I (40). The four-stroke internal combustion engine is often approximated by the cycle that is described below: You can also assume that $C_p = 3.5R$ is constant for each step and that air is an ideal gas.

I. Air at room temperature ($27^\circ C$) enters a one-liter cylindrical volume with a piston at one end and is compressed adiabatically by the piston to 0.1 liters.

II. A quantity of heat due to the combustion enters the chamber at constant volume such that the pressure doubles.

III. The piston moves back adiabatically to the initial volume (1 l).

IV. The hot gasses are allowed to exit the volume. This is equivalent to removing sufficient heat to return the gas to room temperature and 1 atmosphere pressure (1 Bar).

A. What are the changes in enthalpy, work and heat for the four steps which comprise this process?

\[
\begin{array}{cccc}
\Delta H & W & Q & T_{\text{final}} \\
\hline
\text{I} & & & \underline{25^\circ C} \\
\text{II} & & & \\
\text{III} & & & \\
\text{IV} & & & \\
\end{array}
\]

B. What is the thermal efficiency for this process in terms of the temperatures ($T_A$, $T_B$, $T_C$ and/or $T_D$)?

C. Construct an $H$, $P$ diagram for this process.

D. How much heat comes out with the exhaust (~heat removed in step IV)?
Answer:
n Cp = 3.5*8.314J/moleK/22.4liter/mole = 1.299J/K
n Cv = 2.5*8.314J/moleK/22.4liter/mole = 0.928J/K
γ = 1.4

<table>
<thead>
<tr>
<th>ΔH</th>
<th>W</th>
<th>Q</th>
<th>Tfinal</th>
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<tbody>
<tr>
<td>I</td>
<td>584 J</td>
<td>-417 J</td>
<td>0</td>
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</table>

W = nR(T1 - T2)/(γ - 1)
VA/VB = (TB/TA)^{1/(γ - 1)} thus (TB/TA) = 10^{(γ - 1)} = 10^{0.4} = 2.51
TB = 298K*2.51 = 748K; PB/PA = (TB/TA)^{γ/(γ - 1)} = 25Bar
W = n8.314*(298-748)/0.4 = n 9.35kJ = -417.45 joul = nCvΔT
ΔH = n Cp DT = 1.299*450K = 584 joul

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<tr>
<td>II</td>
<td>971.6J</td>
<td>0</td>
<td>684.1J</td>
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TC / TB = PC/PB at Constant Volume
TC = 1496K PC = 50 Bar
ΔH = n Cp ΔT = 1.299*748K = 971.6 joul
VΔP = 0.1 * 25 = 2.5 lbar = 250J
Q = n Cv ΔT = 684.1J

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<th>Tfinal</th>
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<tbody>
<tr>
<td>III</td>
<td>-971.6 J</td>
<td>598J</td>
<td>0</td>
</tr>
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</table>

(TD/TC) = 0.1^{(γ - 1)} = 0.1^{0.4} = 0.389
TD = 1496*0.389 = 581.9 K ; 1.4 Bar
ΔH = n Cp ΔT = 1.299*(581.9-1496)K = -1187.4 joul
W = ΔU = ΔH/γ = -848.1 J = n Cv ΔT = 0.928*ΔT
DH W Q Tfinal
IV -146J 0 -100.4J 25 o C = 298K
\[ \Delta H = n \, C_p \, \Delta T = 1.299 \times (298-581.4) \, K = -146 \, J \]
\[ Q = \Delta U = \Delta H/\gamma = -100.4 \, J \]

C. What is the efficiency for this process in terms of the temperatures (\( T_A \), \( T_B \), \( T_C \) and/or \( T_D \))

\[ h = \frac{W}{Q_{in}} = \frac{Q_{in}}{Q_{in}} = 1 - \frac{C_v \, T_D - T_A}{C_v \, T_C - T_B} \]
\[ C_v \, T_C - T_B = 1 - \frac{T_D - T_A}{112.4/307} = 63.3\% \]

**Extra credit:** What does the change in temperature for the second step tell you about the heat of combustion for gas (assume toluene, \( C_7H_8 \)) considering the stoichiometry for toluene combustion in air dictates the ratio of fuel to air (20% oxygen).

_This cycle is equivalent to two constant volume processes connected by two adiabatic processes. Assume \( C_p \) for air is 7/2\( R \) (or any gas in the system) and 22.4 liters = 1 mole at STP (one atmosphere and 298K). It is often convenient to calculate \( \Delta U \) for the steps also and to calculate \( nC_p \) and \( nC_v \) in J/K for the whole process first._

2. [40]

A piston-cylinder arrangement is shown in the accompanying figure. The cylinder is closed and insulated on all surfaces save one face of the section containing nitrogen. The cylinder is partitioned into two sections, one containing nitrogen, the other containing helium. The two sections are separated by a frictionless piston which does not conduct heat. Initially, each gas occupies a volume of 1 liter and is at 25°C at a pressure of 1.0 bar. Heat is added to the nitrogen across the non-insulated face until the pressure in both gases reaches 3.0 bar.

a) Determine the final volume and temperature of the helium

**Final Volume & Temp. He**

b) Determine the final temperature of the nitrogen
Final Temp. N

c) Determine the heat added to the nitrogen through the left face.

Jouls

Assume that for nitrogen $C_v = 5R/2$, for helium $C_v = 3R/2$.
Both gases are ideal…. What does this means about the number
of moles of each to start?

$$R = 0.08314 \text{ literbar/moleK} = 8.314 \text{ J/moleK}$$

Hint some calculations may be better per mole. Note the relationships between pressures and
volumes in the two sections. Calculate the P, V and T s as soon as you can. What does
this tell you about Q, W and U in each section.

State your assumptions necessary to solve the problem.
Answer: for the He, $p_2/p_1 = (T_2/T_1)_{g/g-1}$ and $g = 1.67$,
thus $p_2 = 4.1 \text{ Bar}$ ($p_1 = 2$) (the same pressure for the $N_2$)
also for the He: $v_2/v_1 = (T_1/T_2)_{1/g -1} = 0.649$ and
$v_2 = 0.649$ for He
So for Nitrogen $v_2 = 1.351 \text{ l}$
But $p_2/p_1$ for $N_2$ is 2.06: $T_2/T_1 = p_2 v_2/p_1 v_1$ for $N_2$
So $T_2/T_1 = 1.351*2.06 = 2.78$ and $T_2 = 829 \text{ K}$
$nD U = nC_v D T = nQ - nW$, but the work into and out of the
He and $N_2$ are equal
work on the helium per mole = $R(T_1 - T_2)/(g - 1)$
Thus the heat into the Nitrogen/ per mole of Nitrogen=
$5R/2 (829 - 298) + R (398-298) / 0.667 = Q/mole = 1457.5R (K)$
= 11036 J/mole
# moles of $N_2 = 2/ 22.4l = .09$ moles -> 993 J of heat added.
3. (35) Using the attached Steam Tables Circle the points that you used and answer the following:

A. We use steam in the Senior Unit Operation Laboratory. To do an energy balance on the heat exchanger you use a valve connected to the steam line at 29.4 psi (gauge pressure) to leak steam out to the lab into an insulated but open container and measure the temperature of the dry stream as 114°C. What is the quality of steam in the steam line?

Enthalpy/gram, Steam Quality

ANS: This is a constant Enthalpy process. One can determine the enthalpy of the steam at 1 bar = 0.1 MPa and 160°C by interpolation in T: \( H = 2704 \, \text{kJ/kg} \)

At 0.3 MPa, \( H^* = 2724.88 \) and \( H^i = 561.43 \); the steam in the pipe comprises \( x \) fraction of steam and \( 1-x \) fraction of liquid water with an enthalpy of

\[ x \times 2724.88 \, \text{kJ/kg} + (1-x) \times 561.43 \, \text{kJ/kg} = 2704 \, \text{kJ/kg} \]

\[ x = \frac{(2704 - 561.43)}{(2724.88 - 561.43)} = 0.99, \text{ this is the steam quality, 99%} \]

B. 2 kg Steam/min enters an adiabatic (assumed) turbine at 3.5 bar gauge pressure and 500°C and exits to the atmosphere at 300°C. How much work is produced per hour if the turbine is adiabatic?

J/min, hp

ANS.: The enthalpy of the steam entering the turbine (0.45 MPa and 500°C) is found by pressure interpolation \( H = \frac{[3484.5 \times (500 \, \text{C} \times 0.5 \, \text{MPa}) + 3485.5 \times (500 \, \text{C} \times 0.4 \, \text{MPa})]}{2} = 3485.0 \, \text{kJ/kg} \)

At (300°C 0.1 MPa) the enthalpy is 3074.5 kJ/kg. The enthalpy difference is 410.5 kJ/kg This gives 811 kJ/min of work in this adiabatic process. The horse power is found

\[ 811,000/(60 \times 745) = \text{18.14 hp} \]

C. How much heat is required to heat 2 kg dry Steam/min steam from saturation at 4 bar absolute pressure to 4 bar absolute pressure and 500°C?

ANS: 3485.5 at 0.4 MPa and 500°C & 2738.05 at saturation at 0.4 MPa. The difference is 727.45 kJ/kg which gives 1454.9 kJ/min of heat added this gives 24.915 kW
J/min, kW

Note: 1 bar = 14.7 psi = 103kPa, gauge pressure + 1 bar = absolute P, 1hp = 745W = 745J/s, 1Aatt- 1J/s