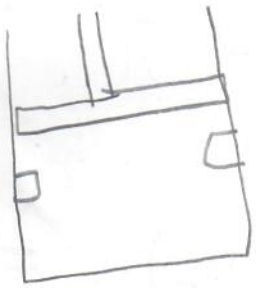
Question #2 [15 pts]

Water contained in a piston-cylinder assembly with a set of stops undergoes two thermodynamic processes in a series from an initial state where the pressure is 1 MPa and the temperature is 400 °C. The water is first cooled as it is compressed at constant pressure of 1 MPa to the saturated vapor state at which the piston hits the set of stops. Afterward, the water is cooled at constant volume to the final temperature of 150 °C. Determine the quality at the final state x and also the overall specific work done and the overall specific heat transfer, both in kJ/kg.



State ①: $P_1 = 1\,MPa \Rightarrow T_{sat} = 179.91°C < T_1$ ∴ superheated

$T_1 = 400°C$ $\quad v_1 = 0.3066\ m^3/kg$ ✓

$u_1 = 2957.3\ kJ/kg$ ✓

State ②: cooled + compressed at C.P.; sat vapor

$P_1 = P_2 = 1\,MPa$ ✓

$x = 1$ b/c saturated vapor, ∴ $v_2 = v_g = 0.19444\ m^3/kg$ ✓

State ③: cooled, C.V.

$T_3 = 150°C$, $v_f < v_3 < v_g$ ∴ two phase mixture

$v_3 = v_2 = 0.19444\ m^3/kg$

$$x = \frac{v_3 - v_f}{v_g - v_f} = \frac{0.19444 - 0.001091}{0.3928 - 0.001091} = 0.49$$ ✓✓

$u_3 = u_f + x u_{fg}$ ✓

$= 613.68 + 0.49(1927.9)$ ✓

$= 1558.35\ kJ/kg$

$W_{1-2} = \int_1^2 P\,dv$ ✓

$= P(v_2 - v_1)$

$= (1000)(0.19444 - 0.3066)$ (-1)

$= -112.16\ kJ/kg$ ✓

b/c C.V. (-2)

$\Delta u = \delta Q - \delta W$

$(u_3 - u_1) = \delta Q - (W_{1-2} + \cancel{W_{2-3}})$

$\delta Q = (u_3 - u_1) - W_{1-2} = (1558.35 - 2957.3) - (-112.16)$

$= -1686.28\ kJ/kg$ ✓

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