DO NOT WRITE ON THE BLUE TABLES. RETURN THE BLUE TABLES WITH YOUR EXAM. DO NOT STAPLE THE EXAM SHEETS TOGETHER. A letter-size formulae sheet, handwritten by you, may be used. Put your answers on the same sheet as the question. Use at least 5 significant digits in your computations and answers where possible. You must give the units of your answers. You must write clearly. Encircle the right answer number in multiple choice. To correct, erase the wrong circle as well as you can and encircle the corrected answer number twice. Best possible answer for multiple choice. For questions asking a number, putting the clear correct formula(s) below the question might result in partial credit even if the answer is wrong. *Not following those requirements will result in reduced or no credit.*

1. (5%) An adiabatic turbine produces 100 kW of power. If the turbine efficiency is 0.75, then a reversible turbine with the same entrance conditions and exit pressure would produce 133 kW.

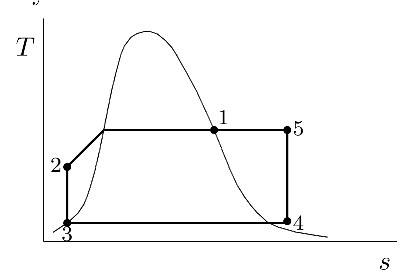
2. (5%) When 2000 kg of sand at 75°C cools down to the surrounding temperature of 5°C, the heat released is 112 MJ and the entropy generated in the entire system is 43.503 kJ/K.

3. (5%) A heat engine that operates in an environment at 5°C and that gets it heat at 100°C will need at least 3.9278 kW of heat input for each kW of power produced.

4. (5%) A reversible pump taking 0.15 kJ/kg of power will pressurize a slow stream of gasoline from 100 kPa to 212.5 kPa.

5. (5%) *Neatly* draw the $T-s$ diagram for the reversible cycle described below. Label the states.

   - 1-2 Isobaric cooling from saturated vapor to compressed liquid.
   - 2-3 Reversible adiabatic expansion to saturated liquid.
   - 3-4 Isothermal heating to superheated vapor.
   - 4-5 Isentropic compression.
   - 5-1 Constant temperature cooling.

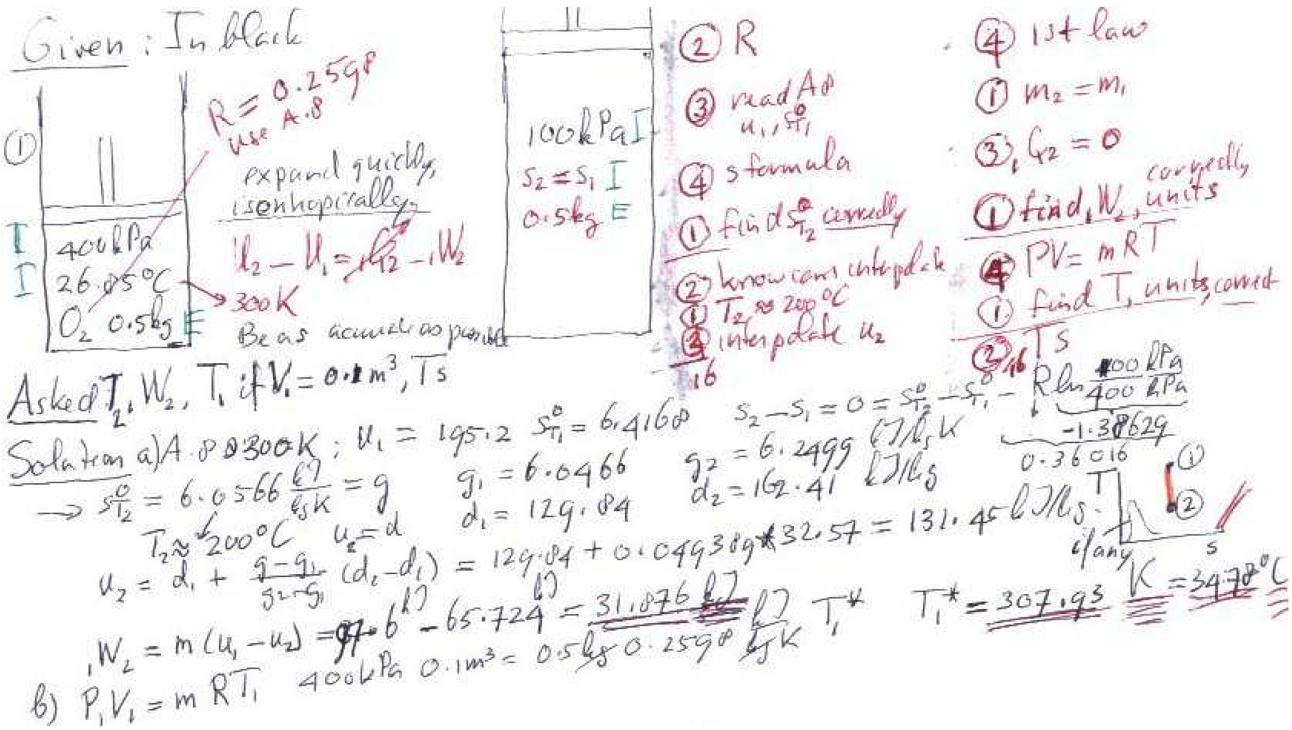


6. (5%) Of the following purported heat engines, case 3 violates the first law, and case 2 violates the second law:
   1. $W = 0$, $Q_L = 2$, $Q_H = 2$.
   2. $W = 2$, $Q_L = 0$, $Q_H = 2$.
   3. $W = 2$, $Q_L = 2$, $Q_H = 0$.

7. (5%) Of the below adiabatic steam turbine designs, at least case 3 would unleash the wrath of the patent office:
   1. In: SUV at 2 MPa and 250°C. Out: 2 phase at 100°C.
   2. In: SUV at 2 MPa and 250°C. Out: 2 phase at 150°C.
   3. In: SUV at 2 MPa and 250°C. Out: 2 phase at 200°C.

8. (32%) To create liquid oxygen, first you must cool it down. A simple way to cool oxygen down a lot is to create compressed oxygen at room temperature, then expand it. To study this, assume you initially have 0.5 kg of oxygen at 26.85°C and 400 kPa. Then you quickly but still isentropically expand it to 100 kPa. (a) Show this process in the Ts diagram. (b) What is the work that is released very accurately (at least 5 significant digits)? (c) What is the final temperature approximately? Finally, (d) Suppose we are not that sure about the initial temperature, but we believe that the initial size of the container is 0.1 m^3. If that is true, what would the real initial temperature be in degrees Centigrade?

   You must show the derivations and reasoning completely and correctly for full credit. You must give simplified units for your answers. Most accurate procedure only unless stated otherwise. Use at least 5 significant digits in your computations and answers. *Give the source of every number.*

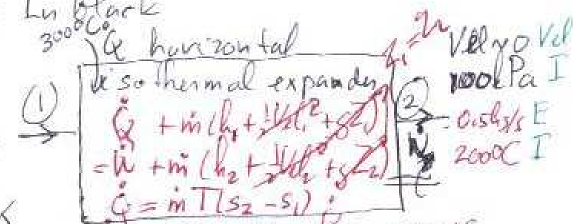


9. (33%) Water at 200°C and 3 kJ/kg-K enters an horizontal isothermal expander at a rate of 0.5 kg/s and with negligible velocity. It comes out at 100 kPa with still negligible velocity.
   1. Construct the initial and final phases in both a combined Pv diagram and a combined Ts one. Mark all lines and points used to do it with their values. Unambiguously number the states in the diagrams. Do not put more info in the diagrams than is needed to construct the phases. State the phases. Also show the specific heat added and work graphically and neatly in the appropriate diagrams.
   2. Find the heat needed and the power produced by the expander.
   3. Assuming that the heat needed to keep the expander isothermal comes from a reservoir at 300°C, what is the entropy generated in the complete system?

   You must show the derivations and reasoning completely and correctly for full credit. You must give simplified units for your answers. Most accurate procedure only unless stated otherwise. Use at least 5 significant digits in your computations and answers. *Give the source of every number.*

Given: In black

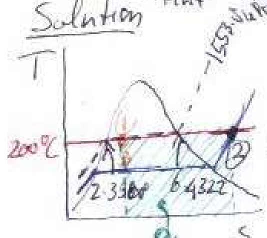
H_2O
E 0.5 kg/s
I 200°C
I 3 kJ/kg K
Vel Vel ~ 0

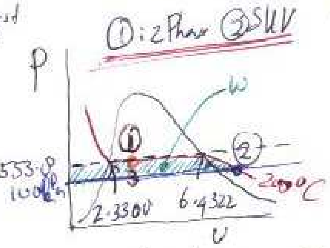


$\dot S_{gen} = \dot m(s_2 - s_1) - \frac{\dot Q}{T_{surr}}$ → 300°C

Asked: $(Ts)_{12q}$, $(Pv)_{12w}$, $\dot Q$, $\dot W$, $\dot S_{gen}$

Solution





1: 2 Phase 2: SHV

Table B.1.1 @ 200°C: $s = s_f + x s_{fg}$

$3 = 2.3308 + x\,4.1014$ $x = 0.16316$ (same if s_f)

$h_1 = 852.43 + x\,1940.75 = 1169.1$ kJ/kg

Table B.1.3 @ 100 kPa & 200°C

$h_2 = 2875.27$ kJ/kg $s_2 = 7.8342$ kJ/kg K

$\dot Q = \dot m T(s_2 - s_1) = 0.5\,\text{kg/s}\,(200 + 273.15)\text{K}\,(7.8342 - 3)\frac{\text{kJ}}{\text{kg K}} = 1143.7\ \text{kW}$

$\dot W = \dot Q + \dot m(h_1 - h_2) = 290.56\ \text{kW}$ ($h_1 - h_2 = -1706.1$)

$\dot S_{gen} = 0.5\frac{\text{kg}}{\text{s}}(7.8342 - 3)\frac{\text{kJ}}{\text{kg K}} - \frac{1143.7\ \text{kW}}{(300 + 273.15)\text{K}} = 0.42172\ \frac{\text{kW}}{\text{K}}$