CLOSED BOOK/CLOSED NOTES. You may reference the tables in your textbook in addition to an 8.5”x11” sheet of handwritten prepared notes. You may optionally use a computer and the Excel add-in functions. No other materials, including electronically stored materials, are allowed for reference. **Staple this sheet as a cover to your packet.**

1) (50%) A mixture with mole fractions of 20% H₂O, 30% CO₂, 40% N₂, and 10% O₂ is compressed isentropically from 100 kPa and 25 C to 800 kPa.
   a) Determine the final temperature of the mixture assuming constant specific heats at room temperature (25C).
   b) If the mixture at state 2 is cooled at constant pressure, at what temperature will the water begin to condense out?

2) (50%) Moist air at 1atm, 30C, and 80% relative humidity is cooled to 20C in a steady flow process. The air enters the duct with a volumetric flow rate of 20 m³/min.
   a) What is the dew-point of the mixture initially?
   b) What is the mass flow rate of dry air (kg air/min)?
   c) Does condensation occur when the mixture is cooled? If yes, how much water condenses (kg H₂O/min)? If no, what is the final relative humidity?
   d) How much heat transfer is required (kW)? Assume any condensate to be at 20C.
mixture is compressed isentropically.

\[
\begin{array}{cccccccc}
\text{P}_1 & 100 \text{ kPa} \\
\text{T}_1 & 298.15 \text{ K} & =25+273.15 \\
\text{P}_2 & 800 \text{ kPa} \\
\text{T}_{\text{room}} & 298.15 \text{ K} & =25+273.15 \\
\end{array}
\]

\[
\begin{array}{cccccccccccc}
\text{gas}_i & \text{y}_i & \text{MW}_i & \text{m}_i & \text{mf}_i & \text{cv}_i & \text{cp}_i & \text{ds0}_i & \text{dsP}_i \\
\text{H}_2\text{O} & 20\% & 18.015 & 3.603 & 0.11544 & 1.406684 & 1.868215 & 0.975608 & -0.95973 \\
\text{CO}_2 & 30\% & 44.01 & 13.203 & 0.423023 & 0.844766 & 0.471253 & -0.39285 \\
\text{N}_2 & 40\% & 28.013 & 11.2052 & 0.359013 & 0.741061 & 0.535539 & -0.61719 \\
\text{O}_2 & 10\% & 31.999 & 3.1999 & 0.102524 & 0.659275 & 0.919111 & 0.484988 & -0.54031 \\
\end{array}
\]

\[
\begin{align*}
=\text{Mgas(A13)} & =\text{m}_i/\text{m}_{\text{tot}} =\text{Cpgas(A13,T}_{\text{room}}) =-\text{Rgas(A10)}*\text{LN(P}_2/\text{P}_1) \\
=\text{y}_i*\text{MW}_i & =\text{Cvgas(A13,T}_{\text{room}}) =\text{s0gas(A10,T}_2b)-\text{s0gas(A10,T}_1) \\
\end{align*}
\]

a) find \( T_2 \) using constant specific heats
first find the \( \text{mf}_i \) and then \( \text{cp}_{\text{mix}}, \text{cv}_{\text{mix}}, \text{k}_{\text{mix}} \). Then use the isentropic relation.
assume 1 mole total and find the \( \text{m}_i \), then \( \text{mf}_i \) in the table above.

\[
\begin{align*}
\text{m}_{\text{tot}} & =31.2111 \text{ kg} =\text{SUM(m}_i) \\
\text{cp}_{\text{mix}} & =1.039861 \text{ kJ/kg-K} =\text{SUMPRODUCT(mf}_i,\text{cp}_i) \\
\text{cv}_{\text{mix}} & =0.773466 \text{ kJ/kg-K} =\text{SUMPRODUCT(cv}_i, \text{mf}_i) \\
\text{k}_{\text{mix}} & =1.344417 =\text{cp}_{\text{mix}}/\text{cv}_{\text{mix}} \\
\end{align*}
\]

Now use the isentropic relation to find the final temperature \( T_{2a} \)

\[
T_{2a} = 507.915 \text{ K} =T_1*(P_2/P_1)^{(k_{mix}-1)/k_{mix})}
\]

5:40

b) repeat but now use variable specific heats.
set up the change in entropy for the mixture as a target cell
then vary the \( T_{2b} \) until the entropy change is zero
add a couple of columns to the table above for \( \text{ds0}_i \) and \( \text{dsP}_i \)
T_{2b} \quad 497.0008 \; \text{K} \quad \text{unknown - initially just a guess}

but we know it is around 500K from part a)

d_{s \text{mix}} \quad 1.11 \times 10^{-5} = \text{SUMPRODUCT}(d_{s0\_i}, m_{f\_i}) + \text{SUMPRODUCT}(d_{sP\_i}, m_{f\_i})

c) cooled at constant pressure P_{2}, what T for condensation of H2O?
this will be the "dew point" temperature of the mixture.
which is the saturation temperature of H2O at the partial pressure of H2O in the mixture

P_{v\_2} \quad 160 \; \text{kPa} \quad = (y_{i\text{ H2O}}) \times P_{2}
T_{dp} \quad \text{#NAME?} \; \text{C} \quad = T_{\text{sat}\_p\_H2O}(P_{v\_2})
Problem 2  Moist air cooled in a duct.

\[ P_1 = 101.325 \text{ kPa} \]
\[ T_1 = 30 \text{ C} \]
\[ \phi_1 = 80\% \]
\[ T_2 = 20 \text{ C} \]
\[ \dot{V}_1 = 20 \text{ m}^3/\text{min} \]

a) dew point temperature? Same as problem 1 find \( T_{sat} \) at \( P_v \)
\[ P_{v_1} \text{ kPa} = \text{psat}_{T_{H2O}}(T_1) \phi_1 \]
\[ T_{dp_1} \text{ C} = T_{sat_p_{H2O}}(P_{v_1}) \]

b) mass flow rate of dry air.
use Dalton’s model: \( \dot{V}_d \) same for air or vapor, \( P = \dot{P}_a = P_1 - P_{v_1} \)
\[ \dot{m}_{a} \text{ kg air/\text{min}} = (P_1 - P_{v_1}) \dot{V}_1 / R_{gas(\text{air})} / (T_1 + 273.15) \]

c) does condensation occur? Compute condensate or final relative humidity
since \( T_{final} < T_{dp} \), yes, condensation occurs.
\[ \omega_1 \text{ kgH2O/kg} = \text{omega}_{PTphi}(P_1, T_1, \phi_1) \]
note the final state is saturated (\( \phi_2 = 100\% \)) b/c condensation is occurring and no reheating
\[ \omega_2 \text{ kgH2O/kg} = \text{omega}_{PTphi}(P_1, T_2, \phi_2) \]
from the moisture balance, \( \dot{m}_{w} = \dot{m}_{a} \omega_1 - \omega_2 \)
\[ \dot{m}_{w} \text{ kgH2O/min} = \dot{m}_{a} \omega_1 - \omega_2 \]

d) how much heat must be removed?
use first law for the overall process. Assume condensate at 20C
\[ h_1 \text{ kJ/kg air} = \text{h_moist_Tomega}(T_1, \omega_1) \]
\[ h_2 \text{ kJ/kg air} = \text{h_moist_Tomega}(T_2, \omega_2) \]
\[ h_w \text{ kJ/kg air} = \text{hL}_{T_{H2O}}(T_2) \]
\[ q_{1-2} \text{ kJ/kg air} = h_2 - h_1 + (\omega_1 - \omega_2) h_w \]
\[ Q_{dot} \text{ kW} = \dot{m}_{a} q_{1-2} / 60 \]