47201 Engineering thermodynamics

Lecture 9b: Diesel cycle (Ch. 10.3)

Diesel cycle

The Diesle cycle is a four stroke internal combustion engine that uses compression ignition rather than spark ignition

- Named after Rudolf Diesel (Germany 1858-1913)

- The cycle intakes pure air and compresses it to a high pressure and temperature. Then fuel in the form of small droplets is injected, which spontaneously combusts due to the high temperature

- Diesel engines typically have higher compression ratios and are built more robustly to withstand the resulting higher pressures.

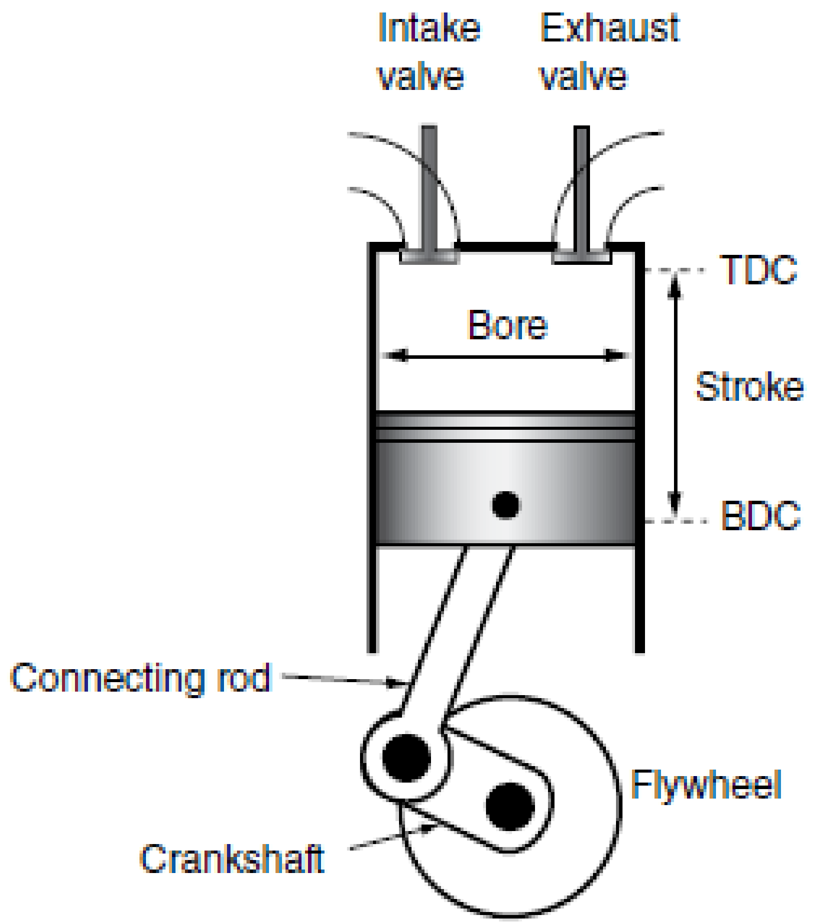


Figure 10.1 Reciprocating engine nomenclature.

Diesel cycle steps

The Diesel cycle is similar to the Otto cycle, with a main difference that combustion occurs concurrently with part of the power stroke. The steps are:

1. Intake of air only

2. Compression of air (higher compression ratio than Otto cycle)

3. Injection of fuel (small droplets) that spontaneously combusts due to the high air temperature and starts the power stroke. Combustion occurs over a longer period (during a portion of the power stroke) than for an Otto cycle

4. Exhaust stroke

Cold air standard Diesel cycle

The difference between a Diesel and Otto cold air standard cycle is the combustion process. For the Diesel cycle, the steps are:

1. Isentropic compression

2. Constant pressure heat addition until the cycle hits the cut-off ratio

3. Insentropic expansion

4. Constant volume heat rejection

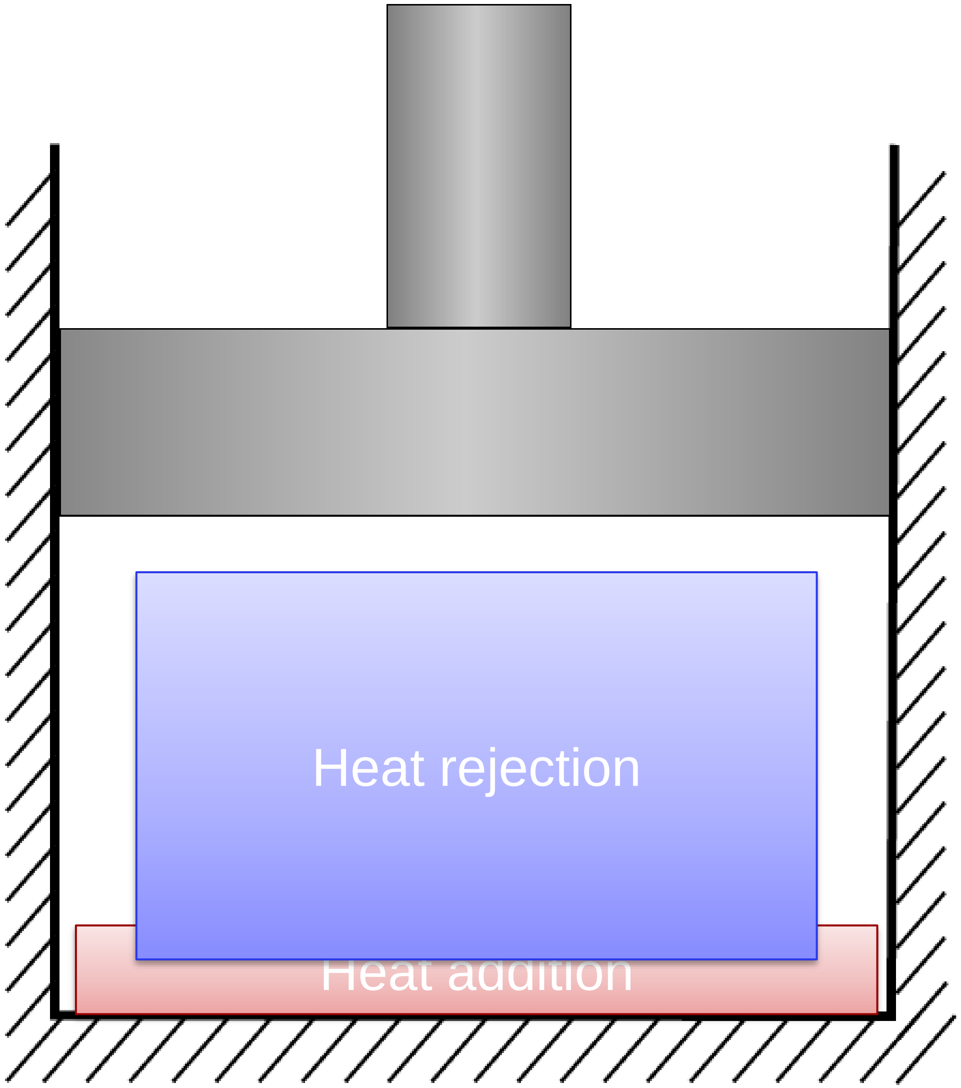
The cold air cycle Diesel cycle

State 1

State 2

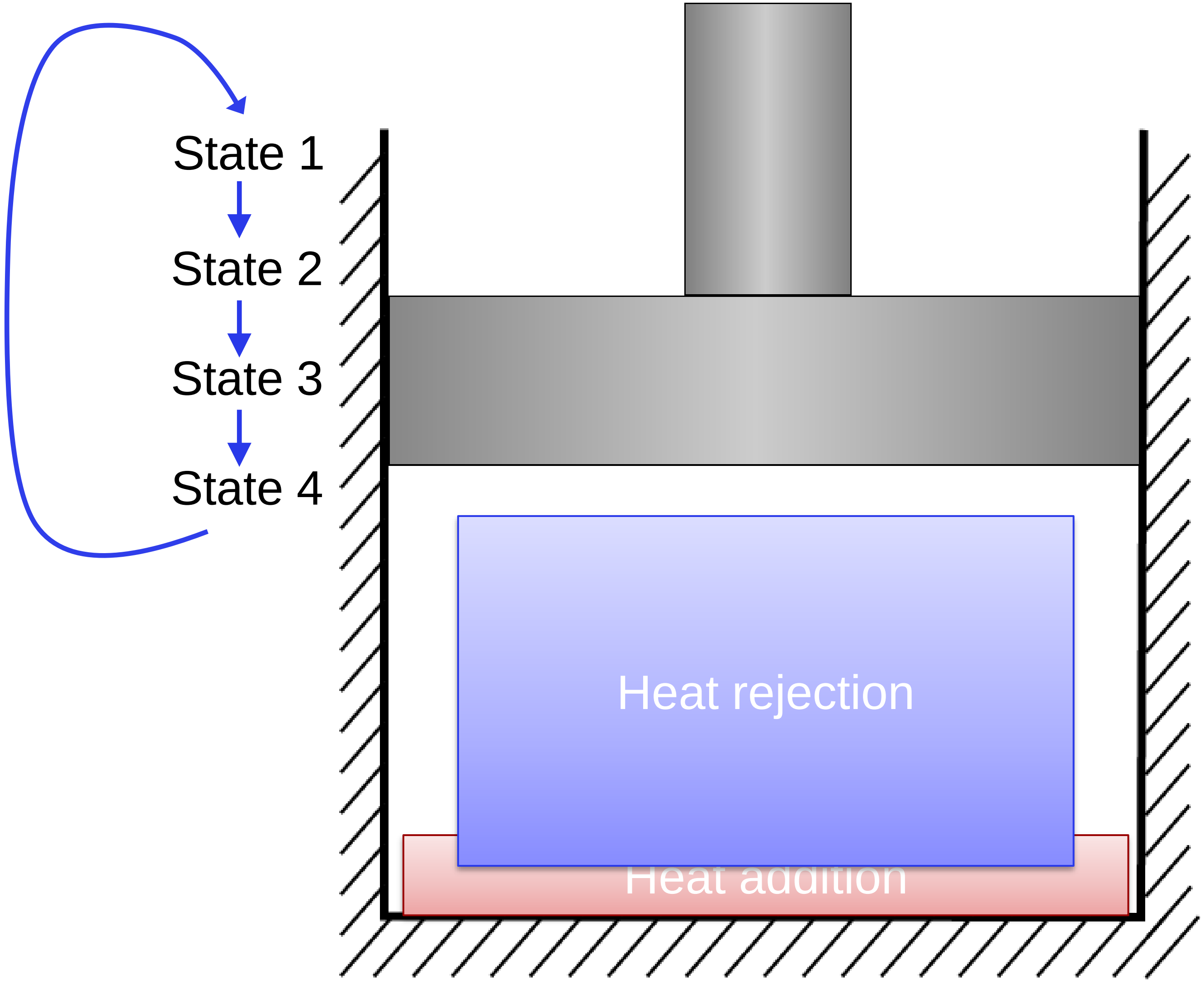
State 3

State 4

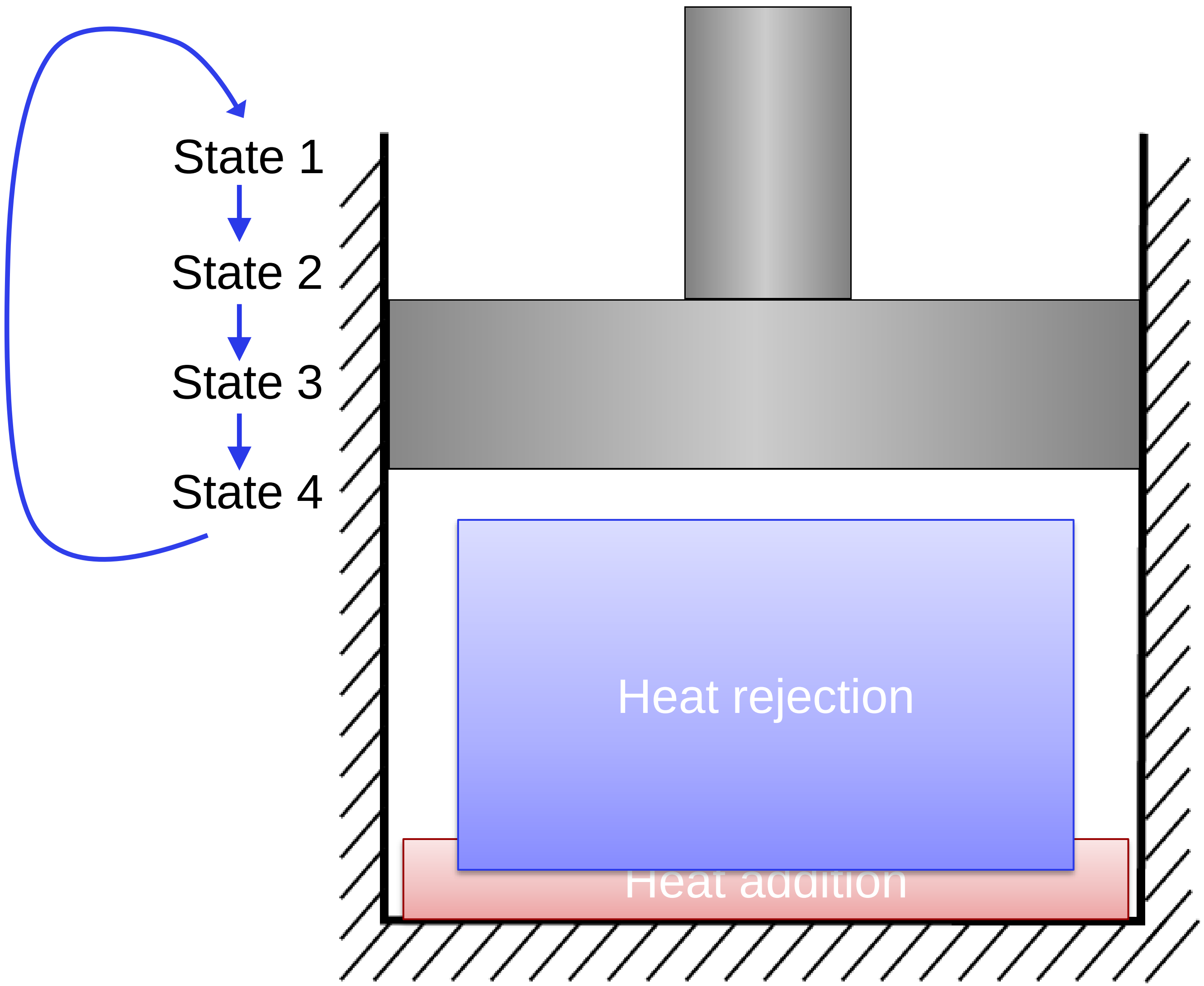


Isentropic compression
Constant pressure heat addition
Isentropic expansion
Constant volume heat rejection

The cold air cycle Diesel analysis P-v diagram



The cold air cycle Diesel analysis T-s diagram



Cut-off ratio

- The cut-off ratio is the ratio of the volumes at the beginning and end of the fuel combustion process:

$$r_c = \frac{V_3}{V_2} \qquad \text{Eq. (10.14)}$$

- And remember that the compression ratio for this cycle is

$$r = \frac{V_1}{V_2} = \frac{V_4}{V_2}$$

Cycle efficiency

- The efficiency is the same as for an Otto cycle:

$$\eta_{th,Diesel} = \frac{W_{ex} - W_{comp}}{Q_H}$$

- Remember that there is work during the combustion phase of the Diesel cycle so:

$$W_{ex} = \mathrm{P}_2(\mathrm{v}_3 - \mathrm{v}_2) + (\mathrm{u}_3 - \mathrm{u}_4)$$

Calculating the heat input for Diesel cycle

- Remember that the heat addition (fuel combustion) occurs at constant pressure. Since there is a Pv term, it is important to use the enthalpý and not internal energy when calculating the heat input:

$$Q_{H,Diesel} = h_3 - h_2$$

Example 10.2

Problem: An engine operating on a cold air standard Diesel cycle with a compression ratio of 20 and a cut-off ratio of 2 compresses air that is at 100 kPa and 25 °C at the start of the cycle. Find the maximum temperature reached in the cycle and the heat added per kilogram of air.

Find: Maximum temperature T_3 reached during the cycle, heat added q per kilogram of air.

Assume:

1. Cyclical steady state
2. Constant pressure combustion to the cut-off ratio
3. Isentropic compression and expansion after the cut-off ratio
4. Cold air standard cycle

Note on the book solution for Ex 10.2

In the solution, T_3 is calculated incorrectly. Eq. 10.12 should have been used. Using Eq. 10.12 gives

$$\frac{T_1}{T_2} = \frac{1}{r^{\gamma-1}}$$

$$T_2 = T_1\ r^{\gamma-1} = 298.15\ K\ 20^{1.4-1} = 988.2\ K$$

While the book gets 701.1 K. This is clearly too low because in Example 10.1, a compression ratio of 9.9 gives a T_2 of 721.1 K.

Example 10.2 solution

The solution procedure is mostly the same as for an Otto cycle, but the combustion step is different. To solve, we will using the following steps:

1. State 1 is fully defined, so we can look up internal energy, entropy etc. directly.

2. We can find state 2 because we know the entropy (s_1) and the compression ratio

3. For state 3, we know the pressure and the volume (based on the cut-off ratio), which will fully define the state. We can look up entropy, enthalpy etc.

4. For state 4, the entropy is known (same as s_3) and we know the volume from the compression ratio and cut-off ratio.

5. The cycle is fully defined, and we can calculate the specific work and efficiency