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. (5%) The air in a theoretical Stirling engine is heated to 1000°C and 2 MPa. If you put the engine in a 25°C, 100 kPa room, then for each kJ of work you get out of the cycle, you would even in the best case have to add at least 1.3058 kJ of heat.

2. (5%) A 2 m^3 volume of air at 100 kPa and 25°C is expanding at a rate of 0.03 m^3/s. It can be assumed that the process is adiabatic. The temperature changes at a rate of -1.7901 °C/s.

3. (5%) A 2 kg/s stream of air at 150°C enters a reversible compressor and gets compressed to 500°C in a process that is polytropic with $n = 1.25$. The power needed to run this compressor will be 1004.5 kW.

4. (5%) A horizontal reversible pump with entrance and exit pipes of equal diameter must compress 2 kg/s of engine oil from 100 kPa to 500 kPa. It will need 903.95 W of power.

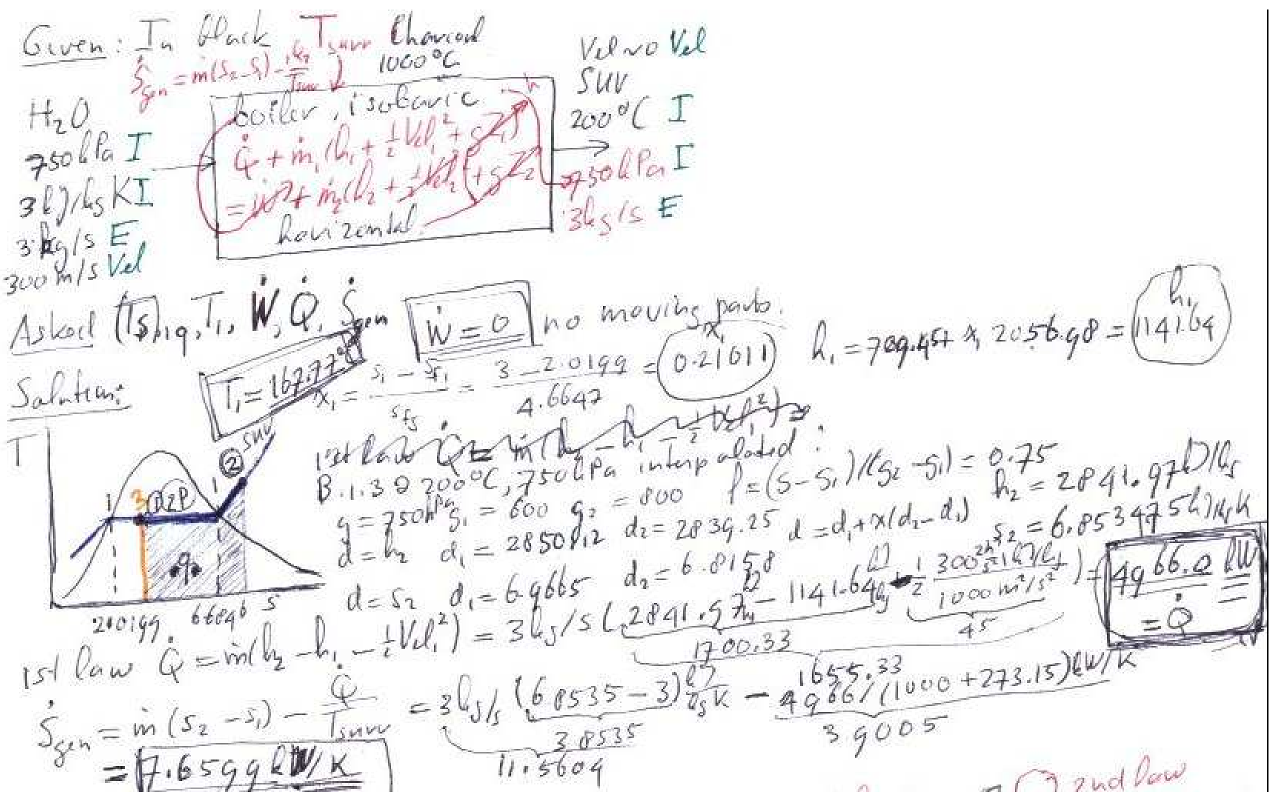
5. (5%) If the temperature of 2 kg of argon changes from 300 K to 1,000 K in an isobaric process, then the internal energy changes by 436.8 kJ

6. (5%) Steam at 600 kPa and 200°C flows through a pipe at a rate of 3 kg/s. If the flow velocity may not exceed 200 m/s, then the pipe diameter must be at least 8.1994 cm.

7. (5%) Assume a substance with known properties. For each of the following combinations of data, enter a y if we can find any intensive quantity from the data, or an n if not. (1) U, S: n. (2) U, s: n. (3) u, S: n. (4) u, s: y.

8. Water at 750 kPa and 3 kJ/kg K enters a horizontal boiler, that can be approximated as isobaric, at a rate of 3 kg/s and a velocity of 300 m/s. It exits as superheated vapor at 200°C with negligible velocity.
   1. Construct the initial phase in a very neat Ts-diagram, marking 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 phase and give the initial temperature.
   2. Mark the final superheated vapor state also in the same diagram. Show the process as a fat line, and show the specific heat graphically.
   3. How much power is generated by the water, and how much heat is going into it?
   4. If the heat going into the boiler comes out of a charcoal flame at 1000°C, then how much entropy is generated in the complete system to heat the water?

   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. Consider an ideal Otto cycle using standard air. At the start of the compression stroke, the 2 L of air is at 90 kPa and 26.85°C. Then the piston compresses it to 0.2 L. Next, in the combustion process, the fuel adds 1800 kJ/kg *air* of heat to the air.

   (a) What is the compression ratio of this engine? What is its thermal efficiency?

   (b) What are the pressure and temperature at the end of the compression stroke? How much heat leaks out during the stroke?

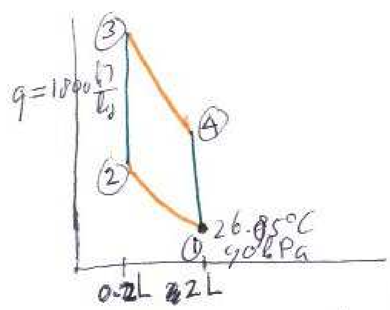
   (c) What is the temperature immediately after the combustion process? How much work does the air do during the combustion process?

   (d) Based on the engine efficiency, what will be the specific work obtained in a complete cycle?

   (e) What is the work obtained in a cycle? And how much heat is added to the air by the fuel to get that work?

   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 diagram



Asked + Solutions

a) r_v, η_{th}: $r_v = \frac{V_1}{V_2} = 10$ $\quad \eta_{th} = 1 - \frac{1}{r_v^{k-1}} = 1 - \frac{1}{10^{1.4-1}}$ (A.T) $= 0.60189$

b) P_2, T_2? $\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^k = 25.189$ $\quad P_2 = 2260.7$ kPa

$T_1 = 300$ K $\quad \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{k-1} = 2.5119$ $\quad T_2 = 753.56$ K

c) T_3? $q = 1800\ \frac{kJ}{kg} = c_v(T_3 - T_2)$ (0.717 A.5) $\quad T_3 = \frac{1800\ kJ/kg}{0.717\ kJ/kg\,K} + 753.56$ K $= 2510.46$ K $+ \ldots = 3264.0$ $\quad T_3 = 3264.0$ K

d) $\eta_{th} = \frac{w}{q_H} \Rightarrow w = \eta_{th}\, q_H = 0.60189 \times 1800$ kJ/kg $= 1083.4$ kJ/kg

e) $P_1 V_1 = m R T_1$ $\quad 90\ kPa\ 2\ L\ \frac{1\ m^3}{1000\ L} = m\ 0.287\ \frac{kJ}{kg\,K}\ 300\ K \Rightarrow m = 0.0020906$ kg

$W = m w = 2.265$ kJ $\quad Q = m q = 3.7631$ kJ