

ME 201

Thermodynamics

Homework #6 Solution

1. (10 pts) What is the enthalpy, internal energy, specific volume, and entropy for steam at 1107°C and 27 MPa?

Solution:

Substance Type: Compressible (steam)

Problem Type: State

We are given steam at 27 MPa and 1107°C. First, we must determine the fluid phase. We go to the saturation pressure table, A-5, and find the boiling temperature at 27 MPa. However, we note that the table does not go up that far. This means we are beyond the critical point and can treat the steam as superheated vapor.

So now we go to the superheat table, A-6, and find that again we do not have a table entry at either 27 MPa or 1107°C. This means we will have to set up a double interpolation. To do so we set up the table shown below and enter the values from the steam tables at 25 MPa, 30 MPa, and 1100°C, 1200°C.

T	P=25 MPa				P=27 MPa				P=30 MPa			
	v	u	h	s	v	u	h	s	v	u	h	s
1100	0.02517	4206.1	4835.4	7.5825	0.0235	4201.7			0.0210	4195.2	4823.9	7.4906
1107												
1200	0.02716	4424.6	5103.5	7.7710					0.0226	4415.3	5094.2	7.6807

We begin our double interpolation by interpolating in pressure, so, for example, at 1100°C for specific volume we have

$$\frac{v(27 \text{ MPa}) - v(25 \text{ MPa})}{v(30 \text{ MPa}) - v(25 \text{ MPa})} = \frac{27 \text{ MPa} - 25 \text{ MPa}}{30 \text{ MPa} - 25 \text{ MPa}}$$

or solving for $v(27 \text{ MPa})$

$$\begin{aligned} v(27 \text{ MPa}) &= 0.02517 + (0.0210 - 0.02517) \frac{27 - 25}{30 - 25} \\ &= 0.0235 \text{ m}^3/\text{kg} \end{aligned}$$

Carrying out these calculations for v , u , h , and s at $P=27 \text{ MPa}$ and both 1100°C and 1200°C and entering in our table gives

T	P=25 MPa				P=27 MPa				P=30 MPa			
	v	u	h	s	v	u	h	s	v	u	h	s
1100	0.02517	4206.1	4835.4	7.5825	0.0235	4201.7	4830.8	7.5457	0.0210	4195.2	4823.9	7.4906
1107												
1200	0.02716	4424.6	5103.5	7.7710	0.0253	4420.9	5099.8	7.7349	0.0226	4415.3	5094.2	7.6807

Now we do the temperature interpolation to give us the properties at 27 MPa and 1107°C.

T	P=25 MPa				P=27 MPa				P=30 MPa			
	v	u	h	s	v	u	h	s	v	u	h	s
1100	0.02517	4206.1	4835.4	7.5825	0.0235	4201.7	4830.8	7.5457	0.0210	4195.2	4823.9	7.4906
1107					0.0236	4217.0	4849.6	7.5589				
1200	0.02716	4424.6	5103.5	7.7710	0.0253	4420.9	5099.8	7.7349	0.0226	4415.3	5094.2	7.6807

2. (5 pts) Determine the internal energy change as saturated liquid refrigerant-134a at -6°F goes to a two phase mixture of quality 0.40 at -6°F.

Solution:

Substance Type: Compressible (R-134a)

Problem Type: Process

State 1

$$T_1 = -6^\circ\text{F}$$

$$P_1 = 18.37 \text{ psia}$$

$$u_1 = 10.302 \text{ Btu/lb}_m$$

phase: sat.liq.

State 2

$$T_2 = -6^\circ\text{F}$$

$$P_2 = 18.37 \text{ psia}$$

$$u_2 = \mathbf{43.708 \text{ Btu/lb}_m}$$

phase: 2 phase

$$x_2 = 0.40$$

Italicized values are from tables, **bold** values are calculated.

At state 1 we know the temperature and that the phase is saturated liquid, so that the state is fixed. Then we can go to the saturation temperature table, Table A-11E, and find through interpolation

$$P_1 = 18.37 \text{ psia and } u_1 = 10.302 \text{ Btu/lb}_m$$

For state 2 we know the temperature and that the phase is a two phase mixture with a quality, x_2 , of 0.40. Then the pressure at state 2 must be the saturation pressure at -6°F or $P_2 = 18.40 \text{ psia}$

We use the definition of quality to determine the enthalpy at state 2.

$$x_2 = \frac{u_2 - u_f}{u_g - u_f}$$

and solving for u_2 gives

$$u_2 = (1 - x_f)u_f + x_2 \cdot u_g$$

At -6°F we have

$$u_f = 10.302 \text{ Btu/lb}_m \text{ and } u_g = 93.812 \text{ Btu/lb}_m$$

which gives

$$u_2 = (0.60)(10.302) + (0.40)(93.812) = 43.706 \text{ Btu/lb}_m$$

So that our enthalpy change is

$$u_2 - u_1 = 43.706 - 10.302 = 33.404 \text{ Btu/lb}_m$$

3. Give the behavior of entropy for steam when
 a. pressure increases, constant temperature (1 pt)

Solution:

We can go to the superheat table and move from one pressure sub-table to another pressure sub-table at constant temperature to find

As P increases at constant T, s decreases.

- b. quality increases (1 pt)

Solution:

For a two phase mixture we have

$$s = s_f + x \cdot s_{fg}$$

So as x increases, s must increase.

- c. temperature increases, constant pressure (1 pt)

Solution:

We go to the superheat tables at a given pressure and observe

As T increases at constant P, s increases.

- d. pressure decreases, constant entropy(1 pt)

Solution:

Obviously,

As P decreases at constant s, s stays constant.

4. Saturated liquid water at 310°C undergoes an isotropic process to 0.35 MPa. Determine the final fluid phase and the enthalpy change. (5 pts)

Solution:

Substance Type: Compressible substance (saturated liquid water)

Problem Type: Process (constant volume)

State 1

$$T_1 = 310^\circ\text{C}$$

$$P_1 = 9.865 \text{ MPa}$$

$$v_1 = 0.001447 \text{ m}^3/\text{kg}$$

$$h_1 = 1402 \text{ kJ/kg}$$

phase: sat.liq.

State 2

$$T_2 = 138.86^\circ\text{C}$$

$$P_2 = 0.35 \text{ MPa}$$

$$v_2 = \mathbf{0.001447 \text{ m}^3/\text{kg}}$$

$$h_2 = \mathbf{585.76 \text{ kJ/kg}}$$

phase: **2 phase**

$$x_2 = \mathbf{0.0007}$$

Italicized values are from tables, **bold** values are calculated.

At state 1 we know the temperature and that we have saturated liquid, so that the state is fixed and we can go to the saturated temperature table, A-4, and find

$$P_1 = 9.865 \text{ MPa}, v_1 = 0.001447 \text{ m}^3/\text{kg} \cdot \text{K}, h_1 = 1402 \text{ kJ/kg}$$

At state 2, we know the pressure, 0.35 MPa, and since we have an isotropic process

$$v_2 = v_1 = 0.001447 \text{ m}^3 / \text{kg}$$

Next we must determine the phase at state 2. Going to the saturation pressure table, A-5, at 0.35 MPa, we find 0.001

$$v_f = .001079 \text{ m}^3/\text{kg} \text{ and } v_g = 0.5242 \text{ m}^3/\text{kg}$$

Since v_2 lies between these two values, we must have a two phase mixture with

$$x = \frac{v_2 - v_f}{v_g - v_f} = \frac{0.001447 - 0.001079}{0.5242 - 0.001079} = 0.0007$$

and a temperature of 138.86°C. Then the enthalpy at 2 is calculated

$$h_2 = h_f + x \cdot h_{fg} = 584.26 + (0.0007)(2147.7) = 585.76 \text{ kJ}/(\text{kg} \cdot \text{K})$$

and our change in enthalpy is -816.24 kJ/kg.