KMU220 CHEMICAL ENGINEERING THERMODYNAMICS I

PRODUCTION OF POWER FROM HEAT0

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Outline

- Steam power plant
- Rankine cycle
- Regenerative cycle
- Internal combustion engines
- Otto engine
- Diesel engine
- Gas-turbine engine
- Jet engines, rocket engines

Power plant

Molecular energy of fuel →

Combustion→

Heat→

Work producing device →

Mechanical energy

Nuclear Power Plant

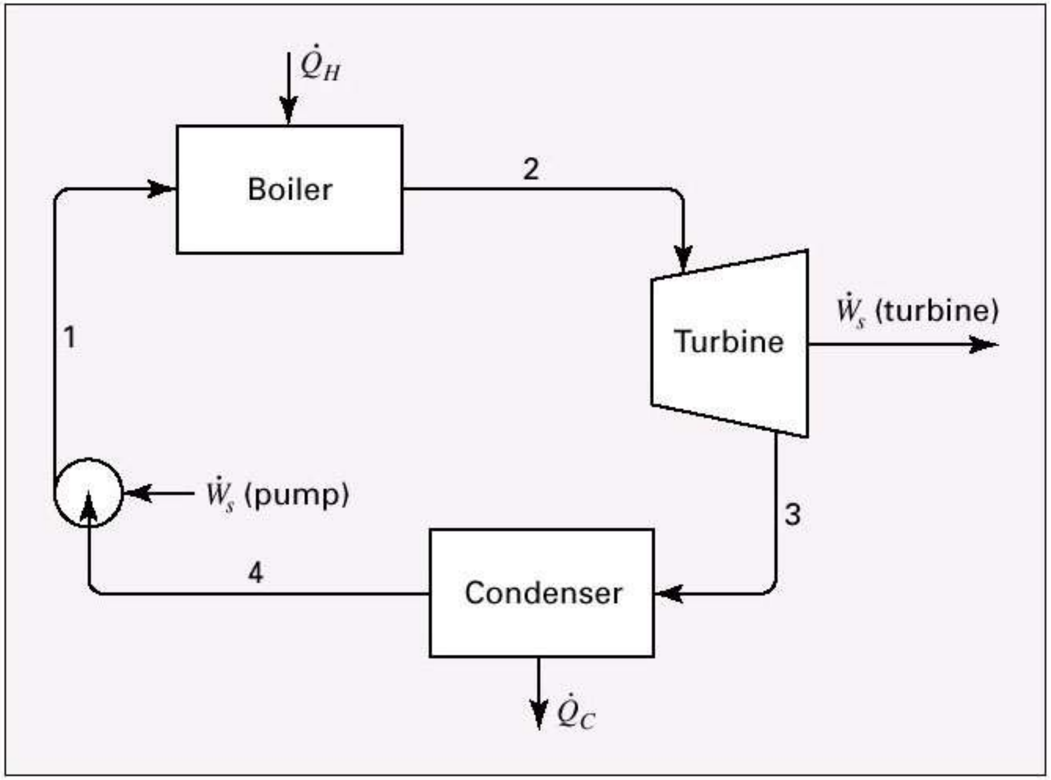
- Energy of nucleus of atom →
- Fission →
- Heat →
- Work producing device % →
- Work

Internal Combustion Engine

- Chemical energy of fuel→
- Work producing device →
- Increase in temperature and increase in internal energy

- Ex: Otto engine, Diesel engine, Gas turbine

Steam power plant



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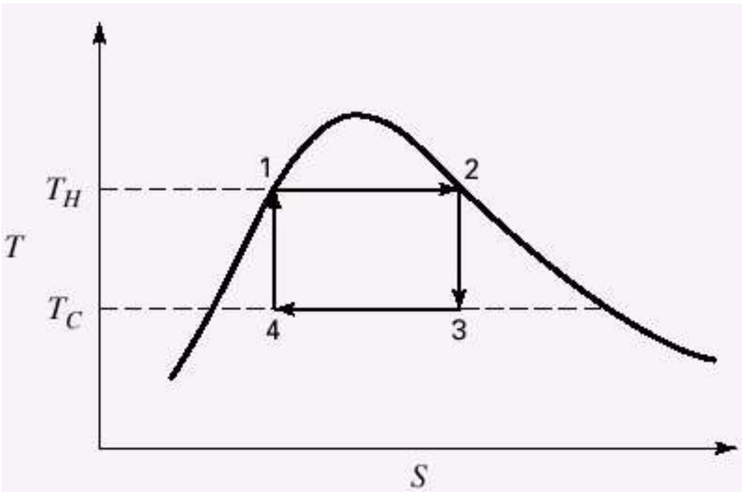
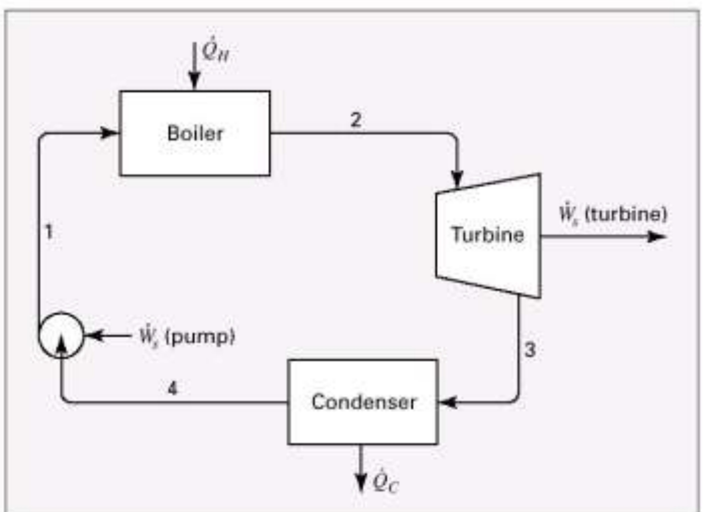
- Large scale heat engine
- Working fluid: water
- Steady state flow
- Cyclic process of:

Pump→Boiler→Turbine→Condenser

Carnot cycle on the TS Diagram





- 1→2 Vaporization in the boiler

Satd liq water absorbs heat @ T_H and produces satd vapor

- 2→3 Rev adiabatic (isentropic) expansion of satd vapor into 2-phase region to produce satd liq+vapor @ T_C
- 3→4 Partial condensation process, heat is rejected @ T_C
- 4→1 Isentropic compression → satd liq water

$$|W| = |Q_H| - |Q_C|$$

$$\eta \equiv \frac{|W|}{|Q_H|} = 1 - \frac{T_C}{T_H}$$

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Other engine cycles

Carnot cycle: Reversible ☺

- Can serve as a standard of comparison for actual steam power plants
- Steps 2→3 and 4→1 may be difficult

Ex Design problems:

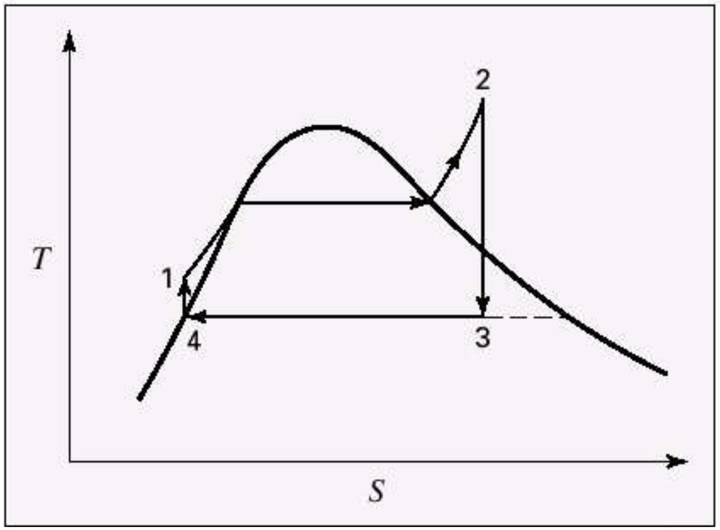
2→3 Turbines take in satd steam → exhaust: high liq content → erosion problems

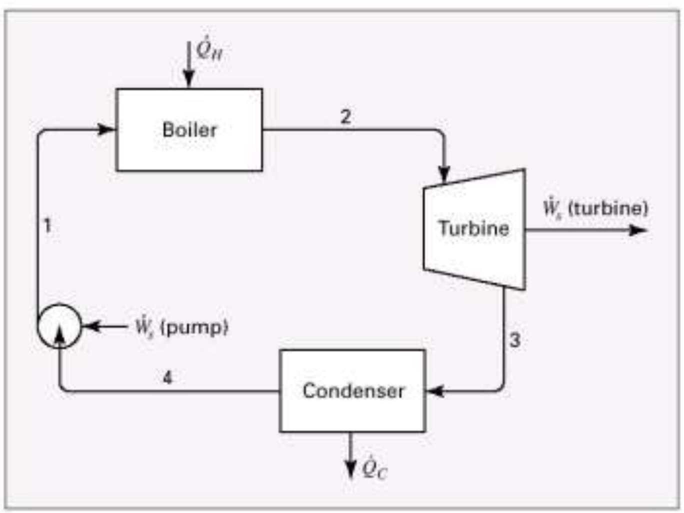
4→1 Pumps take in liq+vap (4) → exhaust: satd liq (1)

Alternative model cycle for fossil-fuel-burning power plants:

RANKINE CYCLE

Rankine cycle





- 1→2 Constant pressure heating in boiler (isobar) **(heating beyond vaporization)**
  - -Heating of subcooled liq water to Tsatn
  - -Vaporization at cnst T and P
  - -Superheating of vapor to T>>Tsatn
- 2→3 Rev adiabatic (isentropic) expansion of vapor in turbine to Pcondenser producing a wet exhaust but due to superheating in step 1-2, moisture content is not too much
- 3→4 Cooling step: **Complete condensation** at cnst P and T in condenser to produce satd liq at pt.4
- 4→1 Reversible adiabatic (isentropic) pumping of satd liq to Pboiler producing compressed (subcooled) liq

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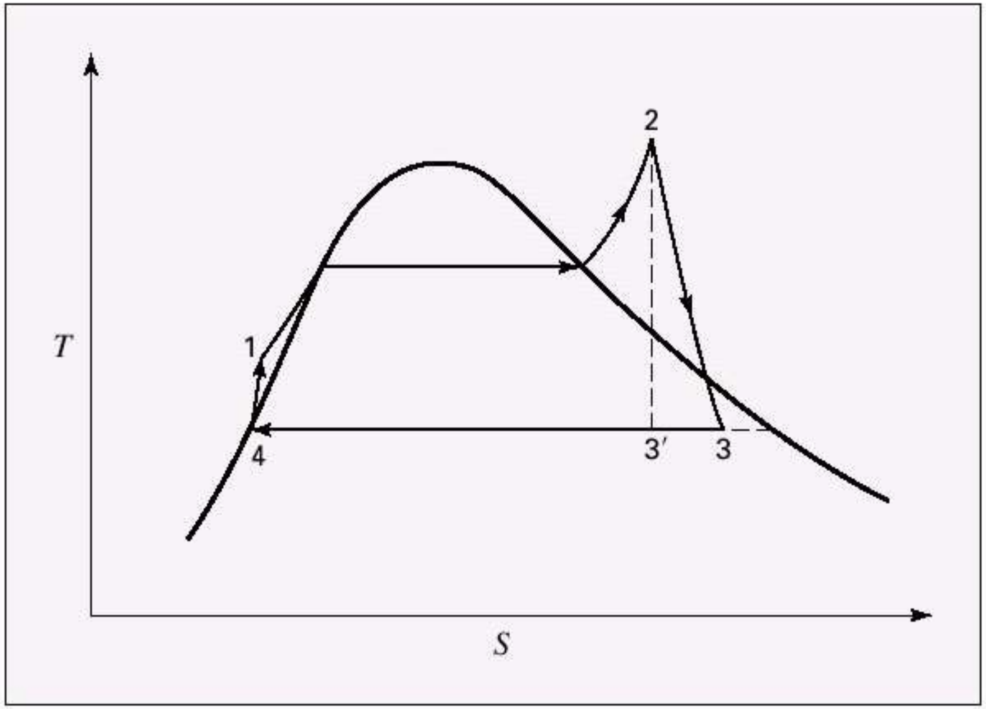
Simple Practical Power Cycle



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Irreversibilities on 1→2 and 4→1

Turbine exhaust is wet but moisture content <10% does not cause serious erosion problems

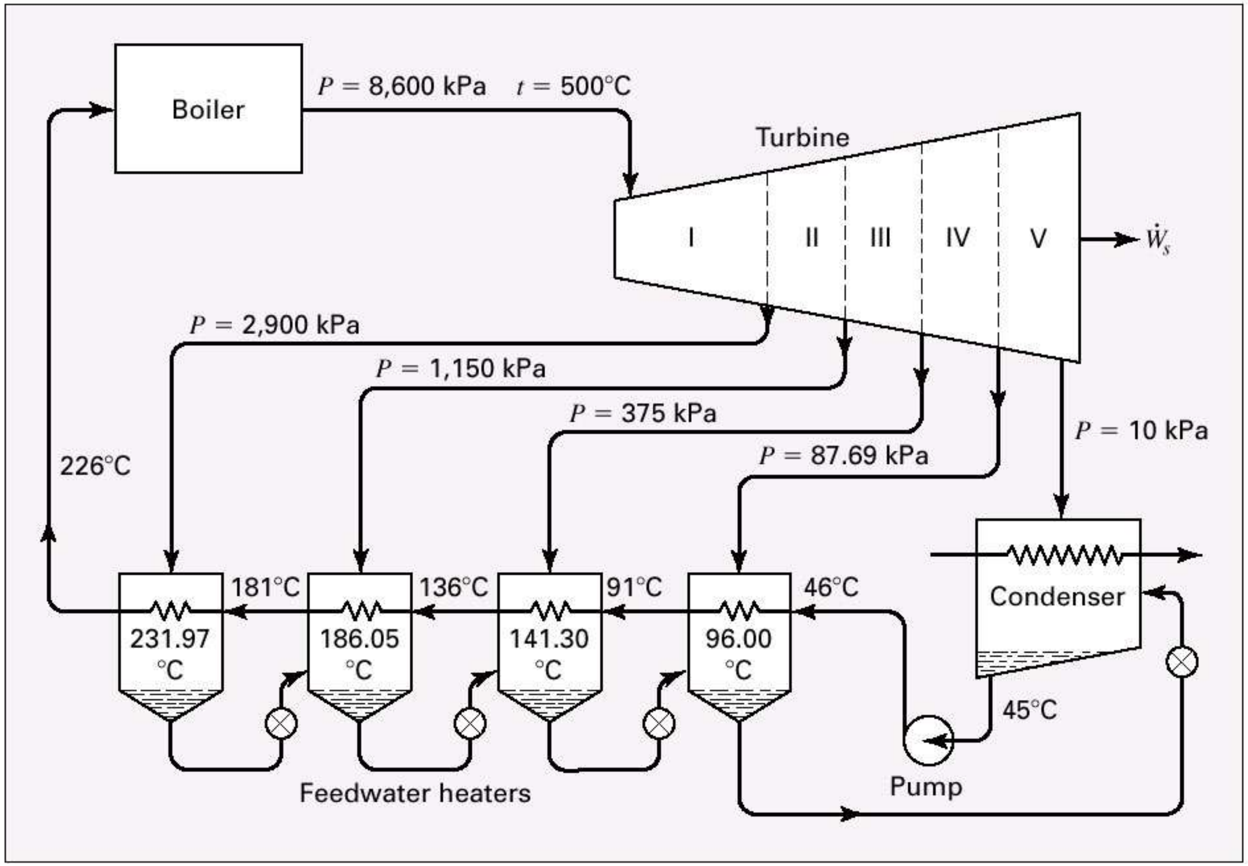
Boiler transfers the heat from burning fuel to the cycle

Condenser transfers the heat from the cycle to the surroundings

$\Delta KE, \Delta PE \sim 0$

$Q = \Delta H$

Regenerative cycle: Steam power plant with feedwater heating



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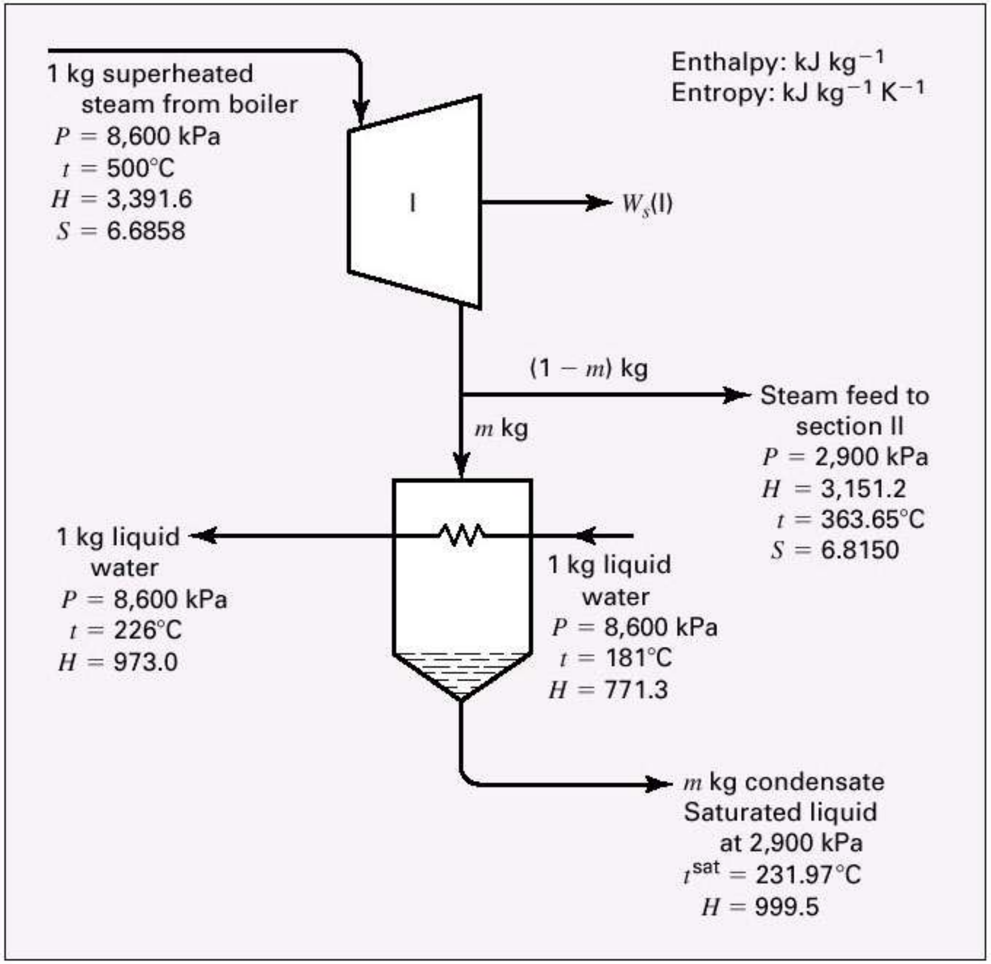
Thermal efficiency of a power plant increases if:

- P and Tvapn in the boiler are increased
- P and T in the condenser are reduced
- Condensation T must be > Cooling medium T

Section I of turbine and 1st feedwater heater



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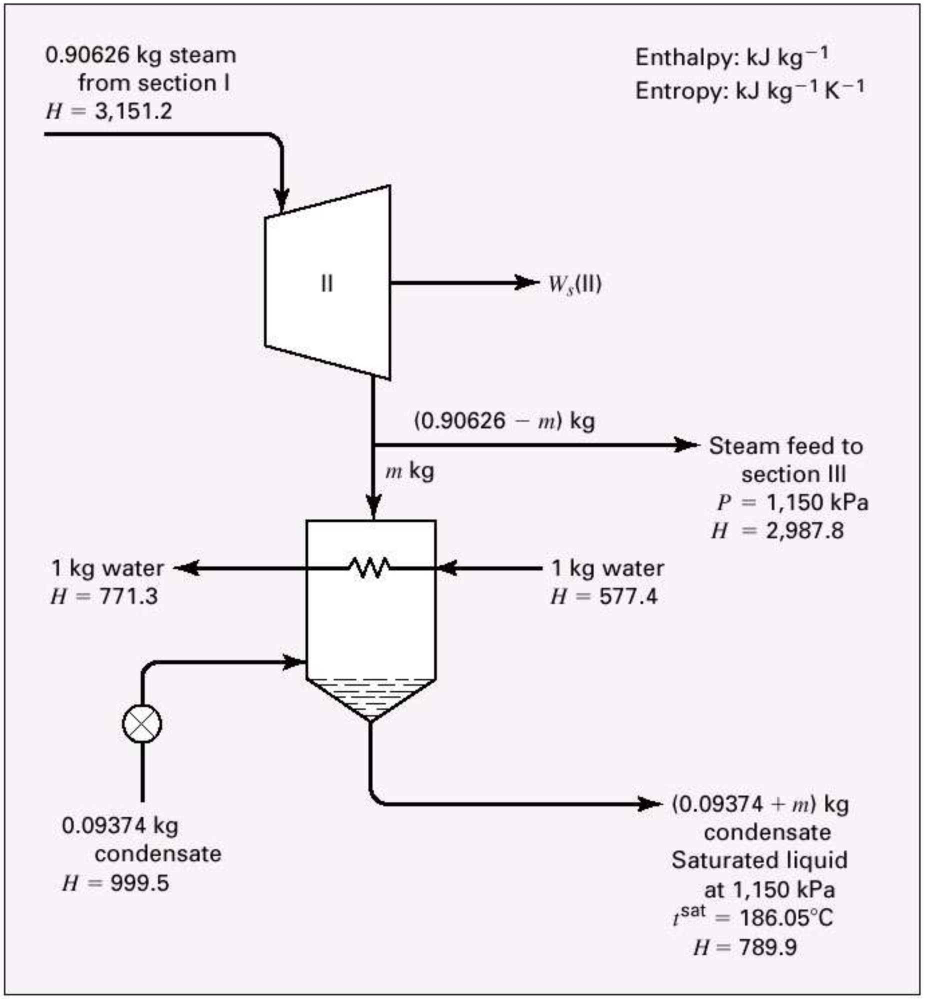
Section II of turbine and 2nd feedwater heater



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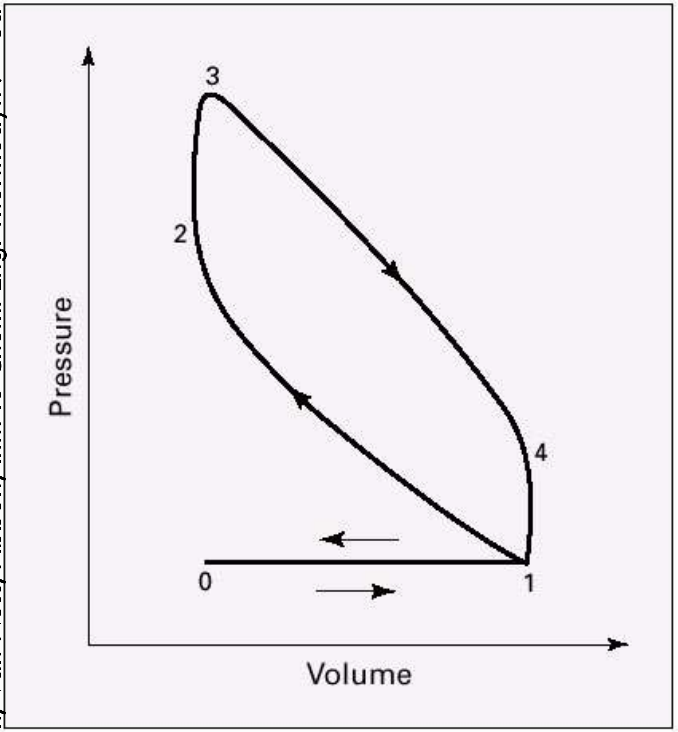
Internal Combustion Engine: Otto Engine



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Used in automobiles. Ex: Gasoline engines

-Subject to same thermodynamic analysis as Carnot cycle. **4 strikes:**

1st stroke: 0→1 intake stroke @P (piston moves outward and draws fuel+air into the cylinder

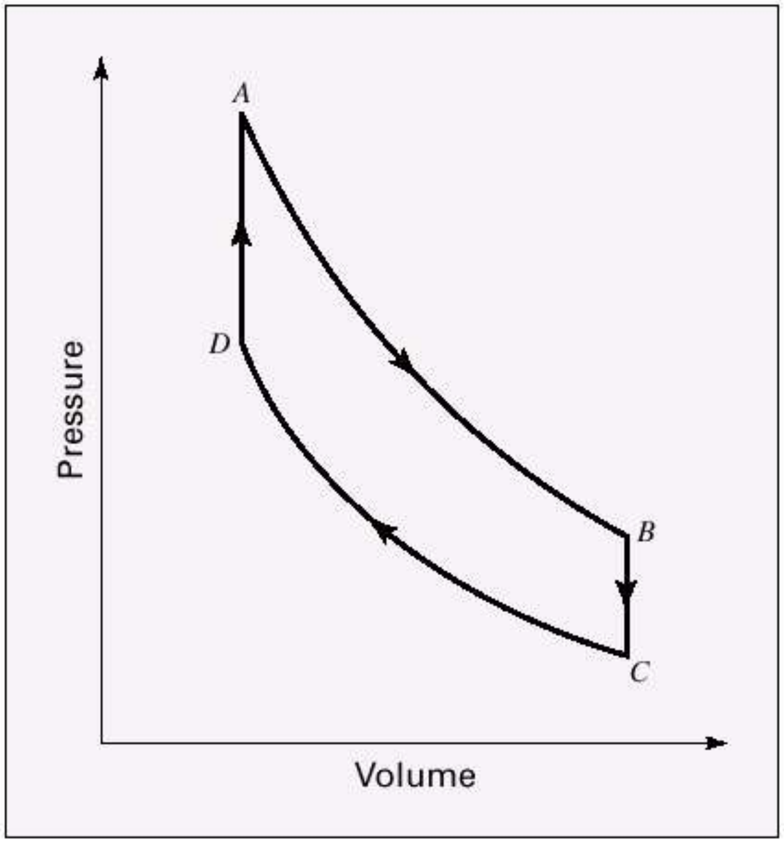
2nd stroke: 1→2→3 all valves closed, full+air → adiabatic compression along 1→2

Ignition→ combustion @V and P↑ along 2→3

3rd stroke: 3→4→1 WORK, high T&P combustion products expand adiabatically along 3→4, exhaust valve opens and P↓ @V along 4→1

4th stroke/exhaust 1→0: piston pushes remaining combustion gases from cylinder

Air-standard Otto cycle



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Engine efficiency η↑ by

1→2 Compression ratio of beginning and end volumes ↑

Idealized Otto cycle:

2 adiabatic+2 cnst-V steps

Working fluid: air (IG, cnst Cp)

CD rev adiabatic compression

DA sufficient heat absorpn by air @V, T&P↑

AB rev. adiabatic expansion of air

BC cnst-V cooling to point C

Air-standard Diesel cycle

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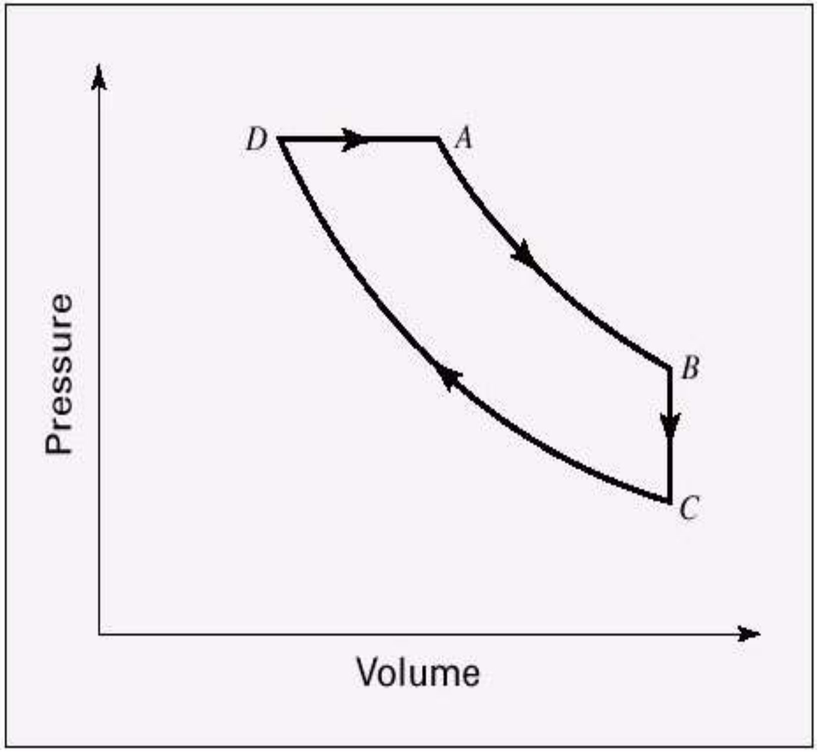


Self ignited: T at the end of compression is sufficiently high (higher compression ratio) to initiate combustion spontaneously.

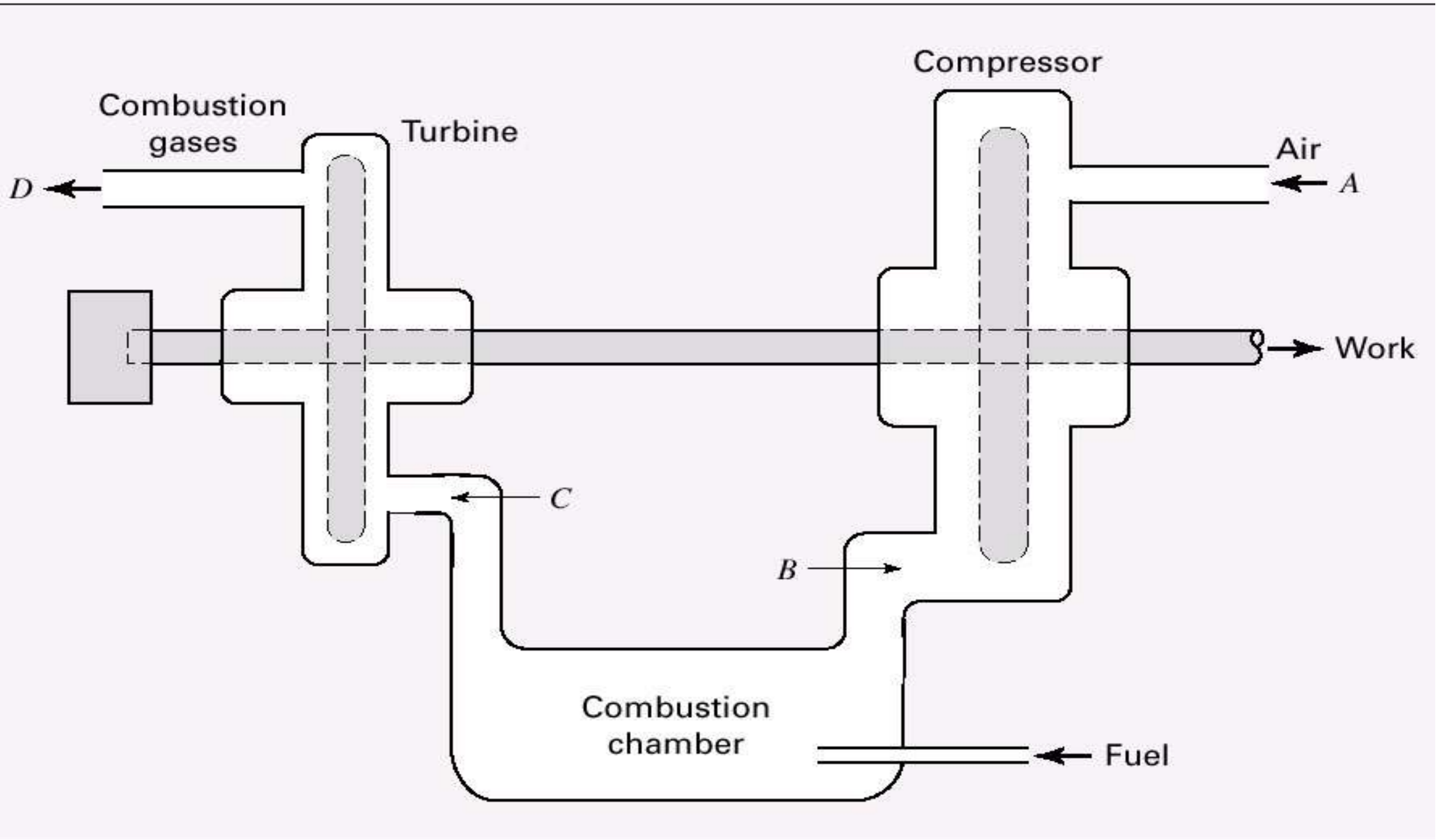
Preignition limits compression ratio attainable in the Otto engine, so the Diesel engine operates at higher compression ratios wt higher η.

BUT

For the same compression ratio:

η -Otto > η-Diesel

Gas-turbine engine



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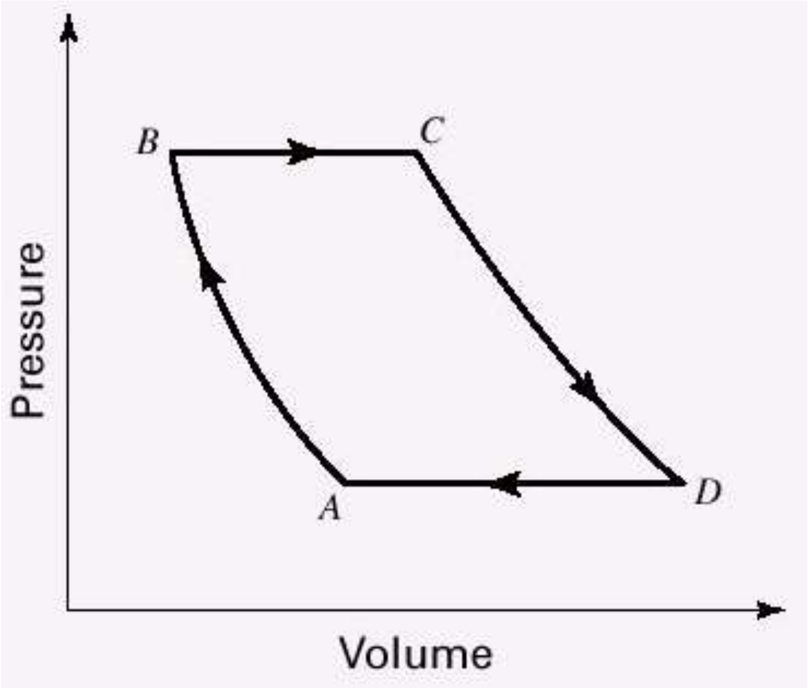
Brayton cycle: ideal cycle for gas-turbine engine



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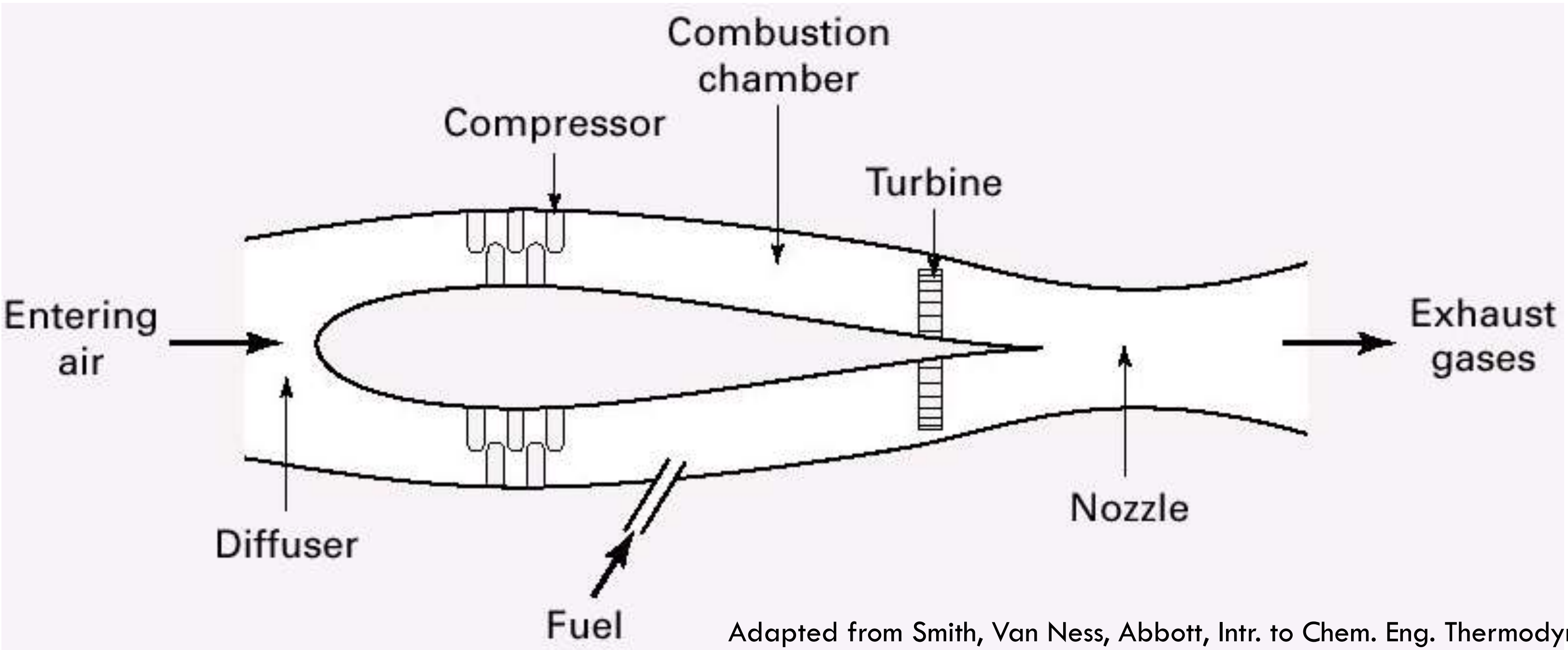
Turbojet power plant



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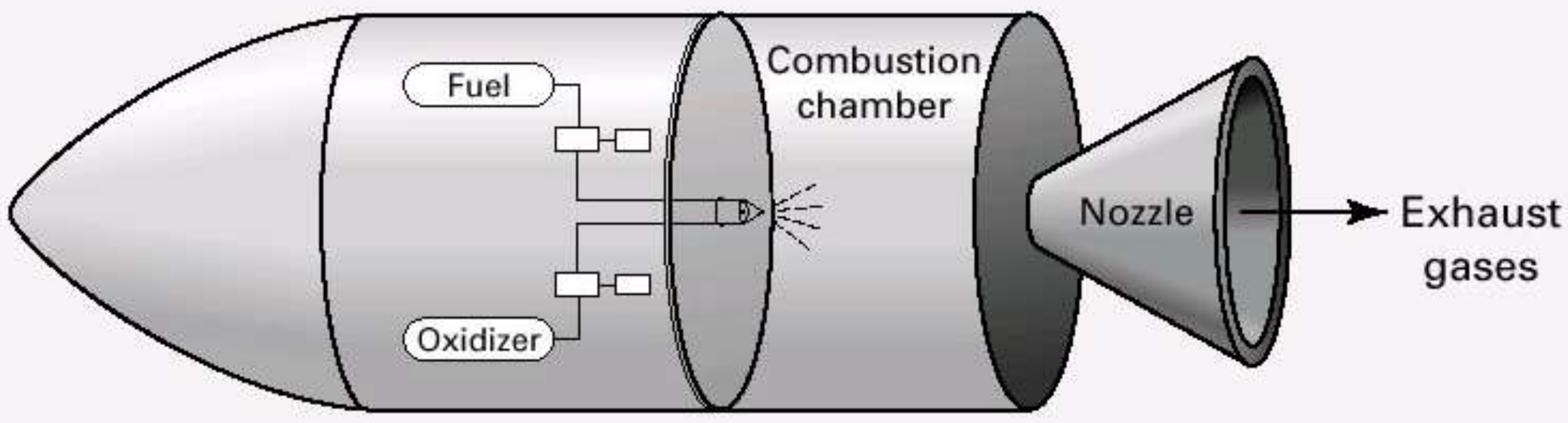
Liquid-fuel rocket engine



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