Problem 1: Each part of this problem is worth 10 points. The standard problem procedure is not required for problem 1, but to receive any credit for problem 1 your answer must be supported by providing appropriate analysis, equations, tables, and/or charts.

(a). Air undergoes a steady-state, steady-flow, adiabatic throttling process. Will the air temperature increase, decrease, or remain the same.

\[ \text{Throttling } h_2 = h_1 \]

Air is ideal gas \( h = h(T) \)

(b). A steady-state, steady-flow diffuser decreases the kinetic energy of the liquid by slowing it down. If the liquid temperature entering the diffuser is the same as that leaving the diffuser, does the heat transfer (1) into the diffuser from the environment or (2) out of the diffuser to the environment? Assume \( P_{\text{in}} = P_{\text{out}} \)

\[
\frac{dE_{cv}}{dt} = Q_{cv} - W_{cv} + \dot{m}_\text{in} \left( h + \frac{V_\text{in}^2}{2} + g z_\text{in} \right) - \dot{m}_\text{out} \left( h + \frac{V_\text{out}^2}{2} + g z_\text{out} \right)
\]

\[
Q_{cv} = \dot{m} \left( U_{\text{out}} - U_{\text{in}} + V (P_{\text{out}} - P_{\text{in}}) + \frac{V_{\text{out}}^2 - V_{\text{in}}^2}{2} \right), \quad U = c T
\]

\[
Q_{cv} = \dot{m} \left( \frac{V_{\text{out}}^2 - V_{\text{in}}^2}{2} \right), \quad \text{since } V_{\text{out}} < V_{\text{in}}, \quad Q_{cv} < 0
\]

(c). Calculate the maximum thermal efficiency of an ideal power cycle operating between 40°C and 1000°C.

\[
\frac{T_L}{T_H} = 1 - \frac{(273 + 40 \, \text{K})}{(273 + 1000 \, \text{K})} = 0.754
\]

(d). A student claims that he has invented a high-efficiency heat pump. The heat pump can take 17 kW of energy from ambient air at -10°C and reject 20 kW of heat to a room at 20°C. Is the claim possible?

\[
\text{COP}_{h, \text{max}} = \frac{T_H}{T_H - T_L} = \frac{273 + 20}{(273 + 20) - [273 + (-10)]} = 9.77
\]

\[
\text{COP}_{h, \text{student}} = \frac{\dot{Q}_H}{|\dot{Q}_H|} = \frac{20 \, \text{KJ}}{(20 - 17) \, \text{KJ}} = 6.67
\]

\[
\text{COP}_{h, \text{student}} < \text{COP}_{h, \text{max}}
\]

Possible
The standard problem solving procedure is required for Problems 2 and 3.

(30/100 points)

Problem 2:

Given:
Under a 1 bar atmospheric pressure, a window-type air conditioner mixes the cold air and warm ambient air before the mixture is routed to a living room. The cold air enters the mixing chamber in the air conditioner at 280 K at a rate of 1.25 m³/s and the warm air enters at 305 K. The ratio of the mass flow rates of the hot to cold air is 0.3. Air leaves the living room at 300 K through exfiltration (flow out the room through window and door cracks) at the same rate as the mixture. Assume the heat gains to the mixing chamber and kinetic energy and potential energy change in the entire system (the air conditioner and the living room) to be negligible. The specific heat of the air is a variable. If you use tables, please do not interpolation but the closest table values.

Find:
(a) The mixture temperature at the inlet of the room (or the outlet of the air conditioner), in K.
(b) The heat gain rate through the room envelope, in kW.

System Sketch:

Assumptions:
$Q_{cv,AC} = 0$, $\Delta K E = 0$, $\Delta P E = 0$, ideal gas, steady flow

Basic Equations:

Steady state, $\dot{W}_{cv} = 0$

$P \frac{dV}{dT} = \frac{d}{dt} \left( \sum_{in} \dot{m}_{in} - \sum_{out} \dot{m}_{out} \right)$

Solution

$\dot{Q}_{cv} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum_{in} \dot{m}_{in} (\bar{h} + \bar{v}^2 / 2 + \bar{p}^2 / \rho) - \sum_{out} \dot{m}_{out} (\bar{h} + \bar{v}^2 / 2 + \bar{p}^2 / \rho)$
Find \( R \) from Table A-1

\[
V = \frac{RT}{P} = \frac{0.2870 \frac{\text{kJ}}{\text{Kg} \cdot \text{K}} \times 280 \text{K}}{1 \times 10^5 \text{Pa}} \quad 1000 \text{N} \cdot \text{m}^2/\text{m} = 0.8036 \text{m}^3/\text{kg}
\]

\[ V = \frac{1.25 \text{ m}^3/\text{s}}{0.8036 \text{ m}^3/\text{kg}} = 1.56 \text{ kg/s} \]

\[ \dot{m}_{\text{cold}} = \frac{V}{V} = 1.25 \text{ m}^3/\text{s} \]

\[ \dot{m}_{\text{warm}} = 0.3 \dot{m}_{\text{cold}} = 0.3 \times 1.56 \text{ kg/s} = 0.47 \text{ kg/s} \]

\[ \dot{m}_{\text{mix}} = \dot{m}_{\text{cold}} + \dot{m}_{\text{warm}} = (1.56 + 0.47) \text{ kg/s} = 2.03 \text{ kg/s} \]

\[ \dot{m}_{\text{cold}} \cdot h_{\text{cold}} + \dot{m}_{\text{warm}} \cdot h_{\text{warm}} - \dot{m}_{\text{mix}} \cdot h_{\text{mix}} = 0 \quad \text{use Table A-1} \]

\[ h_{\text{mix}} = \frac{1.56 \text{ kg/s} \times 280.13 \text{ KJ/kg} + 0.47 \times 305.22 \text{ KJ/kg}}{2.03 \text{ kg/s}} = 285.94 \text{ KJ/kg} \]

\[ T_{\text{mix}} = 285 \text{ K} \quad \text{from Table A-17} \]

(b) \[ \dot{Q}_{\text{cv,room}} = \dot{m}_{\text{mix}} (h_{\text{room}} - h_{\text{mix}}) \]

\[ \dot{Q}_{\text{cv,room}} = 2.03 \text{ kg/s} \left( \frac{300.19 - 285.94}{285.94} \right) \text{ KJ/kg} \]

\[ \dot{Q}_{\text{cv,room}} = 28.92 \text{ kW} \]
Problem 3:
Given:
Steam at 1500 lb/in² (psia) and 1000°F (state 1) enters a two-stage turbine operating at steady state as shown in the following figure. At state 2, 22% of the mass flow in the first stage turbine is extracted at 160 lb/in² (psia) and 450°F. The rest of the steam exists at state 3 as a two-phase liquid-vapor mixture at 1 lb/in² (psia) with a quality of 85%. The turbine develops a power output of 9x10⁸ Btu/h. Neglecting kinetic energy and potential energy effects and heat transfer between the two-stage turbine and its surroundings (adiabatic).

Find: (a). Complete the table below.
(b). Label the three states and draw the processes in the P-v and T-v charts. They do not have to be in scale, but should be reasonably accurate.
(c). The mass flow rate of steam entering the turbine, in lbm/h.

System sketch:

Assumptions:
- Steady state, steady flow
- ΔKE = 0, ΔPE = 0, ΔCV = 0

Basic Equations:
\[ \dot{Q}_c\] 

Solution:

<table>
<thead>
<tr>
<th>State</th>
<th>Pressure (psia)</th>
<th>Temperature (°F)</th>
<th>Enthalpy (Btu/lbm)</th>
<th>Specific Volume (ft³/lbm)</th>
<th>Quality or Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1500</td>
<td>1000</td>
<td>1490.3</td>
<td>0.5400</td>
<td>SHV</td>
</tr>
<tr>
<td>2</td>
<td>160</td>
<td>450</td>
<td>1246.1</td>
<td>3.228</td>
<td>SHV</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>101.70</td>
<td>950.3</td>
<td>2.8356</td>
<td>0.85</td>
</tr>
</tbody>
</table>
Continued Problem 5)

\( \theta_3 = \theta_4 \times \theta_3 \quad 0.85 \)

\( \theta_3 = \theta_f + \theta_v \quad 1.05 \)

\( 74 + 5 \times 05. \quad 50.39 \)

\( 3136 + 0.55 \times 333 \quad 28.56 \)

\( \mathbf{P} \)

\( \mathbf{T} \)

\( W + m \ h = m_3 \ h \)

\( m = \frac{W - c}{h + \frac{m_2}{m_1} h_2 - \frac{m_3}{m_1} h_3} \)

\( 9 \times \frac{8tu}{h} \)

\( 4.90 \times 22 \times 2.46 \quad 22 \times 950 \quad 9.8tu \)

\( \dot{m}_1 = 1.895 \times 10^6 \ \text{lbm/h} \)