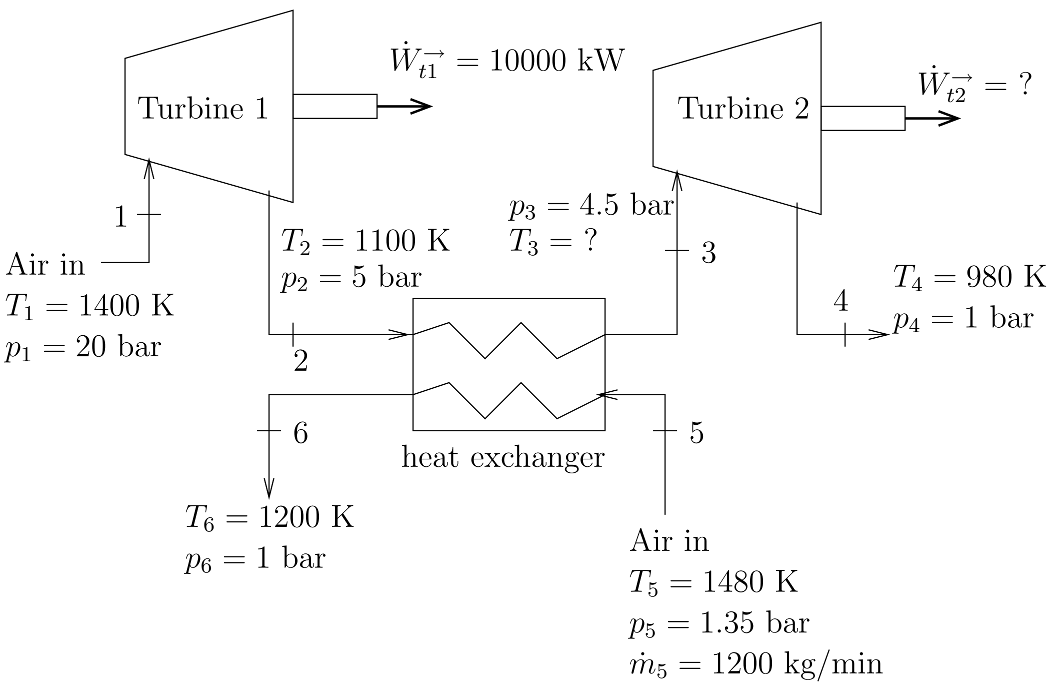
Final Exam

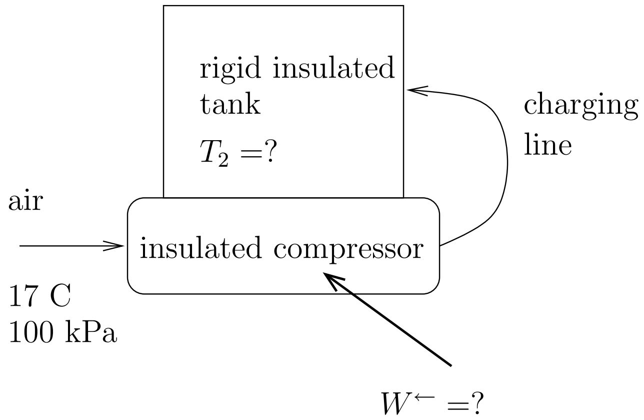
- This is a 120 minutes exam.
- You are allowed to bring in 1 cheat sheet (2 A4 pages).
- You are advised to read the whole exam before you start.
- Make sure you state all the assumptions you make and that you clearly identify any control mass or control volume you utilize in your analysis.
- Good luck!

Name & Section:

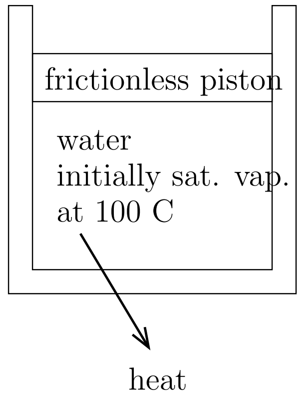
Problem 1 [35 points]
Air as an ideal gas flows through the turbine and heat exchanger arrangement shown in the Figure below. Steady-state data are given on the figure. Stray heat transfer and kinetic and potential energy effects can be ignored. Determine
(a) temperature T_3, in K.
(b) the power output of the second turbine, in kW.
(c) the rates of entropy production, each in kW/K, for the turbines and heat exchanger.
(d) Using the result of part (c), place the components in rank order, beginning with the component contributing most to inefficient operation of the overall system.
(e) What are the isentropic efficiencies of the turbines?



Problem 2 [35 points]
An insulated air tank (of rigid wall) has 0.1 m^3 of air at atmospheric temperature and pressure of 17 °C and 1 bar. An insulated compressor charges the tank reversibly until the pressure inside the tank reaches 10 bar after which the compressor is turned off and the tank is sealed. During the charging process, the air entering the compressor is at atmospheric conditions.
(a) What is the entropy generated in the process ?
(b) What is the final temperature in the tank ?
(c) What is the work (into the compressor) required to charge the tank ?
hint: take your control volume to consist of both compressor and tank.



Problem 2



Problem 3

Problem 3 [35 points]
one kg of saturated water vapor at 100°C is contained in a cylinder fitted with a frictionless piston. The water undergoes a condensation quasi-static process to a final state of saturated liquid at 100°C . The surrounding environment is at temperature $T_0 = 25$°C .
(a) What is the total (water + surrounding) entropy generated by irreversibility if heat of condensation is rejected to the surrounding ? What is the source of irreversibility?
(b) If instead of (a), water during condensation acts as a high temperature reservoir in a reversible cyclic engine that is also interacting with the surrounding, what is the total work produced (by both water and the cyclic engine) ? Make a sketch indicating direction of energy transfers.
(c) [bonus 5 points] What is the maximum work that can be produced by a reversible process starting with a 1 kg of saturated water vapor at 100°C and ending in thermodynamic equilibrium with the environment (of $T_0 = 25$°C and $p_0 = 1$ bar).
Note: Parts (a), (b) and (c) are independent.

Problem 2 solution

(a) Processes are reversible and adiabatic, so entropy generated is zero.

(b) Taking (tank+compressor) First law

$$m_2u_2 - m_1u_1 = (m_2 - m_1)h_{in} + W^{\leftarrow}$$

Applying second law, and noting that entropy transfer due to heat is zero, and entropy generated by irreversibility is zero, and $s_{in} = s_1$, then

$$m_2s_2 - m_1s_1 = (m_2 - m_1)s_{in} \Rightarrow s_2 = s_1$$

Therefore $s_2 = s_1 \Rightarrow s_2^o = s_1^o + R\ln(p_2/p_1) = 6.83521 + 0.287\ln 10 = 7.496$ kJ/kg K. Therefore state 2 is determined by $p_2 = 10$ bar and s_2 yields $T_2 = 555.7$ K and $u_2 = 401.5$ kJ/kg.

(c) First law

$$\begin{aligned} & m_2u_2 - m_1u_1 = (m_2 - m_1)h_{in} + W^{\leftarrow} \\ \Rightarrow \quad & W^{\leftarrow} = \frac{V}{R}\left[\left(\frac{p_2u_2}{T_2} - \frac{p_1u_1}{T_1}\right) - \left(\frac{p_2}{T_2} - \frac{p_1}{T_1}\right)h_{in}\right] \\ = \quad & 31.9 \text{ kJ} \end{aligned}$$

Problem 3 solution

(a) Second law for (water + surrounding),

$$(\Delta S)_{tot} = \Delta S_w + \Delta S_0 = S_{irr}$$

Second law for surrounding

$$\Delta S_0 = \frac{Q^{\rightarrow}}{T_0}$$

First law for water, $Q^{\rightarrow} = mu_{fg} + mp\Delta v = mh_{fg}$. For water $\Delta S_w = -ms_{fg}$. We therefore get

$$(\Delta S)_{tot} = -6.0480 + \frac{1 \times 2257}{298.15} = 1.522 \text{ kJ/K}$$

(b) Applying first law for both water plus cyclic device, we get

$$W^{\rightarrow} = -\Delta U - Q^{\rightarrow} = mu_{fg} - Q_L^{\rightarrow}$$

Second law for (water plus cyclic reservoir) leads to $Q_L^{\rightarrow} = T_0\Delta S = 298.15 \times 6.0480 = 1803.2$ kJ. The total work is then $1 \times 2087.50 - 1803.2 = 284$ kJ.