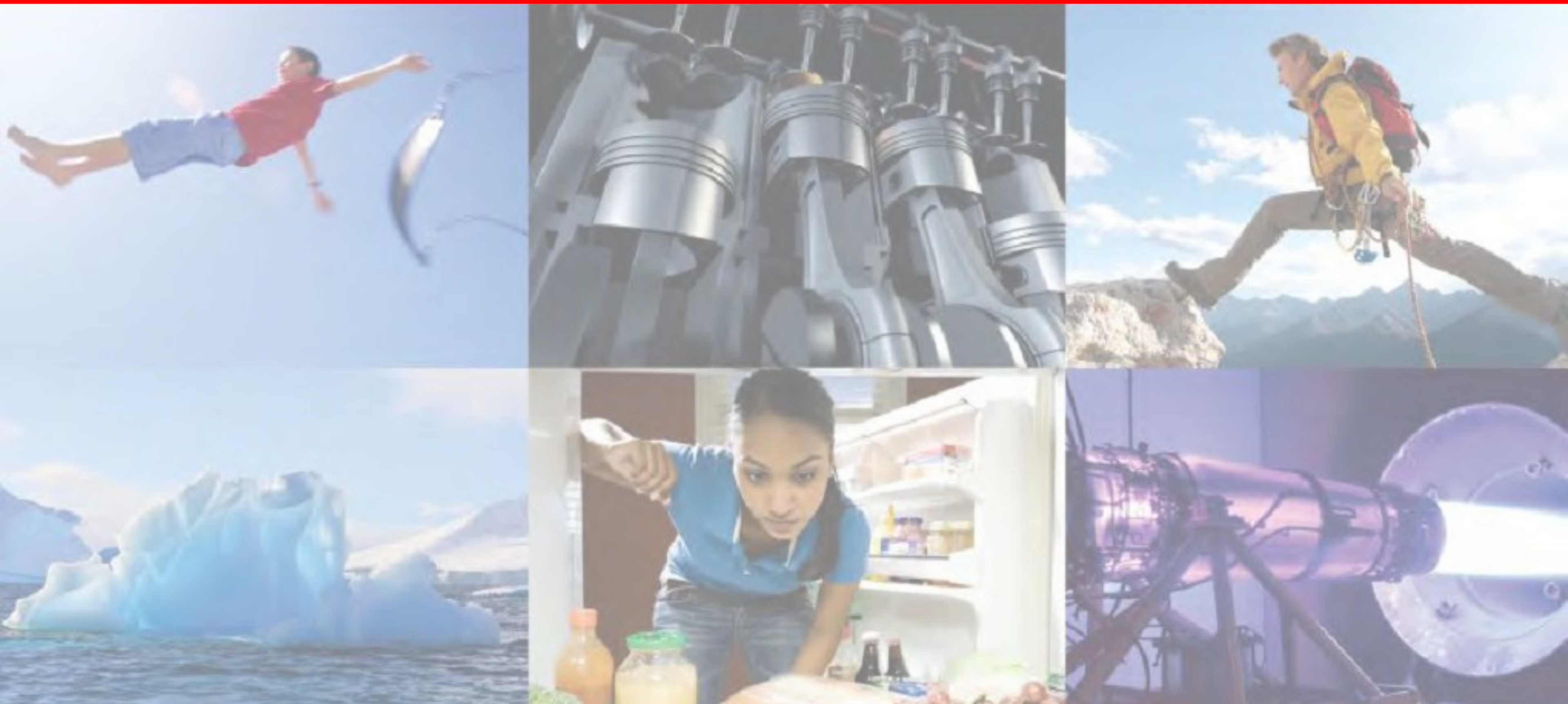


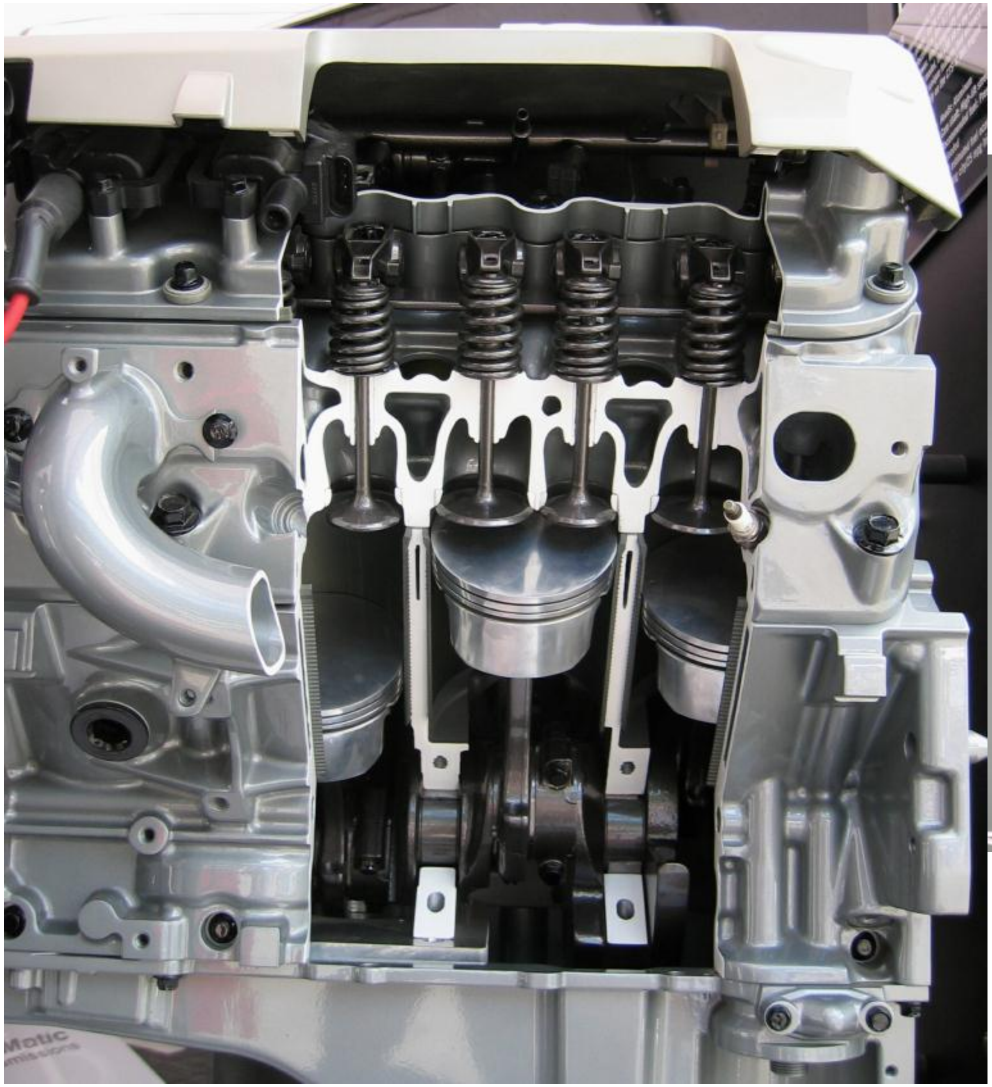
Gas Power System

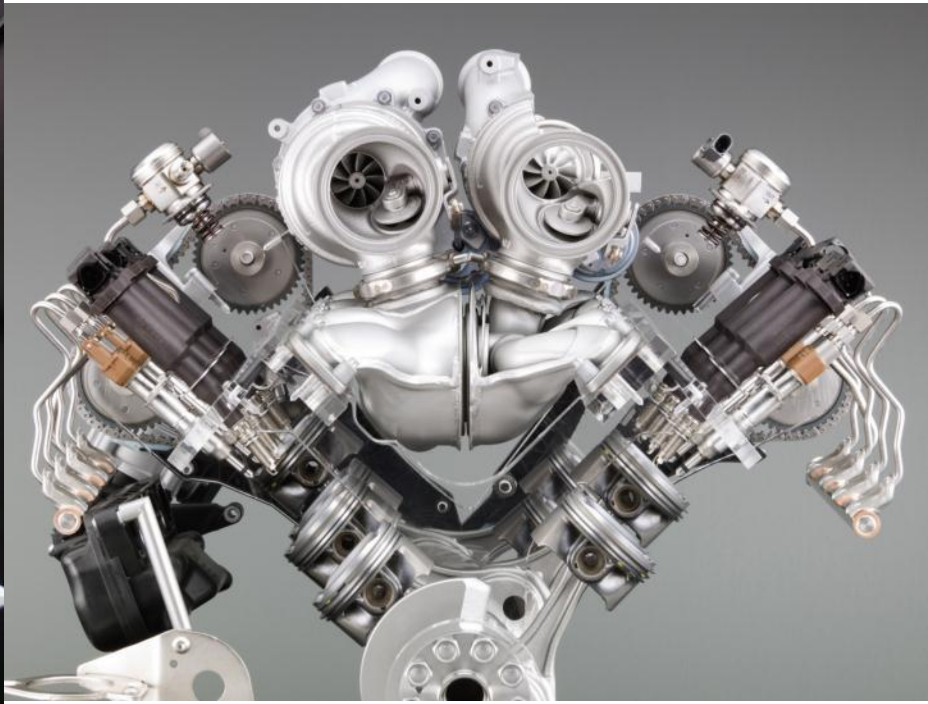
By Ertanto Vetra

Outlines

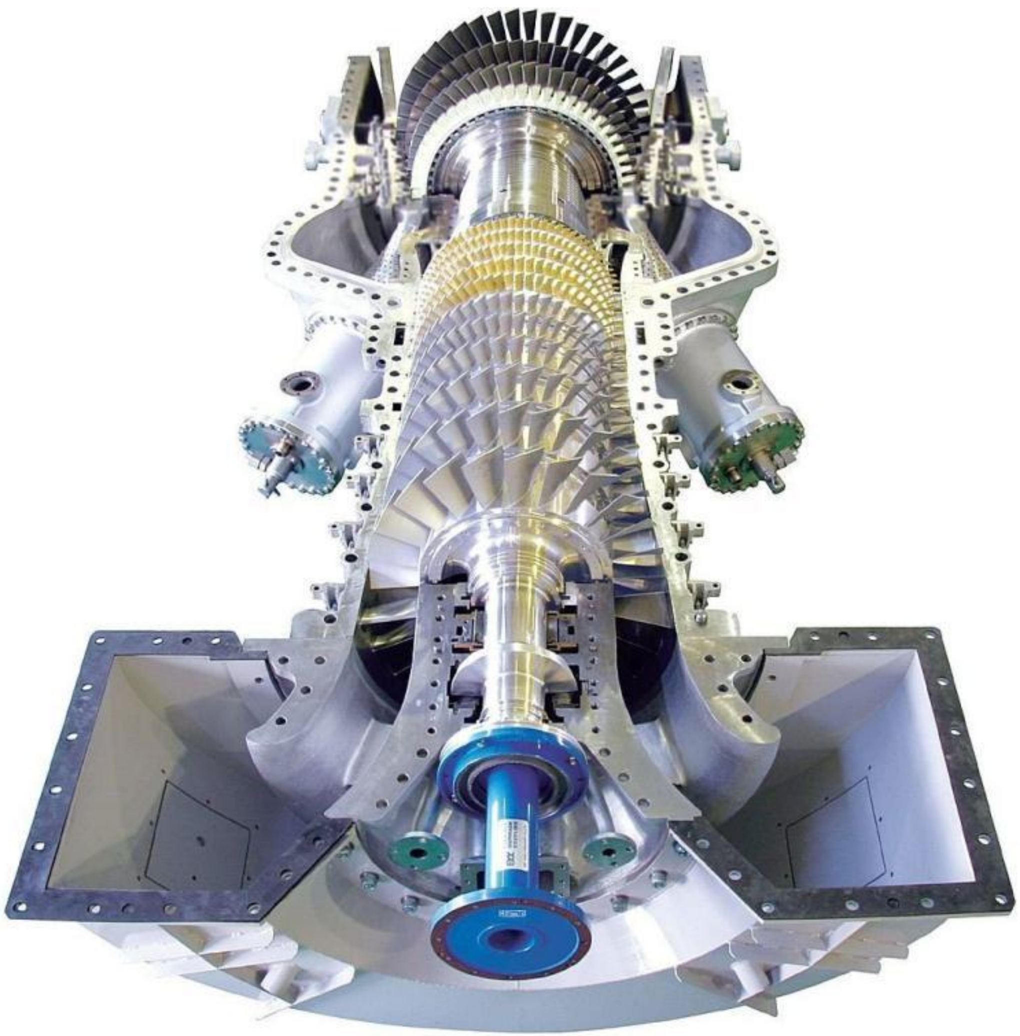
- Introduction
- Internal Combustion Engines
  - Otto Cycles
  - Diesel Cycles
- Gas Turbine Cycles
- Gas Turbine Based Combined Cycles
- Gas Turbines for Aircrafts – Turbojets

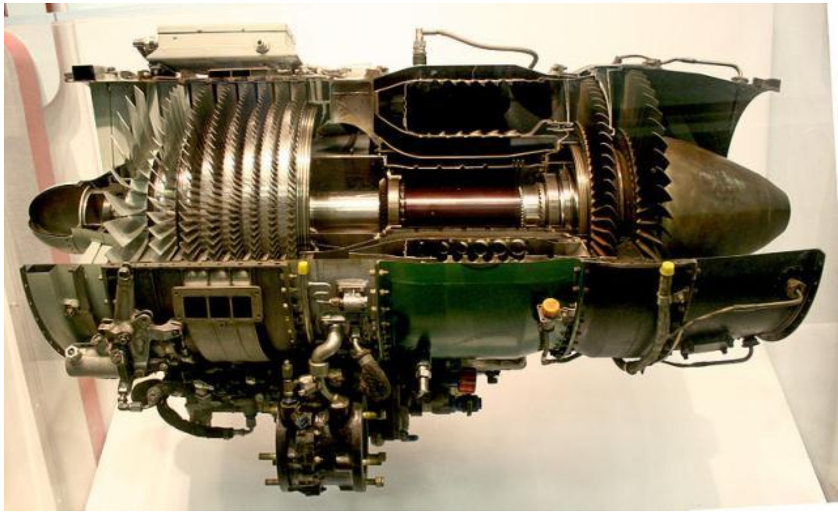
Introduction





Introduction

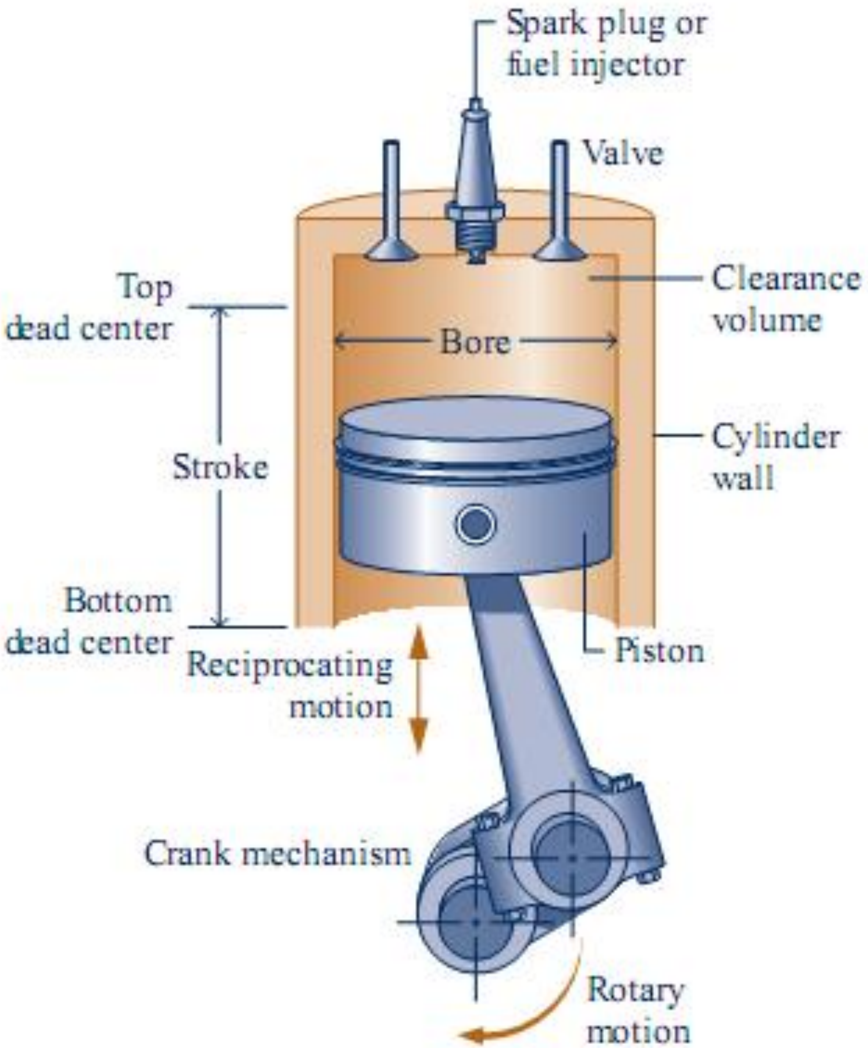


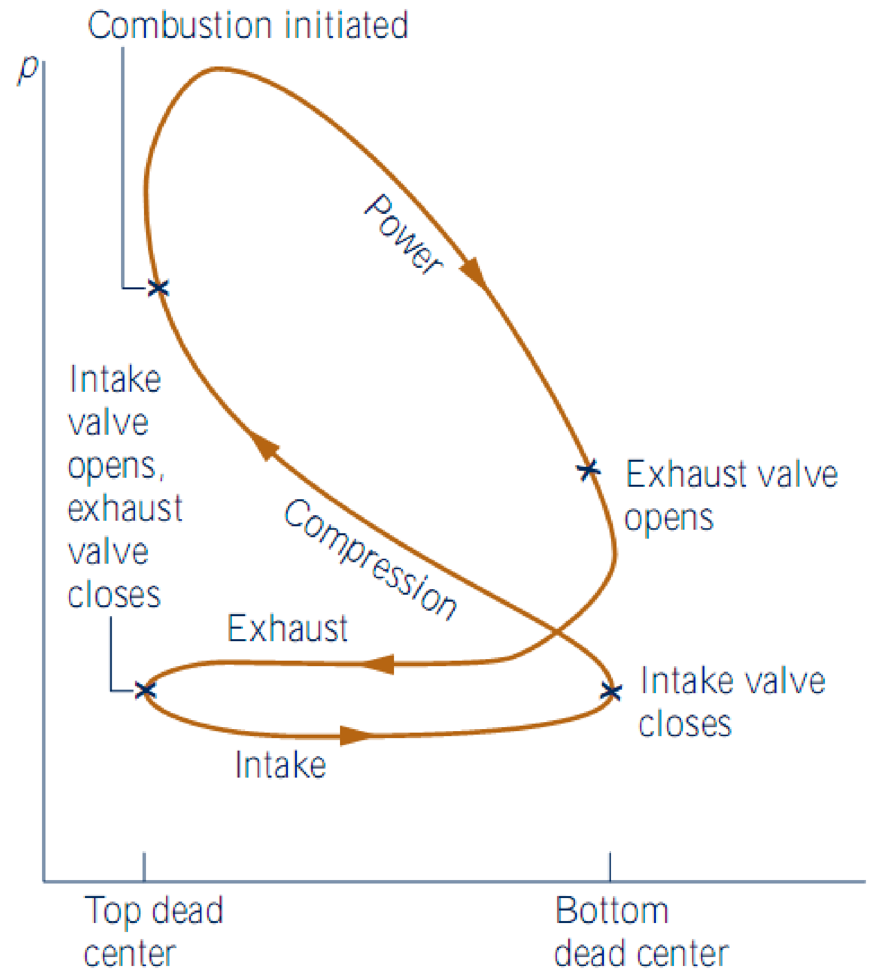


Internal Combustion Engines

- Although most gas turbines are also internal combustion engines, the name is usually applied to reciprocating internal combustion engines of the type commonly used in automobiles, trucks, and buses.
- These engines differ from the power plants because the processes occur within reciprocating piston–cylinder arrangements and not in interconnected series of different components.
- Two principal types of reciprocating internal combustion engines are:
  - the spark ignition engine, and
  - the compression-ignition engine

Terminologies

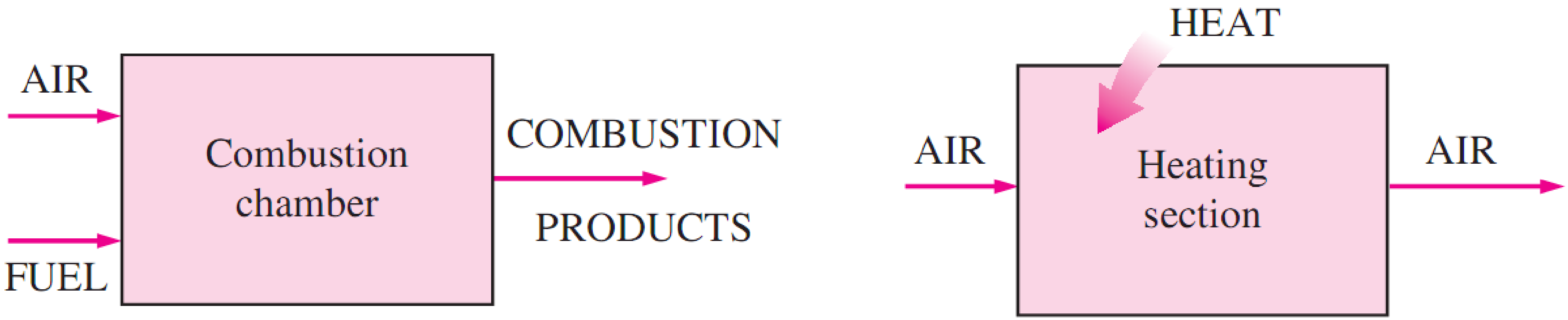




Two Stroke Engines

Four Stroke Engines

Air Standard Analysis

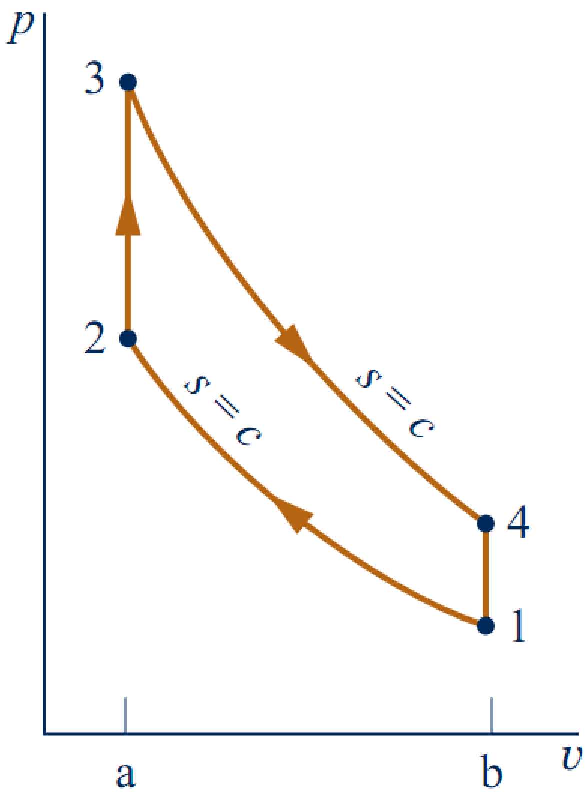


(*a*) Actual (*b*) Ideal

1. A fixed amount of air modeled as an ideal gas is the working fluid.
2. The combustion process is replaced by a heat transfer from an external source.
3. There are no exhaust and intake processes as in an actual engine. The cycle is completed by a constant volume heat transfer process taking place while the piston is at the bottom dead center position.
4. All processes are internally reversible.

In addition, in a **cold air-standard analysis**, the specific heats are assumed constant at their ambient temperature values.

Air Standard Otto Cycles



Process 1–2

isentropic compression of the air as the piston moves from bottom dead center to top dead center.

Process 2–3

constant-volume heat transfer to the air from an external source while the piston is at top dead center. This process is intended to represent the ignition of the fuel–air mixture and the subsequent rapid burning.

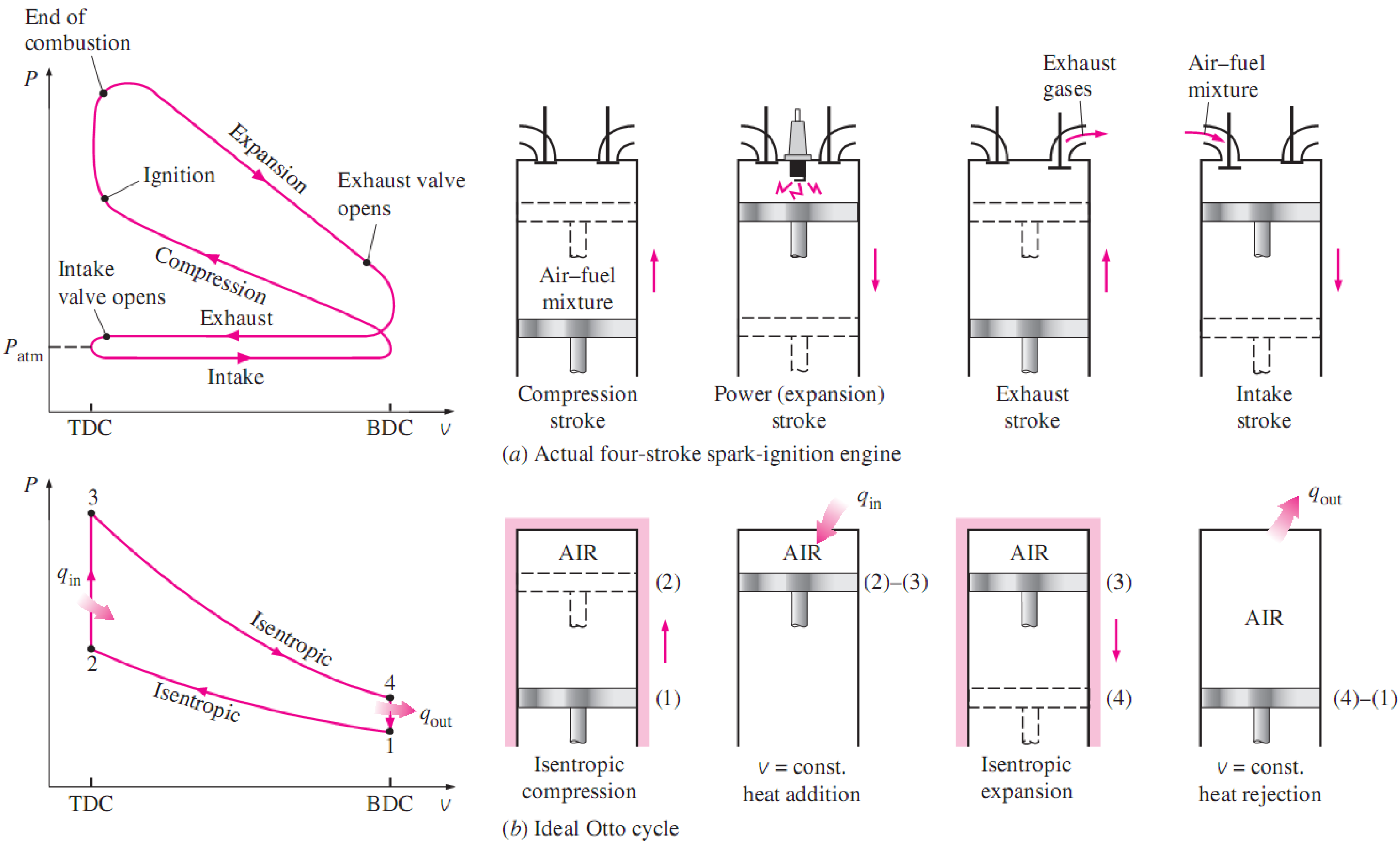
Process 3–4

isentropic expansion (power stroke).

Process 4–1

completes the cycle by a constant-volume process in which heat is rejected from the air while the piston is at bottom dead center.

Actual vs. Ideal Otto Cycle



(*a*) Actual four-stroke spark-ignition engine

(*b*) Ideal Otto cycle

Deviations from ideal cycle

1. The specific heats of the actual gases increase with an increase in temperature.
2. The combustion process replaces the heat-transfer process at high temperature, and combustion maybe incomplete.
3. Each mechanical cycle of the engine involves an inlet and an exhaust process and, because of the pressure drop through the valves, a certain amount of work is required to charge the cylinder with air and exhaust the products of combustion.
4. There is considerable heat transfer between the gases in the cylinder and the cylinder walls.
5. There are irreversibilities associated with pressure and temperature gradients.

Otto Cycle Thermal Efficiency

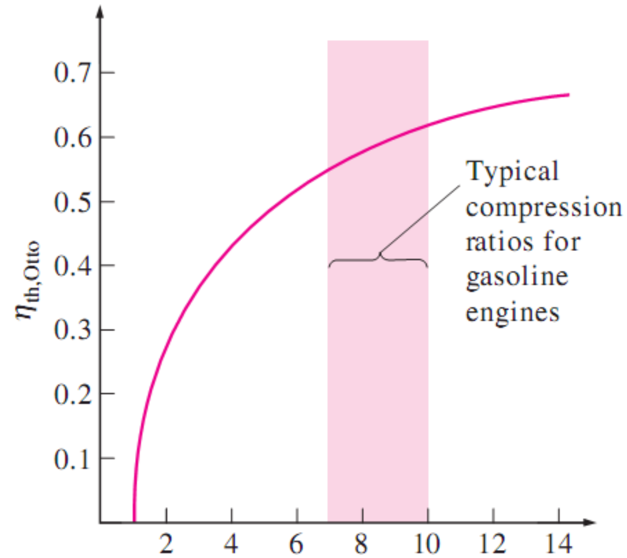
$$\eta = \frac{(u_3 - u_2) - (u_4 - u_1)}{u_3 - u_2} = 1 - \frac{u_4 - u_1}{u_3 - u_2}$$

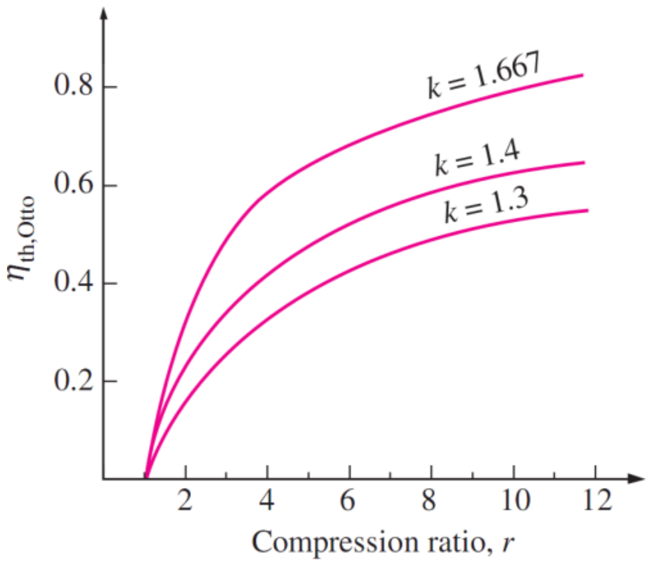
$$\eta = 1 - \frac{1}{r^{k-1}}$$

where

$$\boxed{r = \frac{V_{max}}{V_{min}} = \frac{V_1}{V_2} = \frac{v_1}{v_2}}$$

k is the specific heat ratio c_p/c_v.





Example: Analyzing the Otto Cycle

The temperature at the beginning of the compression process of an air-standard Otto cycle with a compression ratio of 8 is 540 °R, the pressure is 1 atm, and the cylinder volume is 0.02 ft3. The maximum temperature during the cycle is 3600 °R. Determine:

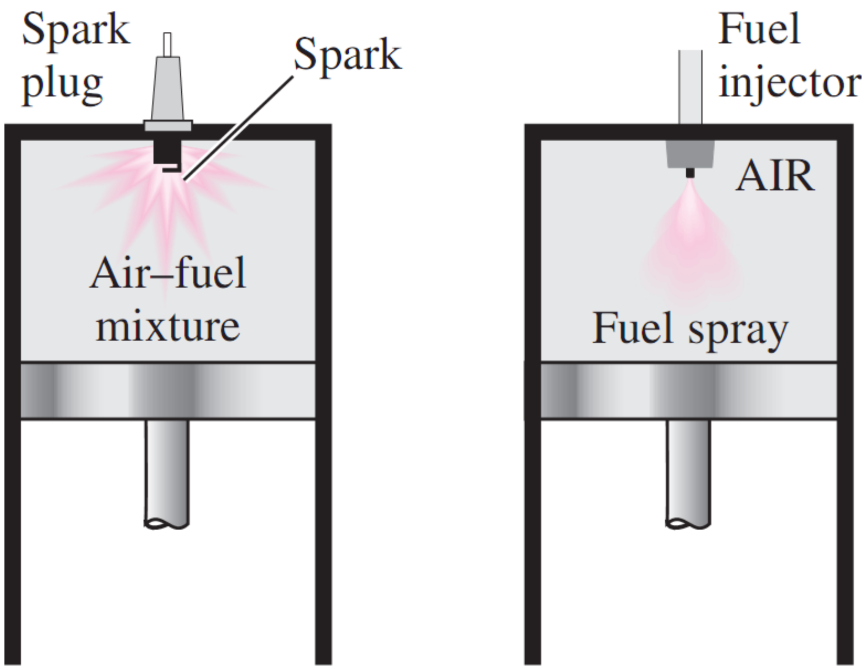
(a) the temperature and pressure at the end of each process of the cycle,

(b) the thermal efficiency, and

(c) the mean effective pressure, in atm

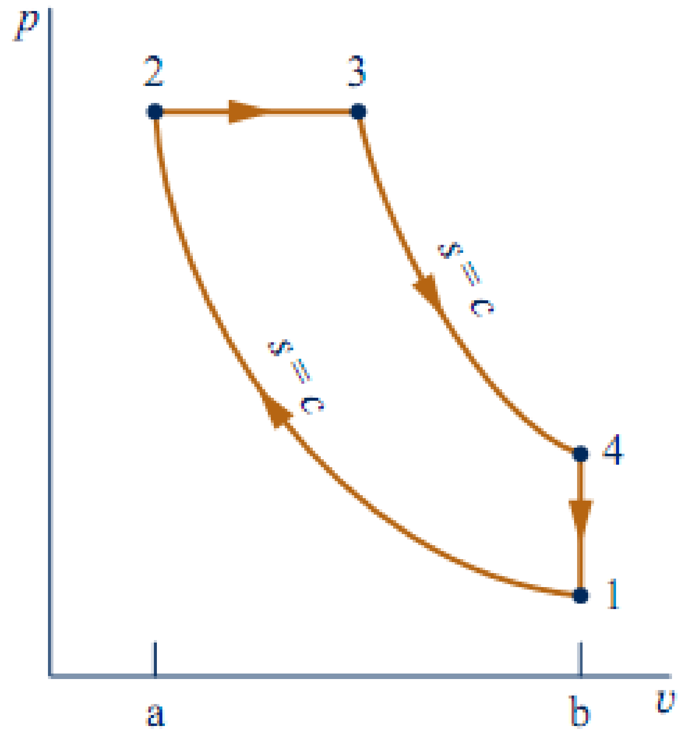
$$\text{mep} = \frac{\text{net work for one cycle}}{\text{displacement volume}}$$

Air Standard Diesel Cycle



Gasoline engine

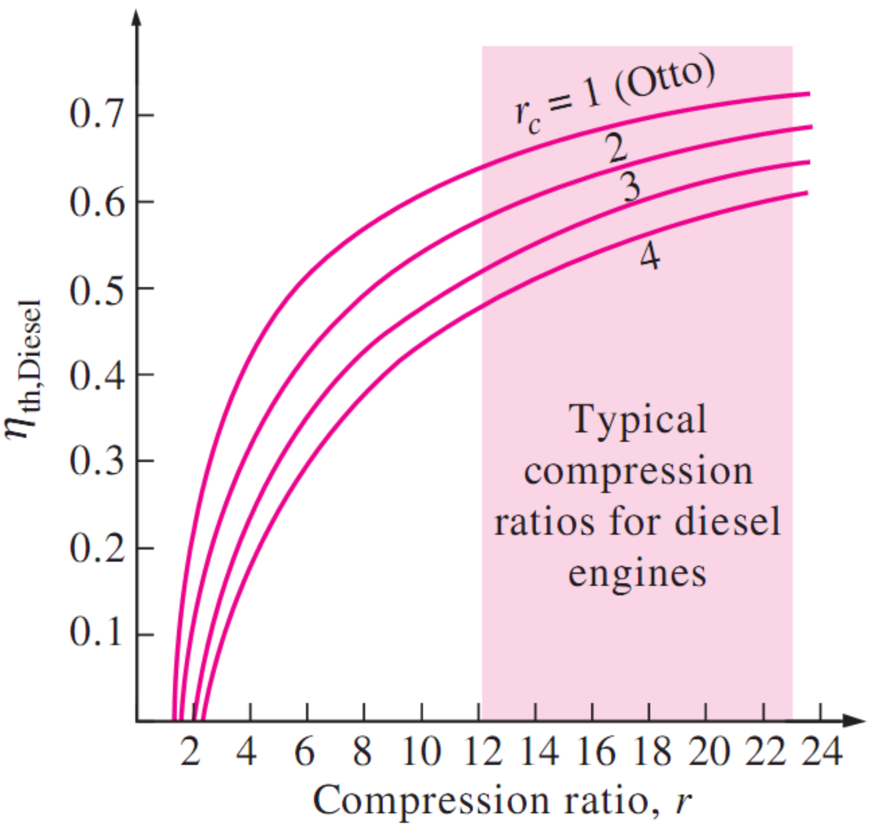
Diesel engine



The only process difference between the Otto and the Diesel cycles is in the combustion process which is isobaric . The remaining three processes are the same for both ideal cycles.

Diesel Cycle Thermal Efficiency

$$\eta = \frac{W_{cycle}/m}{Q_{23}/m} = 1 - \frac{Q_{41}/m}{Q_{23}/m} = 1 - \frac{u_4 - u_1}{h_3 - h_2}$$



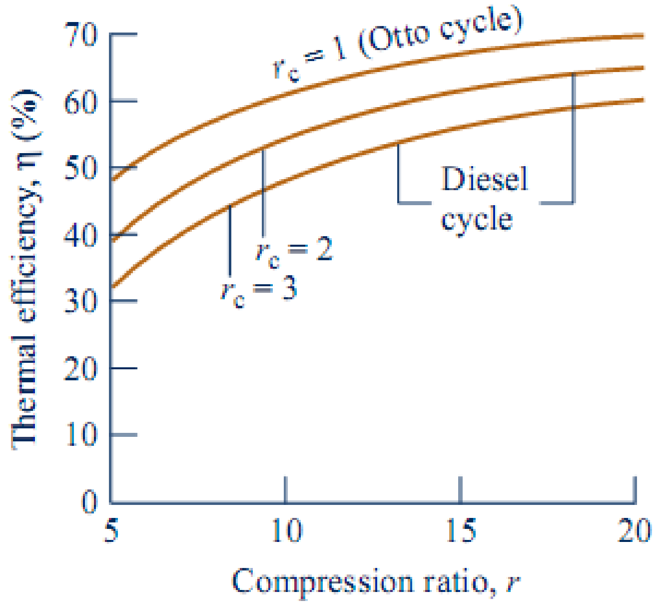


Fig. 9.6 Thermal efficiency of the cold air-standard Diesel cycle, $k = 1.4$.

$$\eta = 1 - \frac{1}{r^{k-1}}\left[\frac{r_c^k - 1}{k(r_c - 1)}\right]$$

where $r_c = V_3/V_2$, called the **cutoff ratio**,

Example: Analyzing the Diesel Cycle

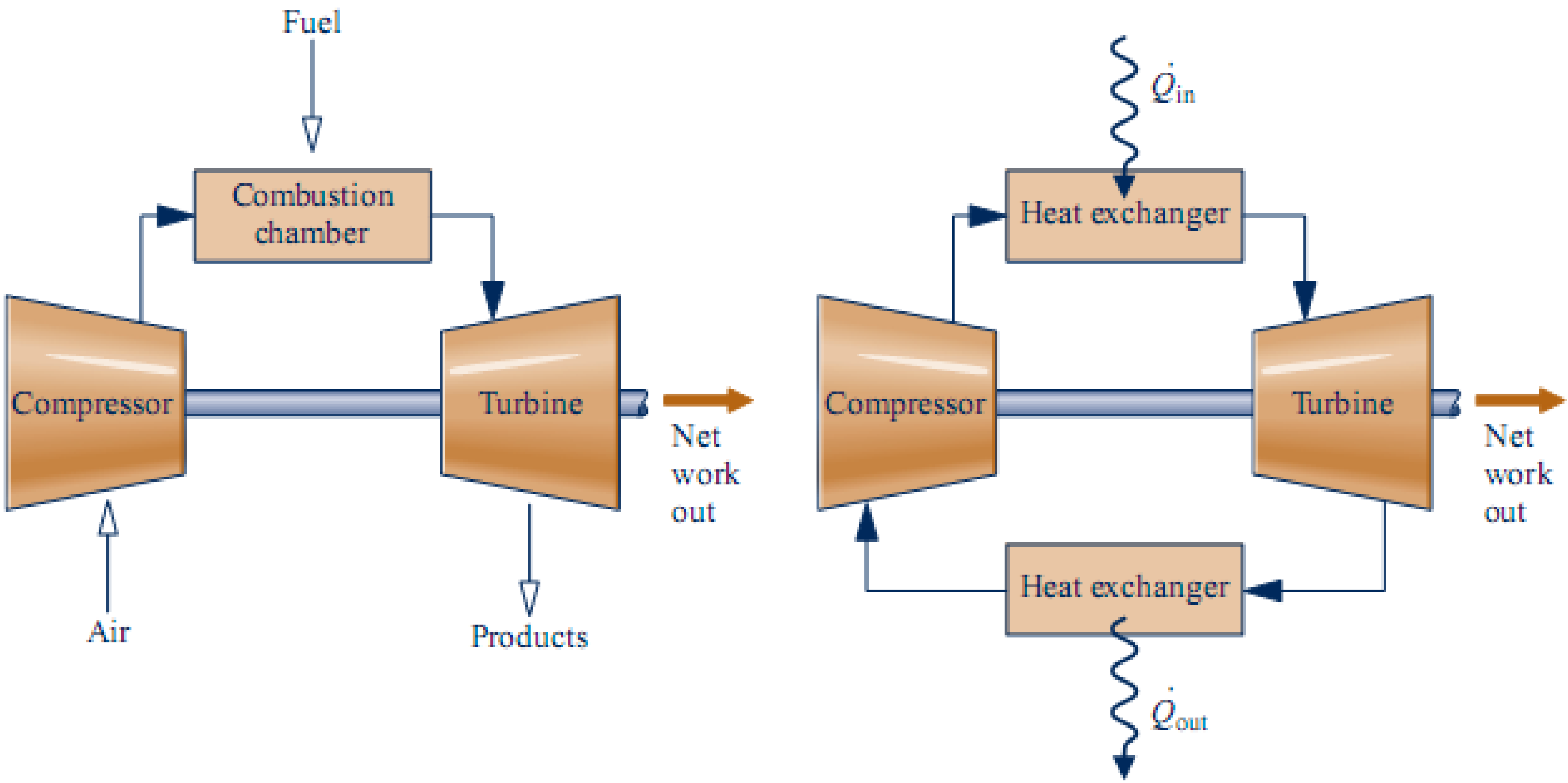
At the beginning of the compression process of an air-standard Diesel cycle operating with a compression ratio of 18, the temperature is 300 K and the pressure is 0.1 MPa. The cutoff ratio for the cycle is 2. Determine:

(a) the temperature and pressure at the end of each process of the cycle,

(b) the thermal efficiency,

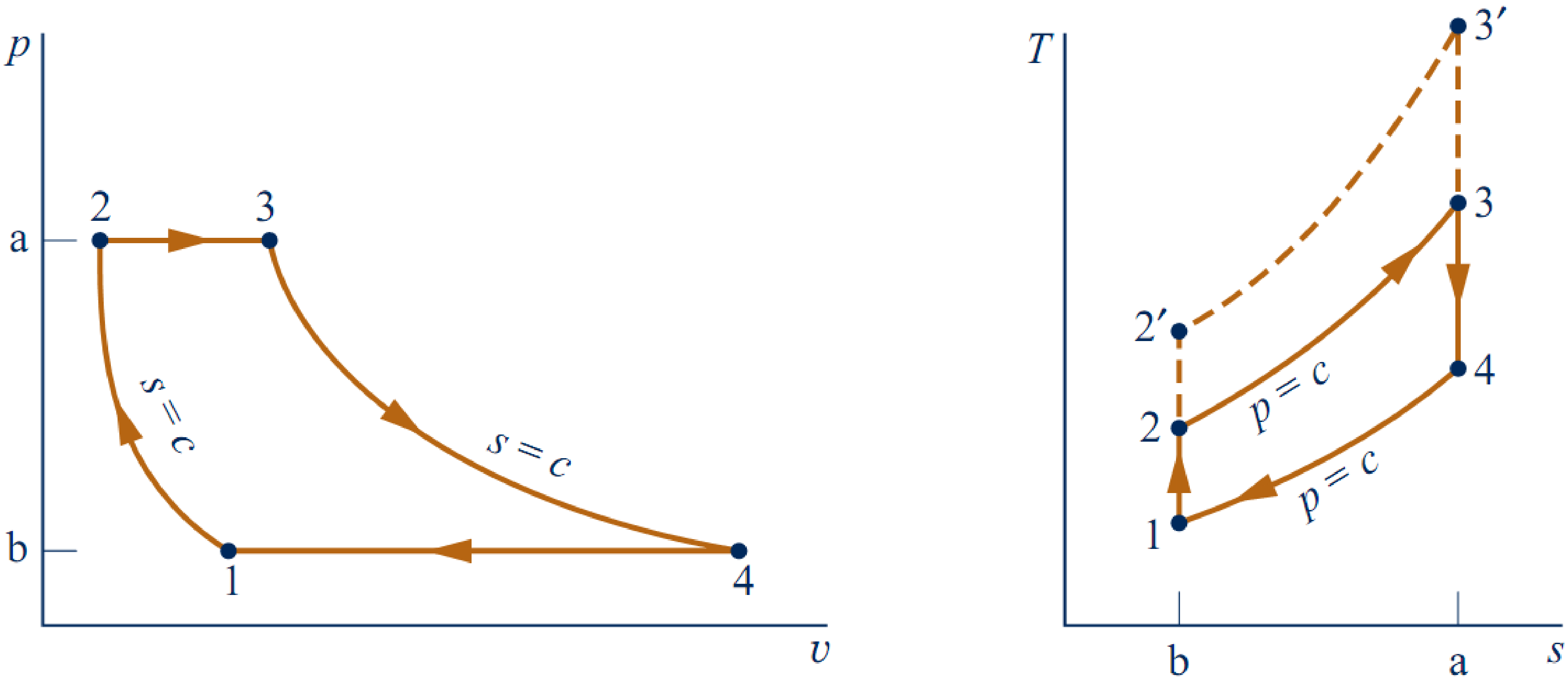
(c) the mean effective pressure, in MPa

Gas Turbine Power Cycle



(*a*) (*b*)

Air Standard Brayton Cycle

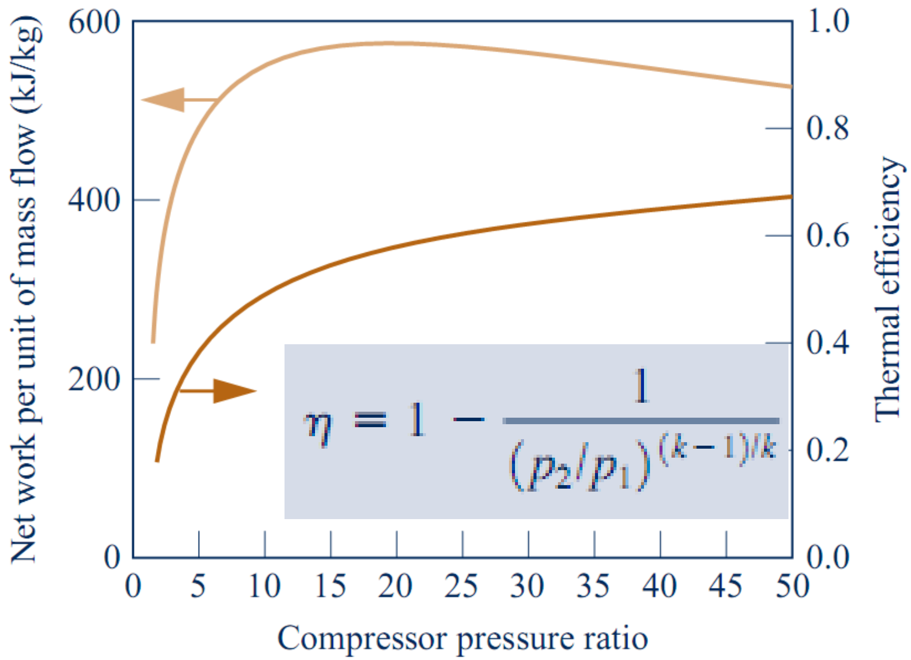


Brayton Cycle Thermal Efficiency

$$\eta = \frac{\dot{W}_t/\dot{m} - \dot{W}_c/\dot{m}}{\dot{Q}_{in}/\dot{m}} = \frac{(h_3 - h_4) - (h_2 - h_1)}{h_3 - h_2}$$

The **back work ratio** for the cycle is

$$\text{bwr} = \frac{\dot{W}_c/\dot{m}}{\dot{W}_t/\dot{m}} = \frac{h_2 - h_1}{h_3 - h_4}$$



$$\eta = 1 - \frac{1}{(p_2/p_1)^{(k-1)/k}}$$

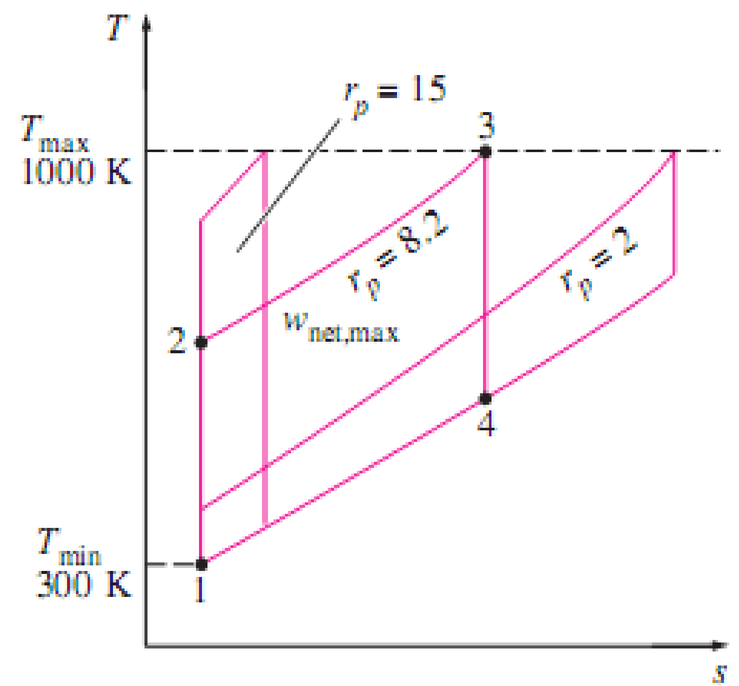


FIGURE 9–33

For fixed values of T_{min} and T_{max}, the net work of the Brayton cycle first increases with the pressure ratio, then reaches a maximum at $r_p = (T_{max}/T_{min})^{k/[2(k-1)]}$, and finally decreases.

Example – Simple Ideal Brayton Cycle

A gas-turbine power plant operating on an ideal Brayton cycle has a pressure ratio of 8. The gas temperature is 300 K at the compressor inlet and 1300 K at the turbine inlet. Utilizing the air-standard assumptions, determine

(a) the gas temperature at the exits of the compressor and the turbine,

(b) the back work ratio, and

(c) the thermal efficiency.

Deviation of Actual Gas-Turbine Cycles

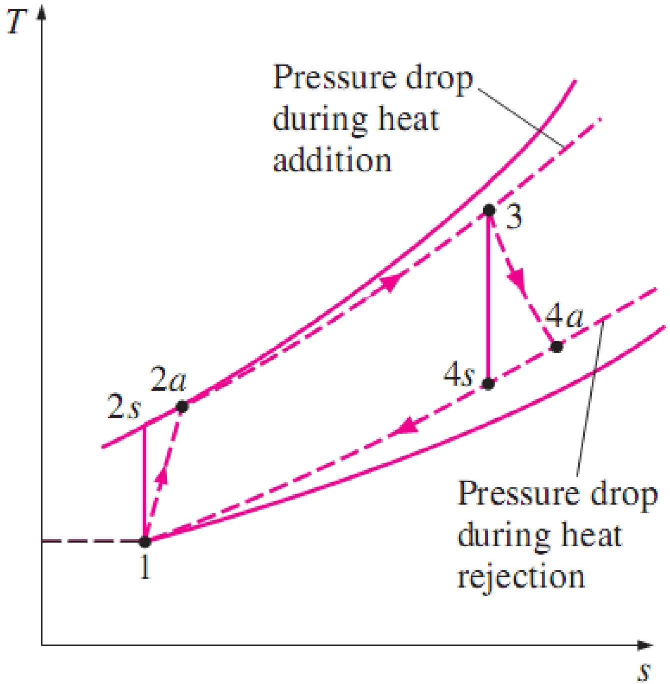


FIGURE 9–36

The deviation of an actual gas-turbine cycle from the ideal Brayton cycle as a result of irreversibilities.

$$\eta_C = \frac{w_s}{w_a} \cong \frac{h_{2s} - h_1}{h_{2a} - h_1}$$

$$\eta_T = \frac{w_a}{w_s} \cong \frac{h_3 - h_{4a}}{h_3 - h_{4s}}$$

Example – Actual Brayton Cycle

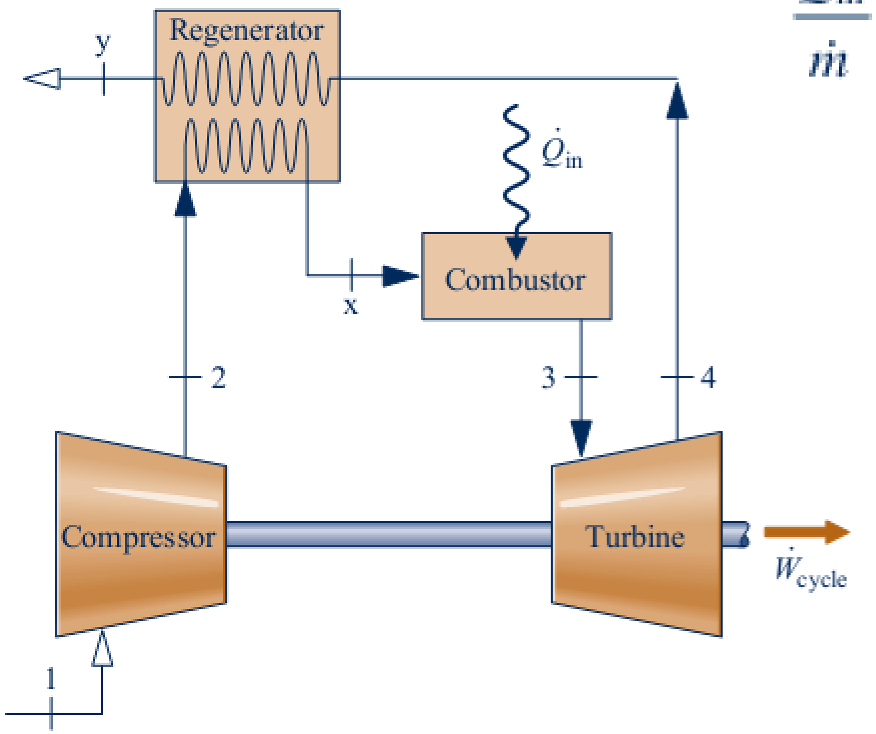
Assuming a compressor efficiency of 80 percent and a turbine efficiency of 85 percent, determine

(a) the back work ratio,

(b) the thermal efficiency, and

(c) the turbine exit temperature of the gas-turbine cycle discussed in previous example

Regenerative Gas Turbine



$$\frac{\dot{Q}_{in}}{\dot{m}} = h_3 - h_x$$

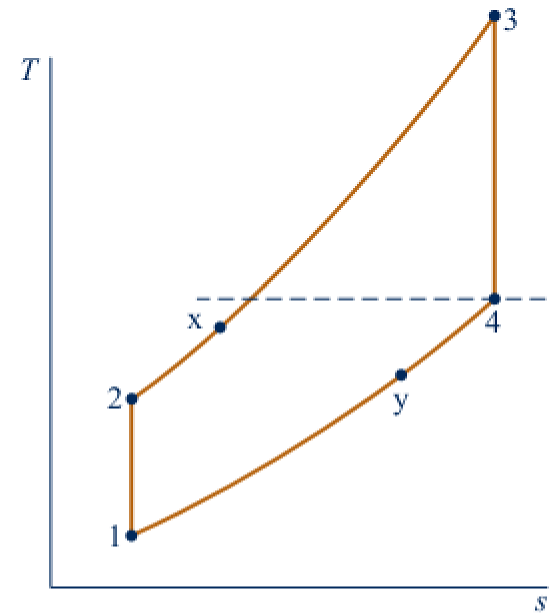
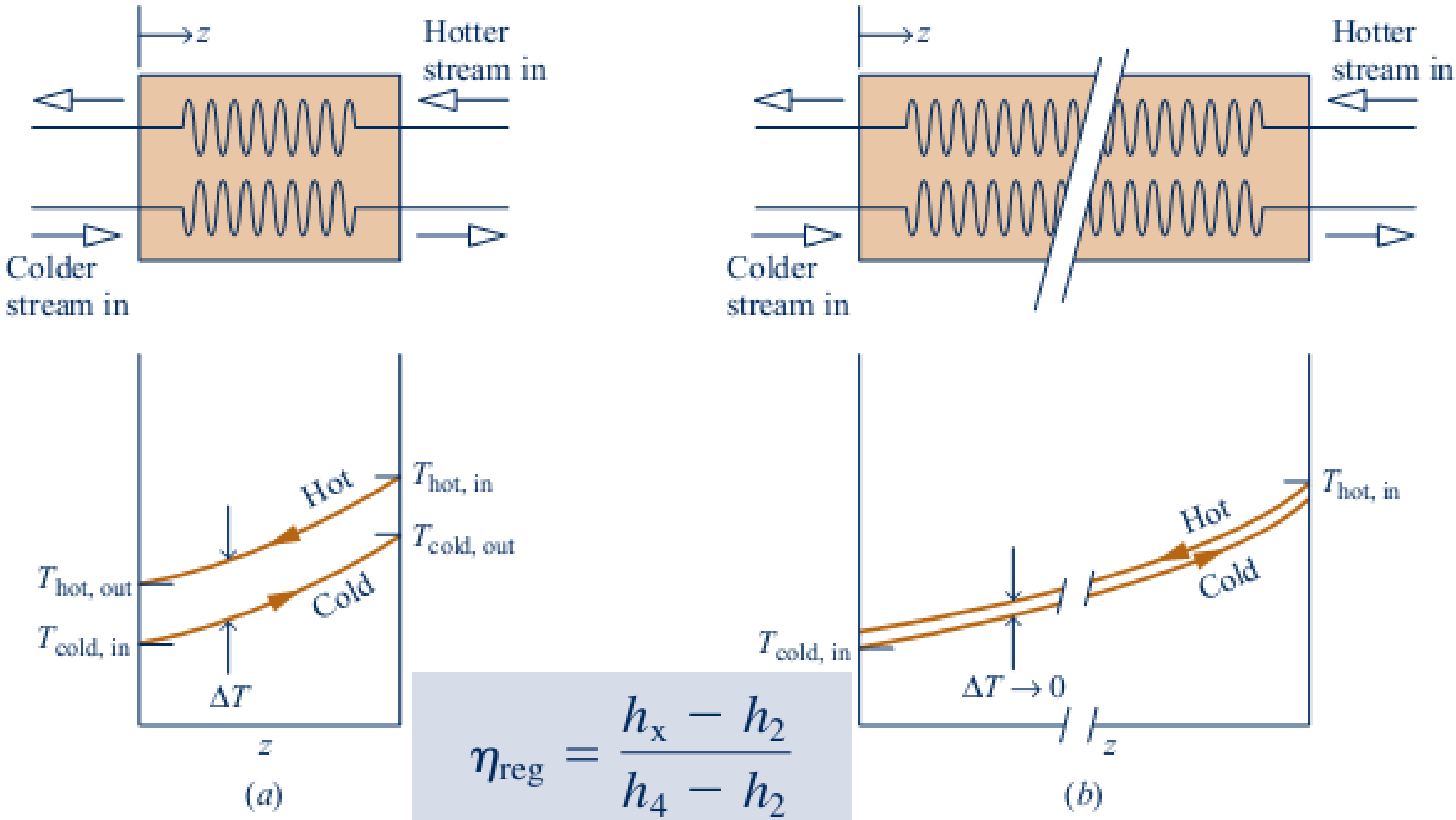


Fig. 9.14 Regenerative air-standard gas turbine cycle.

Regenerator Effectiveness



$$\eta_{reg} = \frac{h_x - h_2}{h_4 - h_2}$$

Fig. 9.15 Temperature distributions in counterflow heat exchangers. (*a*) Actual. (*b*) Reversible.

Gas Turbines with Reheat

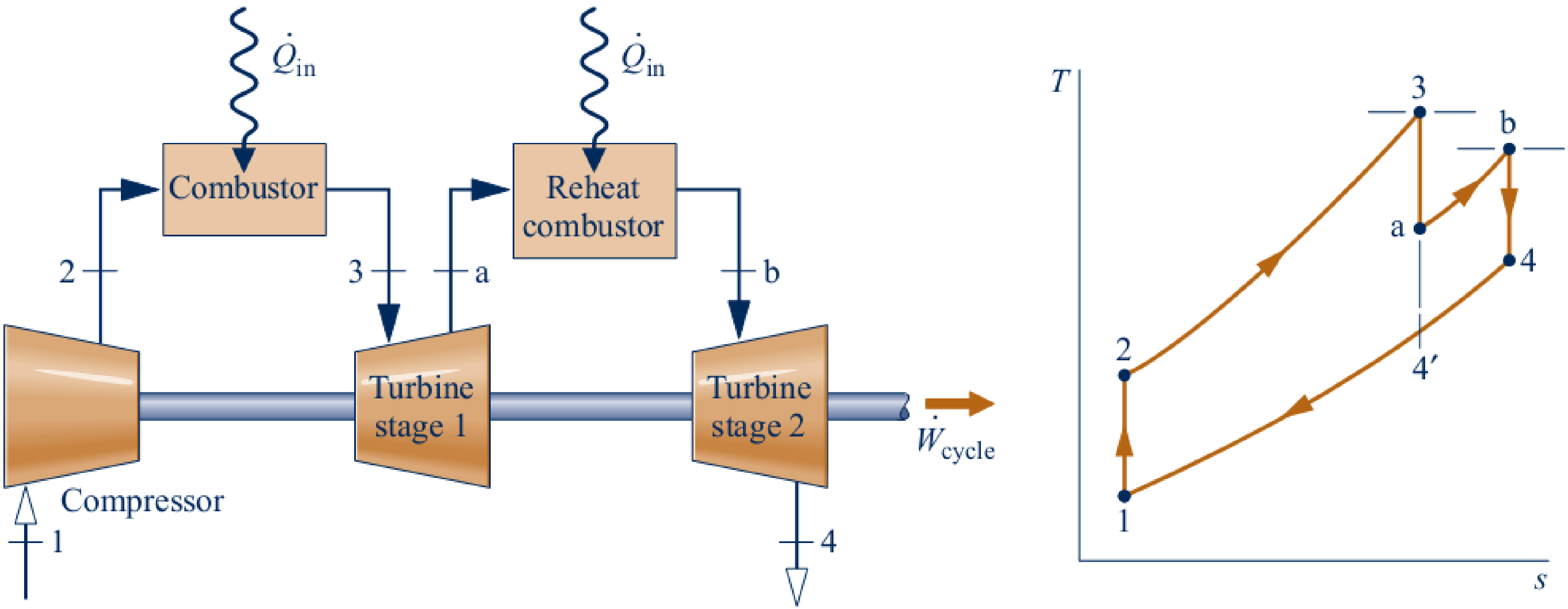
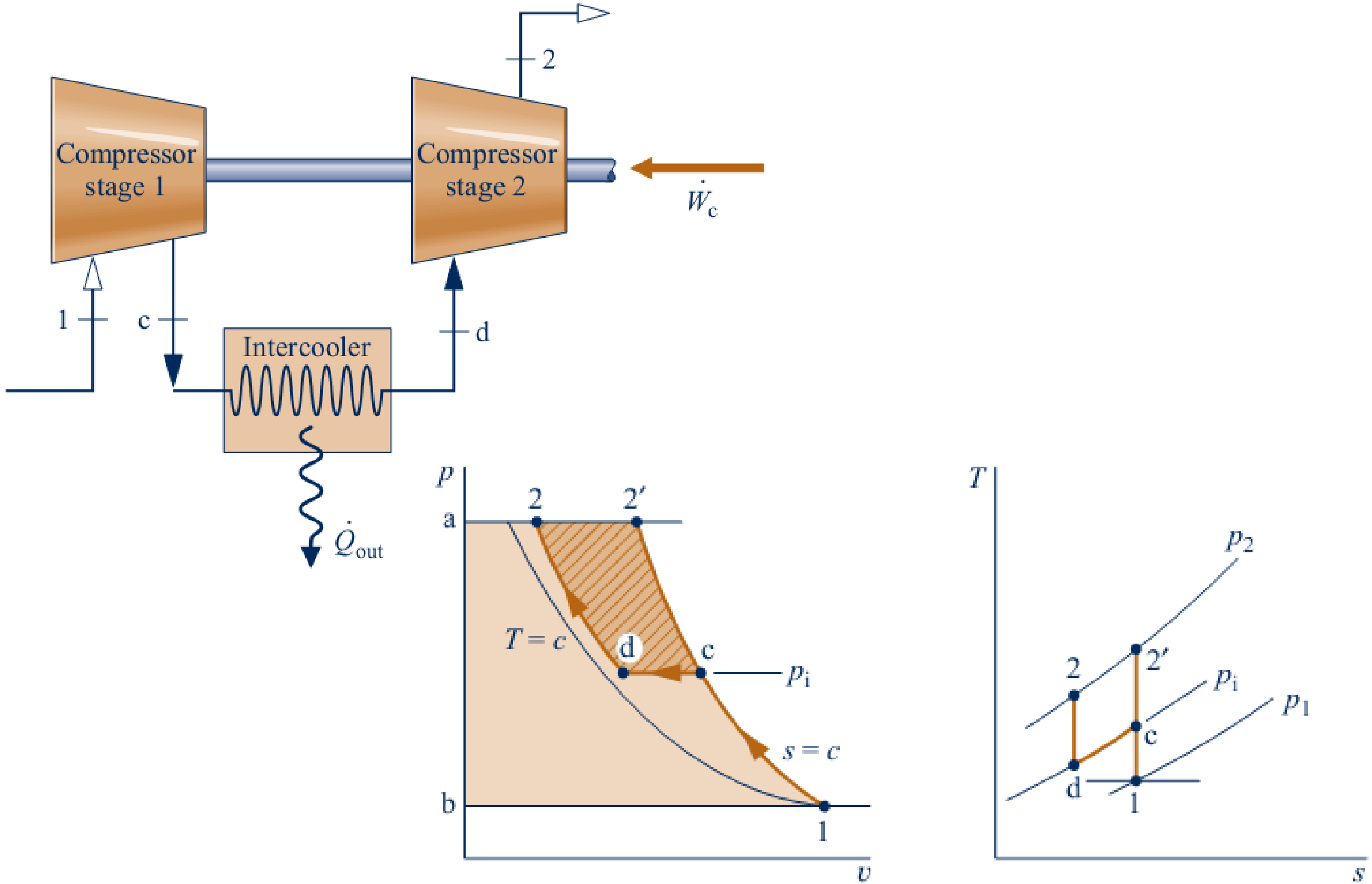


Fig. 9.16 **Ideal gas turbine with reheat.**

Compression with Intercooling



Reheat and Intercooling

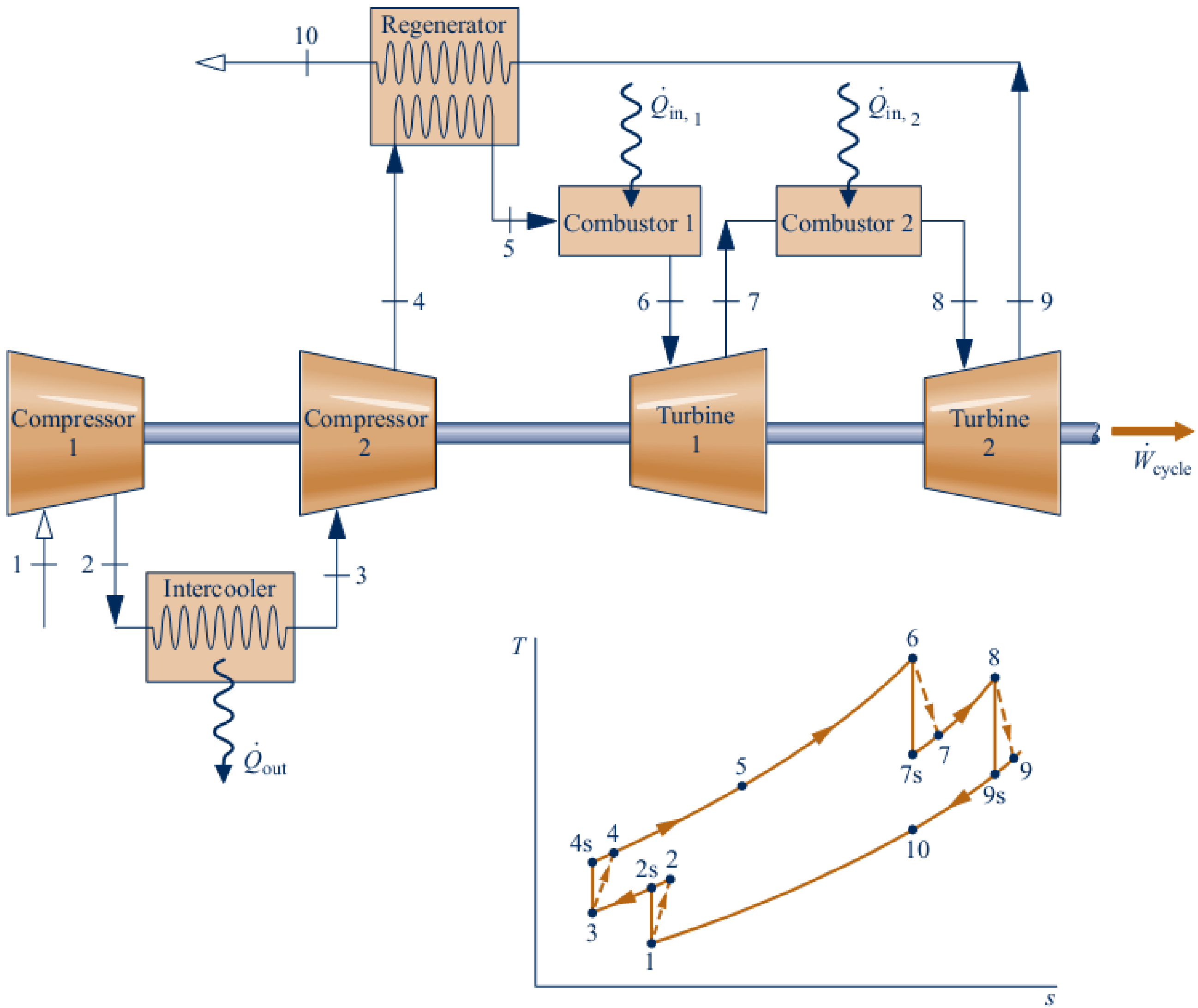
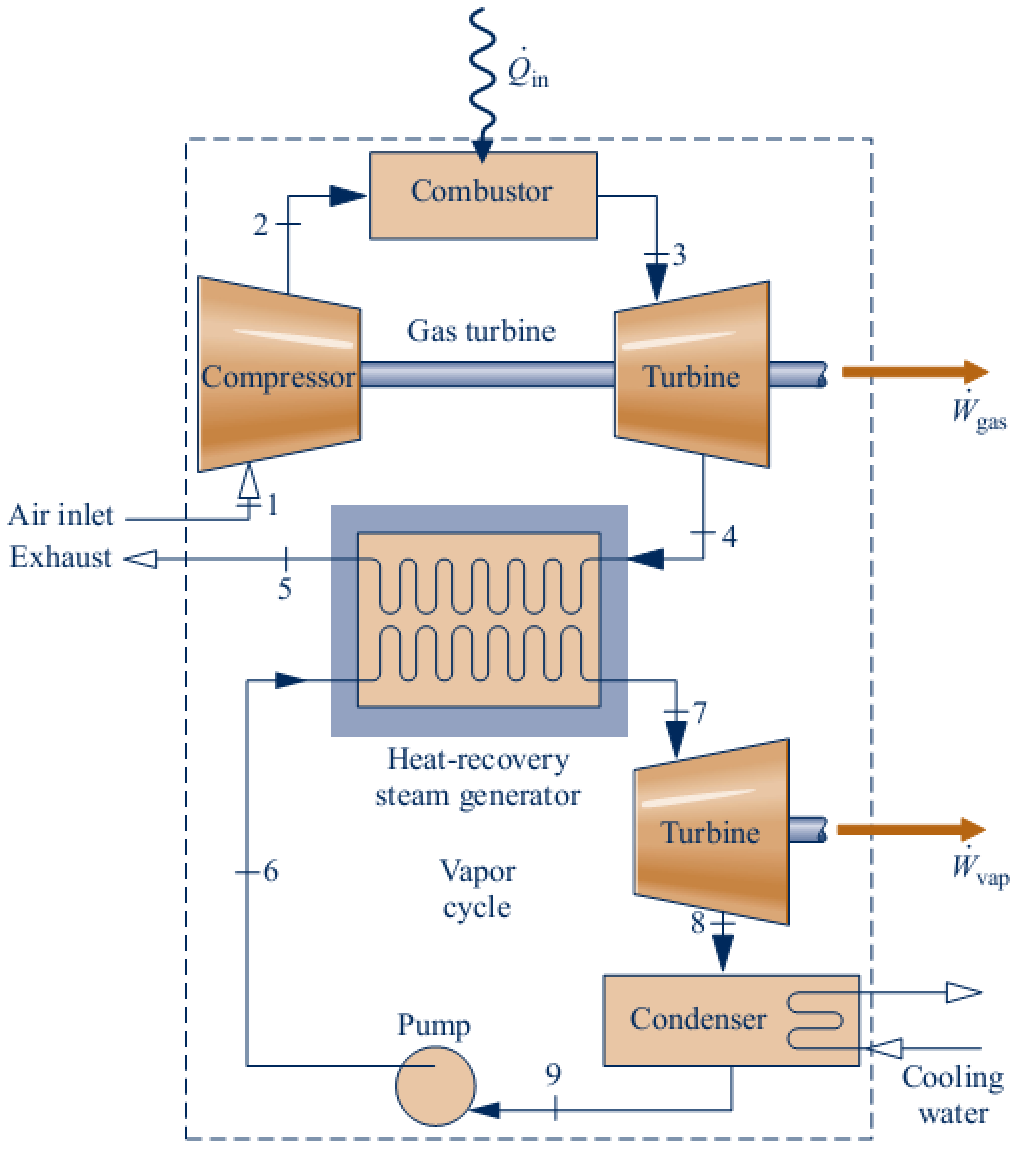


Fig. 9.19 Regenerative gas turbine with intercooling and reheat.

Gas Turbine Based Combined Cycle



IGCC (Integrated Gasification-Combined Cycle) Power Plants

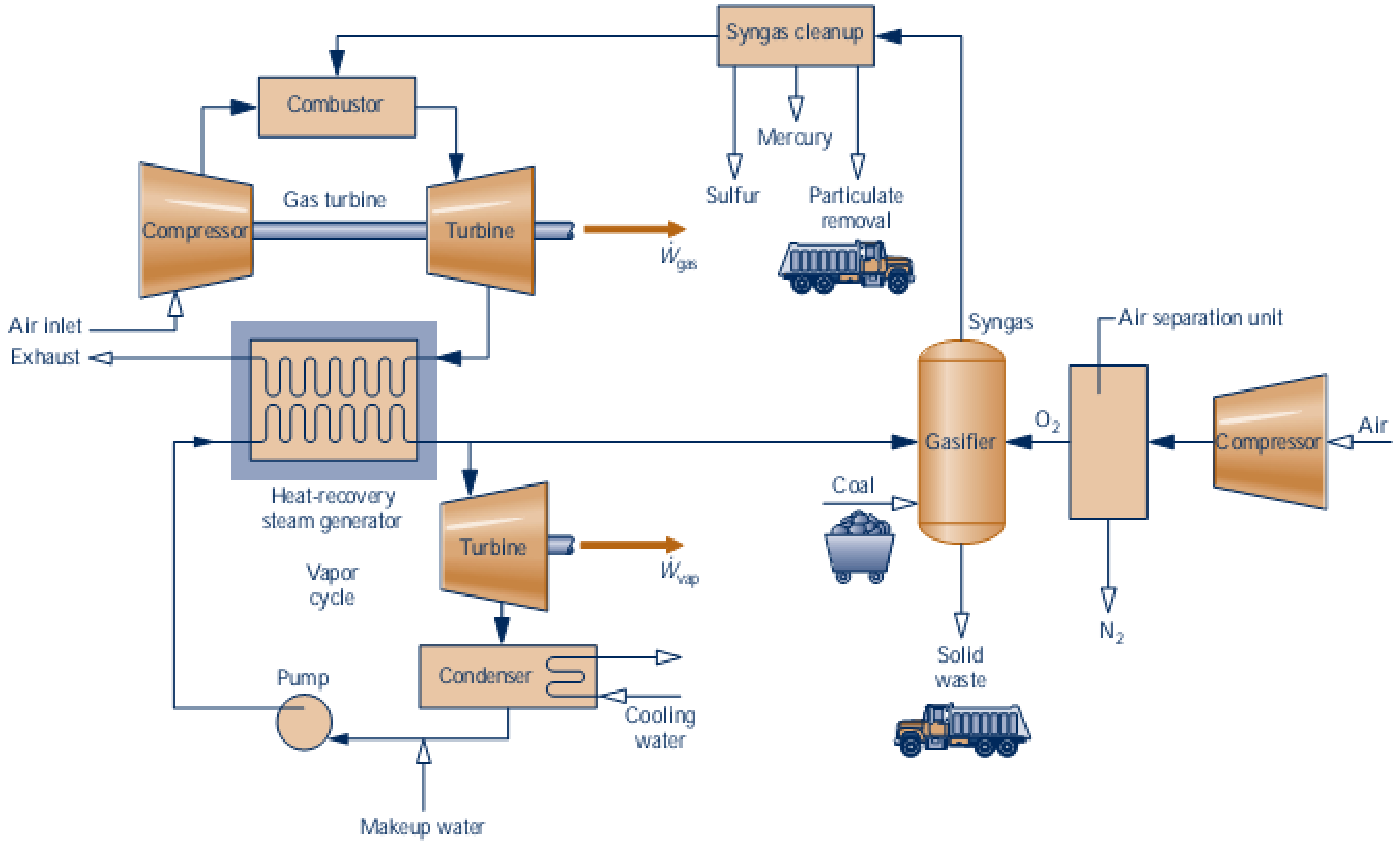


Fig. 9.24 Integrated gasification combined-cycle power plant.