Midterm #1

MEMS 0051 - Introduction to Thermodynamics
Summer 2020

Assigned: June 5$^{\text{th}}$, 2020
Due: June 11$^{\text{th}}$, 2020, 3:55 pm via Gradescope (for written) and Canvs for MATLAB code

Rules

The following listed rules, in addition, but not limited to, those listed on the syllabus, those listed on page 3, and those outlined by Pitt's Academic Integrity Policy, apply to this examination:

1. This test is open notes, open book, open lecture videos, open homework and homework solutions, open quiz and quiz solutions, and you are able to reference previous assessment materials;
2. You can direct general questions to either the MEMS 0051 Slack, or email Dr. Barry or Mr. Dosse. A general question constitutes a point of clarification with a question, for example "Is y in Problem #3 the displacement?" Specific questions about how to solve a problem, pertinent equations, related to general guidance, etc., are *not* permitted;
3. You are *not* to communicate with *any* other student about this exam. Period;
4. You are *not* to use any online resources, such as Chegg, Quora, etc., or any form of thermodynamic property calculator. Seeking external assistance in the form of posting this exam, posting questions from this exam, asking questions pertaining to the problems within the exam, etc., is in direction violation of the Academic Integrity policy.
5. Unsubstantiated results will be marked incorrect;
6. You must complete the Academic Integrity Statement and include it with your exam submission for your exam to be graded.

Problem #1

(20 pts.) Water contained with a piston-cylinder assembly undergoes a series of processes from an initial to a final state. The water is initially at 1,273 [kPa] and a temperature of 554 °C. It is cooled in a constant pressure process until it reaches a saturated vapor state. Thereafter, it is cooled in a constant volume process until the temperature reaches 137.2 °C. Lastly, it is cooled in a constant-pressure process until the temperature reaches 20 °C. Determine:

a) The overall work of this process;
b) The overall heat transfer of this process.

Problem #2

(20 pts). Consider two rigid tanks connected by a valve that is initially closed. Tank A contains water at 400 °C and with a specific volume of 0.25480 [m^3/kg]. Tank B contains 8.2 [kg] of water at a temperature of 110 °C and with a quality of 0.1. The total volume of both tanks is 3 [m^3]. The valve is now opened and the water mixes until it reaches equilibrium. If the final pressure in the tanks is approximately 600 [kPa], determine the following:

a) The initial mass, m, of water in each tank; Let's look at our states and what we know:

State 1A:	State 1B:	State 2:
P_{1A} = ?	P_{1B} = ?	P_2 = 600 [kPa]
T_1 = 400 °C	T_{1B} = 110 °C	T_2 = ?
$\forall_{1A}$ = ?	$\forall_{1B}$ = ?	$\forall_2$ = 3 [m^3]
ν_{1A} = 0.25480 [m^3/kg]	ν_{1B} = ?	ν_2 = ?
u_1 = ?	u_{1B} = ?	u_2 = ?
x_{1A} = ?	x_{1B} = 0.1	x_2 = ?
m_{1A} = ?	m_{1B} = 8.2 [kg]	m_2 = ?

We have enough two independent properties for tank B at state 1. Therefore we can find the specific volume at state 1B using Table B.1.1:

$$\nu_{1B} = \nu_f + x_{1B}\nu_{fg} = ((0.001\,052 + (0.1)(1.209\,09))\ [\mathrm{m^3/kg}]) = 0.121\,96\ [\mathrm{m^3/kg}]$$

The volume of tank B is:

$$\forall_{1B} = m_{1B}\nu_{1B} = (8.2\ [\mathrm{kg}])(0.121\,96\ [\mathrm{m^3/kg}]) = 1\ [\mathrm{m^3}]$$

The volume of tank A is:

$$\forall_{1A} = \forall_2 - \forall_{1B} = 3\ [\mathrm{m^3}] - 1\ [\mathrm{m^3}] = 2\ [\mathrm{m^3}]$$

The mass of water in tank A can now be found:

$$m_{1A} = \frac{\forall_{1A}}{\nu_{1A}} = \frac{2\ [\mathrm{m^3}]}{0.254\,80\ [\mathrm{m^3/kg}]} = 7.85\ [\mathrm{kg}]$$

Finally, per the conservation of mass, the mass in tank 2 is:

$$m_2 = m_{1A} + m_{1B} = 7.85\ [\mathrm{kg}] + 8.2\ [\mathrm{kg}] = 16.05\ [\mathrm{kg}]$$

In summary, the masses are:

$$\boxed{m_{1A} = 7.85\ [\mathrm{kg}], \qquad m_{1B} = 8.2\ [\mathrm{kg}]}$$

b) The volume, $\forall$, of each tank; We found the volume of each tank while determining the mass. In summary, the volumes are:

$$\boxed{\forall_{1A} = 2\ [\mathrm{m^3}], \qquad \forall_{1B} = 1\ [\mathrm{m^3}]}$$

c) The initial pressure, P, temperature, T, and quality, x (if applicable) of the water in each tank;
We see that the given specific volume and temperature correspond to the water in tank A being a superheated vapor. From Table B.1.3, we can find the pressure:

$$P_{1A} = 1,200\ [\mathrm{kPa}]$$

Since we have a given quality and temperature, we know there must be an associated saturation pressure. From Table B.1.1, we can find the pressure:

$$P_{1B} = 143.3\ [\mathrm{kPa}]$$

In summary, the pressure, temperature, and quality in each tank is:

State 1A:	State 1B:
P_{1A} = 1,200 [kPa]	P_{1B} = 143.3 [kPa]
T_1 = 400 °C	T_{1B} = 110 °C
x_{1A} = undefined	x_{1B} = 0.1

d) The final pressure, P, temperature, T, and quality, x (if applicable) of the water after the valve is opened;
We need another independent term to find the temperature and quality of state 2. We can find the specific volume using the conservation of mass:

$$m_2 = m_{1A} + m_{1B} = 7.85\ [\mathrm{kg}] + 8.2\ [\mathrm{kg}] = 16.05\ [\mathrm{kg}]$$

$$\nu_2 = \frac{\forall_2}{m_2} = \frac{3\ [\mathrm{m^3}]}{16.05\ [\mathrm{kg}]} = 0.186\,92\ [\mathrm{m^3/kg}]$$

Looking at Table B.1.2, we can see that the water at state 2 then is a saturated mixture. Using the specific volume, we see the quality is:

$$x_2 = \frac{\nu_2 - \nu_f}{\nu_{fg}} = \frac{(0.186\,92 - 0.001\,101)\ [\mathrm{m^3/kg}]}{(0.314\,57)\ [\mathrm{m^3/kg}]} = 0.590\,7$$

The temperature must be the saturation temperature for a saturation pressure of 600 [kPa]. In summary, the pressure, temperature, and quality at state 2 are:

$$\boxed{P_2 = 600\ [\mathrm{kPa}], \qquad T_2 = 158.85\,^\circ\mathrm{C}, \qquad x_2 = 0.590\,7}$$

e) The heat transferred and work performed during the process; The two tanks are rigid, so the change in volume is zero for the system during the process. The work performed then is:

$$\boxed{W_{1\to 2} = 0 \text{ [kJ]}}$$

The heat transferred during the process can be found using the conservation of energy:

$$Q_{1\to 2} = U_2 - U_1 + W_{1\to 2}$$

We need values for specific internal energy. Using Tables B.1.3 and B.1.1 for state 1:

$$u_{1A} = 2954.90 \text{ [kJ/kg]}, \qquad u_{1B} = u_f + x_{1B}u_{fg} = (461.12 + (0.1)(2,056.96)) \text{ [kJ/kg]} = 666.82 \text{ [kJ/kg]}$$

Using Table B.1.2 for state 2:

$$u_2 = u_f + x_2 u_{fg} = (669.88 + (0.590\,7)(1,897.52)) \text{ [kJ/kg]} = 1,790.75 \text{ [kJ/kg]}$$

The heat transferred during the process is:

$$Q_{1\to 2} = m_2 u_2 - (m_{1A}u_{1A} + m_{1B}u_{1B})$$

$$Q_{1\to 2} = (16.05 \text{ [kg]})(1,790.75 \text{ [kJ/kg]}) - ((7.85 \text{ [kg]})(2954.90 \text{ [kJ/kg]}) + (8.2 \text{ [kg]})(666.82 \text{ [kJ/kg]}))$$

$$\boxed{Q_{1\to 2} = 77.65 \text{ [kJ]}}$$

Problem #3

(30 pts.) A piston-cylinder is filled with 0.187 [kg] of air at a pressure and temperature of 124 [kPa] and 161 °C. The piston is exposed to an atmospheric pressure of 100 [kPa] and is supported by a non-linear spring, i.e. a spring that does not follow Hooke's Law, as shown in the figure. The spring can be compressed a maximum of 1 [m], at which point it is pressed against the bottom of the cylinder and cannot deflect any further. The force in the spring is governed by the function $F_s = -k\sqrt{y}$, where k is the spring constant and is equal to 10 [kN/m$^{1/2}$]. The piston has an area of 0.1 [m^2], a thickness of 0.1 [m], and a density of 7,820 [kg/m^3]. In addition, the area can be considered the same on both sides of the piston. The air is first heated until it reaches a pressure of 225 [kPa]. The air is next cooled, reducing the volume, and the spring deflects upwards by 1.01 [m]. Finally, the air undergoes a polytropic process with an index of -6.77. If the net work of these processes is 1.82 [kJ], Assuming gravity is equal to 9.81 [m/s^2], determine the following:

a) The initial deflection of the spring, y_1; To determine the initial deflection, we need to find the force applied to the spring. Balancing forces, we get:

$$F_1 + F_p = F_{\text{atm}} + F_{s1}$$

$$F_{s1} = (P_1 + P_p - P_{\text{atm}})A_p = ((124 + 7.671 - 100) \text{ [kPa]})(0.1 \text{ [m}^2\text{]}) = 3.167 \text{ [kN]}$$

Rearranging the spring force equation to solve for y_1:

$$y_1 = \left(\frac{F_{s1}}{k}\right)^2 = \left(\frac{3.167 \text{ [kN]}}{10 \text{ [kN/m}^{1/2}\text{]}}\right)^2 = \boxed{0.1 \text{ [m]}}$$

b) The net heat transfer, Q_{net};
We need to carefully move through our states one by one. The only method we have to solve for Q_{net} for air is to assume it is an ideal gas. There will be six states that the air passes through, but three of them are technically irrelevant to the analysis. Our states are:

<u>State 1</u>:	<u>State 2</u>:	<u>State 3</u>:
$P_1 = 124$ [kPa]	$P_2 = ?$ [kPa]	$P_3 = 225$ [kPa]
$T_1 = 434.15$ [K]	$T_2 = ?$	$T_3 = ?$
$\forall_1 = ?$	$\forall_2 = ?$	$\forall_3 = ?$
$y_1 = ?$	$y_2 = ?$	$y_3 = ?$
$P_{s1} = ?$	$P_{s2} = ?$	$P_{s3} = ?$
<u>State 4</u>:	<u>State 5</u>:	<u>State 6</u>:
$P_4 = P_2 = ?$	$P_5 = ?$	$P_6 = ?$
$T_4 = T_2 = ?$	$T_5 = ?$	$T_6 = ?$
$\forall_4 = \forall_2 = ?$	$\forall_5 = ?$	$\forall_6 = ?$
$y_4 = y_2 = ?$	$y_5 = ?$	$y_6 = $ N/A
$P_{s4} = P_{s2} = ?$	$P_{s5} = ?$	$P_{s6} = $ N/A

Let's begin by finding missing state values. The volume for state 1 is:

$$\forall_1 = \frac{mRT_1}{P_1} = \frac{(0.187 \text{ [kg]})(0.287 \text{ [kJ/kg-K]})(434.15 \text{ [K]})}{(124 \text{ [kPa]})} = 0.1879 \text{ [m}^3\text{]}$$

State 2 is a state that occurs because the piston bottoms out in the cylinder and can not compress any further. Since the maximum possible deflection is 1 [m], we can find the pressure and volume at this state. From force balance:

$$P_2 + P_p = P_{\text{atm}} + P_{s2}$$

$$P_2 = 100 \text{ [kPa]} - 7.671 \text{ [kPa]} + \frac{10 \text{ [kN-m}^{-1/2}\text{]}\sqrt{1 \text{ [m]}}}{0.1 \text{ [m}^2\text{]}} = 192.329 \text{ [kPa]}$$

Using the formula for the volume of a cylinder:

$$\forall_2 = \forall_1 + A_p(y_2 - y_1) = 0.1879 \text{ [m}^3\text{]} + (0.1 \text{ [m}^2\text{]})(0.9 \text{ [m]}) = 0.2779 \text{ [m}^3\text{]}$$

The temperature at this state then is:

$$T_2 = \frac{P_2\forall_2}{mR} = \frac{(192.329 \text{ [kPa]})(0.2779 \text{ [m}^3\text{]})}{(0.187 \text{ [kg]})(0.287 \text{ [kJ/kg-K]})} = 995.89 \text{ [K]}$$

We know the volume is now constant moving from state $2 \rightarrow 3$. Using the Ideal Gas Law to find the temperature, summarizing the properties at state 3 we have:

$$P_3 = 225 \text{ [kPa]} \qquad T_3 = 1165.06 \text{ [K]} \qquad \forall_3 = 0.2779 \text{ [m}^3\text{]}$$

The next information we are given is that the spring now deflects upwards by 1.01 [m]. The spring, however, is unable to move until the pressure reaches that found at state 2. This means we once again have an in-between state, i.e. state 4, which will have the same properties as those found at state 2.

At state 4, the spring now deflects upwards by 1.01 [m], which means the force of the spring now acts in the opposite direction. The pressure at state 4 can be found by using a force balance:

$$P_5 + P_p = P_{\text{atm}} + P_{s5}$$

$$P_5 = 100 \text{ [kPa]} - 7.671 \text{ [kPa]} - \frac{10 \text{ [kN-m}^{-1/2}\text{]}\sqrt{(0.01 \text{ [m]})}}{(0.1 \text{ [m}^2\text{]})} = 82.329 \text{ [kPa]}$$

The volume at state 5 is:

$$\forall_5 = \forall_4 - A_p(\Delta y) = 0.2779 \text{ [m}^3\text{]} - (0.1 \text{ [m}^2\text{]})(1.01 \text{ [m]}) = 0.1769 \text{ [m}^3\text{]}$$

From the Ideal Gas Law, the temperature is:

$$T_5 = \frac{P_5\forall_5}{mR} = \frac{(82.329 \text{ [kPa]})(0.1769 \text{ [m}^3\text{]})}{(0.187 \text{ [kg]})(0.287 \text{ [kJ/kg-K]})} = 271.37 \text{ [K]}$$

To find Q_{net}, as well as the final temperature and pressure at state 6, we need to make use of the given net work and the fact that the last process is stated to be polytropic with a known polytropic index. To that end, we need to find the work performed between states. The only work being done is the boundary work from the moving piston. We need the pressure in the cylinder as a function of volume. Let us first consider the pressure as a function of the spring height, y:

$$P(y) = P_0 + \frac{k}{A_P}\sqrt{y}$$

Note that when constructing a formula for the pressure in the cylinder the formula must be representative of the pressure inside the cylinder for all values of y. We know the function must involve the spring and have some initial pressure (since the pressure in the cylinder is not zero when the spring deflection is zero). To do so, we need to know the pressure inside the cylinder when there is no force on the spring, or when $y = 0$. From the balance of forces on the piston:

$$P_0 + P_p = P_{\text{atm}} \implies P_0 = P_{\text{atm}} - P_p = 100 \text{ [kPa]} - 7.671 \text{ [kPa]} = 92.329 \text{ [kPa]}$$

Substituting into the equation $P(y)$:

$$P(y) = 92.329 \text{ [kPa]} + \frac{10 \text{ [kN]}}{0.1 \text{ [m}^2\text{]}}\sqrt{y} \implies P(y) = 92.329 + 100\sqrt{y} \quad \text{[kPa]}$$

To move the equation from height to volume, we need to relate the change in height to the change in volume. The relationship is given by the volume of the cylinder:

$$\forall(y) = \forall_0 + A_p y \implies y = \frac{\forall - \forall_0}{A_p} \implies y(\forall) = \frac{\forall - \forall_0}{0.1 \text{ [m}^2\text{]}}$$

Like the pressure, we need an associated volume for when there is no force on the spring, or $y = 0$. This is found using the volume and deflection at state 1:

$$\forall_0 = \forall_1 + A_p y = 0.1879 \text{ [m}^3\text{]} + (0.1 \text{ [m}^2\text{]})(-0.1 \text{ [m]}) = 0.1779 \text{ [m}^3\text{]}$$

Substituting $\forall_0$ into the equation $y(\forall)$:

$$y(\forall) = \frac{\forall - 0.1779}{0.1} \quad \text{[m}^3\text{]}$$

Substituting $y(\forall)$ into $P(y)$, and noting the change in the direction of the spring force as we cross $y = 0$, we now have the formula for pressure as a function of volume:

$$P(\forall) = 92.329 + 100\sqrt{\frac{\forall - \forall_0}{0.1}}, \quad \text{for } \forall \geq \forall_0$$

$$P(\forall) = 92.329 - 100\sqrt{\frac{\forall_0 - \forall}{0.1}}, \quad \text{for } \forall \leq \forall_0$$

To determine the work performed between states, we can use the formal definition of work:

$$W_{1\to 2} = \int P d\forall = \int (92.329 + 316.228(\forall - 0.1779)^{1/2})d\forall = 92.329\forall + 210.819(\forall - 0.1779)^{3/2}$$

The change in work from states $2 \to 3$ is:

$$W_{1\to 2} = 92.329\forall + 210.819(\forall - 0.1779)^{3/2}\Big|_{0.1879}^{0.2779} = (32.325 - 17.559) \text{ [kJ]} = 14.766 \text{ [kJ]}$$

As the piston is now pressed against the bottom of the cylinder, no work can be performed as the air reaches a pressure of 225 [kPa]. While the air is being cooled, no work can be performed until the pressure reaches the pressure of state 2. Work is once again performed moving from states $4 \to 5$:

$$W_{4\to 5} = 92.329\forall + 210.819(\forall - 0.1779)^{3/2}\Big|_{0.2779}^{0.1779} = (16.425 - 32.325) \text{ [kJ]} = -15.9 \text{ [kJ]}$$

We now switch formulas as we move to the other side of the spring:

$$W_{4\to 5} = 92.329\forall - 210.819(0.1779 - \forall)^{3/2}\Big|_{0.0.1769}^{0.1779} = (16.326 - 16.425)\ [\text{kJ}] = -0.1\ [\text{kJ}]$$

$$W_{1\to 2} = -15.9\ [\text{kJ}] - 0.1\ [\text{kJ}] = -16\ [\text{kJ}]$$

We are given the net work for these processes, so we can now find the work performed moving from state 5 → 6:

$$W_{net} = W_{1\to 2} + W_{2\to 3} + W_{3\to 4} + W_{4\to 5} + W_{5\to 6} = 1.82\ [\text{kJ}]$$

$$W_{5\to 6} = 1.82\ [\text{kJ}] - 14.766\ [\text{kJ}] - (-16\ [\text{kJ}]) = 3.054\ [\text{kJ}]$$

Finally, we get to the point where we have two equations with two unknowns. From the relationship for a polytropic process, we have:

$$P_6\forall_6^n = P_5\forall_5^n \implies P_6\forall_6^{-6.77} = 10,196,131.11\ [\text{kJ}]$$

From the work for a polytropic process, we have:

$$W_{5\to 6} = \frac{P_6\forall_6 - P_5\forall_5}{1-n} = \frac{P_6\forall_6 - 14.564}{7.77} = 3.054\ [\text{kJ}]$$

Rearranging,

$$P_6\forall_6 = 38.294\ [\text{kJ}]$$

Solving these simultaneously yields:

$$P_6 = 191.15\ [\text{kPa}] \qquad \forall_6 = 0.2003\ [\text{m}^3]$$

We can solve the final temperature:

$$T_6 = \frac{P_6\forall_6}{mR} = \frac{(191.15\ [\text{kPa}])(0.2003\ [\text{m}^3])}{(0.187\ [\text{kg}])(0.287\ [\text{kJ/kg-K}])} = 713.4\ [\text{K}]$$

We can finally solve for Q_{net} using different Tables. Assuming Table A7 was used, we need to find the values for specific internal energy at state 1 and state 6:

$$u_1 = 311.37\ [\text{kJ/kg}] \qquad u_6 = 523.23\ [\text{kJ/kg}]$$

$$Q_{net} = m(u_6 - u_1) + W_{net} = (0.187\ [\text{kg}])((523.23 - 311.37)\ [\text{kJ/kg}]) + 1.82\ [\text{kJ}] = \boxed{41.44\ [\text{kJ}]}$$

c) The final pressure, P, and temperature, T, of the air; These were required to find Q_{net}, but to summarize:

$$\boxed{P_6 = 191.15\ [\text{kPa}]} \qquad \boxed{T_6 = 713.4\ [\text{K}]}$$

d) If the air can be treated as an ideal gas. Use P_c = 3,774 [kPa] and T_c = 132.41 [K] for the critical pressure and temperature, respectively; Using the highest pressure and lowest temperature found during the processes, the reduced pressure and temperature are:

$$T_r = \frac{T}{T_c} = \frac{271.37\ [\text{K}]}{132.41\ [\text{K}]} = 2.05 > 2 \qquad P_r = \frac{P}{P_c} = \frac{225\ [\text{kPa}]}{3774\ [\text{kPa}]} = 0.06 << 1$$

The ideal gas criteria are met, therefore the air can be treated as an ideal gas.

<u>Alternate Solution</u>:

Another similar, but less accurate solution can be determined by modeling the movement of the spring as a series of polytropic processes. This will change the total work and final pressure and temperature of the air in the cylinder. To calculate the work from states 1 → 2, we need to calculate the polytropic index:

$$n_{12} = \frac{\ln\left(\frac{P_1}{P_2}\right)}{\ln\left(\frac{\forall_2}{\forall_1}\right)} = \frac{\ln\left(\frac{124\ [\text{kPa}]}{192.35\ [\text{kPa}]}\right)}{\ln\left(\frac{0.2779\ [\text{m}^3]}{0.1879\ [\text{m}^3]}\right)} = -1.122$$

The work from state $1 \to 2$ is:

$$W_{1\to 2} = \frac{P_2\forall_2 - P_1\forall_1}{1-n_{12}} = \frac{(192.329\ [\text{kPa}])(0.2779\ [\text{m}^3]) - (124\ [\text{kPa}])(0.1879\ [\text{m}^3])}{2.122} = 14.208\ [\text{kJ}]$$

To calculate the work from states $4 \to 5$, we need to calculate the polytropic index:

$$n_{45} = \frac{\ln\left(\dfrac{P_4}{P_5}\right)}{\ln\left(\dfrac{\forall_5}{\forall_4}\right)} = \frac{\ln\left(\dfrac{192.329\ [\text{kPa}]}{82.329\ [\text{kPa}]}\right)}{\ln\left(\dfrac{0.1769\ [\text{m}^3]}{0.2779\ [\text{m}^3]}\right)} = -1.879$$

The work from state $4 \to 5$ is:

$$W_{4\to 5} = \frac{P_5\forall_5 - P_4\forall_4}{1-n_{45}} = \frac{(82.329\ [\text{kPa}])(0.1769\ [\text{m}^3]) - (192.329\ [\text{kPa}])(0.2779\ [\text{m}^3])}{2.879} = -13.506\ [\text{kJ}]$$

Using the net work, we can now find the work performed moving from state 5→6:

$$W_{net} = W_{1\to 2} + W_{2\to 3} + W_{3\to 4} + W_{4\to 5} + W_{5\to 6} = 1.82\ [\text{kJ}]$$

$$W_{5\to 6} = 1.82\ [\text{kJ}] - 14.208\ [\text{kJ}] - (-13.506\ [\text{kJ}]) = 1.118\ [\text{kJ}]$$

Finally, we get to the point where we have two equations with two unknowns. From the relationship for a polytropic process, we have:

$$P_6\forall_6^n = P_5\forall_5^n \implies P_6\forall_6^{-6.77} = 10196131.11\ [\text{kJ}]$$

From the work for a polytropic process, we have:

$$W_{5\to 6} = \frac{P_6\forall_6 - P_5\forall_5}{1-n} = \frac{P_6\forall_6 - 14.564}{7.77} = 1.118\ [\text{kJ}]$$

Rearranging,

$$P_6\forall_6 = 23.251\ [\text{kJ}]$$

Solving these simultaneously yields:

$$P_6 = 123.76\ [\text{kPa}] \qquad \forall_6 = 0.1879\ [\text{m}^3]$$

We can solve the final temperature:

$$T_6 = \frac{P_6\forall_6}{mR} = \frac{(123.76\ [\text{kPa}])(0.1879\ [\text{m}^3])}{(0.187\ [\text{kg}])(0.287\ [\text{kJ/kg-K}])} = 433.3\ [\text{K}]$$

We can finally solve for Q_{net} using different Tables. Assuming Table A7 was used, we need to find the values for specific internal energy at state 1 and state 6:

$$u_1 = 311.37\ [\text{kJ/kg}] \qquad u_6 = 310.75\ [\text{kJ/kg}]$$

$$Q_{net} = m(u_6 - u_1) + W_{net} = (0.187\ [\text{kg}])((310.75 - 311.37)\ [\text{kJ/kg}]) + 1.82\ [\text{kJ}] = \boxed{1.704\ [\text{kJ}]}$$

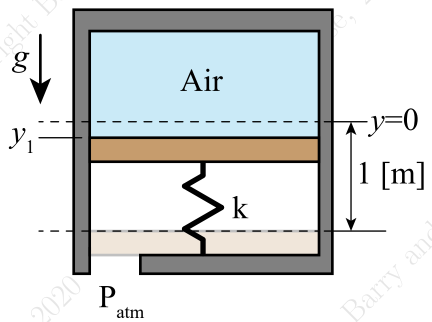
e) The final pressure, P, and temperature, T, of the air; These were required to find Q_{net}, but to summarize:

$$\boxed{P_6 = 123.76\ [\text{kPa}]} \qquad \boxed{T_6 = 433.3\ [\text{K}]}$$

f) If the air can be treated as an ideal gas. Use P_c = 3,774 [kPa] and T_c = 132.41 [K] for the critical pressure and temperature, respectively; Using the highest pressure and lowest temperature found during the processes, the reduced pressure and temperature are:

$$T_r = \frac{T}{T_c} = \frac{271.37\ [\text{K}]}{132.41\ [\text{K}]} = 2.05 > 2 \qquad P_r = \frac{P}{P_c} = \frac{225\ [\text{kPa}]}{3774\ [\text{kPa}]} = 0.06 << 1$$

The ideal gas criteria are met, therefore the air can be treated as an ideal gas.



Note: Image not drawn to scale.

Problem #4

(30 pts). A 2,500 [kg] steel forging is quenched in an 10,000 [kg] bath of oil. If the steel is initially at a temperature of 1,500 [K], and the oil is initially at a temperature of 350 [K], determine the final temperature of the system using the integral average of the specific heats. Assume there is no heat transfer to the surroundings. Note, you will have to fit the data given using "cftool" in MATLAB. You should fit the data using a polynomial fit. You will increase the order of the fit until the Adjusted R-squared value is near 0.99. Your MATLAB script must be submitted with the file name being your Pitt username, for example "MMB49.m".

The specific heat of steel and oil versus temperature are given in the table to the right:

T_{steel} [K]	C_{steel} [kJ/kg-K]	T_{oil} [K]	C_{oil} [kJ/kg-K]
273.2	1.006	313	2.271
280	1.006	323	2.42
288.7	1.006	333	2.59
300	1.006	343	2.757
320	1.007	353	2.852
340	1.009	363	2.976
360	1.01	373	3.092
380	1.012	383	3.197
400	1.014	393	3.293
500	1.03	403	3.337
600	1.054	413	3.483
700	1.075	423	3.59
800	1.099	433	3.701
900	1.121	443	3.778
1100	1.159	453	3.868
1500	1.21	463	3.91
1900	1.241	–	–

Academic Integrity Statement:

I hereby attest that I have received no assistance (from a friend, from another student, from an on-line resource, such as Chegg, etc.), and that I have provided no assistance to another student, during this exam. All the work presented within is solely my own work.

Signature: ____

Date: ________________________