47201 Engineering thermodynamics

Lecture 9a: Otto cycle (Ch. 10.1-2)

Internal combustion engines

Internal combustion engines are most relevant for transportation, where low weight and compact design are major constraints. Some design aspects that minimize size are:

1. Instead of having a closed circuit with a working fluid, air from the atmosphere is brought into the combustion chamber and exhausted back out to the atmosphere
2. There is no separate combustor or boiler. Instead fuel is burned (generating heat) in the same components used for power production
3. Much of the heat is rejected when the exhaust is vented to atmosphere, which reduces heat exchanger sizes

Otto cycle

The Otto cycle is a four cycle internal combustion engine that is by far the most common cycle used for gasoline engines

- Named after Nicolaus August Otto (Germany 1832-1891)

- Spark ignition engine, which means that a spark plug is used to ignite the mixture of fuel and air in the cylinder

- Output is mechanical work delivered by the crackshaft

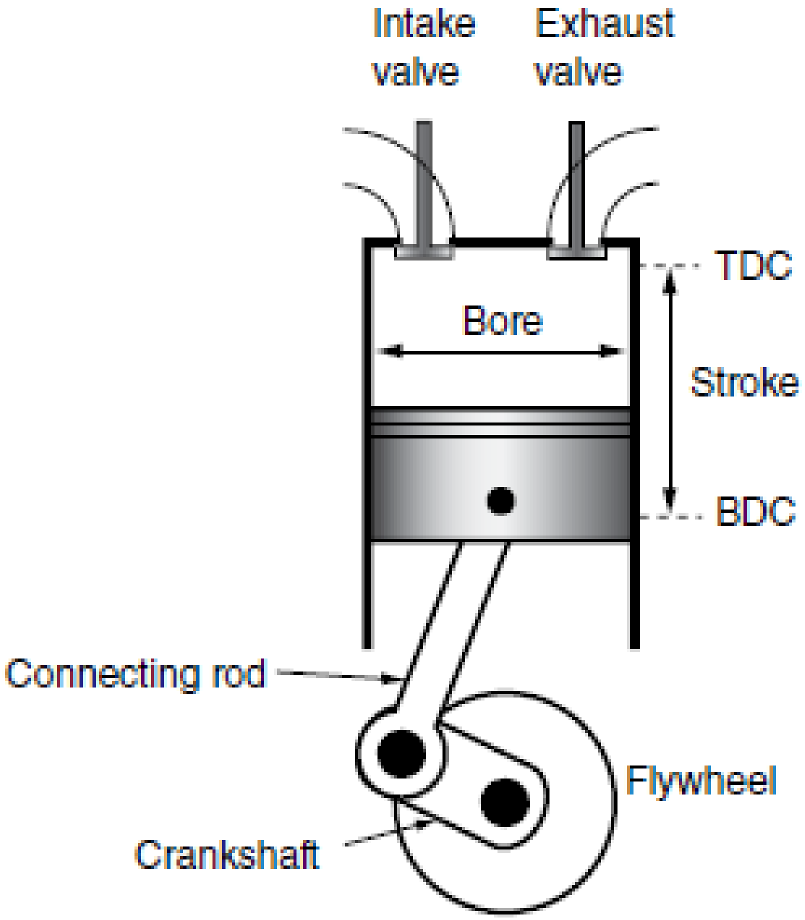


Figure 10.1 Reciprocating engine nomenclature.

Otto cycle steps

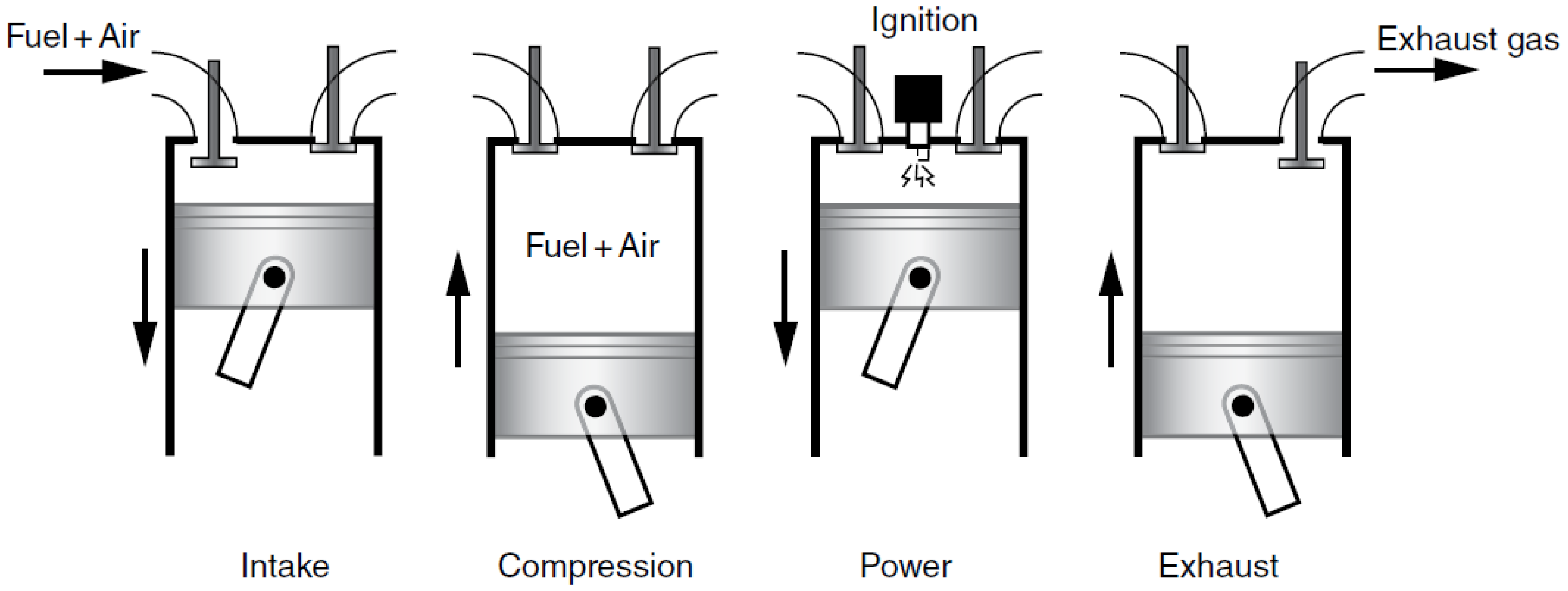


Figure 10.2 Four-stroke cycle for a spark-ignition engine.

Thermodynamic model of the Otto cycle

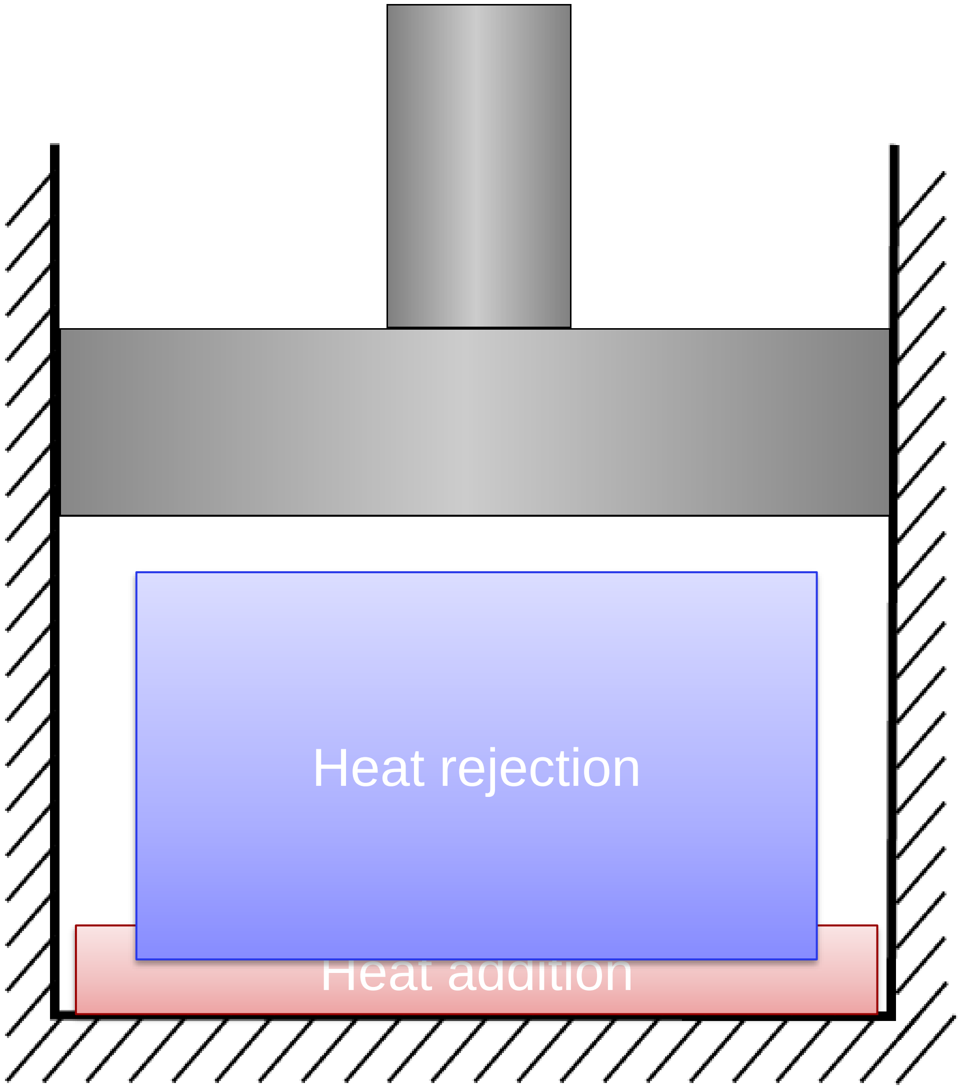
We will use the air standard model to look at Otto cycle engines. The simplifying assumptions are:

1. The working fluid is air, which behaves as an ideal gas
2. All processes are reversible
3. Fuel addition is approximated as a heat addition from an external source
4. Exhausting combustion products and taking in fresh air is equivalent to heat loss to the surroundings

- Also assume that the work associated with intake and exhaust of the air/fuel mixture is negligible.

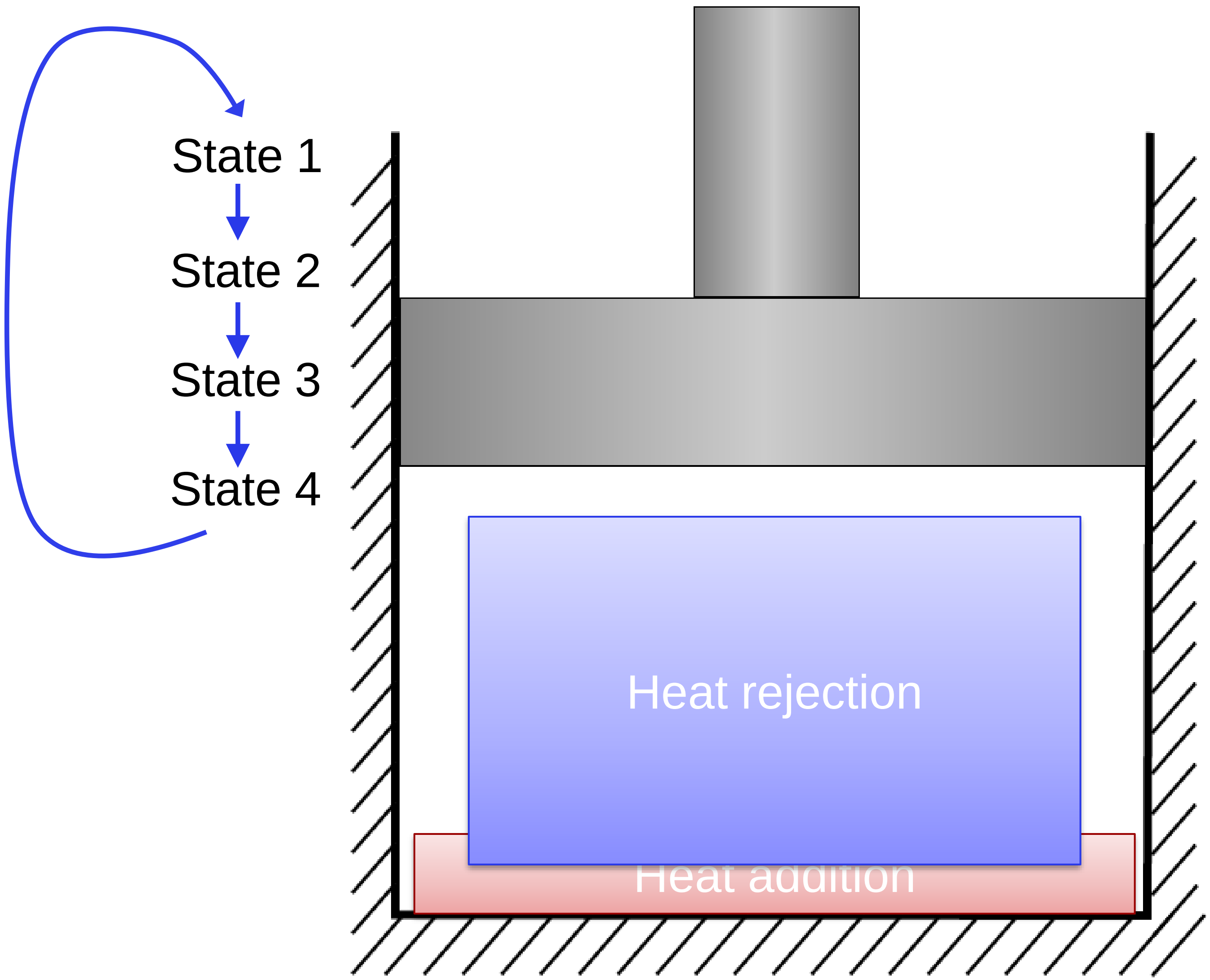
The air cycle Otto analysis

State 1
State 2
State 3
State 4

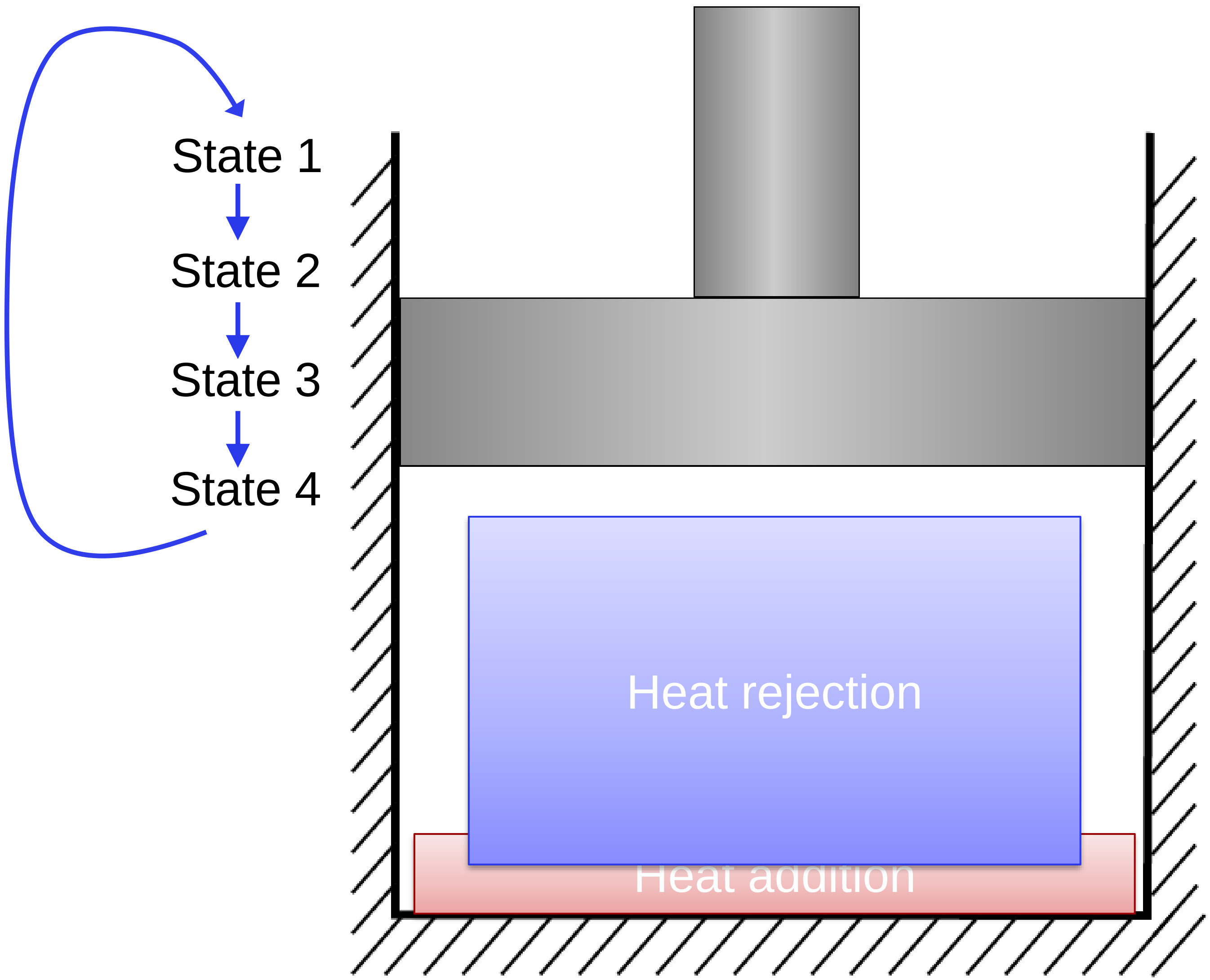


Isentropic compression
Constant volume heat addition
Isentropic expansion
Constant volume heat rejection

The air cycle Otto analysis p-v diagram



The air cycle Otto analysis T-s diagram



Compression ratio

- The compression ratio is a widely used term to describe an ICE, and it is defined as:

$$r = \frac{V_{max}}{V_{min}} \qquad \text{Eq. (10.1)}$$

Cycle efficiency

- The efficiency is calculated based on the net work output over the thermal energy provided:

$$\eta_{th,Otto} = \frac{W_{ex} - W_{comp}}{Q_H} \qquad \text{Eq. (10.4)}$$

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Example 10.1

Problem: An engine operating on a cold air standard Otto cycle takes air at 100 kPa and 25 C and compresses it isentropically to 2.2 MPa. The work output from the cycle is 200 kJ / kg of air. Find the efficiency of the cycle, and the maximum temperature reached in the cycle.

Find: Efficiency $\eta_{th,\mathrm{Otto}}$ of the Otto cycle, maximum temperature T_3 reached.

Known: Cold air standard Otto cycle, intake air pressure P_1 = 100 kPa, intake temperature T_1 = 25 C, pressure after compression P_2 = 2.2 MPa, work output w_{net} = 200 kJ / kg.

Assume:

1. Cyclical steady state
2. Isentropic compression and expansion
3. Air behaves as an ideal gas

Example 10.1 Solution

The uses a solution for a constant specific heat, but let's look at a more general solution. To solve, we will

1. The temperature and pressure at state 1 (before compression) are given. So we can look up the enthalpy and entropy from some table
2. Compression is isentropic, so we know s_2 and P_2 so we can find the temperature at state 2
3. State 3 will depend on the heat input, but that is unknown.
4. State 4 has the same entropy as state 3 and the same pressure as state 1
5. Since we know the net work from the system, we can solve for the heat addition that completes the cycle.