ECE 309
Introduction to Thermodynamics and Heat Transfer

Tutorial # 2

Properties of Pure Substances

Problem 1
Complete the following table for substance water:

	P [kPa]	**T [°C]**	***v* [m³/kg]**	***x***
a.	500	20		
b.	500		0.20	
c.	1400	200		
d.		300		0.8

Solution:
1a.
Step 1: Write the known and unknown properties at the given state
Known: P = 500 kPa, T = 20°C
Unknown: v =?; x = ?

Step 2: Browse the saturated water table for temperature (Table A-4 in Appendix 1) to find the saturated pressure at the given temperature
Let's go to saturated water: temperature (Table A-4)

From Table A-4, we can find
@ T = 20°C; P_{sat} = 2.339 kPa

Step 3: Compare the given pressure with the saturation pressure to find the location of state
Since $P > P_{sat}$ at given temperature → subcooled or compressed region

Step 4: Determine the unknown properties
In the absence of tables of properties for the compressed or subcooled region, we can assume the properties of saturated liquid as the properties of compressed or subcooled region with negligible error.

i.e., $v = v_f$ = 0.001002 m³/kg x = undefined

1b.
Step 1: Write the known and unknown properties at the given state
Known: P = 500 kPa, v = 0.20 m³/kg
Unknown: T = ?; x = ?

Step 2: Browse the saturated water pressure table (Table A-5 in Appendix 1) to find the saturated temperature and specific volumes at the given pressure

From Table A-5, we can find

@ P = 500 kPa (0.5 MPa); T_{sat} = 151.86°C, v_f = 0.001093 m³/kg, & v_g = 0.3749 m³/kg

Step 3: Compare the given specific volume with the specific volumes of saturated liquid and saturated vapor to find the location of state

Since v lies between v_f & v_g → saturated liquid-vapor mixture region

Step 4: Determine the unknown properties

We know that

$v = v_f + x v_{fg} = v_f + x(v_g - v_f)$

$$x = \frac{v - v_f}{v_g - v_f} = \frac{0.20 - 0.001093}{0.3749 - 0.001093} = 0.5321;$$

Since temperature and pressure are dependent in the saturated liquid-vapor mixture region, therefore T = T_{sat} at P = 500 kPa

T = 151.86°C , **x = 0.5321**

1c.

Step 1: Write the known and unknown properties at the given state

Known: P = 1400 kPa, T = 200°C

Unknown: v = ?; x = ?

Step 2: Browse the saturated water table either temperature or pressure (Table A-4 or A-5 in Appendix 1) to find the saturated pressure at the given temperature or saturated temperature at the given pressure

Let's go to saturated water: temperature and pressure tables (Table A-4 & A-5)

From Table A-4, we can find

@ T = 200°C; P_{sat} = 1553.8 kPa

From Table A-5, we can find

@ P = 1400 kPa (1.4 MPa); T_{sat} = 195.07°C

Step 3: Compare the given temperature (or pressure) with the saturation temperature (or saturation pressure) to find the location of state

Since T > T_{sat} at given pressure or P < P_{sat} at given temperature → superheated region

Step 4: Determine the unknown properties

Since in the superheated region, pressure and temperature are independent properties, therefore from Table A-6, we can find v at the given temperature and pressure

v = 0.14302 m³/kg , **x = undefined**

1d.

Step 1: Write the known and unknown properties at the given state

Known: T = 300^{o}C, $x = 0.8$

Unknown: P = ?; v = ?

Step 2: Browse the saturated water temperature table (Table A-4 in Appendix 1) to find the saturated pressure and specific volume at the given temperature

From Table A-4, we can find

@ T = 300^{o}C; P_{sat} = 8581 kPa, v_f = 0.001404 m^3/kg, & v_g = 0.02167 m^3/kg

Step 3: Finding the location of state

Since x *is* given → saturated liquid-vapor mixture region

Step 4: Determine the unknown properties

We know that

$v = v_f + xv_{fg} = v_f + x(v_g - v_f) = 0.001404 + 0.8 \times (0.02167 - 0.001404) = 0.0176$ m^3/kg

Since temperature and pressure are dependent in the saturated liquid-vapor mixture region, therefore P = P_{sat} at T = 300^{o}C

$\boxed{P = 8581 \text{ kPa}}$, $\boxed{v = 0.0176 \text{ m}^3/\text{kg}}$

Problem 2

A rigid tank contains 10 kg of air at 150 kPa and 20ºC. More air is added to the tank until the pressure and temperature rise to 250 kPa and 30ºC, respectively. Determine the amount of air added to the tank.

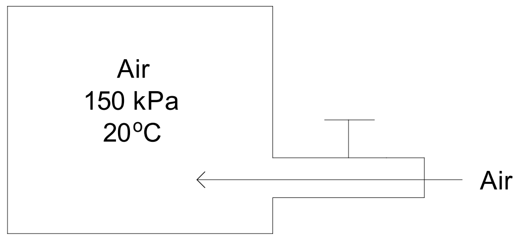

Figure P2

Solution:

Step 1: Write the known and unknown quantities given in the problem

Known: Initial condition (*i*)

m_i = 10 kg, P_i = 150 kPa, T_i = 20ºC

Final condition (*f*)

P_f = 250 kPa, T_f = 30ºC

Unknown: Volume of the tank V = ?, m_f = ?

Step 2: List what is required to solve for

In the present problem, we are required to solve for the amount of air added to the tank to reach the final condition

i.e., $\Delta m = m_f - m_i$ (2.1)

Step 3: Make necessary assumption

Since air is given as the substance in this problem, it can be assumed as an ideal gas and we can use ideal gas relation to determine the unknown quantities.

$$PV = mRT \quad (2.2)$$

Step 4: Solve for the unknown quantities and determine the amount of air added to the tank

Using the given initial condition, we can find the volume of the tank through ideal gas relation

$$V = \frac{m_i R T_i}{P_i} = \frac{(10kg)(0.287kPa \cdot m^3 / kg \cdot K)(293K)}{150kPa} = 5.606m^3 \quad (2.3)$$

Since the tank is rigid, volume remains constant i.e., $V_i = V_f = V$

Again using the ideal gas relation, we can find the mass of air at the final condition

$$m_f = \frac{P_f V}{R T_f} = \frac{(250 kPa)(5.606 m^3)}{(0.287 kPa \cdot m^3 / kg \cdot K)(303 K)} = 16.12 kg \tag{2.4}$$

Finally, the amount of air added to the tank can be determined from Equation (2.1)

$$\boxed{\Delta m = m_f - m_i = 16.12 - 10.00 = 6.12\ kg}$$