

Thermodynamics of Energy Conversion

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EXERCISES 6

1) Calculate the Carnot efficiency and “real” efficiency of the steam turbine if the dry steam enters with 500°C and leaves the turbine with 120°C. How much coal does a power station with 1 GW_{el} use per day?

$$\text{Carnot efficiency} = 1 - 393\text{K}/773\text{K} = 0.49$$

$$\text{Real efficiency} = 1 - \sqrt{393/773} = 0.29$$

$$m(\text{Coal}) = P[W] \cdot t[s] / h[J/kg] \cdot g[-] = 1\text{GW} \cdot 24\text{h} / 9 \text{ kWh/kg} = 2.7 \cdot 10^6 \text{ kg} / 0.51 = 5510 \text{ t coal/day}$$

2) Calculate the minimum adiabatic compression from 20°C and 1 bar in order to reach the auto ignition temperature of Methane (632°C)?

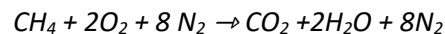
$$\text{Adiabatic compression: } \Delta W = n \cdot c_V \cdot \Delta T$$

from Chap. 4 we have:

$$\frac{p}{p_0} = \left(\frac{T}{T_0} \right)^{\frac{c_V}{R} + 1}, \quad \frac{c_V}{R} = \frac{7}{2} \text{ for a polyatomic gas (CH}_4\text{)}.$$

$$(905/293)^{(9/2)} = (p/p_0) = 160; \quad p = p_0 \cdot 160 = 160 \cdot 1 \text{ bar} = 160 \text{ bar}$$

3) Calculate the temperature and volume increase due to the combustion in the gas (CH₄) turbine. The combustion takes place with air.



$$\begin{aligned} \Delta H_R &= \Delta H_f(\text{CO}_2) + 2\Delta H_f(\text{H}_2\text{O}, g) - \Delta H_f(\text{CH}_4) - 2\Delta H_f(\text{O}_2) \\ &= -393.5 + 2 \cdot (-241.8) - (-74.9) - 0 = -802.2 \text{ kJ} \end{aligned}$$

$$c_p = c_p(\text{CO}_2) + 13c_p(\text{H}_2\text{O}, g) + 8c_p(\text{N}_2) = 37 + 2 \cdot 34 + 8 \cdot 29 = 337 \text{ J/K}$$

$$\Delta T = \Delta H_R / c_p = 802200 / 337 = 2380 \text{ K}$$

$$V/V_0 = T/T_0 = (2381 + 632 + 273) / (632 + 273) = 3.63$$

4) Calculate the acceleration of an airplane, when it reaches 280 km/h in 30 sec. What is the consumption of fuel (m = 550 t) for the takeoff?

$$a = 280 / 3.6 \text{ m/s} / 30\text{s} = 2.6 \text{ m/s}^2$$

$$\text{Kinetic energy} = 0.5 \cdot m \cdot v^2 = 0.5 \cdot 550000 \text{ kg} \cdot (280/3.6)^2 \text{ m}^2/\text{s}^2 = 1.6 \cdot 10^6 \text{ kJ} = 444 \text{ kWh}$$

$$\text{Kerosene } 12 \text{ kWh/kg, efficiency } 30\% \rightarrow \text{Fuel consumption: } 444 \text{ kWh} / 12 \text{ kWh/kg} / 0.3 = 124 \text{ kg.}$$

5) Calculate the energy consumption of an airplane per passenger and 100 km. (A380, 10'000 km, 550 passenger, 130'000 kg kerosene)?

$$130000 \text{ kg} / 10000 \text{ km} / 550 \cdot 100 \text{ km} = 2.4 \text{ kg/passenger/100km}$$

$$2.4 \text{ kg/passenger/100 km} \cdot 12 \text{ kWh/kg} = 28.8 \text{ kWh/passenger/100 km}$$