DO NOT WRITE ON THE BLUE TABLES. RETURN THE BLUE TABLES WITH YOUR EXAM. DO NOT STAPLE THE EXAM SHEETS TOGETHER. Two letter-size formulae sheets, 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. (3%) To compress ethanol from 100 kPa to 300 kPa using a reversible pump requires 255 J/kg of power.

2. (3%) A heat engine takes in 20 kW of heat at 800°C and operates in a 25°C environment. The maximum power it can be producing is 14.44 kW.

3. (3%) Helium at 100°C enters a reversible turbine at a rate of 0.5 kg/s and expands to 20°C in a process that is polytropic with $n = 1.7$. This produces a power output of 201.78 kW.

4. (3%) If the enthalpy of 2 kg of helium increases by 300 kJ, then the temperature increases by 28.88 °C.

5. (3%) Steam at 500 kPa and 250°C flows through a pipe with a velocity of 110 m/s at a rate of 0.5 kg/s. The diameter of the pipe is ___5.24___ cm.

6. (3%) Assume a substance with known properties. For each of the following combinations of data, enter a y if we can find the state and amount of the substance from the data, or an n if not. (1) V, u, m: _y_. (2) V, v, m: _n_. (3) V, v, ρ: _n_. (4) V, ρ, m: _n_.

7. (3%) A bicycle pump contains air at 85 kPa and 1 m^3/kg that is expanding at a rate of 0.5 m^3/kg-s and getting colder at a rate of 50°C/s. Heat must be leaking out of the air at a rate of ___6.65___ kW/kg.

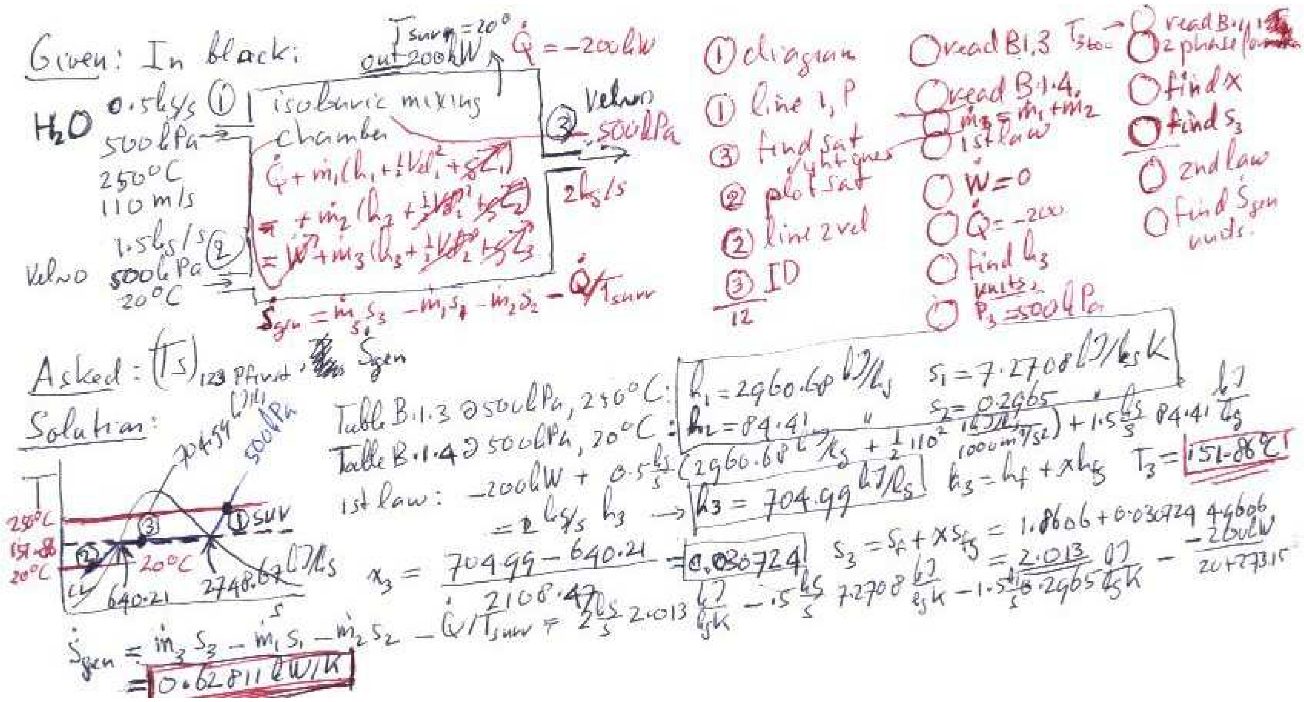
8. (3%) A thermometer inserted in a pan of boiling water indicates a temperature of 95°C. The ambient pressure must be ___84.55___ kPa.

9. (3%) The "Engineering Toolbox" lists the value of what the book calls the "molecular mass" for dry air as 28.9647. (This is really the molar mass.) In that case, the specific gas constant of air is to 6 significant digits equal to ___0.287057___ in units of ___kJ/kg K___.

10. (3%) If a container with 4 kg of ethanol at 20°C is put in a 5°C refrigerator, it will release ___147.6___ kJ of heat into the fridge. The entropy generated by this irreversible process is ___0.013813___ kJ/K.

11. (35%) A 0.5 kg/s stream of water at 500 kPa and 250°C enters an isobaric mixing chamber at a speed of 110 m/s. A second 1.5 kg/s stream of water at 500 kPa and 20°C enters the chamber with negligible velocity. The water leaves the mixing chamber with negligible velocity. The hot mixing chamber *loses* heat to the 20°C environment at a rate of 200 kW.
    1. Construct the phases of both incoming streams in a *single* very neat Ts-diagram. To do so, draw the common 500 kPa pressure line first, and take the construction from there. Mark all lines and points used to do it with their values. Do not put more info in the diagram than is needed to construct the phase. *State the phases.*
    2. After finding enough information to do so, construct the state of the exiting water also in the same Ts-diagram as before. The same conditions apply.
    3. Find the entropy that is generated in the complete system, including environment.

    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.*



12. (35%) Consider an ideal Diesel cycle using standard air. Draw the Pv diagram of this cycle very neatly, and large enough that you can put the values of P, T, and v next to each point. Number the successive points such that 1 is the intake air, at the start of the compression stroke. It is given that the intake air is at 290 K and 95 kPa. The engine is to be designed such that the peak temperature and pressure, in state 3 after the combustion, are 2400 K and 6000 kPa. (Since steel melts at about 1750 K, you may not want to go much higher than roughly 2400 K.)

    (a) Put the given numbers next to points 1 and 3 in the Pv diagram. Compute and add the specific volumes at these points. Make sure you check your numbers, or you will get all the rest wrong, and that is a lot of credit to lose.

    (b) You should now have enough information to compute points 2 and 4 from what is already known about their neighboring points. Do so, except that you do not need to find P_4. Add the other numbers to the diagram.

    (c) Finally find the heat of combustion, the heat released to the environment, the work produced, and the thermal efficiency of the engine. All in the only units you can find these quantities.

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: Diesel cycle, After combustion: $P_3 = 6{,}000$ kPa $T_3 = 2400$ K; Before compression: $P_1 = 95$ kPa, 290 K; (1750 K steel melts)

Asked: 1) v_3, v_1 2) P_2, T_2, v_2 3) T_4, v_4 4) r_v 5) q_H, q_L, w, η_{th}

Solution

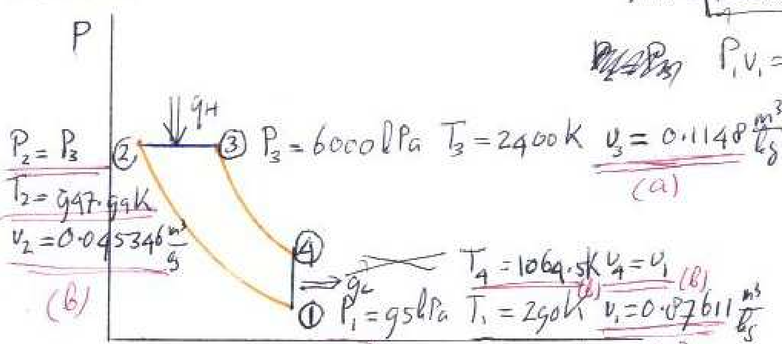
Air: $R = 0.287$ $c_v = 0.717$ $c_p = 1.004$ $\frac{\text{kJ}}{\text{kg K}}$ $k = 1.4$

$P_1 v_1 = RT_1 \to v_1 = v_4$ $P_3 v_3 = RT_3 \to v_3$

$P_2 = P_3$ $T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \to T_2$

$P v_2 = R T_2 \to v_2$ (or $\left(\frac{v_2}{v_1}\right) = \left(\frac{P_1}{P_2}\right)^{\frac{1}{k}}$)

$T_4 = T_3 \left(\frac{v_3}{v_4}\right)^{k-1} \to T_4$



$q_H = c_p(T_3 - T_2) = 1457.8$ kJ/kg

$q_L = c_v(T_4 - T_1) = 555.35$ kJ/kg

$w = q_H - q_L = 902.46 \frac{\text{kJ}}{\text{kg}}$ $\eta_{th} = \frac{w}{q_H} = 0.61903$

(3) Read A5 (c)
(4) $Pv = RT$
(2) Find v_1, v_3, units
(3) diagram

(c)
(2) $P_2 = P_3$
(2) $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$
(1) find T_2
(1) find v_2

(2) $v_4 = v_1$
(2) $\frac{T_4}{T_3} = \left(\frac{v_3}{v_4}\right)^{k-1}$
(1) find T_4
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(2) $q_H = c_p(T_3 - T_2)$
(1) value, units
(2) $q_L = c_v(T_4 - T_1)$
(1) value, units
(2) $w = q_H - q_L$
(1) value, units
(2) $\eta_{th} = w/q_H$
(1) value, units