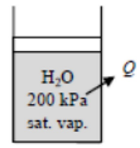
Homework 8

Sunday, April 18, 2021 10:41 PM

"I pledge my honor I have abided by the Stevens Honor system."

\- Alex Haskins

1. Saturated water vapor at 200 kPa is condensed into a saturated liquid via a constant-pressure process inside of a piston-cylinder device. To complete this process, heat is removed from the system and transferred to the environment which is at a constant temperature of 90°C. Is this process possible? *Hint: determine the entropy generation.* [25]



@ 200 kPa $\quad h_1 = h_g = 2706.3\ kJ/kg$

$s_1 = s_g = 7.1270\ kJ/kgK$

$T = 90 + 273 = 363K$

$h_2 = h_f = 504.71\ kJ/kg$

$s_2 = s_f = 1.5302\ kJ/\ kJ/kgK$

$Q = h_2 - h_1 = 504.71 - 2706.3 = -2201.6\ kJ/kg$

$\Delta S_{sys} = S_{in} - S_{out} + S_{gen}$

$s_2 - s_1 = \dfrac{Q}{T} - 0 + s_{gen}$

$1.5302 - 7.1270 = \dfrac{-2201.6}{363} + S_{gen}$

$S_{gen} = .4682\ kJ/kgK$

$S_{gen} > 0$

$\boxed{\therefore \text{ Yes it is possible}}$

2. A 12 cm diameter piston-cylinder device contains air at a pressure of 100 kPa at 24°C. The piston is initially 20 cm from the base of the cylinder. The gas is now compressed and 0.1 kJ of boundary work is added to the gas. The temperature of the gas remains constant during this process. [25]
   a. How much heat was transferred to/from the gas?

Isothermal process

$$\Delta Q = \Delta W = .1 \, kJ$$

   b. What is the final volume and pressure in the cylinder?

$$W = nRT \ln\left(\frac{V_f}{V_i}\right) \approx -nRT \ln\left(\frac{V_f}{V_i}\right) \approx -P_1 V_1 \ln\left(\frac{V_f}{V_i}\right)$$

$V_f < V_i$

$$.1 = -P_1 V_1 \ln\left(\frac{V_f}{V_i}\right)$$

$$100 = -100000\,(2.261 \times 10^{-3}) \ln\left(\frac{V_f}{V_i}\right)$$

$$\ln(V_i) - \ln(V_f) = \frac{100}{226.1}$$

$$\ln(V_f) = -\ln(V_i) + \frac{100}{226.1} = -\ln(2.26 \times 10^{-3}) + \frac{100}{226.1} = 6.1 + .44$$

$$-\ln(V_f) = 6.54 = -6.54$$

$$V_f = e^{-6.54}$$

$$\boxed{V_f = 1.445 \times 10^{-3} \, m^3}$$

$$V_i = \pi r^2 h = \pi (.06)^2 (.2) = 2.261 \times 10^{-3} \, m^3$$

$$P_i V_i = P_f V_f$$

$$P_f = \frac{P_i V_i}{V_f} = \frac{100\,(2.261 \times 10^{-3})}{1.445 \times 10^{-3}}$$

$$\boxed{P_f = 156.5\ kPa}$$

c. Find the change in entropy of the gas. Why is this value negative if entropy always increases in actual processes?

$$\Delta s = \frac{\Delta Q}{T} = \frac{-100}{(24+273}$$

$$\boxed{\Delta s = -.337\ J/K}$$

With equally positive change due to compression

3. Steam enters a steady adiabatic turbine at 7 MPa, 600°C and leaves at 50kPa, 150°C. If the power output of the turbine is 3MW, find: [25]
   a. The enthalpy and entropy at the inlet and exit of the turbine

@ 7 MPa $\quad T_{sat} = 285.829\,°C \quad$ (superheated)

$h_1 = 3650.6\ kJ/kg \quad s_1 = 7.0910\ kJ/kgK$

@ 50 kPa $\quad T_{sat} = 81.317\,°C \quad$ (Superheated)

$h_2 = 2780.2\ kJ/kg \quad s_2 = 7.9413\ kJ/kgK$

$s_f = 1.0912\ kJ/kgK$

$s_{fg} = 6.5018\ kJ/kgK$

   b. Show this process on a *T-s* diagram, include both the isentropic and actual processes. Show the saturation line (steam dome)

$s_1 = s_2 = s_f + x\,(s_{fg})$

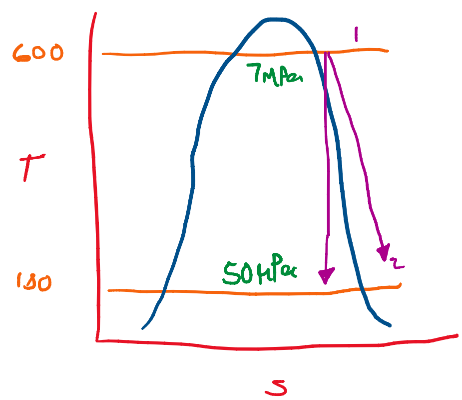
$$7.0910 = 1.0912 + x\,(6.5018)$$

$$x = .9227$$

@ 50 kPa $h_f = 340.54\ kJ/kg$ $h_{fg} = 2304.7\ kJ/kg$

$$h_2 = h_f + x\,h_{fg} = 340.54 + .9227\,(2304.7)$$

$$h_s = 2467.0866\ kJ/kg$$



c. The isentropic efficiency of the turbine

$$\eta_t = \frac{W_{actual}}{W_{ideal}} = \frac{h_1 - h_2}{h_1 - h_s} = \frac{3650.6 - 2780.2}{3650.6 - 2467.0866} = .7354$$

$$\boxed{\eta_t = 73.54\%}$$

d. The mass flow rate of the steam flowing through the turbine

$$\dot{m} h_1 = \dot{m} h_2 + \dot{W}$$

$$\dot{m} h_1 = \dot{m} h_2 + \dot{W}$$

$$\dot{m}(h_1 - h_2) = \dot{W}$$

$$\dot{m}(3650.6 - 2780.2) = 3000$$

$$\boxed{\dot{m} = 3.446 \text{ kg/s}}$$

4. Air at 200 kPa and 800K enters an adiabatic nozzle at low velocity (can be considered negligible) and is discharged at a pressure of 90 kPa. If the isentropic efficiency of the nozzle is 90%, determine: [25]
    a. The exit temperature if the process is isentropic

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = 800\left(\frac{90}{200}\right)^{\frac{1.4-1}{1.4}}$$

$$\boxed{T_2 = 636.8 \text{ K}}$$

    b. The maximum possible exit velocity

$$h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2}$$

$$h_1 + 0 = h_2 + \frac{V_2^2}{2}$$

$$V_2 = \sqrt{2(h_1 - h_2)} = \sqrt{2c_p(T_1 - T_2)}$$

$$V_2 = \sqrt{2(1.099)(800 - 636.8)(1000)}$$

$$\boxed{V_2 = 599 \text{ m/s}}$$

c. The actual exit temperature

$$\eta = \frac{h_1 - h_2}{h_1 - h_s} = \frac{c_p(T_1 - T_2)}{c_p(T_1 - T_2)} = \frac{T_1 - T_2}{T_1 - T_s}$$

$$.9 = \frac{800 - T_2}{800 - 636.8}$$

$$\boxed{T_2 = 653.12\ K}$$

d. The actual exit velocity

$$\eta = \frac{V_2^2}{V_s^2}$$

$$V_2 = \sqrt{\eta V_s^2} = \sqrt{.9(599)}$$

$$\boxed{V_2 = 568.26\ m/s}$$