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MAE 320 THERODYNAMICS
EXAM 2 - Practice

Name: Answer Key

You are allowed one sheet of notes.

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1. A (liquid) water tank has two inflows of 10 kg/s and 20 kg/s and an outflow of 25 kg/s.
   a) What is the rate of water accumulation in the tank?
   b) How much water is accumulated after 10 minutes?

a) $\frac{dm_{cv}}{dt} = \dot{m}_{cv} = \sum_i \dot{m}_i - \sum_e \dot{m}_e = 10 + 20 - 25 = \underline{5 \text{ kg/s}}$

5 b) $\Delta m_{cv} = \dot{m}_{cv} \Delta t = 5 \frac{kg}{s} \times 10 \text{ min} \times \frac{60 s}{min} = \underline{3000 \text{ kg}}$

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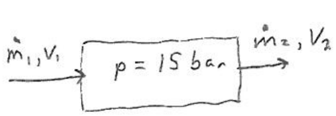
2. A steam engine boiler has a pressure of 15 bar. Liquid water is injected at 80 °C (and 15 bar) at a rate of 1 liter per minute. Steam exits the boiler as a saturated vapor at a rate of 150 liters per minute.
   a) What is the rate of water (mass) accumulation in the tank?
   b) What mass of water would be accumulated after 10 minutes (if the pressure and flow rates stayed the same)?



For liquid water, $v_1 = 0.001 \frac{m^3}{kg}$ ← Good

For sat. liquid water at 80°C, from Table A-2: $v_1 = 1.0291 \times 10^{-3} \frac{m^3}{kg}$ ← Better

For water at 80°C & 15 bar, interpolating between sat. liquid (Table A-2) & comp. liquid (Table A-5): $v_1 = \left(1.0291 + \frac{15 - 0.4739}{25 - 0.4739}(1.028 - 1.0291)\right) \times 10^{-3} = 1.028449 \times 10^{-3} \frac{m^3}{kg}$ ← Best

For sat. vapor water at 15 bar (Table A-3): $v_2 = 0.1318 \frac{m^3}{kg}$

10 $\dot{m}_1 = \frac{\dot{V}_1}{v_1} = \frac{1 \frac{l}{min} \times \frac{1 m^3}{1000 l} \times \frac{1 min}{60 sec}}{1.028449 \times 10^{-3} \frac{m^3}{kg}} = 0.0162056 \frac{kg}{s}$

$\dot{m}_2 = \frac{\dot{V}_2}{v_2} = \frac{150 \frac{l}{min} \times \frac{1 m^3}{1000 l} \times \frac{1 min}{60 sec}}{0.1318 \, m^3/kg} = 0.0189681 \frac{kg}{s}$

a) $\dot{m}_{cv} = \dot{m}_1 - \dot{m}_2 = 0.0162056 - 0.0189681 = \underline{-2.76 \times 10^{-3} \text{ kg/s}}$

b) $\Delta m_{cv} = \dot{m}_{cv} \Delta t = -2.76 \times 10^{-3} \text{ kg/s} \times 10 \text{ min} \times \frac{60 sec}{1 min} = \underline{-1.66 \text{ kg}}$ ← Negative means the water level is going down.

3. Liquid water at ~~1000~~ 0.001 m^3/kg is piped to the boiler at a rate of 0.02 kg/s through a 25 mm internal diameter pipe.

Find: a) What is volumetric flow rate? ($\dot{V}$)

b) What is the velocity of the water in the pipe? (V)

Given: $v = 0.001\ m^3/kg$ $\quad \dot{m} = 0.02\ kg/s$ $\quad A = \frac{\pi}{4}(0.025)^2 = 4.9087\times10^{-4}\ m^2$

Solution: a) $\dot{V} = \dot{m} v = 0.02\ \frac{kg}{s} \times 0.001\ \frac{m^3}{kg} = 2\times10^{-5}\ \frac{m^3}{s}$

5 b) $\dot{m} = \frac{AV}{v}$

$V = \frac{\dot{m} v}{A} = \frac{0.02\ kg/s \times 0.001\ m^3/kg}{4.9087\times10^{-4}\ m^2} = 0.407\ m/s$

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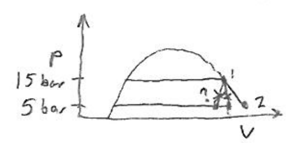
4. A valve between a boiler and a steam whistle throttles saturated vapor from 15 bar to 5 bar.

Find: a) What is the temperature on the 15 bar side of the valve? (T_1)

b) What is the temperature on the 5 bar side of the valve? (T_2)

Given: $p_1 = 15$ bar → Throttle → $p_2 = 5$ bar

sat. vap. → sat. vap.?



5 Solution:

a) From Table A-4 or Table A-3, for 15 bar, sat. vap. $T_1 = 198.3°C$, $h_1 = 2792.2\ \frac{kJ}{kg}$

b) For "throttle" from Energy Rate Balance: $h_1 = h_2$ $\quad \therefore h_2 = 2792.2\ \frac{kJ}{kg}$

From Table A-4 or Table A-3, for 5 bar, sat. vap., $h_g = 2748.7\ \frac{kJ}{kg} < h_2$

$\therefore$ is superheated.

Interpolating from Table A-4, for 5 bar, $T_2 = 151.86 + \frac{(2792.2 - 2748.7)}{(2812.0 - 2748.7)} \times (180 - 151.86) = 171.2°C$

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5. A steam locomotive operates with a boiler pressure of 15 bar. What is the maximum (Carnot) efficiency possible for the locomotive?

Carnot efficiency for heat engine $\eta_{max} = 1 - \frac{T_c}{T_H}$

For T_H, use "adiabatic flame temperature" as in class example? Don't know what
5 kind of fuel. Cannot look up temperature. Also, there is heat transfer, so is not adiabatic anyways. So T_H will be lower anyways. (Cannot be higher.) How much lower? Must be at least hotter than boiler, so use boiler temperature, which can be obtained.

From Table A-3 or A-4, for $p = 15$ bar $T_H = T_{sat} = 198.3°C = 471.45\ K$

For T_c, no information is given, but assume ambient temperature on a nice day: $T_c = 20°C = 293.15\ K$

$\eta_{max} = 1 - \frac{293.15}{471.45} = 0.378 \approx 38\%$

- Note that on a cold day, efficiency could likely be even better!