SCHOOL OF ENGINEERING
MECHANICAL ENGINEERING

Thermodynamics and energetics I: Exercise 6

The first part of the exercise deals with the analysis of open systems where you get to apply the 1st law of thermodynamics for open systems (exercises 1 to 3).
The second part of the exercise deals with the 2nd law of thermodynamics. You get to apply some basic ideas of the 2nd law (exercises 4-6).

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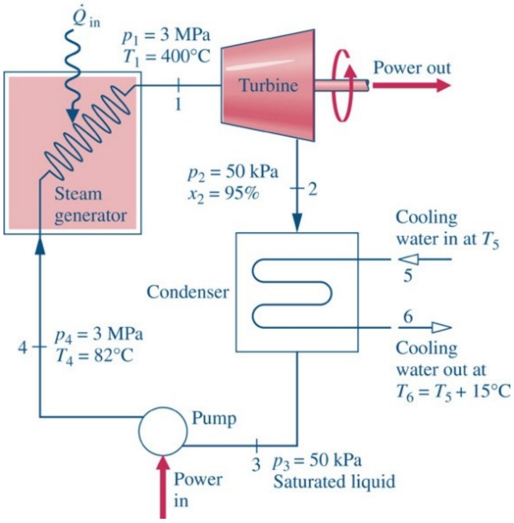
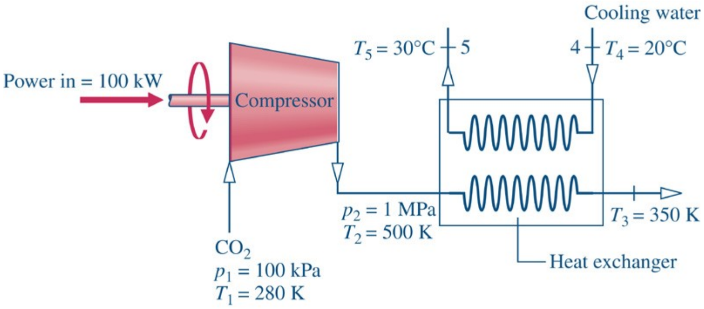
1. A simple steam power plant operates at steady state with water circulating through the components (see figure) with a mass flow rate of 90 kg/s. Kinetic and potential effects can be neglected. The turbine and the pump can be assumed adiabatic. Determine:
   (a) the thermal efficiency of the cycle (enthalpies of water/water vapor can be evaluated with CoolProp).
   (b) the mass flow rate of the cooling water through the condenser. (ignore pressure loss along the cooling line, assume liquid water as incompressible substance with $c_{\mathrm{p,water}} = 4.185$ kJ/(kg K))



2. Carbon dioxide modeled as an ideal gas flows through an adiabatic compressor and a heat exchanger as shown in the figure. A separate liquid cooling water stream flows through the heat exchanger. Assume operation at the steady state and that changes in kinetic and gravitational potential energy can be neglected. Determine:
   (a) the mass flow rate of CO_2. (use $c_{\mathrm{p,CO_2}}(T)$ correlation from Table A-21 (attached) despite that it is valid only between 300 K and 1000 K)

(b) the mass flow rate of the cooling water. (ignore pressure loss along the cooling line, assume liquid water as incompressible substance with $c_{\text{p,water}} = 4.185$ kJ/(kg K))



3. A well-insulated chamber of volume 0.028 m^3 contains initially air at 101.4 kPa and 38°C. Connected to the chamber are supply and discharge pipes equipped with valves that control the flow into and out of the chamber. The supply of air is at 207 kPa and 93°C. Both valves are opened simultaneously, allowing air to flow with a mass flow rate $\dot{m}$ through each valve. The air within the chamber is well mixed, so temperature and pressure at any time can be taken as uniform throughout. Neglecting kinetic and potential energy effects, and assuming perfect gas (constant specific heats, and a specific heat ratio k = 1.4) for the air, plot the temperature and pressure of the air in the chamber versus time for $\dot{m} = 0.01$, 0.05, 0.1 kg/s.

4. The data listed below are claimed for a power cycle operating between hot and cold reservoirs at 1000 K and 300 K. For each case determine whether the cycle operation is reversible, irreversible, or impossible.

Cycle	Q_{H}	W_{cycle}	Q_{C}
1	600 kJ	300 kJ	300 kJ
2	400 kJ	280 kJ	120 kJ
3	700 kJ	300 kJ	500 kJ
4	800 kJ	600 kJ	200 kJ

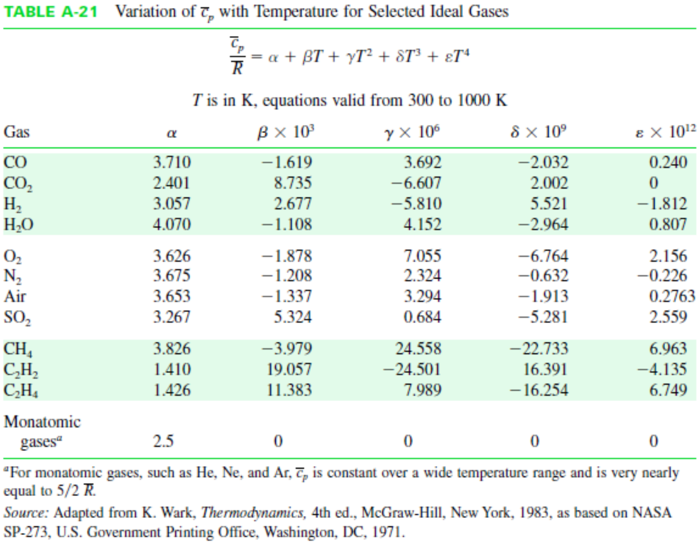


TABLE A-21 Variation of $\overline{c}_p$ with Temperature for Selected Ideal Gases

$$\frac{\overline{c}_p}{\overline{R}} = \alpha + \beta T + \gamma T^2 + \delta T^3 + \varepsilon T^4$$

T is in K, equations valid from 300 to 1000 K

Gas	α	$\beta \times 10^3$	$\gamma \times 10^6$	$\delta \times 10^9$	$\varepsilon \times 10^{12}$
CO	3.710	−1.619	3.692	−2.032	0.240
CO_2	2.401	8.735	−6.607	2.002	0
H_2	3.057	2.677	−5.810	5.521	−1.812
H_2O	4.070	−1.108	4.152	−2.964	0.807
O_2	3.626	−1.878	7.055	−6.764	2.156
N_2	3.675	−1.208	2.324	−0.632	−0.226
Air	3.653	−1.337	3.294	−1.913	0.2763
SO_2	3.267	5.324	0.684	−5.281	2.559
CH_4	3.826	−3.979	24.558	−22.733	6.963
C_2H_2	1.410	19.057	−24.501	16.391	−4.135
C_2H_4	1.426	11.383	7.989	−16.254	6.749
Monatomic gases[a]	2.5	0	0	0	0

[a] For monatomic gases, such as He, Ne, and Ar, $\overline{c}_p$ is constant over a wide temperature range and is very nearly equal to $5/2\ \overline{R}$.

Source: Adapted from K. Wark, *Thermodynamics,* 4th ed., McGraw-Hill, New York, 1983, as based on NASA SP-273, U.S. Government Printing Office, Washington, DC, 1971.