



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

WASTE TO ENERGY CONVERSION

EFFICIENCY IMPROVEMENT OF POWER PLANT-2

DR. PRASENJIT MONDAL
CHEMICAL ENGINEERING DEPARTMENT



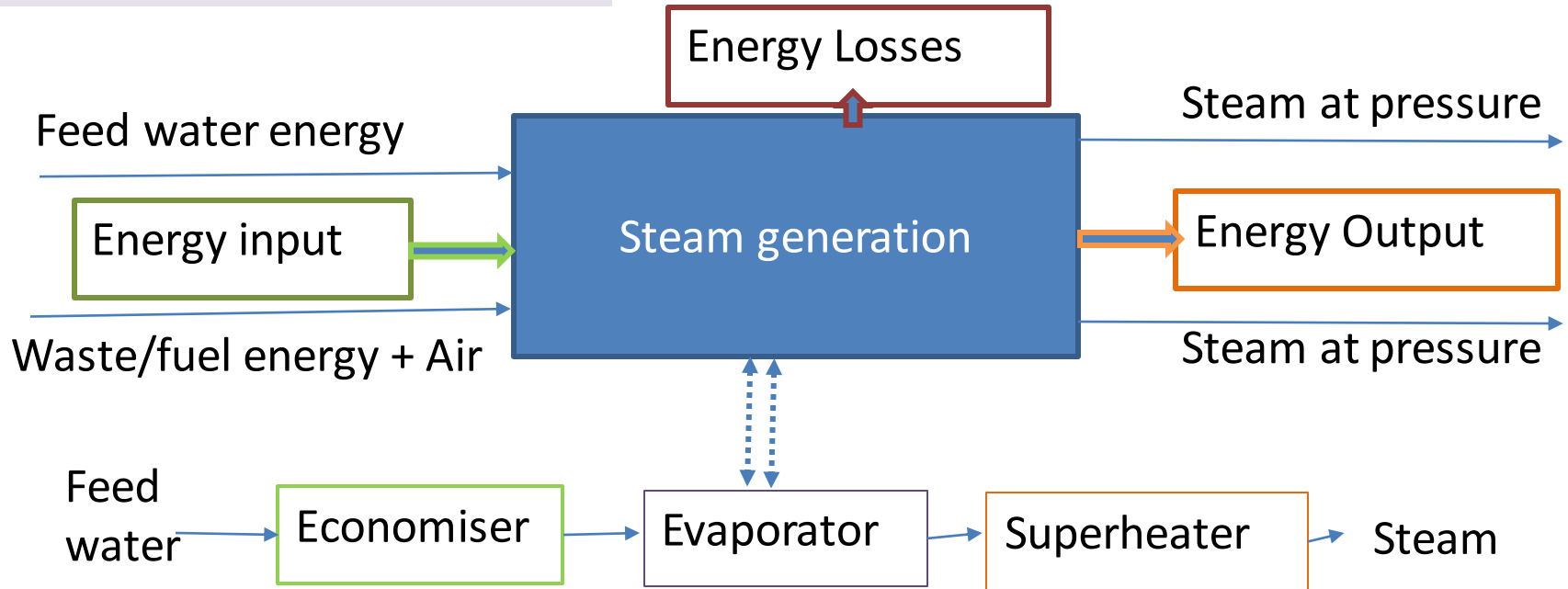
Contents

- Power generation flowsheet
- Performance of waste based power plant
- Factors influencing power efficiency
- Thermodynamic cycles for power generation
- Cogeneration and heat recovery
- Overall plant efficiency
- Energy analysis of steam process (boiler)
- Types of turbines and their cycles for power generation
- Working of combined cycle and efficiency improvement
- Efficiency calculation through thermodynamic laws



Energy analysis of steam process (boiler)

Heat balance in steam process



$$\text{Energy output} = \text{energy input} - \text{losses}$$

Energy analysis of steam process (boiler)

Useful energy calculation

- Useful energy indicates the energy available in the produced steam, which depends on steam generate rates, waste/ fuel burning rate, temperature and pressure of the steam, mass fraction of inlet steam from the high pressure turbine before reheating and can be quantified as :

$$\text{Useful energy } Q_1 = (W_s/W_f) * [(H_2 - H_1) + (1 - m_1) * (H_4 - H_3)] \text{ kJ/kg}$$

Where W_s = steam generation rate in kg/s

W_f = fuel burning rate in kg/s

m_1 = mass fraction of inlet steam from the high pressure turbine before reheating

H_1 = enthalpy of feed water before economiser

H_2 = enthalpy of steam after evaporator ; H_3 = enthalpy of steam before superheater; H_4 = enthalpy of steam after superheater



Energy analysis of steam process (boiler)

Total energy, losses and efficiency of steam generator

Total energy is the energy released in complete combustion of 1 kg of fuel = HHV (High heating value) of the wastes or fuel

Energy losses include:

Energy loss due to moisture in waste/ fuel Q_2

Energy loss due to hydrogen in waste/ fuel Q_3

Energy loss due to unburned carbon Q_4

Energy loss due to dry exhaust gas Q_5

Energy loss due to incomplete combustion of Q_6

Energy loss due to convection and radiation from boiler surface Q_7

Energy loss due to moisture coming with air supplied Q_8

Energy loss due to ash and slag Q_9

Useful energy = HHV- energy losses

Or HHV= Useful energy + energy losses

Efficiency of steam generator = Useful energy (Q_1)/HHV



Energy analysis of steam process (boiler)

Computation of energy losses

Energy loss due to moisture in fuel Q_2

$$= M[4.187(100-T_a) + 2256.8 + 2.09(T_g - 100)] \text{ kJ/kg}$$

Energy loss due to hydrogen in fuel Q_3

$$Q_3 = 9H[4.187(100-T_a) + 2256.8 + 2.09(T_g - 100)] \text{ kJ/kg}$$

Energy loss due to unburned carbon Q_4 :

= mass of unburned carbon * its heating value

$$= (C - C_{ab}) * (394000/12) = 32833 * (C - C_{ab}) \text{ kJ/kg carbon}$$

C_{ab} = carbon absorbed in burning process.



Energy analysis of steam process (boiler)

Computation of energy losses

Energy loss due to dry exhaust gas $Q_5 = W_{deg} * C_p * (T_g - T_a)$ kJ/kg

W_{deg} = mass of dry exhaust gas produced per kg of fuel

C_p = average specific heat of dry exhaust gas in kJ/kg/°C

T_g = exhaust gas temperature in °C

T_a = ambient temperature in °C

Energy loss due to incomplete combustion

Loss of energy per kg of C oxidized to CO = $283000/12 = 23583$ kJ/kg

Loss of energy per kg of fuel $Q_6 = 23583$ (kJ/kg carbon) * W_{deg} * (kg deg/kg fuel) * $[28CO/(44CO_2 + 28CO + 32O_2 + 28N_2)]$ * (kg CO/kg deg) * (12 * kg Carbon/28 * kg CO) kJ/kg fuel
= $10107 * W_{deg} * [28CO/(44CO_2 + 28CO + 32O_2 + 28N_2)]$ kJ/kg fuel

Energy loss due to convection and radiation from boiler surface Q_7

$$= (H_c + H_r) * A_s * (T_w - T_a) / W_f \text{ kJ/kg}$$

H_c = Convective heat transfer coefficient in $\text{kJ/m}^2/^{\circ}\text{K}$

H_r = Radiative heat transfer coefficient in $\text{kJ/m}^2/^{\circ}\text{K}$

A_s = Total surface area exposed to the ambient air in m^2

T_w = Temperature of the wall surface of the boiler in $^{\circ}\text{C}$

Energy analysis of steam process (boiler)

Computation of energy losses

Energy loss due to moisture coming with air supplied Q_8

$$= \gamma_A * W_A * C_P(T_g - T_a) \text{ kJ/kg}$$

Where γ_A = specific humidity of air (kg moisture/kg dry air)

W_A = Amount of air used per kg of fuel (kg air/kg fuel)

C_P = specific heat of superheated water vapour in kJ/kg/°C

Energy loss due to ash and slag Q_9

$$= [(C - C_{ab}) + A] * C_p(T_{fu} - T_a) \text{ kJ/kg}$$

C_{ab} = carbon absorbed in burning process

A is ash produced from 1 kg waste/fuel

C_p = Average specific heat of ash and slag in kJ/kg/°C

T_{fu} = temperature in furnace in °C



Energy analysis of steam process (boiler)

Efficiency of steam generator

Energy released in complete combustion of 1 kg of fuel = HHV

The energy balance equation is

Useful energy = HHV- energy losses

$$= \text{HHV} - (Q_2 + Q_3 + Q_4 + Q_5 + Q_6 + Q_7 + Q_8 + Q_9)$$

$$= \text{HHV} - \sum_{i=2}^9 Q_i$$

Efficiency of
steam generator = Q_1/HHV

$$= (W_s/W_f) * [(H_2 - H_1) + (1 - m_1) * (H_4 - H_3)]/(\text{HHV})$$



Types of turbines & cycles used for power generation

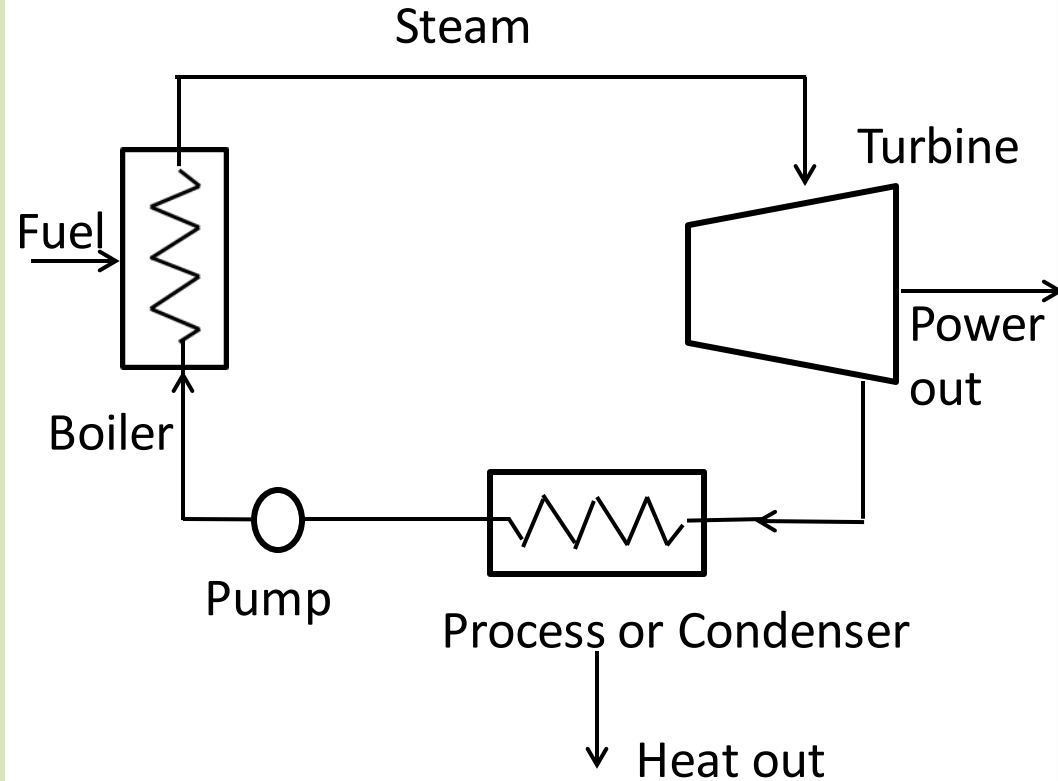
- Steam turbine (Steam turbine cycle)
- Gas turbine (Gas turbine cycle)
- Both Gas and steam turbines (Combined cycle)



Types of turbines & cycles used for power generation

Steam turbine cycle

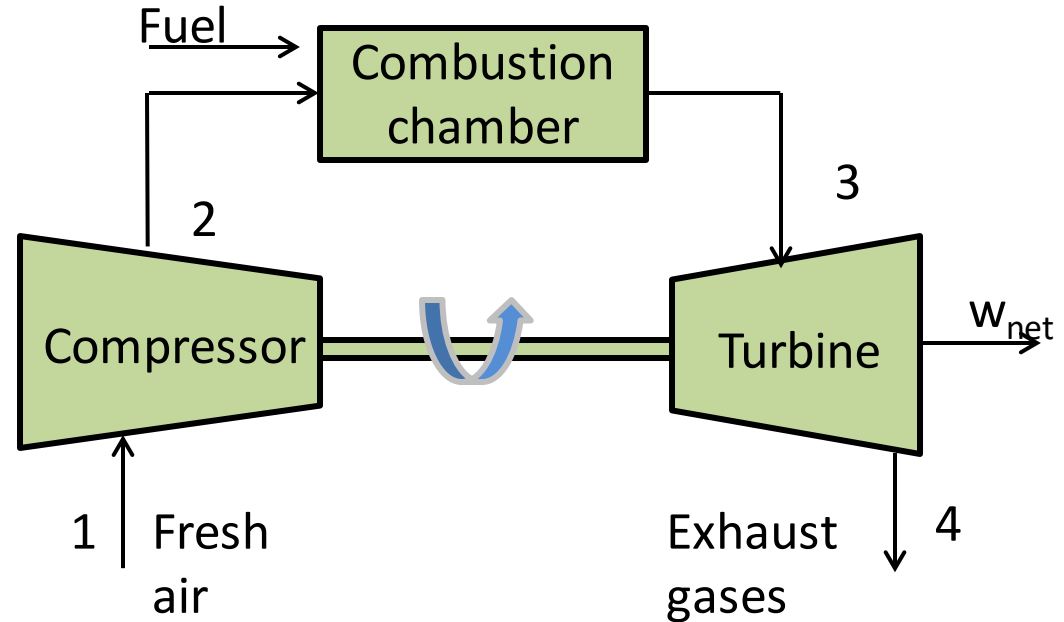
- Water is pumped into the boiler.
- The fuel(exhaust from incinerator) is used to generate steam inside the boiler.
- The high pressure steam produced from the boiler is passed through the turbine and generates electricity.
- The exhaust from the turbine (low pressure steam) is sent to a condenser where it is condensed and recirculated to the boiler through the pump.



Types of turbines & cycles used for power generation

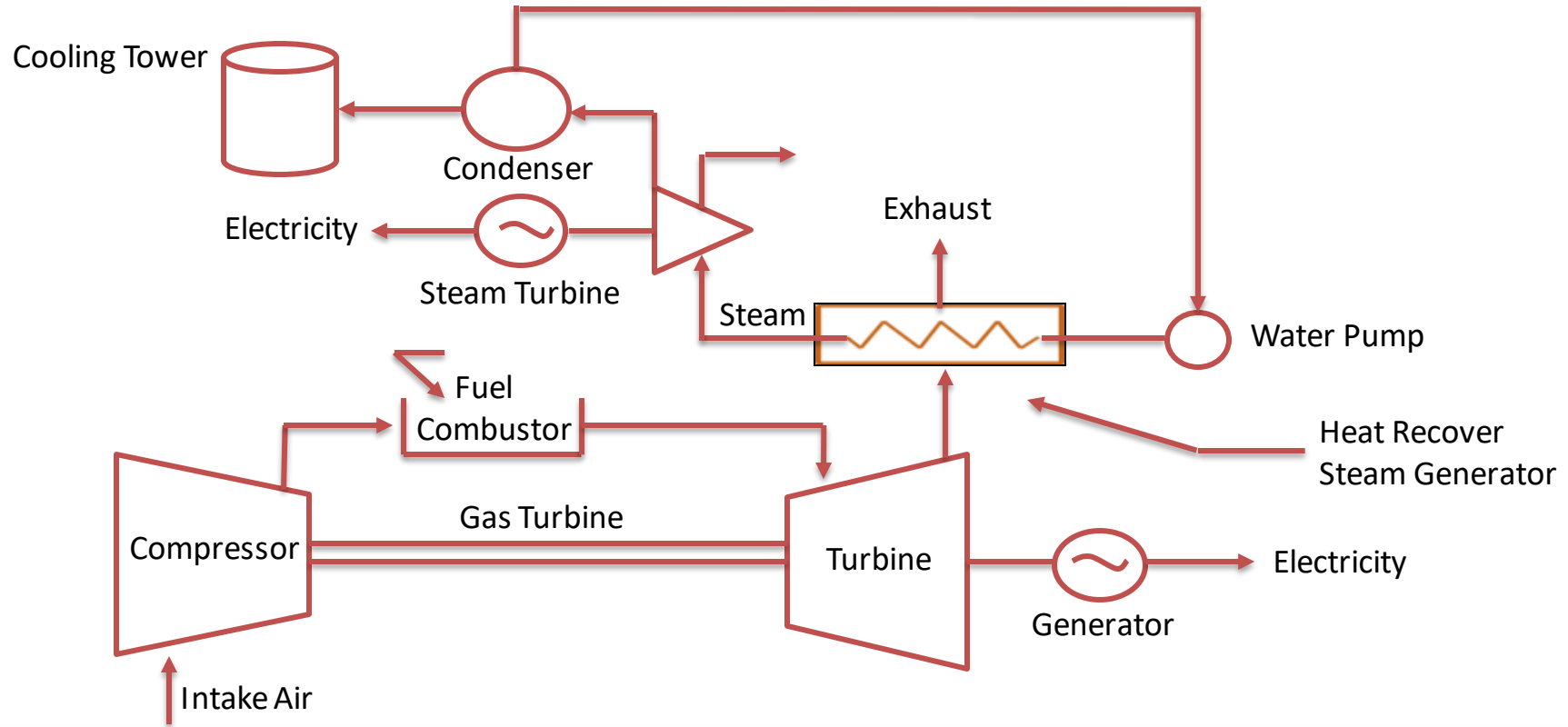
Gas turbine cycle

- Fresh air is compressed and sent to the combustion chamber along with the fuel.
- The exhaust gas from the combustion chamber (1500-1800 °C) is directly sent to the gas turbine and generates electricity.
- The exhaust from the turbine is released .



Types of turbines & cycles used for power generation

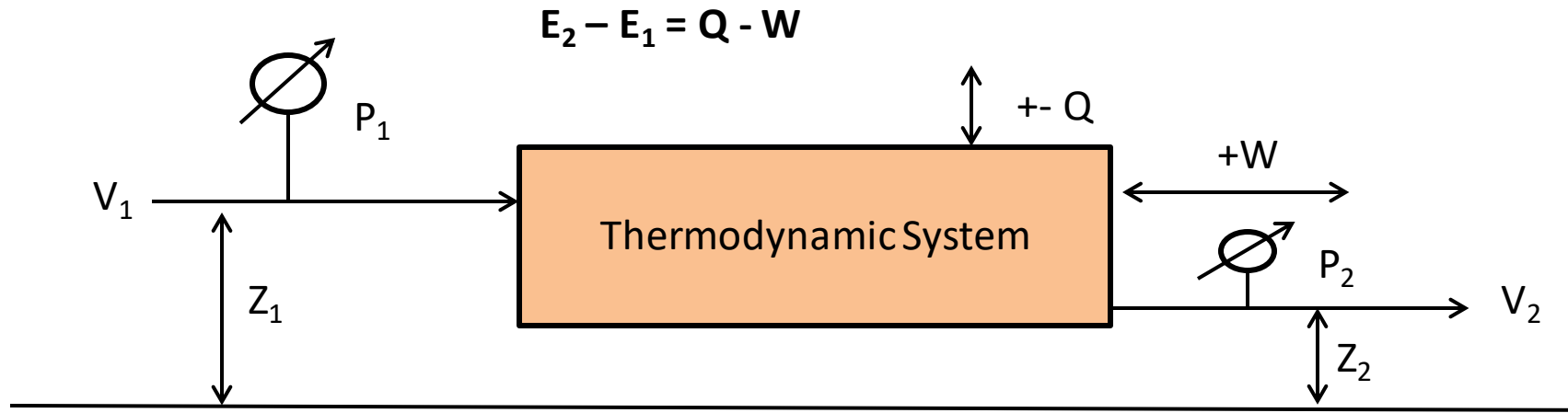
Combined steam and gas turbine cycle



Working of combined cycle and improvement of efficiency

- At first , exhaust gas from incinerator is passed through the gas turbine.
- The exhaust from gas turbine at a lower temperature is further sent to boiler to produce steam.
- This steam is passed through the steam turbine and the exhaust is condensed and resend to the boiler.
- The exhaust from the gas turbine is not wasted , Instead it is sent to boiler for waste heat recovery.
- The quantity of electricity generated is increased as it is produced in two stages.
- The efficiency of the overall system is increased in case of combined cycle.

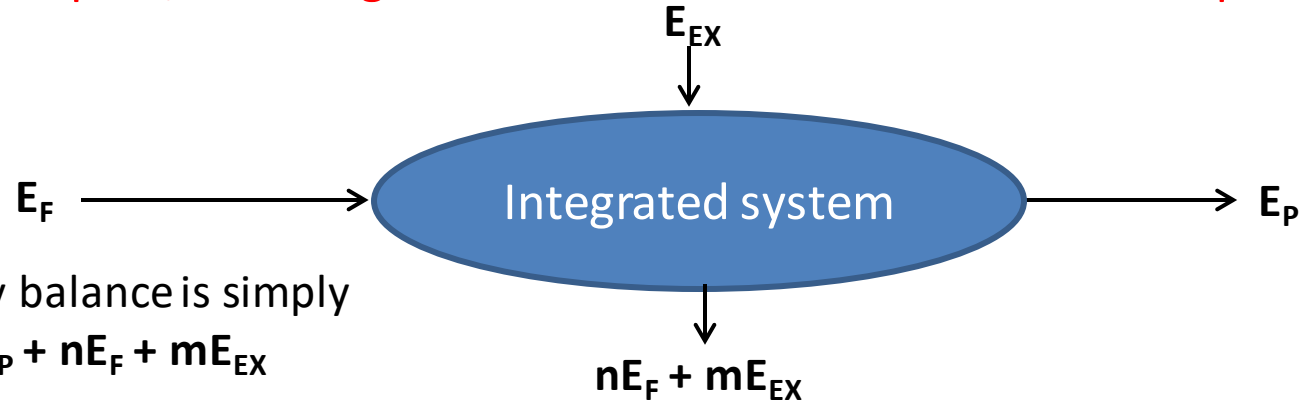




Efficiency of the process can be computed on the basis of Thermodynamic laws

- Through first law .
- Through second law.

First-law treatments generally involve energy and material balances to relate the energy inputs and outputs, including heat losses and other undesirable outputs.



The first-law energy balance is simply

$$E_F + E_{EX} = E_P + nE_F + mE_{EX}$$

These are used to calculate simple ratios of energy produced to energy consumed, or net energy production ratios (NEPRs),

The NEPRs can be defined as follows (Klass, 1976): $N_1 = [E_P - (nE_F + mE_{EX})] / (nE_F + mE_{EX})$

Efficiency calculation through thermodynamic laws

Through first law

Where N_1 = net energy production ratio

E_p = sum of energy contents of salable energy products

E_F = energy content of feedstock or combined feedstocks

E_x = sum of energy values of all external energy inputs except feedstock

n = fraction of primary energy source content (E_F) diverted to other than salable energy products

m = fraction of external energy source content (E_x) diverted to other than salable energy products

In most cases, m is 1.0 because none of the external energy inputs contribute to E_p .

If nE_F is zero (when feed energy is exclusively used to produce salable products), presuming m is 1.0, the calculation for N_2 is as follows:

$$N_2 = (E_p - E_x) / E_x \quad (2)$$

In either calculation, a positive N means that the system replaces the specified energy inputs, $(nE_F + mE_x)$ or E_x , with the equivalent in salable energy products and also provides an additional amount of salable energy.



- The second law qualifies the first law by explaining the conversion between heat and work.
- All forms of energy including work can be converted to heat, but the converse is not generally true.
- The Kelvin-Planck statement says that only a portion of heat from a heat-work cycle in a steam power plant can be converted to work. The balance heat must be rejected to a sink of lower temperature.

Performance parameters in second-law NEAs have been defined as effectiveness (e), which is the increase in availability of the desired product divided by the decrease in the availability required (Reistad, 1975).



Availability is the maximum amount of work or thermal energy obtainable from a system as it attains equilibrium with its surroundings.

$$A = (H - H_o) - T_o(S - S_o)$$

Where A = availability of stream

H = enthalpy of stream at flowing condition

H_o = enthalpy of stream with all components in equilibrium with environment

T_o = temperature of environment

S = entropy of stream at flowing conditions

S_o = entropy of stream with all components in equilibrium with environment

Donald L. Klass,
Biomass for
Renewable Energy,
Fuels, and
Chemicals,
Academic Press,
1998

It is the same as the change in Gibbs free energy at constant pressure and temperature, and is the same as the change in enthalpy if the system is isentropic.

Net energy production ratios can be calculated by second-law availability analyses for various types of hardware and chemical reactions to help pinpoint where improvements potentially reside and the magnitude of the improvements.



Thanks...

