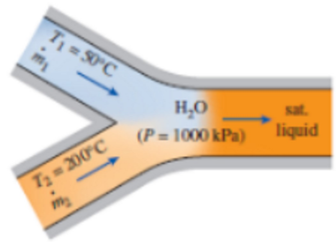
Homework 6

Sunday, March 28, 2021   11:31 PM

"I pledge my honor I have abided by the Stevens Honor system."
- Alex [signature]

1. The efficiency of a steam power plant can be increased by bleeding off some of the steam that would normally enter the turbine and using it to preheat the water entering the boiler. In this process, liquid water at 50°C and 1000 kPa is mixed with superheated steam at 200°C and 1000 kPa. If the plant operators want to produce a saturated liquid at 1000 kPa, what ratio of mass flow rates of water and superheated steam are required? [20]



$$m_w h_w + m_s h_s = h_{sat}(m_w + m_s)$$

$h_w = 210.19$ kJ/kg at 50°C and 1000 kPa

$h_s = 2828.27$ kJ/kg at 200°C and 1000 kPa

$h_{sat} = 762.68$ kJ/kg at 1000 kPa

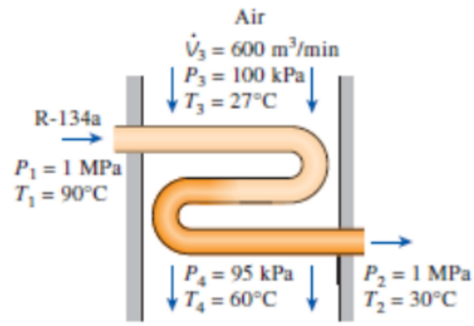
Using table

$$r = \frac{m_w}{m_s} \qquad m_w = r\, m_s$$

$$r\, m_s(210.19) + m_s(2828.27) = (1+r)m_s(762.68)$$

$$\boxed{r = 3.74}$$

2. Take a look at the back of a fridge or AC unit. You will see a 'radiator' that is used to remove heat from the R134a fluid that circulates within the refrigeration system. Using this heat exchanger, the refrigerant-134a at 1 MPa and 90°C is to be cooled to 1 MPa and 30°C by air. The air enters at 100 kPa and 27°C with a volume flow rate of 600 m³/min and leaves at 95 kPa and 60°C. Determine the mass flow rate of the refrigerant. [20]



$$\underbrace{h_1 = 472.8 \text{ kJ at } 90°C \qquad h_2 = 241.7 \text{ kJ/kg at } 30°C}_{1 \text{ MPa}}$$

$\dot{m}_{air} = \rho_{air}(\dot{V})$

$\dot{m}_{air} = (1.16)\left(\frac{600}{60}\right)$

$\dot{m}_{air} = 11.6$ kg/s

$\dot{Q}_{in} = \dot{m}_{air}(c_p(T_4 - T_3))$

$\dot{Q}_{in} = 11.6(1(60 - 27))$

$\dot{Q}_{in} = 384.71$ kJ/s

$\dot{Q}_{out} = \dot{Q}_{in}$

$\dot{m}(h_1 - h_2) = 384.71$

$\dot{m}(472.8 - 241.7) = 384.71$

$$\boxed{\dot{m} = 1.7 \text{ kg/s}}$$

3. Orange juice must be heated to pasteurize it for storage. This is achieved by passing the juice through a tubular heat exchanger. The juice must be heated from 4°C to 93°C. Saturated vapor enters the outer tube of the heat exchanger at 150 kPa and exits as a saturated liquid at the same pressure. For an orange juice flow rate of 2000 kg/hr (juice cp = 3.9 kJ/kg.K), determine the required steam flow rate in kg/s. [20]

$T_{sat} = T_1 - T_2$

$h_r = 99.3.818$ kJ/

$T_{sat} = T_1 - T_2$

$T_1 - T_2 = 542.697°C$ $h_{fg} = 993.818 \, kJ/kg$

$\dot{Q}_{in} = \dot{Q}_{out}$

$\dot{m} = m(c_p(T_1 - T_2))$

$\dot{m} = 2000(3.9(93-4))$

$\dot{m} = \frac{698.52 \, kg/hr}{3600}$

$\boxed{\dot{m} = .194 \, kg/s}$

4. Refrigerant-134a enters a compressor at 180 kPa as a saturated vapor with a flow rate of 0.35 m³/min and leaves at 700 kPa. The power supplied to the refrigerant during compression process is 2.35 kW. What is the temperature of R-134a at the exit of the compressor? [20]

$h_1 = 242.86 \, kJ/kg$ $v_1 = .1104 \, m^3/kg$

$P = 180 \, kPa$

$\dot{m} = \frac{\dot{V}_1}{v_1} = \frac{.35}{.1104(60)} = .0528 \, kg/s$

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

$h_2 = h_1 + \frac{\dot{W}_{in}}{\dot{m}} = 242.86 + \frac{2.35}{.0528} = 287.4 \, kJ/kg$

$h_1 < h_2$

$$\left.\begin{aligned} h_1 &= 278.59 \text{ kJ/kg at } 40°C \\ h_2 &= 288.53 \text{ kJ/kg at } 50°C \end{aligned}\right\} 700 \text{ kPa}$$

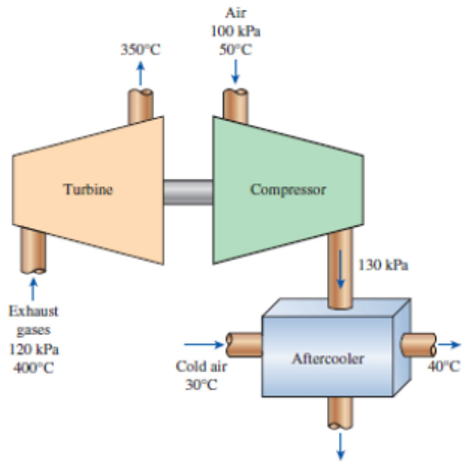
$$\frac{T - T_1}{T_2 - T_1} = \frac{h - h_1}{h_2 - h_1}$$

$$\frac{T - 40}{50 - 40} = \frac{287.4 - 278.57}{288.53 - 278.57}$$

$$T = 10(.887) + 40$$

$$\boxed{T = 46.9°C}$$

5. **Turbochargers:** 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.



Problem Statement: In a turbocharger, exhaust gases (air) 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 of a gasoline engine to experience autoignition. To avoid this, an aftercooler is placed after the compressor to cool the warm air by 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. 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 cool the compressed air to 80°C. [20]

Exhaust gas: $c_p = 1.063$ kJ/kg·K at 673 K

Warm air: $c_p = 1.008$ kJ/kg·K at 323 K

air: $c_p = 1.005$ kJ/kg·K at 303 K

$$W_T = \dot{m}(h_1 - h_2) = \dot{m}(c_p(T_1 - T_2))$$

$$W_T = .02(1.063(400-350)) = 1.063 \text{ kW}$$

$$W_T = W_c = 1.063 \text{ kW}$$

$$W_c = \dot{m}(c_p(T_4 - T_3))$$

$$1.063 = .018(1.008(T_4 - 323))$$

$$T_4 = 381.59 \text{ K} - 273$$

$$\boxed{\text{A.)} \quad T_4 = 108.59\,^\circ C}$$

$$Q_{out} = Q_{in}$$

$$\dot{m}\left(c_p\left(T_4 - T_5\right)\right) = \dot{m}_c\left(c_{p_c}\left(T_7 - T_6\right)\right)$$

$$.018\left(1.008\left(108.59 - 80\right)\right) = \dot{m}_c\left(1.005\left(40 - 30\right)\right)$$

$$\dot{m}_c = \frac{.5187}{10.05} = .0516 \ kg/s$$

$$v_c = \frac{RT_6}{P} = \frac{.787(303)}{100} = .8696 \ m^3/kg$$

$$\dot{V}_c = \dot{m}_c v_c = .0516(.8696)$$

$$\boxed{\text{B.)} \quad \dot{V}_c = .0449 \ m^3/s}$$