Problem-1 (10%)
The absolute pressure in a tank is 85 kPa and the local ambient absolute pressure is 97 kPa. If a U-tube with mercury, density 13550 kg/m³, is attached to the tank to measure the vacuum, what column height difference would it show?

\[ \Delta P = P_0 - P_{\text{tank}} = \rho g H \]

\[ H = \frac{(P_0 - P_{\text{tank}})}{\rho g} = \frac{[(97 - 85) \times 1000]}{(13550 \times 9.80665)} \]

\[ = 0.090 \, \text{m} = 90 \, \text{mm} \]
Problem-2 (20%)
Find the missing properties of $T$, $P$, $v$, $u$, $h$ and $x$ if applicable and plot the location of the three states as points in the $T$-$v$ and the $P$-$v$ diagrams

a. Water at 5000 kPa, $u = 800$ kJ/kg
b. Water at 5000 kPa, $v = 0.06$ m$^3$/kg
c. R-134a at 35°C, $v = 0.01$ m$^3$/kg

Solution:

a) Look in Table B.1.2 at 5000 kPa

\[
u < u_f = 1147.78 \quad \Rightarrow \quad \text{compressed liquid}
\]

Table B.1.4: between 180 °C and 200 °C

\[
T = 180 + (200 - 180) \frac{800 - 759.62}{848.08 - 759.62} = 180 + 20 \times 0.4567 = 189.1 \text{ °C}
\]

\[
v = 0.001124 + 0.4567 (0.001153 - 0.001124) = 0.001137
\]

b) Look in Table B.1.2 at 5000 kPa

\[
v > v_g = 0.03944 \quad \Rightarrow \quad \text{superheated vapor}
\]

Table B.1.3: between 400 °C and 450 °C.

\[
T = 400 + 50 \times ((0.06 - 0.05781) / (0.0633 - 0.05781)) = 400 + 50 \times 0.3989 = 419.95 \text{ °C}
\]

\[
h = 3195.64 + 0.3989 \times (3316.15 - 3195.64) = 3243.71
\]

c) B.5.1: $v_f < v < v_g$

\[
\Rightarrow \text{2-phase, } P = P_{\text{sat}} = 887.6 \text{ kPa.}
\]

\[
x = (v - v_f) / v_{fg} = (0.01 - 0.000857) / 0.02224 = 0.4111
\]

\[
u = u_f + x u_{fg} = 248.34 + 0.4111 \times 148.68 = 309.46 \text{ kJ/kg}
\]
Problem-3 (20%)
A piston/cylinder assembly contains 1 kg of liquid water at 20°C and 300 kPa. There is a linear spring mounted on the piston such that when the water is heated the pressure reaches 1 MPa with a volume of 0.1 m³. Find the final temperature and the heat transfer in the process.

Show the process on P-v diagram provided below.

Solution:

Take CV as the water.

\[ m_2 = m_1 = m; \quad m(u_2 - u_1) = \int P \, dv \]

State 1: Compressed liquid, take saturated liquid at same temperature.

\[ v_1 = v_f(20) = 0.001002 \text{ m}^3/\text{kg}, \quad u_1 = u_f = 83.94 \text{ kJ/kg} \]

State 2: \[ v_2 = V_2/m = 0.1/1 = 0.1 \text{ m}^3/\text{kg} \] and \[ P = 1000 \text{ kPa} \]

\[ \Rightarrow \text{Two phase as } v_2 < v_g \quad \text{so} \quad T_2 = T_{sat} = 179.9°C \]

\[ x_2 = (v_2 - v_f)/v_g = (0.1 - 0.001127)/0.19332 = 0.51145 \]

\[ u_2 = u_f + x_2 u_g = 780.08 + 0.51147 \times 1806.32 = 1703.96 \text{ kJ/kg} \]

Work is done while piston moves at linearly varying pressure, so we get

\[ \int_1^2 P \, dv = \text{area} = P_{avg} \times (V_2 - V_1) \]

\[ = 0.5 \times (300 + 1000)(0.1 - 0.001) = 64.35 \text{ kJ} \]

Heat transfer is found from the energy equation

\[ \int Q_2 = m(u_2 - u_1) + \int W_2 = 1 \times (1703.96 - 83.94) + 64.35 = 1684 \text{ kJ} \]
Problem-4 (20%) 
Superheated refrigerant R-134a at 20°C, 0.5 MPa is cooled in a piston/cylinder arrangement at constant temperature to a final two-phase state with quality of 50%. The refrigerant mass is 5 kg, and during this process 500 kJ of heat is removed. Find the initial and final volumes and the necessary work.

Show the process and work on P-v diagram provided below.

Solution:
C.V. R-134a, this is a control mass.
Continuity: \( m_2 = m_1 = m \)

Energy Eq.3.11: \( m(u_2 - u_1) = Q_2 + W_2 = -500 + W_2 \)

State 1: \( T_1, P_1 \), Table B.5.2. \( v_1 = 0.04225 \text{ m}^3/\text{kg} \); \( u_1 = 390.52 \text{ kJ/kg} \)

\[ \Rightarrow V_1 = mv_1 = 0.211 \text{ m}^3 \]

State 2: \( T_2, x_2 \Rightarrow \) Table B.5.1

\( u_2 = 227.03 + 0.5 \times 162.16 = 308.11 \text{ kJ/kg} \),

\( v_2 = 0.000817 + 0.5 \times 0.03524 = 0.018437 \text{ m}^3/\text{kg} \) \( 
\Rightarrow V_2 = mv_2 = 0.0922 \text{ m}^3 \)

\( W_2 = -500 - m(u_2 - u_1) = -500 - 5 \times (308.11 - 390.52) = -87.9 \text{ kJ} \)
Problem-5 (30%)

A rigid tank is divided into two rooms by a membrane, both containing water, shown in Fig. below. Room A is at 300 kPa, \( v = 1.0 \) m\(^3\)/kg, \( V_A = 1 \) m\(^3\), and room B contains 1.0 kg at 1.0 MPa, 600°C. The membrane now ruptures and heat transfer takes place so the water comes to a uniform state at 100°C. Find the heat transfer during the process.

C.V.: Both rooms A and B in tank

Continuity Eq.: \( m_2 = m_{A1} + m_{B1} \);
Energy Eq.: \( m_2u_2 - m_{A1}u_{A1} - m_{B1}u_{B1} = Q_{12} - W_{12} \)

**State 1A:** (P, v) Table B.1.2,
\( P=300 \) Kpa, \( v_g = 0.60582 < v = 1 \) m\(^3\)/kg (Super heated)

Table B.1.3,

<table>
<thead>
<tr>
<th>T(C)</th>
<th>v (m(^3)/kg)</th>
<th>U (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>0.87529</td>
<td>2806.69</td>
</tr>
<tr>
<td>?</td>
<td>1.0</td>
<td>?</td>
</tr>
<tr>
<td>400</td>
<td>1.03151</td>
<td>2965.53</td>
</tr>
</tbody>
</table>

\( u_{A1} = 2933.78 \) kJ/kg, \( m_{A1} = V_A/v_{A1} = 1/1 = 1 \) kg

**State 1B:** Table B.1.3, \( v_{B1} = 0.40109, u_{B1} = 3296.76 \)
\( V_B = m_{B1}v_{B1} = 0.40109 \) m\(^3\)
Process constant total volume: \( V_{tot} = V_A + V_B = 1.40109 \) m\(^3\) and \( W_{12} = 0 \)
\( m_2 = m_{A1} + m_{B1} = 2.0 \) kg \( \Rightarrow \) \( v_2 = V_{tot}/m_2 = 0.70055 \) m\(^3\)/kg

**State 2:** \( T_2, v_2 \), Table B.1.1 two-phase as \( v_2 < v_g = 1.67290 \) m\(^3\)/kg
\( x = (v_2 - v_f)/(v_{fg}) = (0.70055 - 0.001044)/1.67185 = 0.418 \)
\( u_2 = u_f + x(u_{fg}) = 418.91 + 0.418 \times 2087.58 = 1291.52 \) kJ/kg
Heat transfer is from the energy equation
\( Q_{12} = m_2u_2 - m_{A1}u_{A1} - m_{B1}u_{B1} = -3647.50 \) kJ