Thermodynamics and Heat Transfer Assignment Week 2
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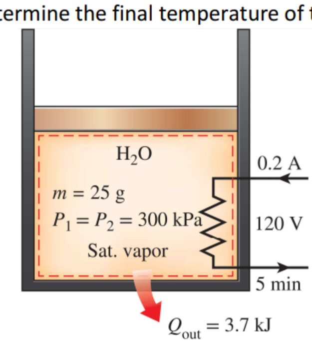
1. A piston–cylinder device contains 25 g of saturated water vapor that is maintained at a constant pressure of 300 kPa. A resistance heater within the cylinder is turned on and passes a current of 0.2 A for 5 min from a 120-V source. At the same time, a heat loss of 3.7 kJ occurs. (a) Show that for a closed system the boundary work Wb and the change in internal energy ΔU in the first-law relation can be combined into one term, ΔH, for a constant-pressure process. (b) Determine the final temperature of the steam.? **(10 Points) (Lecture 3)**



Exercise 1:

$m = 25g$, $P_1 = P_2 = 300 kPa$ in saturated vapour , $Q_{out} = 3.7 kJ$

a) Cylinder is stationary $\Rightarrow \Delta KE = \Delta PE = 0$

Thermodynamics first law : $\Delta E = Q - W = \Delta KE + \Delta PE + \Delta U$

$\Rightarrow \Delta E = \Delta U = Q - W$

ΔE brought by the wires are trivial and can be omitted

We have : $Q - W = \Delta U$

$\Rightarrow Q - W_{boundary} - W_{electrical} = \Delta U$

$\Rightarrow Q - P\Delta V - W_{electrical} = \Delta U$

$\Rightarrow Q - W_{electrical} = \Delta U + P\Delta V$, where $P = P_1 = P_2$

$\Rightarrow Q - W_{electrical} = (U_2 + P_2V_2) - (U_1 + P_1V_1)$

$\Rightarrow Q - W_{electrical} = H_2 - H_1$ (proven)

b) Determine the final temperature of the steam ?

Electrical work done by the wires:

$W_e = VI\Delta t = (120V)(0.2A)(300s) = 7200J$

State$_1$: $\left.\begin{array}{l} P_1 = 300 kPa \\ \text{Saturated vapor} \end{array}\right\} h_1 = h_g @ 300 kPa = 2724.9 kJ/kg$

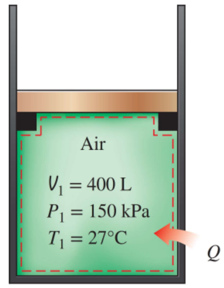
Proven forom (a), we have: $W_{electrical} - Q_{out} = \Delta H = m(h_2 - h_1)$

$\Rightarrow 7200 J - 3700 J = 0.025 kg (h_2 - 2724.9 \times 10^3) J/kg$

$\Rightarrow h_2 = 2864.9 kJ/kg$

State 2: $\left.\begin{array}{l} P_2 = 300 kPa \\ h_2 = 2864.9 kJ/kg \end{array}\right\} \Rightarrow T_2 = 200°C$ (answer)

2. A piston–cylinder device initially contains air at 150 kPa and 27°C. At this state, the piston is resting on a pair of stops, as shown in Fig. 4–32, and the enclosed volume is 400 L. The mass of the piston is such that a 350-kPa pressure is required to move it. The air is now heated until its volume has doubled. Determine (a) the final temperature, (b) the work done by the air, and (c) the total heat transferred to the air. **(10 Points) (Lecture 3)**



Exercise 2:

$P_1 = 150$ kPa $\quad T_1 = 27°C \quad V_1 = 400\ell = 0.4m^3 \quad V_3 = 2V_1 = 800\ell$

$P_3 = 350$ kPa

Assumptions:

- Air is an ideal gas
- Stationary system: $\Delta KE = \Delta PE = 0 \Rightarrow \Delta E = \Delta U$
- Volume unchanged before pistol moving. Pressure remains constant afterwards
- $W_{other} = 0$

a) Find the final temperature

Ideal gas law relation: $\frac{PV}{T} = k \Rightarrow \frac{P_1 V_1}{T_1} = \frac{P_3 V_3}{T_3}$

$\Rightarrow \frac{(150\,kPa)(0.4m^3)}{\cancel{27°C}\ 300.15K} = \frac{(350\,kPa)(0.8m^3)}{T_3}$ where $27°C = 300.15K$

$\Rightarrow T_3 = 1400.7K = 1127.55°C$ (answer)

b) The work done by the air

Area under the process curve on the P-V diagram

$A = (V_2 - V_1)P_2 = (0.4m^3)(350kPa) = 140\,m^3 \cdot kPa$

$\Rightarrow W_{13} = 140\,kJ$ (answer)

c) Total heat transferred to the air

Energy balance on the system: $E_{in} - E_{out} = \Delta E_{system}$

$\Rightarrow Q_{in} - W_{b,out} = \Delta U = m(u_3 - u_1)$

Mass of the system from ideal gas relation:

$m = \frac{P_1 V_1}{RT_1} = \frac{(150kPa)(0.4m^3)}{(0.287\,kPa \cdot m^3/kg \cdot K)(300.15K)} = 0.697\,kg$

Internal energies: $u_1 = u@300K = 214.07\,kJ/kg$

$u_3 = u@1400K = 1113.52\,kJ/kg$

From equation above: $Q_{in} - W_{b,out} = m(u_3 - u_1)$

$\Rightarrow Q_{in} - 140\,kJ = (0.697\,kg)(1113.52 - 214.07)\,kJ/kg$

$\Rightarrow Q_{in} = 767\,kJ$ (answer)

3. Determine the enthalpy of liquid water at 100°C and 15 MPa (a) by using compressed liquid tables, (b) by approximating it as a saturated liquid, and (c) by using the correction given by $h_{@P,T} \cong h_{f\ @\ T} + v_{f\ @\ T}(P - P_{sat\ @\ T})$. **(15 Points) (Lecture 3)**

Exercise 3:

a) From compressed liquid tables, the enthalpy is

$\left.\begin{array}{l} P = 15\,MPa \\ T = 100°C \end{array}\right\} \rightarrow h = 430.39\ kJ/kg$ (answer)

b) Approximating the compressed liquid as a saturated liquid

$h \cong h_{f@100°C} = 419.17\ kJ/kg$ (answer)

c) From equation: $h_{@P,T} \cong h_{f@T} + v_{f@T}(P - P_{sat@T})$

$= 419.17\ kJ/kg + 10^{-3}\ m^3/kg(15000 - 101.42)\ kPa$

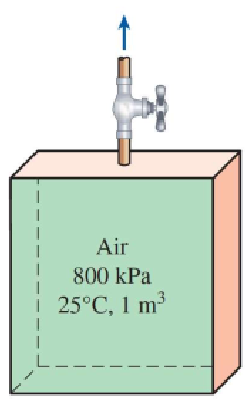
$= 434.07\ kJ/kg$ (answer)

4. A tank with an internal volume of 1 m3 contains air at 800 kPa and 25°C. A valve on the tank is opened, allowing air to escape, and the pressure inside quickly drops to 150 kPa, at which point the valve is closed. Assume there is negligible heat transfer from the tank to the air left in the tank.

(a) Using the approximation $h_e \approx constant = h_{e,avg} = 0.5(h_1 + h_2)$, calculate the mass withdrawn during the process.

(b) Consider the same process but broken into two parts. That is, consider an intermediate state at $P_2 = 400kPa$, calculate the mass removed during the process from $P_1 = 800kPa$ to P_2 and then the mass removed during the process from P_2 to $P_3 = 150kPa$, using the type of approximation used in part (a), and add the two to get the total mass removed.

(c) Calculate the mass removed if the variation of he is accounted for. **(15 Points) (Lecture 4)**



Exercise 4:

$V = 1\,m^3$ $T_1 = 25^\circ C$ $P_1 = 800\,kPa$ $P_2 = 150\,kPa$ $c_p = 1.005\,kJ/kg\cdot K$

$k = 1.4$ $c_v = 0.718\,kJ/kg\cdot K$

a) Calculate mass withdrawn from the process

Mass balance: $-m_e = m_2 - m_1$

Energy balance: $E_{in} - E_{out} = \Delta E_{sys} \Rightarrow -m_e h_e = m_2 u_2 - m_1 u_1$

Since $h_e = 0.5(h_1 + h_2)$

$$\Rightarrow -(m_1 - m_2)\,0.5(h_1 + h_2) = m_2 u_2 - m_1 u_1$$

$$\Rightarrow -\left(\frac{P_1}{T_1} - \frac{P_2}{T_2}\right) c_p \frac{T_1 + T_2}{2} = c_v (P_2 - P_1) \quad (\text{Eq } 1)$$

$$\Rightarrow -\left(\frac{800}{298.15} - \frac{150}{T_2}\right) 1.005\, \frac{298.15 + T_2}{2} = 0.718(150 - 800)$$

$\Rightarrow T_2 = 191\,K$

The initial and final mass are given by:

$$m_1 = \frac{P_1 V}{RT_1} = \frac{800\,kPa \times 1\,m^3}{0.287 \times 298.15\,K} = 9.35\,kg$$

$$m_2 = \frac{P_2 V}{RT_2} = \frac{150\,kPa \times 1\,m^3}{0.287 \times 191\,K} = 2.736\,kg$$

$\Rightarrow$ The withdrawn mass: $m_e = m_1 - m_2 = 9.35 - 2.736 = 6.614\,kg$ (answer)

b) There are two processes: Using the equation 1, we can find T_2

(1) $P_1 = 800\,kPa$, $P_2 = 400\,kPa \Rightarrow T_2 = 245\,K$

(2) $P_1 = 400\,kPa$, $P_2 = 150\,kPa \Rightarrow T_2 = 186\,K$

Process (1): $m_{e_1} = \dfrac{P_1 V}{RT_1} - \dfrac{P_2 V}{RT_2} = \dfrac{800}{0.287 \times 298.15} - \dfrac{400}{0.287 \times 245} = 3.66\,kg$

Process (2): $m_{e_2} = \dfrac{P_1 V}{RT_1} - \dfrac{P_2 V}{RT_2} = \dfrac{400}{0.287 \times 245} - \dfrac{150}{0.287 \times 186} = 2.88\,kg$

$\Rightarrow$ Total withdrawn mass: $\sum m_e = m_{e_1} + m_{e_2} = 3.66 + 2.88 = 6.54\,kg$ (answer)

c) Applying the given formula to find T_2, we have

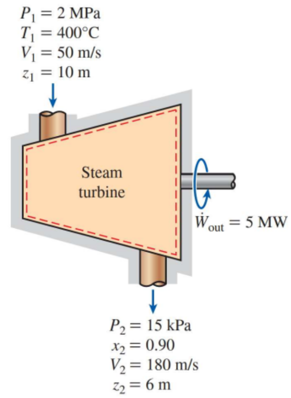
$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = 298.15\left(\frac{150}{800}\right)^{2/7} = 184.8\,K$$

The withdrawn mass is

$$m_e = m_1 - m_2 = \frac{P_1 V}{RT_1} - \frac{P_2 V}{RT_2} = \frac{800}{0.287 \times 298.15} - \frac{400}{0.287 \times 184.8}$$

$\Rightarrow m_e = 6.52\,kg$ (answer)

5. The power output of an adiabatic steam turbine is 5 MW, and the inlet and the exit conditions of the steam are as indicated in Fig. 5–31. (a) Compare the magnitudes of Δh, Δke, and Δpe. (b) Determine the work done per unit mass of the steam flowing through the turbine. (c) Calculate the mass flow rate of the steam. **(20 Points) (Lecture 4)**



Exercise 5:

Assumptions

- Steady flow process: $\Delta m_{CV} = \Delta E_{CV} = 0$
- Adiabatic: $Q = 0$

a) At inlet, steam is in a superheated vapor state and its enthalpy is

$$\left.\begin{array}{l} P_1 = 2\,MPa \\ T_1 = 400°C \end{array}\right\} \Rightarrow h_1 = 3248\ kJ/kg$$

The enthalpy at this state: $h_2 = h_f + x_2 h_{fg}$

$\Rightarrow h_2 = 225.94 + (0.9)(2372.3) = 2361.01\ kJ/kg$

Then: $\Delta h = h_2 - h_1 = 2361.01 - 3248.4 = -887.39\ kJ/kg$

$\Delta KE = \frac{1}{2}(V_2^2 - V_1^2) = \frac{1}{2}(180^2 - 50^2) = 14.95\ kJ/kg$

$\Delta PE = g(z_2 - z_1) = 9.81(6 - 10) = -0.04\ kJ/kg$

b) Determine W/unit mass by the steam through the turbine

Energy balance for this system:

$\dot{E}_{in} - \dot{E}_{out} = dE_{system}/dt = 0$ (Since system is steady)

The work done by the turbine per unit mass

$w_{out} = (h_1 - h_2) + \frac{1}{2}(v_1^2 - v_2^2) + g(z_1 - z_2)$

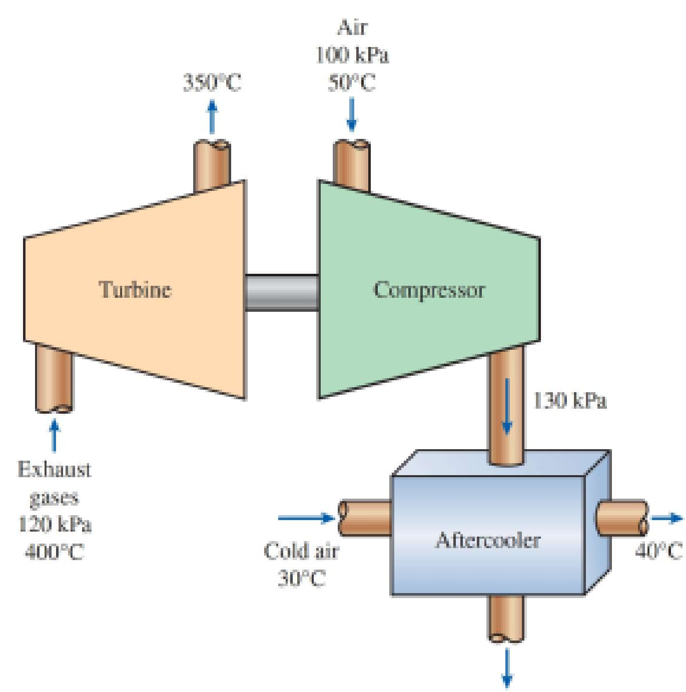
$= -(\Delta h + \Delta KE + \Delta PE)$

$= -(-887.39 + 14.95 - 0.04) = 872.48\ kJ/kg$ (answer)

c) Calculate mass flow rate of the steam

$\dot{m} = \frac{\dot{W}_{out}}{w_{out}} = \frac{5000\ kJ/s}{872.48\ kJ/kg} = 5.73\ kg/s$ (answer)

6. The turbocharger of an internal combustion engine consists of a turbine and a compressor. Hot exhaust gases flow through the turbine to produce work, and the work output from the turbine is used as the work input to the compressor. The pressure of ambient air is increased as it flows through the compressor before it enters the engine cylinders. Thus, the purpose of a turbocharger is to increase the pressure of air so that more air gets into the cylinder. Consequently, more fuel can be burned and more power can be produced by the engine.In a turbocharger, exhaust gases enter the turbine at 400°C and 120 kPa at a rate of 0.02 kg/s and leave at 350°C. Air enters the compressor at 50°C and 100 kPa and leaves at 130 kPa at a rate of 0.018 kg/s. The compressor increases the air pressure with a side effect: It also increases the air temperature, which increases the possibility that a gasoline engine will experience an engine knock. To avoid this, an aftercooler is placed after the compressor to cool the warm air with cold ambient air before it enters the engine cylinders. It is estimated that the aftercooler must decrease the air temperature below 80°C if knock is to be avoided. The cold ambient air enters the aftercooler at 30°C and leaves at 40°C. Disregarding any frictional losses in the turbine and the compressor and treating the exhaust gases as air, determine (a) the temperature of the air at the compressor outlet and (b) the minimum volume flow rate of ambient air required to avoid knock. **(30 Points) (Lecture 4)**



Exercise 6:

a) An energy balance on the turbine gives

$$\dot{W}_T = \dot{m}_{exh} c_{p,exh} (T_{exh,1} - T_{exh,2})$$
$$= (0.02\,kg/s)(1.063\,kJ/kg\cdot K)(400C - 350C)$$
$$= 1.063\,kW$$

An energy balance on the compressor gives the air temperature at compressor outlet

$$\dot{W}_T = \dot{W}_C = \dot{m}_a c_{p,a} (T_{a,2} - T_{a,1})$$
$$\Rightarrow 1.063\,kW = 0.018\,kg/s \cdot 1.008\,kJ/kg\cdot K\,(T_{a,2} - 50)$$
$$\Rightarrow T_{a,2} = 108.58\,°C \text{ (answer)}$$

b) An energy balance on the aftercooler gives mass flow rate of cold ambient air

$$\dot{m}_a c_{p,a} (T_{a,2} - T_{a,3}) = \dot{m}_{ca} c_{p,ca} (T_{ca,2} - T_{ca,1})$$
$$\Rightarrow 0.018\,kg/s \cdot 1.008\,(108.6 - 80)C = \dot{m}_{ca} \cdot 1.005\,(40 - 30)C$$
$$\Rightarrow \dot{m}_{ca} = 0.0516\,kg/s$$

Specific volume of cold ambient air:

$$v_{ca} = \frac{RT}{P} = \frac{(0.287\,kJ/kgK)(303K)}{100\,kPa} = 0.8696\,m^3/kg$$

Volume flow rate: $\dot{V}_{ca} = \dot{m} v_{ca} = (0.0516\,kg/s)(0.8696\,m^3/kg)$

$$= 0.0449\,m^3/s \text{ (answer)}$$

7. **Your free feedback on the first weeks and time spent on this learning exercise.** (This does not affect the grading)

I spent 5 hours doing this assignment. Many concepts are quite difficult to understand but overall everything is decently clear