Putting your name and e-mail on the first page only will be enough for a remote exam. Two letter-size formulae sheets, handwritten by you, may be used. Put your answers on the same sheet as the question and continue on the next blank page if needed. (Do not submit pages that are blank except for the header.) You must give the units of your answers. You must write clearly. 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.

Use at least 5 significant digits in your computations and answers.

Not following those requirements will result in reduced or no credit.

1. (3%) To cool a nuclear reactor, a horizontal reversible pump with entrance and exit pipes of equal diameter uses 20 kW of electricity to compress 7 kg/s of molten sodium entering at the ambient pressure of 100 kPa. The pressure of the exiting molten sodium will be ___2754.3___ kPa.

2. (3%) If the temperature of 4 kg of molten sodium is decreasing at a rate of 3°C/s, then the heat that leaks out must be ___16.56___ kW.

3. (3%) If 4 kg of molten sodium cools down from 400°C to its melting point of 98°C, the heat released by the sodium is ___1667___ kJ, its entropy decreases by ___3.2864___ kJ/K, and the entropy generated in the complete system, including the 20°C surroundings is ___2.4002___ kJ/K.

4. (3%) You have saturated vapor in an adiabatic piston/cylinder combination. If you pull up on the piston a bit, liquid will condense. However, if you mess around with the piston, like push it down suitably, you can make the liquid disappear again. At that point, the temperature of the saturated vapor can be either ___the same or less___.

5. (3%) A geothermal engine which extracts heat at 40°C and dumps its waste heat to the 10°C river will for each MW of heat removed from the geothermal reservoir produce no more than 95.801 kW of work.

6. (3%) Should a water droplet that is evaporating be considered a control mass or a control volume, and why?
As a control volume since there is outflow .

7. (3%) A 3 kg/s stream of a gas with a molar mass of 30 enters a reversible compressor at 300 K and is compressed to 900 K in a process that is polytropic with $n = 1.4$. The work needed to run the compressor is 1746 kW.

8. (3%) If argon is compressed from 300 K and 100 kPa to 500 K and 900 kPa, its internal energy changes by 62.4 kJ/kg, its enthalpy changes by 104 kJ/kg, and its entropy changes by -0.19161 kJ/kg-K.

9. (3%) A 3 m^3 volume of air at 100 kPa and 25°C is expanding at a rate of 0.05 m^3/s. It can be assumed that the process is adiabatic. The temperature increases at a rate of -1.9891 °C/s.

10. (3%) Assume a substance with known properties. For each of the following combinations of data, enter a y if we can find the current state of the substance from it, or an n if not. (1) H, S: n. (2) H, s: n. (3) h, S: n. (4) h, s: y. (5) m, H, S: y. (6) m, ρ, V: n.

11. A 0.3 kg/s stream of water at 500 kPa and 20°C enters an evaporator (a heat exchanger in which the substance is put to a boil) with negligible velocity. The water comes out at 100 kPa with a specific entropy of 6 kJ/kg-K at a velocity of 200 m/s.

    (a) Construct the initial state in a very neat Ts diagram, pressure line first. See below for requirements.
    (b) Similarly, construct the final state in a very neat Pv diagram, pressure line first again.
    (c) What is the heat added to the water in the evaporator and what is the work produced?
    (d) Assuming that the added heat comes from a 150°C surroundings, what is the entropy generated in the complete system?
    (e) What is the diameter of the exit pipe?

    Phase contructions must be very neat. They must have every line and point used marked with its value. Do not put more info in the diagram than is needed to construct the phase. *State the phase.* Make sure it is completely clear *what point* in the diagram this phase refers to.

    You must use 5 *significant* digits in all your computations and answers.

    Box your answers and arrange them by subquestion letter.

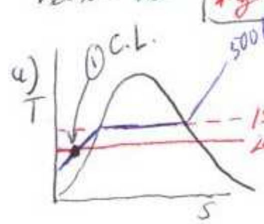
    You must show the derivations and reasoning completely and correctly for full credit. You must give simplified units for your answers. Most accurate procedure only unless stated otherwise. Use at least 5 significant digits in your computations and answers. *Give the source of every number.*

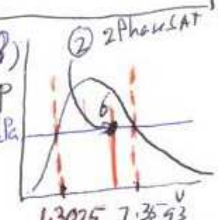
Given: in black

0.3 kg/s E, 500 kPa I, 20°C I, Vel NO Vel → evaporator → 0.3 kg/s, 100 kPa I, 6 kJ/kg,K = s I, 200 m/s Vel

evaporator:
$\dot Q + \dot m_1 (h_1 + \frac12 Vel_1^2 + gz_1)$
$= \dot W + \dot m_2 (h_2 + \frac12 Vel_2^2 + gz_2)$
$\dot S_{gen} = \dot m (s_2 - s_1) - \dot Q / T_{sur}$

(1) diagram (2) line (3) liquid SAT, R.O.O. (2) plot sat (2) line 2 vel (2) ID (3) ID — 12
(1) $\dot m_2 = \dot m_1$ (2) $\dot W = 0$ (2) Read B.1.4 (1) Read B.1.2 (2) 2 phase (1) find x (1) find h, v — 11
(3) 1st law (1) find $\dot Q$, units (2) 2nd law (1) find $\dot S_{gen}$ units (2) mass flow (1) find D, units — 12

a) 

b) 

c) B.1.4 @ 500 kPa, 20°C: (not 25.94) 11
$h_1 = 84.41$ $s_1 = 0.2965$
B.1.2 @ 100 kPa:
$h_f = 417.44$ $h_{fg} = 2258.02$ $h_g = 2675.46$
$s_f = 1.3025$ $s_{fg} = 6.0568$ $s_g = 7.3593$
$v_f = 0.001043$ $v_{fg} = 1.69296$ $v_g = 1.694$

$s_2 = s_f + x_2 s_{fg} \rightarrow x_2 = \frac{s_2 - s_f}{s_{fg}} = \frac{6 - 1.3025}{6.0568} = 0.77557$

$h_2 = h_f + x_2 h_{fg} = 2168.7$ kJ/kg

$\dot Q + \dot m (h_1) = \dot m (h_2 + \frac12 Vel_2^2)$ $\boxed{\dot W = 0}$

$\dot Q = \dot m (h_2 - h_1 + \frac12 Vel_2^2) = 0.3 \frac{kg}{s} \left(2168.7 \frac{kJ}{kg} - 84.41 \frac{kJ}{kg} + \frac12 (200)^2 \frac{m^2}{s^2} \frac{1\ kJ/kg}{1000\ m^2/s^2}\right)$

(2084.3, 20, 2104.3)

$\boxed{\dot Q = 631.29\ kW}$

d) $\dot S_{gen} = \dot m (s_2 - s_1) - \frac{\dot Q}{T_{sur}}$
$= 0.3 \frac{kg}{s} (6 - 0.2965) \frac{kJ}{kg,K} - \frac{631.29\ kJ/s}{(150 + 273.15) K} = \boxed{0.2191 \frac{kJ}{K s}} = \dot S_{gen}$

e) $v_2 = v_f + x\, v_{fg} = 0.001043 + 0.77557 \cdot 1.69296 = 1.3141\ m^3/kg$

$\dot m = \frac{A\, Vel}{v}$ $A = \frac{\dot m v}{Vel} = \frac{0.3\ kg/s \cdot 1.3141\ m^3/kg}{200\ m/s} = 0.0019711\ m^2 = \frac{\pi}{4} D^2$

$D = \sqrt{\frac{4A}{\pi}} = \boxed{0.050096\ m = D}$ (5 cm)

12. In this question, you are asked to study the effect of increasing the compression ratio on an ideal Otto cycle (as happened in about the 1970s for the nonideal car engines). In all cases, the intake air at the start of the compression stroke is at 85 kPa and 6.85°C.

    (a) Very neatly and accurately, draw the Pv and Ts diagrams of the cycle. Mark the intake air state as 1.

    (b) Now first assume that the compression ratio is 7. Also assume that the specific heat added during the combustion is $1800 \times 6/7$ kJ/kg. (The 6/7 reflects that of the intake air only 6 parts out of 7 are fresh air with oxygen in it to burn fuel.) From that compute the efficiency, specific work per cycle, and the peak pressure and temperature in the cycle.

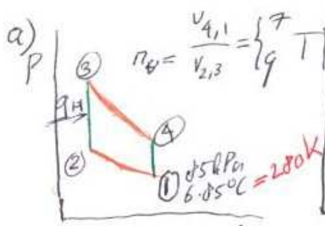
    (c) Repeat if the compression ratio is 9 and the heat added $1800 \times 8/9$ kJ/kg. Comment on what the differences mean.

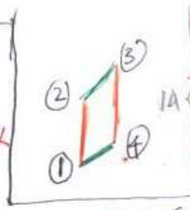
    (d) Staying with the latter case, and assuming that the displaced volume of the engine is 0.8 L per cylinder (with the total initial volume 9/8 times bigger than that), and that it is a two cylinder engine, and that the engine runs at 2000 rpm, what would be the power produced? Convert to metric horsepower.

You must use 5 *significant* digits in all your computations and answers.

Box your answers and arrange them by subquestion letter.

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.*

a)




(3) find R, c_v, k; (2) draw Ts, Pv; (2) identify ①pt; (3) know $r_v = v_1/v_2$; (2) know η eq; (2) find η (b, c) — 14
(3) find T_2, P_2 (b); (3) find T_3, P_3 (b) units; (2) find T_2, P_2 (c); (2) find T_3 P_3 (c); (2) know $w = \eta q_H$; (2) find w (b, c) units — 14
(4) $PV = mRT$ or $Pv = RT$; (1) find m; (2) find $\dot W$ units — 7

b) $\eta_{th} = 1 - \frac{1}{r_v^{k-1}} = 1 - \frac{1}{7^{0.4}} =$ **0.54084 = η_{th}**

$w = \eta_{th} q_H = 0.54084 \times 1800 \times \frac{6}{7}$; **w = 834.44 kJ/kg**

$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{k-1}$ $T_2 = 280\text{ K}\ 7^{0.4} = 609.81\text{ K}$ } since polytropic n = k (and also use $s_2 = s_1$ in $s_2 - s_1 = \ldots$)

$\frac{P_2}{P_1} = \left(\frac{v_1}{v_2}\right)^k$ $P_2 = 85\text{ kPa}\ 7^{1.4} = 1295.9\text{ kPa}$

$\frac{P_3}{P_2} = \frac{RT_3/v_3}{RT_2/v_2} = \frac{T_3}{T_2}$ (or compute v_1, then $v_2 = \frac{1}{7} v_1$, then $P_3 = RT_3/v_3$)

$q_H = 1800 \times \frac{6}{7} = c_v (T_3 - T_2)$ $T_3 = T_2 + 1800 \times \frac{6}{7}/c_v = 609.81 + 1800\frac{6}{7}/.717$; 1542.9; **$T_3$ = 2761.6 K**

$P_3 = P_2 \frac{T_3}{T_2} =$ **5868.5 kPa = P_3** 0.94541; .13506; $v_2 = v_3 = 0.10505\ \text{m}^3/\text{kg}$

c) 7→9: **η_{th} = 0.58476** **w = 935.61** T_2 = 674.3 K P_2 = 1842.3 kPa **T_3 = 2905.8 K** **P_3 = 7939.1 kPa**

$T_3 = T_2 + 1800 \times \frac{8}{9}/c_v$ (1600)

About 10% increase in efficiency: good, higher P_3, T_3: bad (materials, sealing)

$m = \frac{P_1 V_1}{RT_1} = \frac{85\text{ kPa}\ 0.0008 \frac{9}{8}\text{ m}^3}{0.287\ 280}$ or $m = V_1/v_1$; $m = 0.00095197$ kg

d) $w = 935.61 \frac{\text{kJ}}{\text{kg cycle}}$

$\dot W = 935.61 \frac{\text{kJ}}{\text{kg cycle}} \times 0.00095197\text{ kg} \times 2000 \frac{\text{rev}}{\text{min}} \times \frac{1\text{ cycle}}{2\text{ rev}} \frac{1\text{ min}}{60\text{ s}}$; 0.89067 kJ/cycle; 890.67 kJ/min; 14.84 kJ/s

$14.84\text{ kW} \times 2\text{ cylinders} \times \frac{1\text{ hp}}{0.735499\text{ kW}} =$ **40.356 hp = $\dot W$**