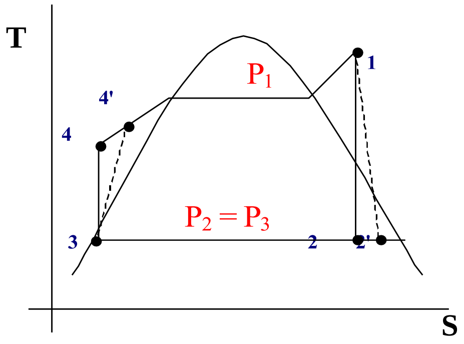
Steam Power Plant Cycle

Rankine Cycle

Components:
  a. Steam Turbine
  b. Condenser
  c. Pump
  d. Steam Generator or boiler

Processes:
  1 to 2 – Isentropic Expansion (S = C)
  2 to 3 – constant pressure Heat Rejection (P = C)
  3 to 4 – Isentropic pumping (S = C)
  4 to 1 – Constant pressure Heat Addition (P = C)





A. Turbine Work (W_t) (considering S = C; Q = 0; $\Delta KE = 0$; $\Delta PE = 0$)

$$\mathbf{W_t = m_s(h_1 - h_2)}\ \text{KW}$$

Where:

m_s – steam flow rate, kg/sec
h – enthalpy, KJ/kg
W_t – turbine power, KW

B. Heat Rejected in the Condenser (Q_R)

$$\mathbf{Q_R = m(h_2 - h_3)\ \ KW}$$

C. Pump Work (W_P)

$$\mathbf{WP = m(h_4 - h_3)}$$

D. Heat added to Boiler (Q_A)

$$\mathbf{Q_A = m(h_1 - h_4)\ KW}$$

E. Thermal efficiency

$$e = \frac{W}{\text{Heat Added}} \times 100\%$$

$$e = \frac{W}{Q_A} \times 100\%$$

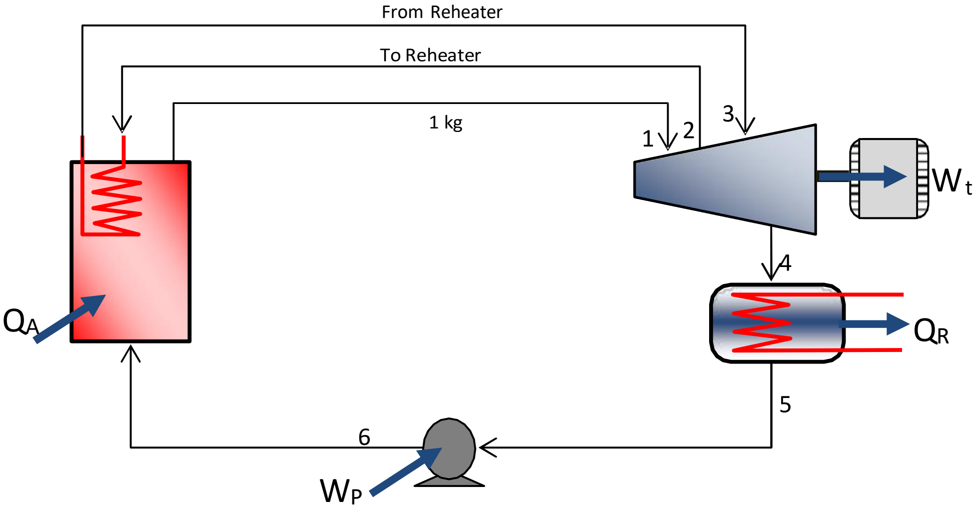
F. Net Work

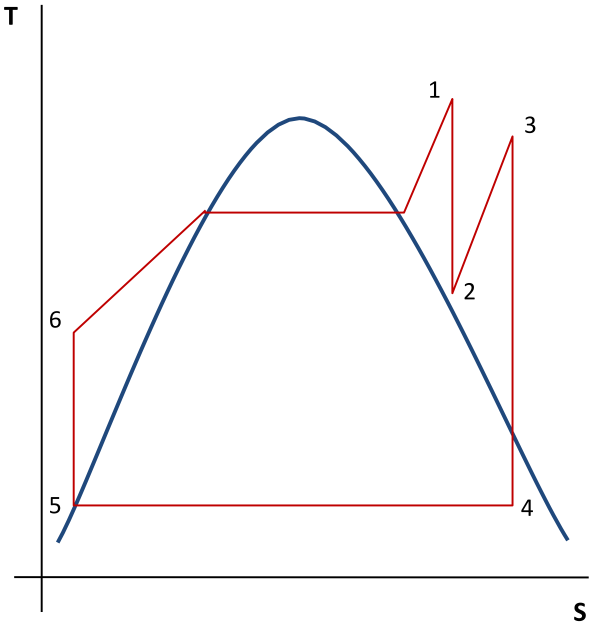
$$\mathbf{W = W_t - W_p}$$

G. Boiler Efficiency (E_B)

$$e_B = \frac{Q_A}{Q_S} \times 100\%$$

Reheat Cycle Steam Power Plant: In a reheat cycle, after partial expansion of steam in the turbine the steam re-enters a section in the steam generator called the re-heater and re-heating the steam almost the same to initial temperature and then re-expands again to the turbine. This will result to an increase in thermal efficiency of the cycle, with significant increase in turbine work and heat added.





Turbine Work

$$W_t = m_s\left[(h_1 - h_2) + (h_3 - h_4\right] \quad KW$$

Heat Rejected

$$Q_R = m_s(h_4 - h_5) \quad KW$$

Pump Work

$$W_P = m_s(h_6 - h_5) \quad KW$$

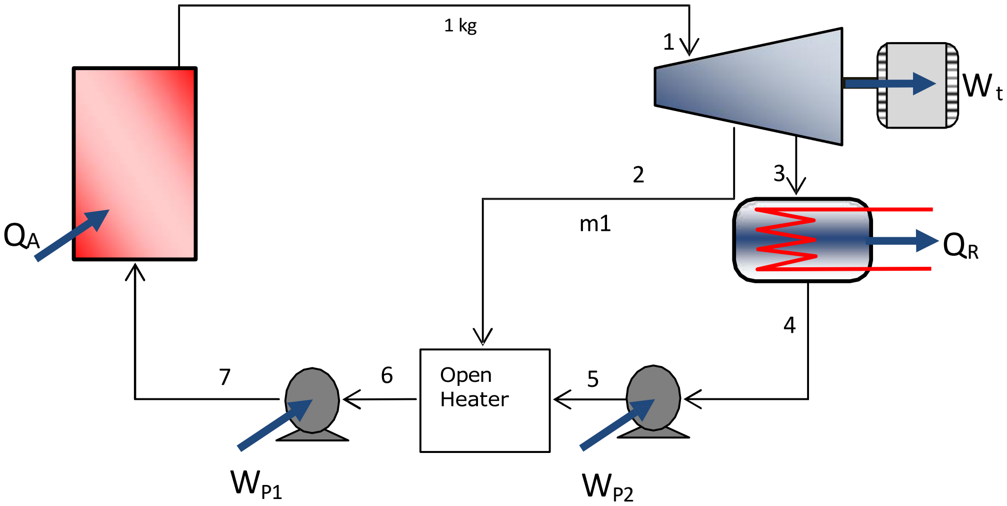
Heat Added

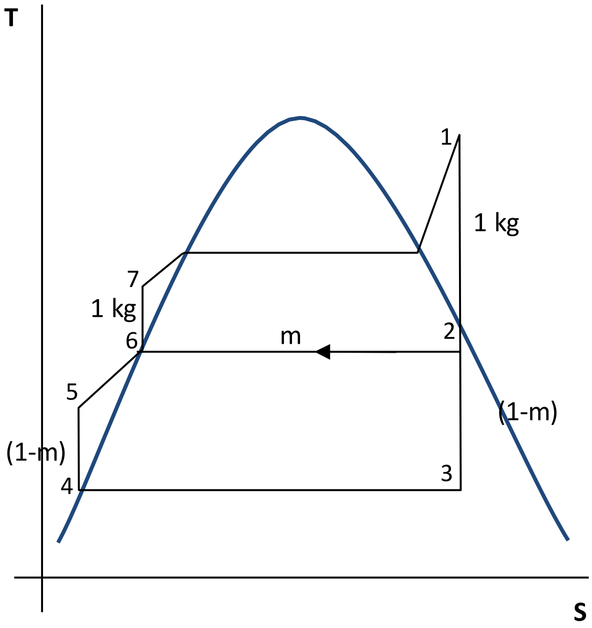
$$Q_A = m_s\left[h_1 - h_6) + (h_3 - h_2)\right] \quad KW$$

Where:

ms – mass flow rate of steam, kg/sec

Regenerative Cycle: In a regenerative cycle some of the steam after initial expansion is extracted for feed-water heating by mixing the bled steam with the condensate or drains from other heater. The remaining steam re-expands again in the turbine. The thermal efficiency also increases due to the decrease in heat added to boiler.





Let: m – fraction of steam extracted for feed-water heating, kg/kg
Turbine Work

$$W_t = m_s\left[(h_1 - h_2) + (1-m)(h_2 - h_3)\right] KW$$

Heat Rejected

$$Q_R = m_s\left[(1-m)(h_3 - h_4)\right] KW$$

Pump Work

a. Condensate pump (W_{P1})
b. Feed-water pump W_{P2})

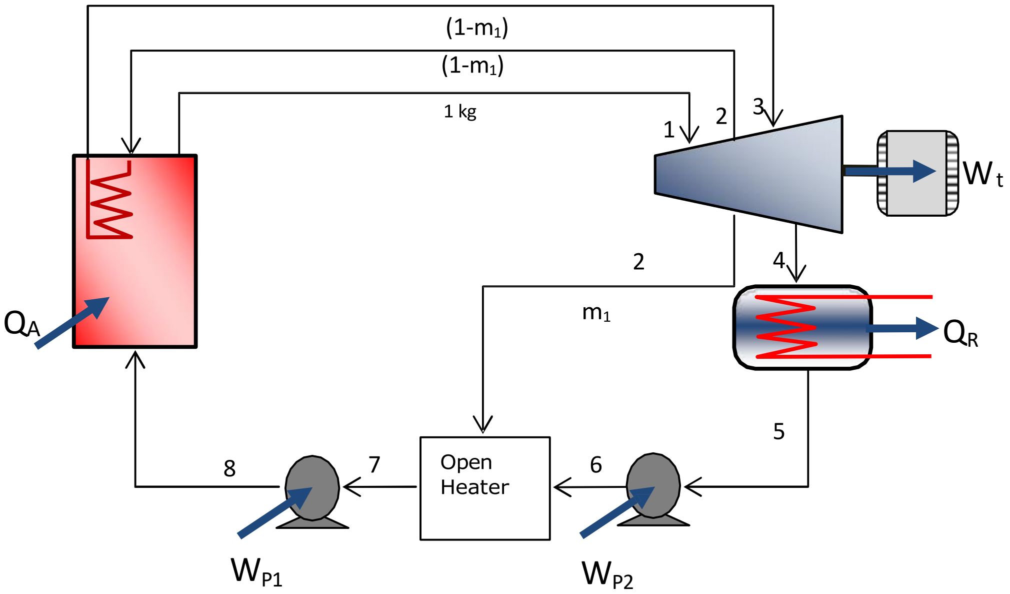
$$W_P = W_{P1} + W_{P2}$$
$$W_{P1} = m_s(1-m)(h_5 - h_4)\ \ KW$$
$$W_{P2} = m_s((h_7 - h_6)\ \ KW$$

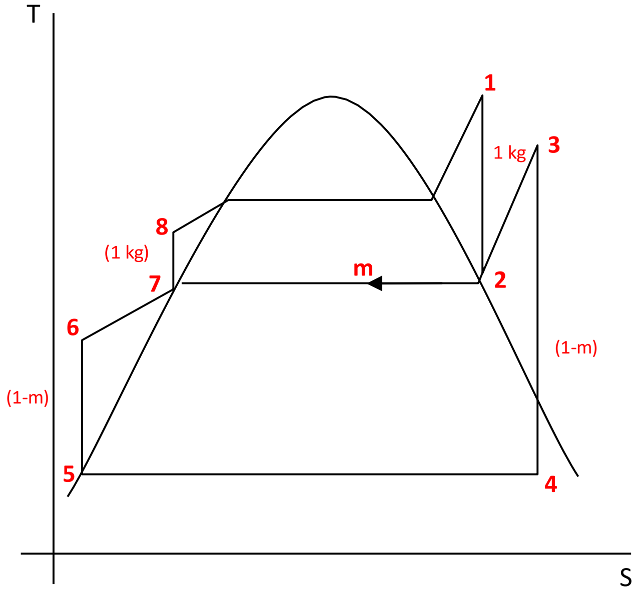
Heat Added

$$Q_A = m_s\left[(h_1 - h_7)\right] KW$$

Reheat – Regenerative Cycle: In a reheat – regenerative cycle further increase in thermal efficiency will occur because of the combine effects of reheating and regenerative feed-water heating. Significantly heat added decreases, total pump work decreases while turbine work increases.

Single stage reheat and single stage regenerative cycle that uses an open type feedwater heater





Turbine Work

$$W_t = m_s\left[(h_1 - h_2) + (1-m)(h_3 - h_4)\right] KW$$

Heat Rejected

$$Q_R = m_s\left[(1-m)(h_4 - h_5)\right] KW$$

Pump Work

$$W_{P1} = m_s\left[(1-m)(h_6 - h_5)\right] KW$$

$$W_{P2} = m_s\left[(h_8 \text{-} h_7)\right]\ KW$$

$$W_P = W_{P1} + W_{P2}$$

Heat Added

$$Q_A = m_s\left[(h_1 - h_8) + (1-m)(h_3 - h_2)\right] KW$$

STEAM RATE

$$SR = \frac{\text{Steam Flow Rate}}{\text{KW Produced}}\ \frac{kg}{KW\text{-}hr}$$

when SR is based on the turbine power

$$SR = \frac{3600 m_s}{W_t}\ \frac{kg}{KW\text{-}hr}$$

where :

m_s steam flow rate in kg/sec

W_t turbine work in KW

HEAT RATE

$$HR = \frac{\text{Heat Supplied}}{\text{KW Produced}}\ \frac{KJ}{KW\text{-}hr}$$

when HR is based on the turbine power

$$HR = \frac{3600 Q_A}{W_t}\ \frac{KJ}{KW\text{-}hr}$$

where:

Q_A Heat added in KW

W_t turbine work in KW

Turbine Efficiency

$$\eta_t = \frac{\text{Actual Turbine Work}}{\text{Ideal Turbine Work}} \times 100\%$$

$$\eta t = \frac{W_{t'}}{W_t} \times 100\%$$

Pump Efficiency

$$\eta_P = \frac{\text{Ideal Pump Work}}{\text{Actual Pump Work}} \times 100\%$$

$$\eta_P = \frac{W_P}{W_{P'}} \times 100\%$$

Boiler or Steam Generator Efficiency

$$e_B = \frac{\text{Heat Absorbed by Boiler}}{\text{Actual Heat supplied to Boiler}} \times 100\%$$

$$e_B = \frac{Q_A}{Q_s} \times 100\%$$

EXAMPLE

A coal fired steam power plant operates on the Rankine Cycle. The steam enters the turbine at 7000 KPa and 550°C with a velocity of 30 m/sec. It discharges to the condenser at 20 KPa with a velocity of 90 m/sec. For a mass flow rate of steam of 37.8 kg/sec, Determine

a. The ideal turbine work in KW
b. The net power produced in KW
c. The thermal efficiency of the cycle
d. The cooling water required in the condenser if cooling water enters at 20°C and leaves at 35°C
e. The coal consumption in kg/hr if the boiler efficiency is 82% and heating value of coal is 32,000 KJ/kg

From Steam Table

$h_1 = 3529.8$; $S_1 = 6.9465$
$h_2 = 2288.3$; $x_2 = 86.4\%$
$h_3 = 251.33$; $S_3 = 0.8321$
$h_4 = 258.43$

Solution:

a. $W = Q - \Delta h - \Delta KE - \Delta PE$
$Q = 0$; $\Delta PE = 0$
$Wt = (h_1 - h_2) - \Delta KE$
$Wt = 46{,}792.6$ KW

b. $Wp = 268.38$ KW
$W = 46{,}524.2$ KW

c. $Q_A = 123{,}657.8$ KW
$e = 37.62\%$

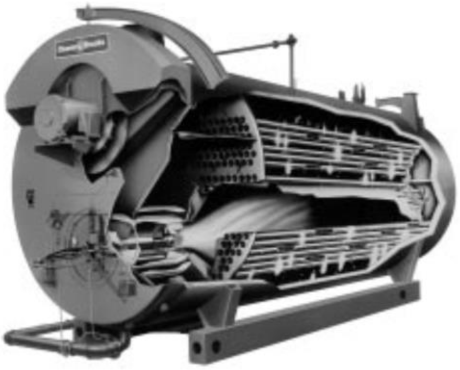
d. $Q_R = 76{,}997.5$ KW
$MW = 1225.99$ kg/sec

e. $m_f = 16{,}965.25$ KG/hr

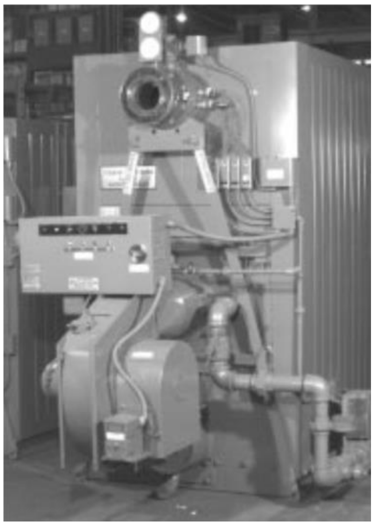
GENERAL BOILER DESCRIPTION

1. Fire-Tube boiler: Hot gas is inside the tubes while water on the outside.
2. Water-Tube boiler: Water is inside the tube while hot gas is on the outside.

The **fire-tube** boiler design uses tubes to direct the hot gases from the combustion process through the boiler to a safe point of discharge. The tubes are submerged in the boiler water and transfer the heat from the hot gases into the water.
Inside a firetube boiler the hot gases travel down the furnace during the combustion process, (first pass). The rear head seals the gasses in the lower portion of the head. The gas is redirected through the second pass tubes. In the front head the hot gasses are sealed from escaping out the stack and turned and redirected through the third pass tubes. The hot gas travels toward the upper portion of the rear head where it's turned and directed through the fourth pass tubes. From there, after giving up most of the energy from the combustion process, the gas is directed into the stack and vented to the atmosphere.



The **water-tube** boiler design uses tubes to direct the boiler water through the hot gases from the combustion process, allowing the hot gases to transfer its heat through the tube wall into the water. The boiler water flows by convection from the lower drum to the upper drum.
Either of the fire-tube or water-tube boiler design concepts is available in what is popularly known as the packaged boiler, a concept introduced by Cleaver- Brooks in 1931. A packaged boiler is shipped from the manufacturer as a complete assembly, with burner, control systems, operating and safetycontrols, all piped and/or wired into the assembly. Equipment of this type needs only to be positioned into its intended location, utility connections made and a means provided to direct the flue gases to a safe point of discharge. Most packaged firetube boilers are available in capacities of 500,000 Btu/hr up to 26,800,000 Btu/hr output. These boilers are normally rated on the basis of boiler horsepower (BHP) output. One boiler horsepower = 33,472 Btu per hour.
Packaged water-tube boilers, designed for commercial applications, are normally available in sizes as small as 1,200,000 Btu/hr output. Industrial watertube boilers can be provided in packaged format in capacities of up to 134,000,000 Btu/hr.



Boiler Auxiliaries and Accessories

Superheater – a heat exchanger that is used to increase the temperature of the water vapor greater than the saturation temperature corresponding the boiler pressure.

Evaporator – a heat exchanger that changes saturated liquid to saturated vapor.

Economizers – is the heat exchanger that raises the temperature of the water leaving the highest pressure feedwater heater to the saturation temperature corresponding to the boiler pressure.

Air Preheater – is a heat exchanger use to preheat air that utilizes some of the energy left in the flue gases before exhausting them to the atmosphere.

Fans – a mechanical machine that assist to push the air in, pull the gas out or both.

Stoker – combustion equipment for firing solid fuels (used in water tube boilers)

Burners – combustion equipment for firing liquid and gaseous fuels.

Feedwater pump – a pump that delivers water into the boiler.

Pressure Gauge – indicates the pressure of steam in the boiler.

Safety Valve – A safety device which automatically releases the steam in case of over pressure.

Temperature Gauge – indicates the temperature of steam in the boiler.

Fusible Plug – a metal plug with a definite melting point through which the steam is released in case of excessive temperature which is usually caused by low water level.

Water Walls – water tubes installed in the furnace to protect the furnace against high temperature and also serve as extension of heat transfer area for the feed-water.

Gage Glass (Water column) – indicates the water level existing in the boiler.

Baffles – direct the flow of the hot gases to effect efficient heat transfer between the hot gases and the heated water.

Furnace – encloses the combustion equipment so that the heat generated will be utilized effectively.

Soot blower – device which uses steam or compressed air to remove the soot that has accumulated in the boiler tubes and drums.

Blowdown Valve – valve through which the impurities that settle in the mud drum are remove. Sometimes called blow 0ff valve.

Breeching – the duct that connects the boiler and the chimney.

Chimney or Smokestack – a structure usually built of steel or concrete that is used to dispose the exhaust gases at suitable height to avoid pollution in the vicinity of the plant.

BOILER PERFORMANCE

1. Heat Generated by Fuel

$$Q_s = m_f\,(HHV)\ \text{KJ/hr}$$

Where: m_f – fuel consumption, kg/hr

HHV – higher heating value of fuel KJ/kg

2. Rated Boiler Horsepower(RBHp)

a) For Water Tube Type

$$RBHp = \frac{HS}{0.91}$$

b) For Fire Tube Type

$$RBHp = \frac{HS}{1.1}$$

Where: HS – required heating surface, m^2

3. Developed Boiler Horsepower (DBHp)

$$\text{Dev. Bo. HP} = \frac{m_s\,(h_s - h_f)}{15.65\,(2257)}$$

$$\text{Dev. Bo. HP} = \frac{m_s\,(h_s - h_f)}{35,322}$$

One Boiler Horsepower is equivalent to the generation of 15.65 kg/hr of steam from water at 100°C to saturated steam at 100°C. The latent heat of vaporization of water at 100°C was taken at 2257 KJ/kg.

4. Percentage Rating

$$\%R = \frac{\text{Rated Bo.Hp}}{} \text{ x } 100\%$$

5. ASME Evaporation Units

ASME Evap. Units = $m_s(h_s - h_f)$ KJ/hr

6. Factor of Evaporation (FE)

$$FE = \frac{(\quad {}_s - \quad {}_f}{2257 \; (\qquad)}$$

7. Boiler Efficiency

$$\eta_B = \frac{m_s(h_s - h_f)}{m_f(HHV)} \text{ x } 100\%$$

8. Net Boiler Efficiency

$$\eta_N = \frac{m_s(h_s - h_f) - \textbf{Auxiliaries}}{m_f(HHV)} \text{ x } 100\%$$

9. Actual Specific Evaporation

$$\text{Actual Sp. Evap.} = \frac{m_s}{m_f} \quad \frac{\text{kg of steam}}{\text{kg of fuel}}$$

10. Equivalent Evaporation

Equiv. Evap. = m_s (FE)

11. Equivalent Specific Evaporation

$$\text{Equiv. Sp. Evap.} = \frac{m_s}{m_f}(FE)$$

BOILER HEAT BALANCE

Energy supplied to the boiler by 1 kg of fuel is distributed among the following items in the ASME short-form heat balance, all expressed in units of KJ/kg of fuel.

1. Heat absorbed by steam generating unit

$$Q_1 = \frac{m_s(h_s - h_f)}{m_f} \text{ KJ/kg}$$

Where: m_s – steam flow rate in kg/hr

m_f – fuel consumption in kg/hr

h_s – enthalpy of steam, KJ/kg

h_f – enthalpy of fed water, KJ/kg

2. Heat loss due to Dry Flue Gas

$$Q_2 = m_{dg}(1.026)(t_g - t_a) \text{ KJ/kg}$$

Where: m_{dg} – mass of dry flue gas, Kg_{gas}/Kg_{fuel}

3. Heat loss due to Moisture in Fuel

$$Q_3 = M(h' - h_{f'}) \text{ KJ/kg}$$

Where: h' – enthalpy of superheated steam at flue gas Temperature, KJ/kg

$h_{f'}$ – enthalpy of liquid at temperature of fuel entering furnace, KJ/kg

$$Q_3 = M(2493 + 1.926t_g - 4.187t_f) \text{ KJ/kg when } t_g < 302°C$$

$$Q_3 = M(2482 + 2.094t_g - 4.187t_f) \text{ KJ/kg when } t_g > 302°C$$

4. Heat loss due to moisture from the combustion of hydrogen

$$Q_4 = 9H_2(h' - h_{f'}) \text{ KJ/kg}$$

$$Q_4 = 9H_2 (2493 + 1.926t_g - 4.187t_f) \text{ KJ/kg when}$$

$$t_g < 302°C$$

$$Q_4 = 9H_2 (2482 + 2.094t_g - 4.187t_f) \text{ KJ/kg when}$$

$$t_g > 302°C$$

5. Heat loss due to moisture in air supplied

$Q_5 = W(1.926)m_{aa}(t_g - t_a)$ KJ/kg

$Q_5 = \%age\ saturation(W_s)(1.926)m_{aa}(t_g - t_a)$ KJ/kg

6. Heat loss due to incomplete combustion

$Q_6 = 23516C_i$ KJ/kg

$$Q_6 = 23516\frac{CO}{CO_2 + CO}C_{ab}\ \text{KJ/kg}$$

7. Heat loss due to unconsumed carbon in the refuse

$Q_7 = 33{,}820(C - C_{ab})$

Wher: $(C - C_{ab}) = (W_r - A)$

$(W_r - A) = W_rC_r$

$$W_r = \frac{A}{1 - C_r}$$

C – carbon in fuel, kg/kg

C_{ab} – carbon actually burned, kg/kg

W_r – weight of dry refuse kg/kg

C_r – weight of combustible in the refuse, kg/kg

8. Heat loss due radiation and unaccounted-for losses

$Q_8 = HHV - (Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 + Q_7)$

Problems (Steam Generators)

1. A steam generator uses coal as fuel having the ultimate analysis as follows:
   C = 72% ; H_2 = 5%; O_2 = 10%; N_2= 1.2%; S = 3.3%; M = 0.1% & A = 8.4%
   If this coal is burned with 20% excess air, Determine
   a) the A/F ratio in kga/kgf
   b) the volume of wet flue gas at101 KPa and 282°C per kg of coal
   c) the %age of CO_2 by volume in the dry flue gas
   d) the dew point of the products
   e) the fuel consumption in Metric tons per hour for a steaming capacity of 100 Metric tons/hour, Factor of Evaporation of 1.15 and a steam generator efficiency of 73%.
2. A water tube boiler generates 7,300 kg of steam per hour at a pressure of1.4 MPa and a quality of 98% when the feed-water is 24°C. Find
   a) Factor of Evaporation
   b) Equivalent Evaporation
   c) Developed Boiler Horsepower
   d) %rating developed if the heating surface is 190 m2
   e) Overall efficiency if coal having a HHV of 5000 KCal/kg as fired is used at the rate of 3000 L/hr.
3. A water tube boiler generates 8,000 kg of steam per hour at a pressure of 1.4 MPa and a quality of 985 when the feed-water is 24°C. Find
   a) Factor of Evaporation
   b) Equivalent Evaporation in kg/hr
   c) Boiler horsepower developed
   d) Percent rating developed if the heating surface is 185.9 m2
   e) Overall efficiency if coal having a HHV of 20,940 KJ/kg as fired is used at a rate of 1500 kg/hr
4. At a load of 43,000 KW in a steam turbine generating set, 3600 RPM, the following data appear in the log sheet.
   Steam flow -190 Metric Tons/hour
   Steam pressure - 8.93 MPaa
   Steam temperature - 535□C
   Feed-water temperature - 230□C
   Fuel Flow:
   Bunker Oil -3.4 Metric Tons/hr
   HHV =10,000 KCal/hr
   Local coal -18 Metric Tons/hr
   HHV = 5350 KCal/hr
   Determine thee overall boiler efficiency.
   h at 8.93 MPa and 535°C - 3475.7 KJ/kg
   hf at 230°C- 990.12 KJ/kg
5. A coal fired steam boiler uses 3000 kg of coal per hour. Air required for combustion is 15.5 kg/kg of coal at a barometric pressure of 98.2 KPa. The flue gas has a temperature of 285°C and an average molecular weight of 30. Assuming an ash loss of 11% and allowable gas velocity of 7.5 m/sec, find the diameter of the chimney. (D = 1.91 m)
6. Two boilers are operating steadily on 136,500 kg of coal contained in a bunker. One boiler is producing 2386 kg of steam/hr at 1.15 FE and an efficiency of 75%, and the other boiler produces 2047 kg of steam/hr at 1.10 FE and an efficiency of 70%. How many hours will the coal in the bunker run the boilers if the heating value of the coal is 32,000 KJ/kg. (281.5 hrs)

7. An industrial plant is to be designed based upon the following requirements; 5000 KW output and generator efficiency of 98%. Steam is extracted at the rate of7.6 kg/sec at 0.2 MPa for industrial use. Turbine inlet pressure is 1.2 MPa and temperature of 260□C, exhaust at 0.014 MPa. Brake turbine efficiency is 75%. Extracted and exhaust steam are returned to the boiler as liquid at 93□C, respectively. Determine
    a) Supplied steam to the turbine in kg/hr
    b) Total heat supplied to the boiler in KJ/hr
    At 1.2 MPa and 260□C
    h = 2957.6 KJ/kg
    S = 6.8721 KJ/kg-K
    At 93□C; hf = 389.54 KJ/kg
    At 0.014 MPa
    Sf = 0.7366 KJ/kg-K ; sfg = 7.2959 KJ/kg-K
    hf = 219.99 KJ/kg ; hfg = 2376.6 KJ/kg
    At 0.2 MPa
    sf = 1.55301 KJ/kg-K ; sfg = 5.5970 KJ/kg-K
    hf = 504.7 KJ/kg ; hfg = 2201.9 KJ/kg
    At S1 = S2 to 0.20 MPa ;
    h2 = 2606.28 KJ/kg
    At S3 = S4 to 0.014 MPa
    h3 = 2218.596 KJ/kg
8. In a test of a Bobcock and Wilcox boiler with hand-fired furnace, the following date were taken;
    Rated HP - 350
    Grate Surface - 2.323 m2
    Duration of test - 24 hours
    Steam pressure - 1.2 MPa
    Feed-water temperature - 34□C
    Quality of steam formed - 99%
    Total weight of coal fired (wet) - 7110 kg
    Moisture in coal - 7.5%
    Total weight of water fed to boiler - 54,000 kg
   Determine:
    a) Factor of Evaporation
    b) Dry coal per m2 of grate surface per hour
    c) Equivalent evaporation per hr - m2 of heating surface
    d) Equivalent evaporation per hour
    e) Boiler HP Developed
    f) Percentage of Rated capacity developed
    g) The equivalent evaporation per kg of dry coal
    h) Combined efficiency of boiler, furnace and grate if the coal has a heating value of 28,590 KJ/kg
9. Coal with HHV = 6700 KCal/kg is consumed at the rate of 600 kg/hr in a steam generator with a Rated Boiler HP of 200. The feed-water temperature is 82□C and steam generator is at 1.08 MPaa saturated. The Developed Boiler HP is equivalent to 305. Determine:
    a) Heating Surface, m2
    b) Rate of steam generated, kg/hr
    c) Percentage Rating
    d) ASME Evaporation units, J/hr

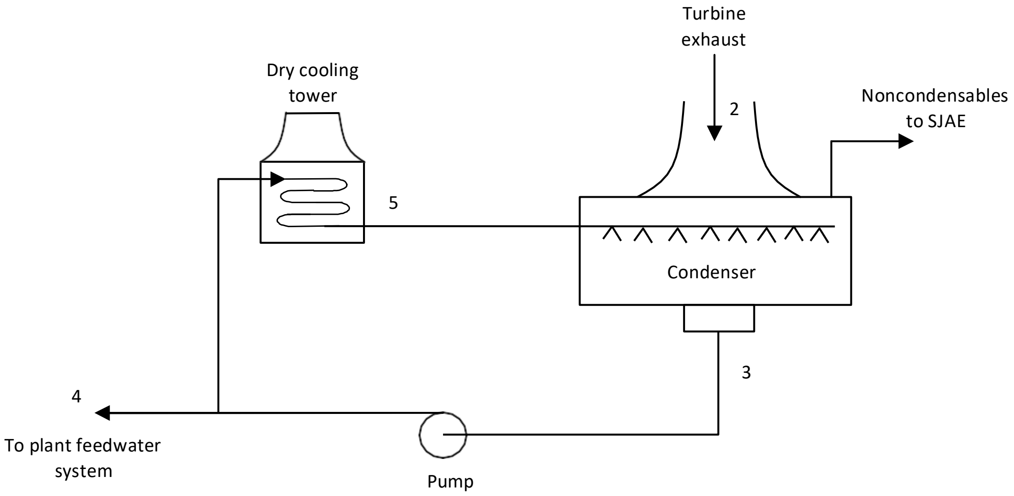
   e) Factor of Evaporation
   f) Overall thermal efficiency
   g) Actual specific evaporation, kg steam/kg of coal
   h) Equivalent specific evaporation

10. The boiler, furnace and grate efficiency of a steam generator is 82%. Coal with a moisture content of 12% is burned at the rate of 10,000 kg per hour. The heating value per kg of dry coal is 28,000 KJ. Steam is generated at 3.2 MPa and a temperature of 320□C. Feed-water temperature is 95□C. Determine:
    a) the kg of steam generated per hour
    b) the Developed Boiler Hp.
    c) the Equivalent evaporation in kg per kg of coal as fired
    d) the cost to evaporate 500 kg of steam if coal costs P 150 per Metric Ton

CONDENSERS

Direct - contact or Open, condensers

This type of condenser are used in special cases, such as when dry cooling towers are used in geothermal power plants and in power that use temperature differences in ocean waters (OTEC). Modern direct contact condensers are of the spray type. Early designs were of the ***barometric*** or ***jet type***.



Schematic Diagram of a Direct - contact condenser of the Spray type

By mass balance

$$m_2 = m_4$$

$$m_3 = m_2 + m_5$$

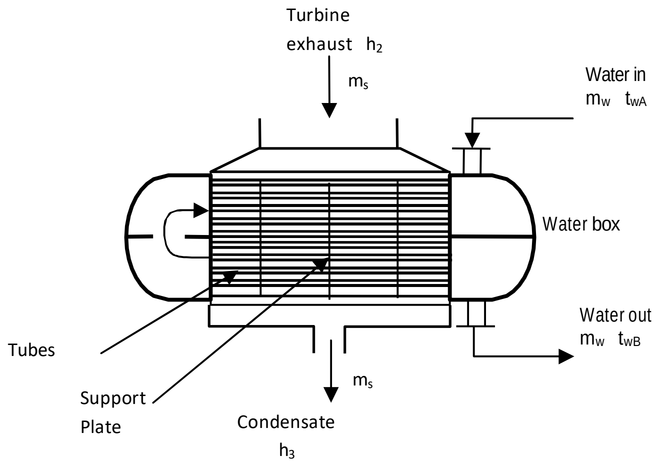
By Energy balance

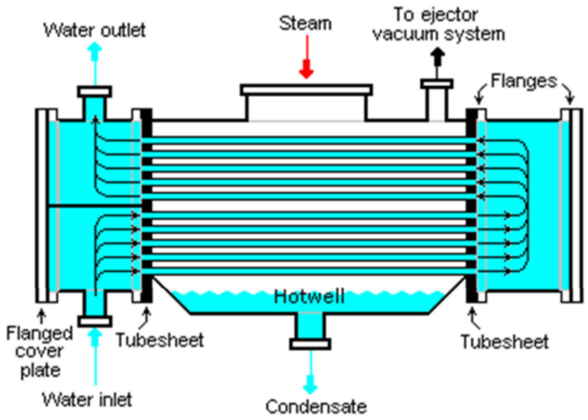
$$m_2h_2 + m_5h_5 = m_3 = h_3$$

And the ratio of circulating water to steam flow

$$\frac{m_5}{m_2} = \frac{h_2 - h_3}{h_3 - h_5}$$

Surface Condenser





Let

$$Q = Q_R = Q_w$$

Q_R – heat rejected by steam
Q_w – heat absorbed by cooling water
m_s – steam flow rate in kg/sec
m_w – cooling water flow rate in kg/sec
t_{wA} – inlet temperature of cooling water in °C
t_{wB} – outlet temperature of cooling water in °C
$C_{pw} = 4.187$ KJ/kg-°C (specific heat of water)

$$Q_R = Q_w$$

$$Q_R = m_s(h_2 - h_3) \text{ KW}$$
$$Q_w = m_w C_{pw} (t_{wB} - t_{wA})$$

In terms of Overall coefficient of heat transfer U:

$$Q = \frac{UA(LMTD)}{1000}\ KW$$

where :

U - overall coefficient of heat transfer in $\frac{W}{m^2 - {}^\circ C}$ or $\frac{W}{m^2 - K}$

LMTD – log mean temperature difference, °C

A – total heat transfer surface area, m^2

$$A = \pi DL(N_t)$$

D – outside diameter of tubes, m

L - length of tubes, m

N_t - total number of tubes

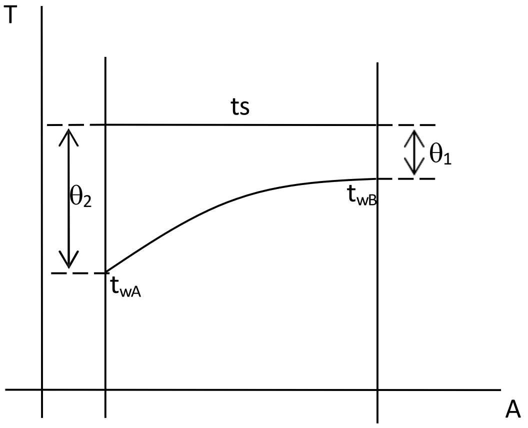
$$LMTD = \frac{t_{wB} - t_{wA}}{\ln \frac{t_s - t_{wA}}{t_s - t_{wB}}}$$

t_s – saturation temperature of steam, °C

TTD – Terminal Temperature difference

TTD = $t_s - t_{wB}$

TEMPERATURE – AREA DIAGRAM



$$\theta_2 = t_s - t_{wA}$$

$$\theta_1 = t_s - t_{wB}$$

$$LMTD = \frac{\theta_2 - \theta_1}{\ln \frac{\theta_2}{\theta_1}}$$

Problem

A 10,000 KW turbine generator uses 5 kg/KW-hr of steam at rated load. Steam supply pressure is 4.5 MPa and 370°C and the pressure in the surface condenser is 3.4 KPa (tsat = . Temperature of inlet circulating water is 16°C and outlet of 22°C. Combined efficiency of the turbo-generator set is 92%. The condenser tubes are 2 mm; 1.2 mm thickness. Water velocity is 3.5 m/sec. Overall coefficient of heat transfer U = 4 W/m^2-°C. Tube sheet thickness is 10 mm. Determine:

a. Cooling water required in L/min
b. Number of tubes for 2-Pass design
c. Actual length of tubes

Other Data are as follows:

h_1 = 3131.4 ;S_1 = 6.5897
h_2 = 1967.1 ;S_2 = 6.5897 x2 = 76.17
h_3 = 109.75 ;S_3 = 0.3836
h_4 = 114.27

GEOTHERMAL POWER PLANT

Geothermal energy is the power obtained by using heat from the Earth's interior. Most geothermal resources are in regions of active volcanism. Hot springs, geysers, pools of boiling mud, and fumaroles (vents of volcanic gases and heated groundwater) are the most easily exploited sources of such energy

The most useful geothermal resources are hot water and steam trapped in subsurface formations or reservoirs and having temperatures ranging from 176° to 662° F (80° to 350° C). Water and steam hotter than 356° F (180° C) are the most easily exploited for electric-power generation and are utilized by most existing geothermal power plants. In these plants hot underground water is drilled from wells and passes through a separator-collector where the hot water is flashed to steam, which is then used to drive a steam turbine whose mechanical energy is then converted to electricity by a generator.