



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

WASTE TO ENERGY CONVERSION

EFFICIENCY IMPROVEMENT OF POWER PLANT-1

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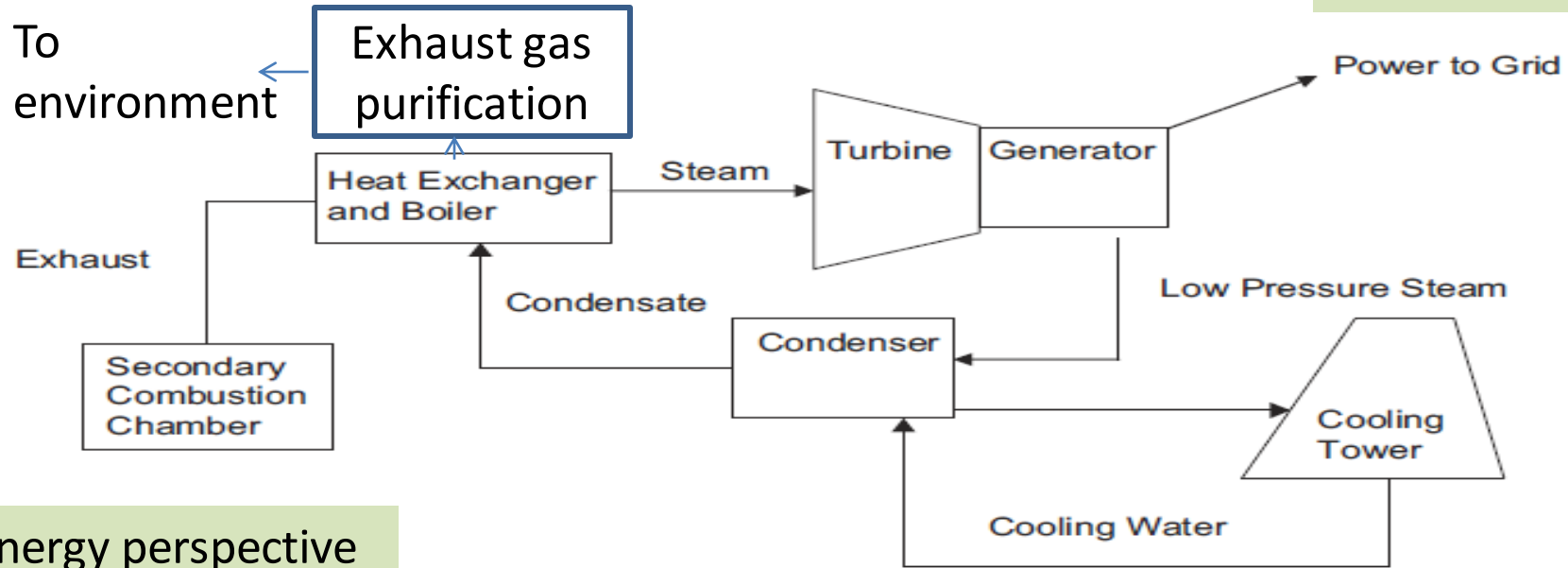
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Power generation flowsheet

Process flowsheet



Energy perspective

Energy in biomass & wastes

Thermal processing

Flue gas

Solid residue

Heat transfer in Boiler

Electricity production in Turbine-generator



Performance of waste based power plant

Over all energy production from a WTE facility depends upon

- Heating value of the waste
- Efficiency of the thermal processing unit
- Thermal efficiency of the boiler
- Efficiency of the turbine-generator
- Energy requirements of the air-pollution control system.
- Any other in-place energy uses



Performance of waste based power plant

The performance of a power plant can be expressed by heat rate as well as thermal efficiency.

Heat rate (HR) : It is the ratio of fuel energy input to electrical energy output

*HR = Heat energy input supplied by fuel to the power plant for a period (Kcal) /
Energy output from the power plant in a period (kWh)*

$$= [(MC * CV) / (energy\ generated * time)] \text{ (Kcal /kWh)}$$

Where: MC – quantity of fuel / feed consumed during the period; CV-
calorific value of feed

Performance of waste based power plant

Thermal efficiency

It is an indication of how well the plant is being operated as compared to the design characteristics

$$\text{Thermal Efficiency} \quad \eta = \frac{\text{energy generated} * \text{time}}{MC * CV} \times 100$$

Where: MC – quantity of fuel / feed consumed; CV- calorific value of feed

$$\text{Thermal efficiency} = 100 / [(MC * CV) / \text{energy generated} * \text{time}]$$

$$= 100 / [\text{heat energy input supplied by fuel to the power plant for a period (Kcal)} / \text{energy generated for the period (KWh)}]$$

$$= 100 / \text{HR (KCal/kWh)}$$

$$\text{As } 1 \text{ KWh} = 859.8456 \text{ Kcal}$$

$$= [100 * 859.8456 / \text{Heat rate (HR in KCal/kWh)}] \%$$



Performance of waste based power plant

- If the average heat rate of a power plant in 2015 is 2611 KCal/kWh , calculate the average efficiency of the plant.

Answer

Thermal efficiency (%)

$$= 100 / [(MC \cdot CV) / \text{energy generated} \cdot \text{time}]$$

$$= 100 / [\text{heat energy input supplied by fuel to the power plant for a period (Kcal)} / \text{energy generated for the period (KWh)}]$$

$$= 100 / \text{HR (Kcal/kWh)}$$

$$= 100 \cdot 859.8456 / \text{HR}$$

$$= 100 \cdot 859.8456 / 2611 = 33 \%$$



Factors influencing power efficiency

- ❖ Turbine types and boiler design
- ❖ On top of plant size and fuel heating value, the design choices having the greatest impact on power production efficiency are:
 - The pressure of the steam produced by boilers (standard at 40bar/600 psi or high pressure at 65bar/950 psi or higher)
 - The type of condensing device (air cooled or water cooled)
 - The heat source to pre-heat combustion air (if pre-heating is necessary)
 - Steam or energy recovered on flue gases
 - The number of boilers and turbines.



Thermodynamic cycles for power generation

Rankine cycle

- The process of the power generation can be represented thermodynamically through the **Rankine cycle**.

Step 1: Adiabatic **compression(isentropic)**

- The pump performs reversible adiabatic compression of a liquid.

Step 2: Isobaric expansion

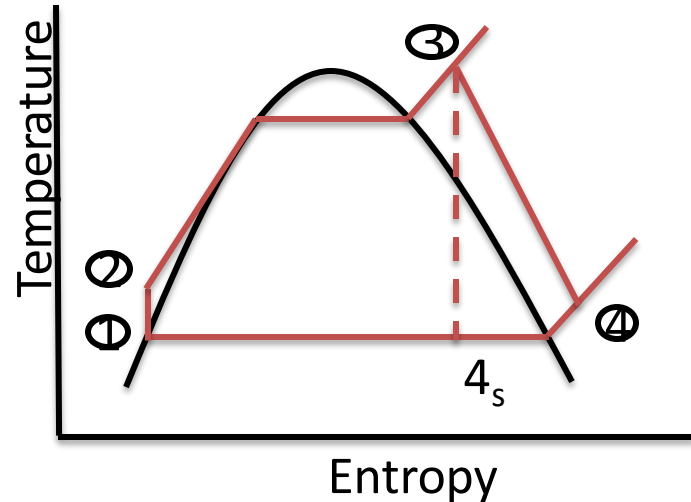
- The boiler transforms the liquid to vapour in a constant pressure heat transfer process.

Step 3: Adiabatic expansion

- The turbine performs reversible adiabatic expansion of vapour.

Step 4: Isobaric compression

- The condenser transforms the vapour to liquid in a constant pressure heat transfer process.



An ideal Rankine cycle gives maximum net work output by generating no entropy by the pump and turbine. Vertical lines for representing Processes 1-2 and 3-4 ([isentropic](#)) more closely resemble that of the Carnot cycle.

Ideal conditions can be achieved when no fluid friction and heat loss is considered.

Irreversibility in the inherent components caused by fluid friction as well as the heat loss to the surroundings are responsible for the variation of actual vapor power cycle from the ideal Rankine cycle .

Fluid friction causes pressure drops in the boiler, the condenser, and the piping between the components, and as a result the steam leaves the boiler at a lower pressure; heat loss reduces the net work output, thus heat addition to the steam in the boiler is required to maintain the same level of net work output.

Thermodynamic efficiency of simple Rankine cycle $\eta_{\text{thermo}} = W_{\text{turb}}/Q_{\text{in}}$

η_{thermo} = ratio of net power output to heat input

Carnot efficiency = $[1 - T_C/T_H]$

Unless the pressure and temperature reach [super critical](#) levels in the steam boiler, the temperature range the cycle can operate over is quite small.

When steam turbine entry temperatures are typically around 565 °C and steam condenser temperatures are around 30 °C a theoretical maximum [Carnot efficiency](#) for the steam turbine alone is about 63% compared with an actual overall thermal efficiency of up to 42% for a modern coal-fired power station.

Due to low steam turbine entry temperature (compared to a [gas turbine](#)) Rankine (steam) cycle is often used as a bottoming cycle to recover otherwise rejected heat in [combined-cycle gas turbine](#) power stations.



Brayton cycle for gas turbine

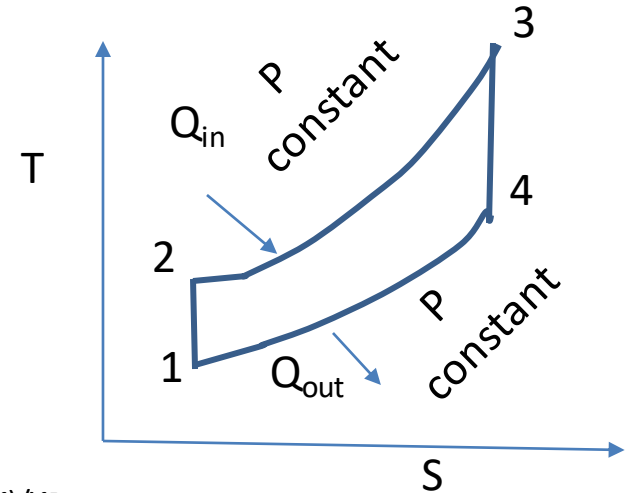
Ideal Brayton cycle:

Step 1. (1-2) isentropic process – Ambient air is drawn into the compressor, where it is pressurized.

Step 2 (2-3) isobaric process – the compressed air then runs through a combustion chamber, where fuel is burned, heating that air—a constant-pressure process, since the chamber is open to flow in and out.

Step 3 (3-4) isentropic process – the heated, pressurized air then gives up its energy, expanding through a turbine (or series of turbines). Some of the work extracted by the turbine is used to drive the compressor.

Step 4(4-1) isobaric process – heat rejection (in the atmosphere).



Efficiency of ideal Brayton cycle $\eta = [1 - (T_1/T_2)] = [1 - (P_1/P_2)^{(1-\gamma)/\gamma}]$ Where γ is heat capacity ratio

The highest temperature in the cycle occurs at the end of the combustion process, and it is limited by the maximum temperature that the turbine blades can withstand (1500-1800°C)

For a fixed turbine inlet temperature, the net work output per cycle increases with the pressure ratio (thus the thermal efficiency). In most common designs, the pressure ratio of a gas turbine ranges from about 11 to 16

With less work output per cycle, a larger mass flow rate (thus a larger system) is needed to maintain the same power output, which may not be economical.

Actual Brayton cycle:

1. [adiabatic process](#) – compression
2. isobaric process – heat addition
3. adiabatic process – expansion
4. isobaric process – heat rejection

Neither the compression nor the expansion can be truly isentropic and the losses through the compressor and the expander are responsible for deviation from ideal cycle and lower working [inefficiencies](#).

Classification of thermodynamic cycles

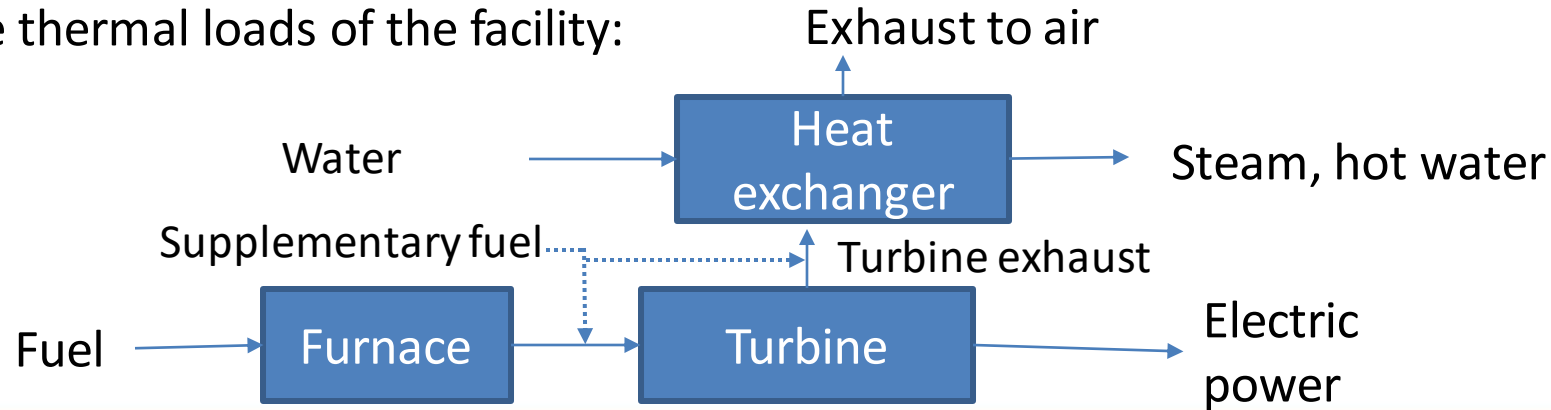
Bottoming cycle

Topping cycle

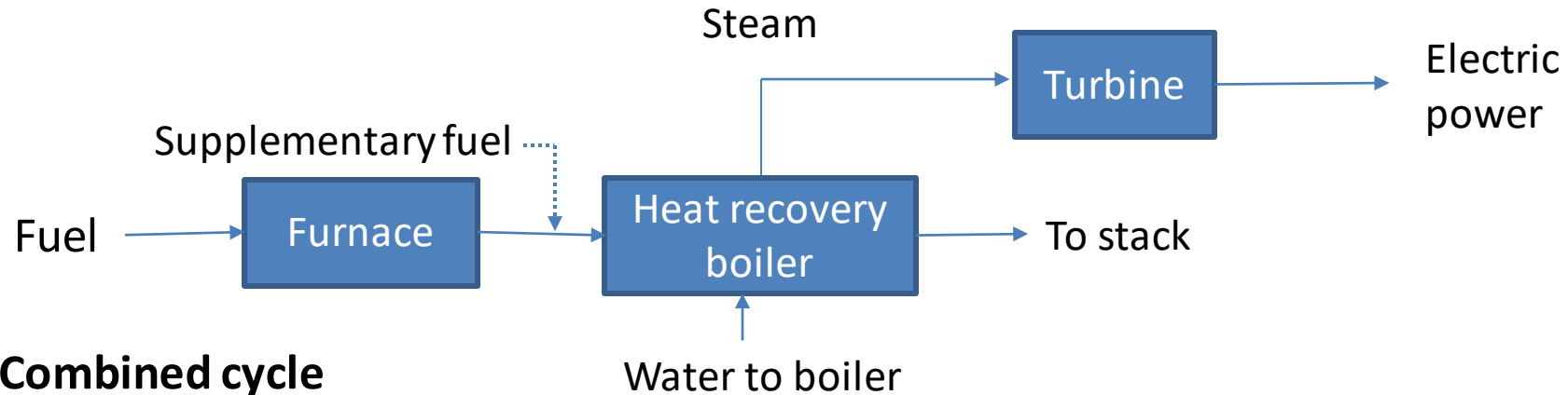
Combine cycle

Topping cycle

Electrical or mechanical power is produced first and then heat is recovered to meet the thermal loads of the facility:



Bottoming cycle



Combined cycle

It is a hybrid cycle and contains both topping and bottoming cycles

Gas turbine exhaust can be used to produce steam for Rankine cycle with additional fuel burning

Gas turbine exhaust can be fired in the duct with additional fuel to provide much greater pressure useful in steam turbine

Cogeneration and additional energy recovery

Cogeneration indicates combined heat and power (CHP) generation, which refers to a group of proven technologies that operate together for the concurrent generation of electricity and useful heat in a process as a result energy-efficiency increases with respect to the separate generation of electricity and useful heat.

In separate production of electricity, some energy must be discarded as waste heat, but in cogeneration some of this thermal energy is put to use.

Trigeneration or combined cooling, heat and power (CCHP) refers to the simultaneous generation of electricity and useful heating and cooling from the combustion of a fuel or a solar heat collector.

$$\eta = [(\text{Electrical power output} + \text{Heat output} + \text{Cooling output}) / \text{Total Heat input}]$$



<i>Energy utilization</i>	<i>Recovery</i>	<i>Overall efficiency^a</i>	
Heat only	Heat	80%	80%
Steam only	Steam	80%	80%
Power only	Power	35%	35%
Combined steam and power	Steam	0-75%	35-75%
	Power	0-35%	
Combined heat and power	Heat	60-65%	85%
	Power	20-25%	

a. Efficiencies defined as useable energy related to energy content (lower calorific value) of the waste

<http://documents.worldbank.org/curated/en/886281468740211060/pdf/multi-page.pdf>

Over all efficiency of power plant

$$\text{Overall unit efficiency, } \eta = \eta_{\text{Boiler}} * \eta_{\text{Turb}} * \eta_{\text{Gen}} * \eta_{\text{wrks}}$$

Where:

η_{Boiler} – boiler efficiency

η_{Turb} - turbine efficiency

η_{Gen} – generator efficiency

η_{wrks} – works efficiency

Thanks...

