EEL-2023/ELE-2303

POWER GENERATION AND TRANSMISSION

LO 2: Thermal Power Plants

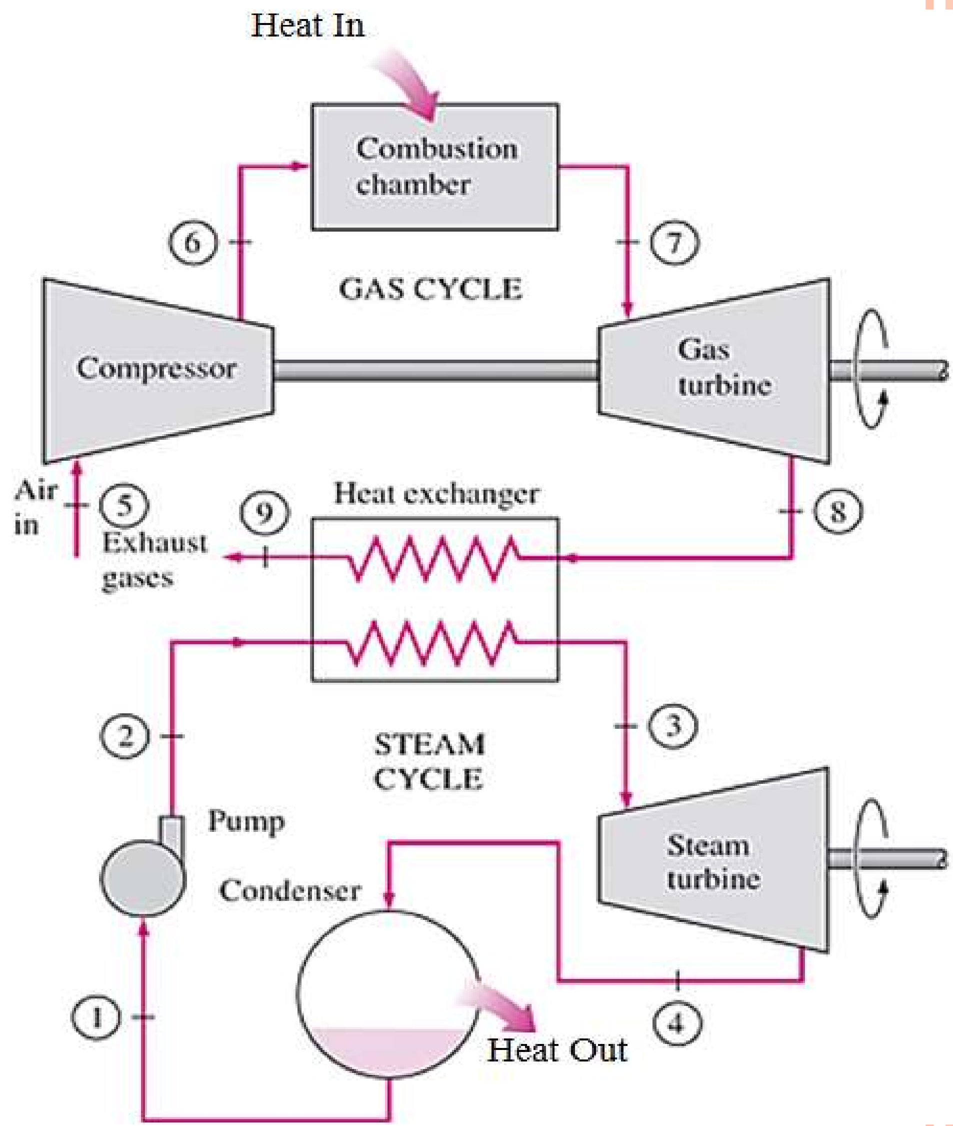
Additional Notes

Combined Cycle Power Plant

- **Combined Cycle** Power Plant is a combination of **Gas Cycle** and **Steam Cycle**.

- The **Steam Cycle** is also called as the **Rankine Cycle**.

- The **Gas Cycle** is also called as the **Brayton Cycle**.



THE RANKINE CYCLE

The Rankine cycle is standard for steam power plants that are built around the world. The basic Rankine cycle consists of four main phases:

- Steam Generator (boiler)
- Turbine
- Steam Condenser
- Pump

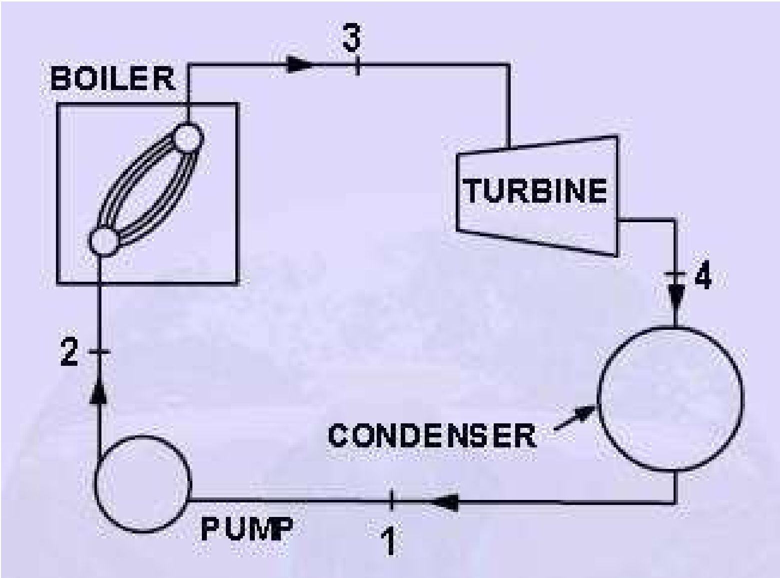
THE RANKINE CYCLE

Process 1-2: Water from the condenser at low pressure is pumped into the boiler at high pressure. This process is reversible adiabatic.

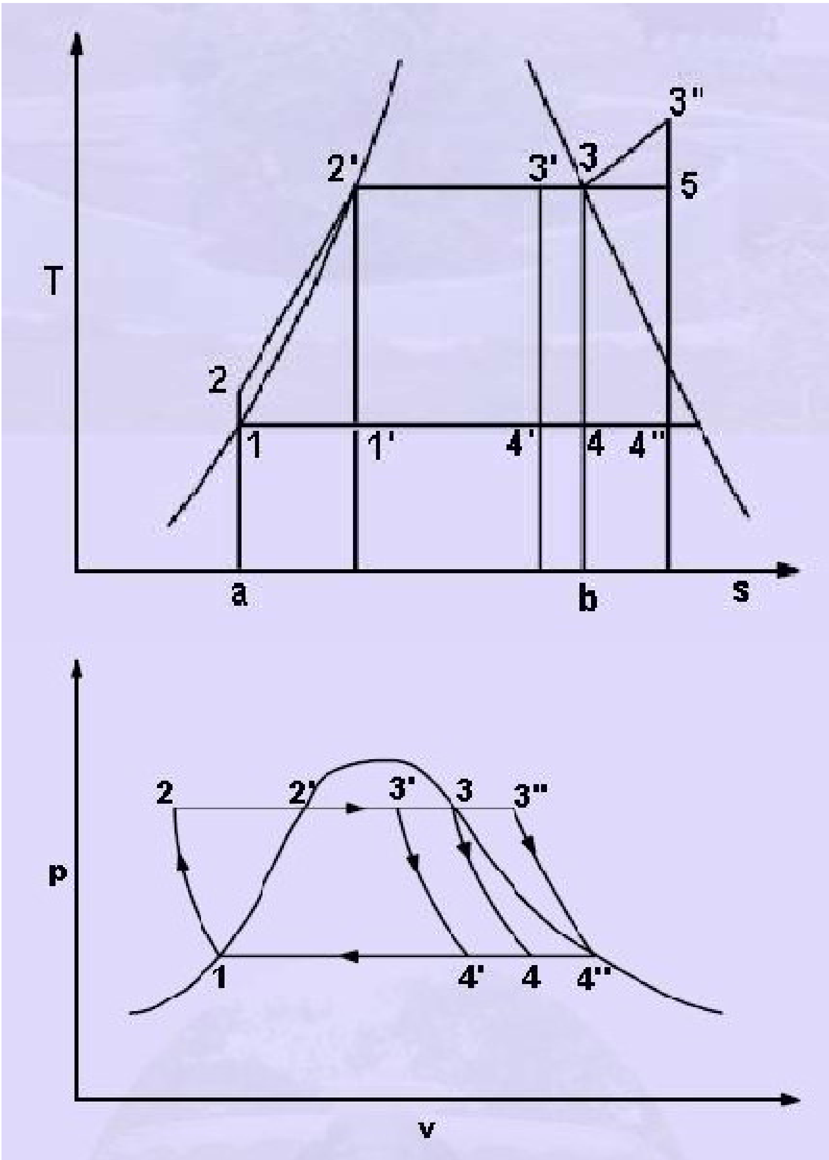
Process 2-3: Water is converted into steam at constant pressure by the addition of heat in the boiler.

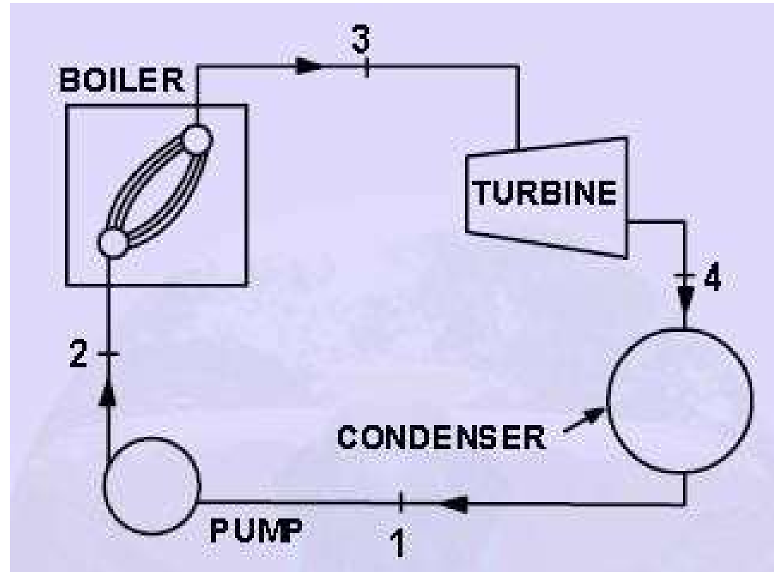
Process 3-4: Reversible adiabatic expansion of steam in the steam turbine.

Process 4-1: Constant pressure heat rejection in the condenser to convert condensate into water.



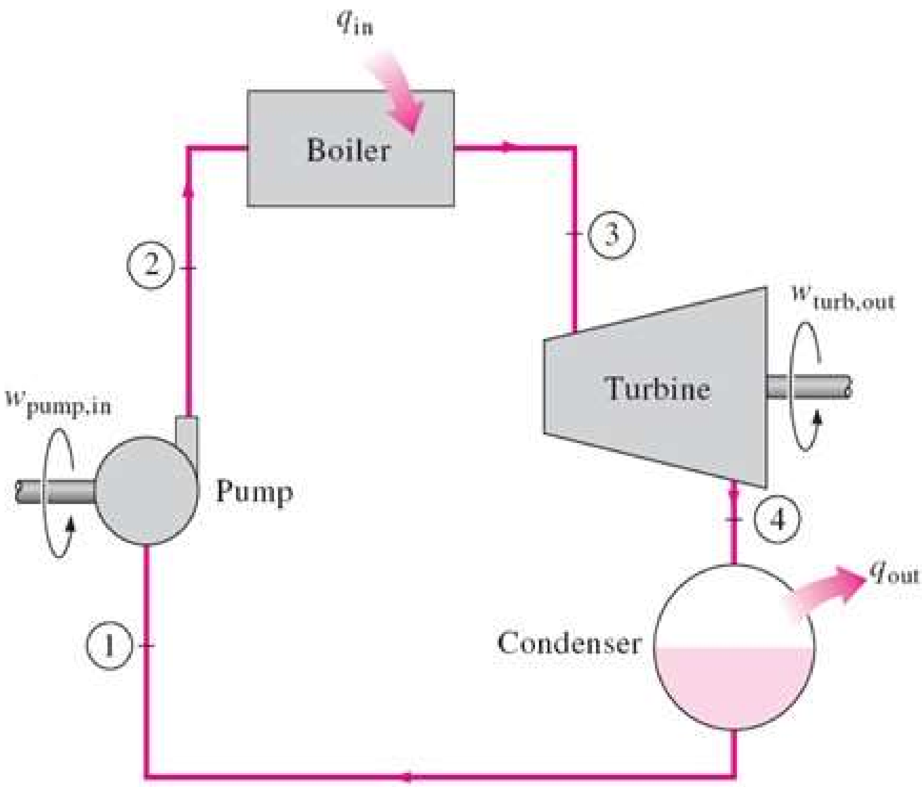
The Rankine Cycle

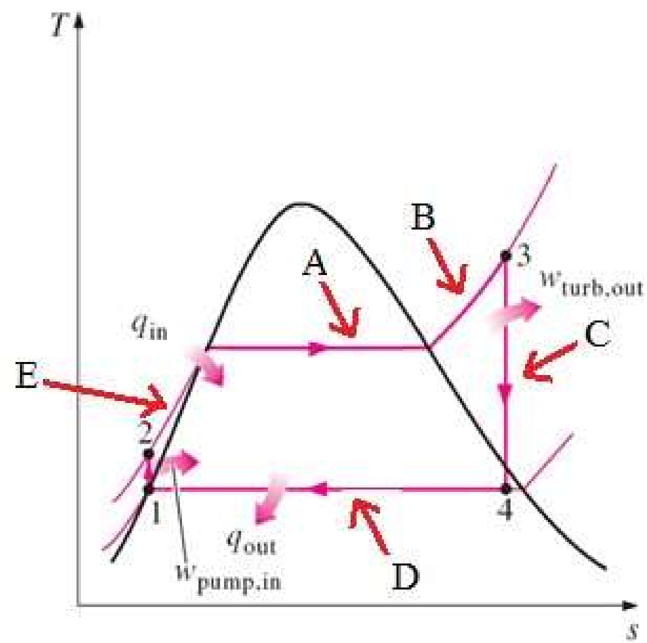




The steam leaving the boiler may be dry and saturated, wet or superheated. The corresponding T-s diagrams are 1-2-3-4-1; 1-2-3’-4’-1 or 1-2-3”-4”-1.

THE RANKINE CYCLE





THE RANKINE CYCLE

- In this cycle, water is heated in the steam generator to produce high temperature and pressure steam, ***superheated steam***.
- This steam is then expanded in a turbine to produce electricity from a generator that is connected to the turbine.
- The steam from the turbine is then condensed back into water in the condenser.
- The pump then returns the water to the steam generator.

The Rankine Cycle

Figure 1 shows a temperature-entropy diagram or T-s diagram.

- Entropy is basically a measure of the amount of thermal energy notavailable to do work.
- The total area under the T-s diagram represents the work done during thecomplete cycle.
- The heat added to the water in the heating cycle causes the water to turn to steam , expanding greatly at high pressure and in turn doing work in turning the turbine.

THE RANKINE CYCLE

The stages in the Rankine Cycle (Fig. 1) are :-

- E – the cold water is heated to boiling point
- A – heat, qin is added to the water in the boiler at constant temperature converting itto steam.
- B – more heat is added in a *superheater,* raising the temperature and *pressure* of the steam.
- C – the steam expands through the turbine giving up energy to turn the turbine and losing energy while its temperature drops.
- D – the steam is then cooled in a *condenser,* changing back to water and then *pumped* back into the boiler to continue the cycle.

Thermal Power Plant Efficiency

- The efficiency of thermal generating stations is always low because of the inherent low efficiency of the turbines.
- The maximum efficiency of any machine that converts heat energy into mechanical energy is given by the equation:

$$\eta = (1 - \frac{T_2}{T_1}) \times 100$$

where,

η is the efficiency

T_1 = Temperature of the gas entering the turbine (in Kelvin)

T_2 = Temperature of the gas leaving the turbine (in Kelvin)

BRAYTON CYCLE – GAS TURBINE CYCLE

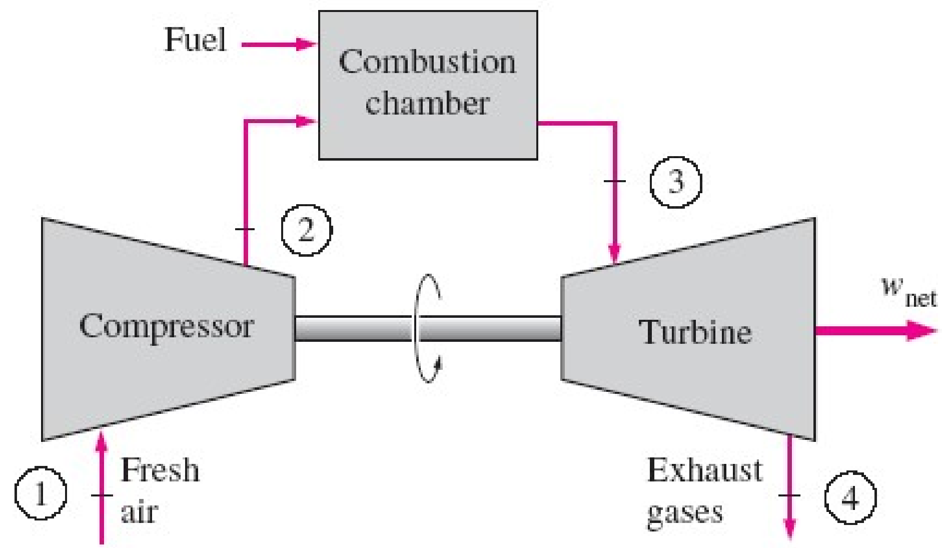
The **Brayton cycle** or **Joule Cycle** is made up of four internally reversible processes:

1-2 Compression

2-3 Heat addition

3-4 Expansion

4-1 Heat rejection



Brayton Cycle – Gas Turbine Cycle

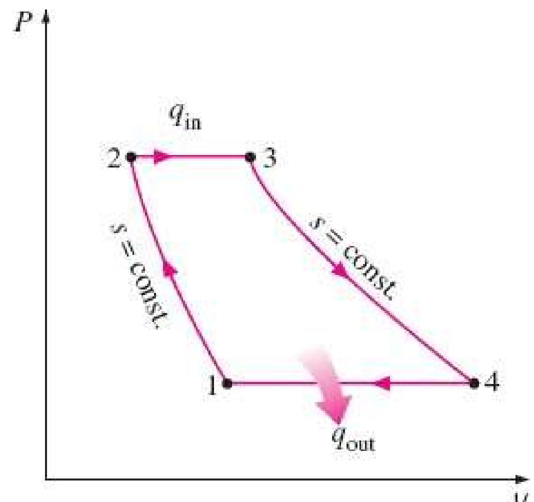
The **Brayton cycle** is made up of four internally reversible processes:

1-2 Isentropic (constant entropy) compression (in a compressor)

2-3 Constant-pressure heat addition

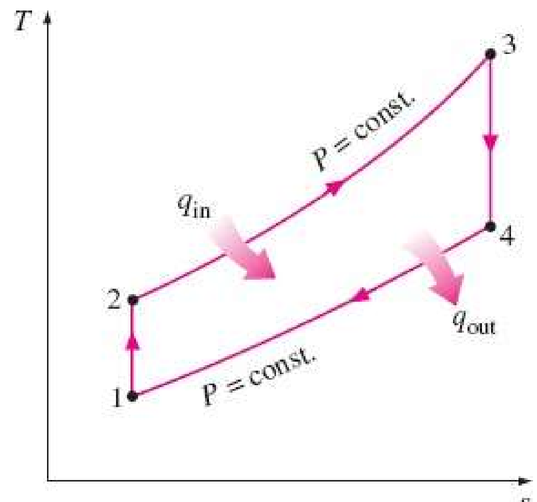
3-4 Isentropic expansion (in a turbine)

4-1 Constant-pressure heat rejection



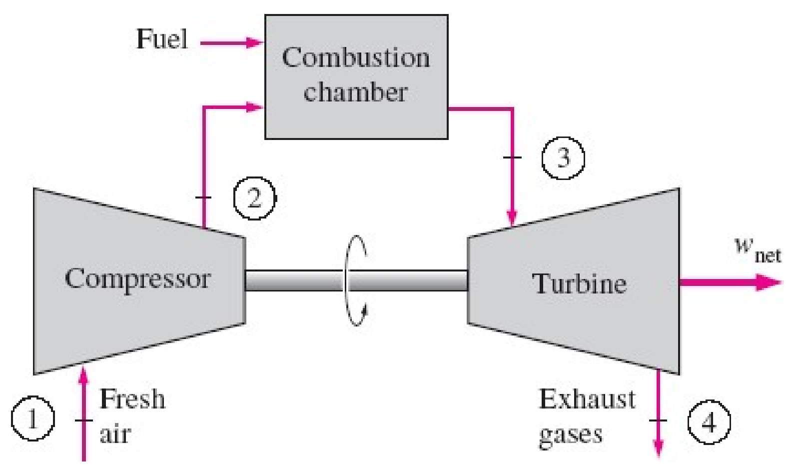
(b) P-v diagram

Pressure vs. Volume



(a) T-s diagram

Temperature vs. Entropy



Overall Thermal Efficiency

- Useful Work = Energy released in turbine minus energy absorbed by compressor.
- The compressor requires typically approximately 30% - 50% of the energy released by the turbine.

$$Overall\ Thermal\ Efficiency = \frac{Useful\ Work}{Fuel\ Chemical\ Energy} * 100\%$$

- Typical overall thermal efficiency of a combustion turbine is 20% - 40%.

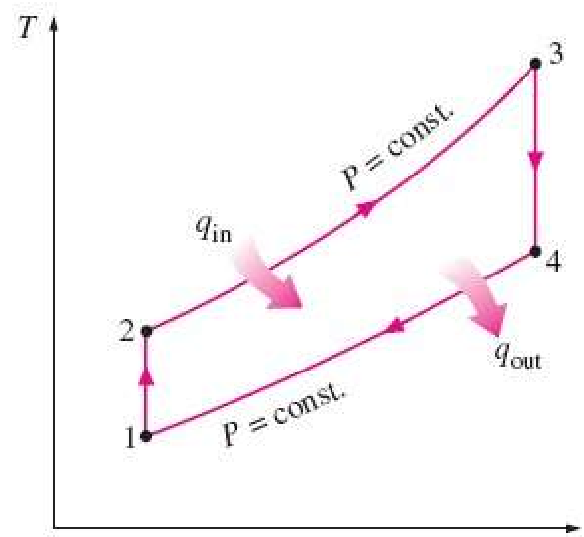
OVERALL THERMAL EFFICIENCY

$$Overall\ Thermal\ Efficiency = \frac{Useful\ Work}{Fuel\ Chemical\ Energy}$$

$$\eta = \frac{P_{net}}{Q_{in}}$$

$$\eta = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

$$\eta = 1 - r^{-0.286}$$



(a) T-s diagram

where r is the compression ratio, and temperatures are in Kelvin.

EXAMPLE 1

A gas turbine has a pressure ratio of 6:1. The inlet temperature to the compressor is 10˚C. The outlet temperature from the compressor is 199.4˚C. The inlet temperature to the turbine is 950˚C. Find:

a) The gas turbine thermal efficiency.

b) The outlet temperature from the turbine.

c) The net output power if the inlet heat power is 150.8 MW.

EXAMPLE 1

A gas turbine has a pressure ratio of 6:1. The inlet temperature to the compressor is 10˚C. The outlet temperature from the compressor is 199.4˚C. The inlet temperature to the turbine is 950˚C. Find:

a) The gas turbine cycle thermal efficiency.

$$\eta = 1 - r^{-0.286}$$

$$\eta = 40\%$$

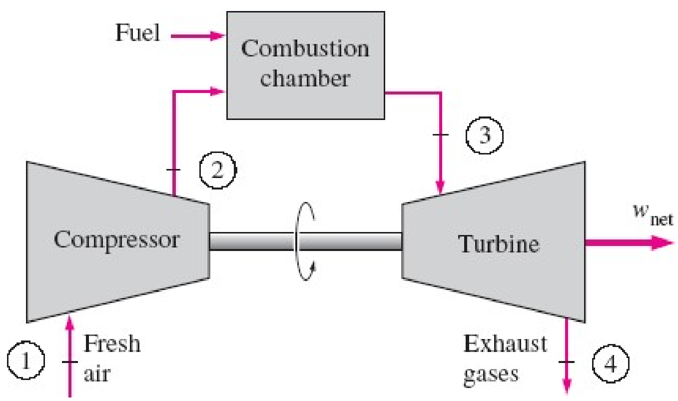
EXAMPLE 1

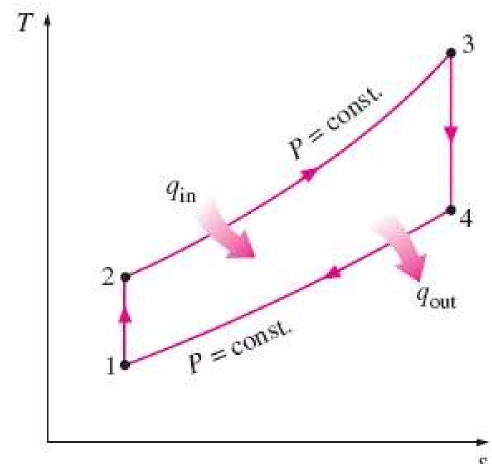
A gas turbine has a pressure ratio of 6:1. The inlet temperature to the compressor is 10˚C. The outlet temperature from the compressor is 199.4˚C. The inlet temperature to the turbine is 950˚C. Find:

a) The gas turbine thermal efficiency. $\eta = 40\%$

b) The outlet temperature from the turbine.

$$\eta = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$





(a) T-s diagram

EXAMPLE 1

A gas turbine has a pressure ratio of 6:1. The inlet temperature to the compressor is 10˚C. The outlet temperature from the compressor is 199.4˚C. The inlet temperature to the turbine is 950˚C. Find:

a) The gas turbine thermal efficiency. $\eta = 40\%$

b) The outlet temperature from the turbine.

T_1 = 10+273 = 283 K
T_2 = 199.4+273 = 472.4 K
T_3 = 950+273 = 1223 K

$$\eta = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

→ T_4 = 733.36 K = 460.36 ˚C.

Example 1

A gas turbine has a pressure ratio of 6:1. The inlet temperature to the compressor is 10˚C. The outlet temperature from the compressor is 199.4˚C. The inlet temperature to the turbine is 950˚C. Find:

a) The gas turbine thermal efficiency. $\eta = 40\%$

b) The outlet temperature from the turbine.

$T_4 = 733.36$ K = 460.36 ˚C.

c) The net output power if the inlet heat power is 150.8 MW.

$Q_{in} = 150.8$ MW

$$\eta = \frac{P_{net}}{Q_{in}} \rightarrow P_{net} = 60.32 \text{ MW}$$

COGENERATION

COGENERATION

- Cogeneration is the simultaneous production of various forms of energy from one power source (normally associated with heat and power-mechanical or electrical).
- The engine produces primary electrical power whereas thermal energy in the exhaust gases is converted in the heat recovery boiler Heat Recovery Boiler into steam. This process steam could be used in another application such as heating the sea water in the desalination units.

COGENERATION

- A Cogeneration Plant
  - Power generation facility that also provides thermal energy (steam) to a thermal host.
- Typical thermal hosts
  - water desalination plant
  - paper mills,
  - chemical plants,
  - refineries, etc…
  - potentially any user that uses large quantities of steam on a continuous basis.