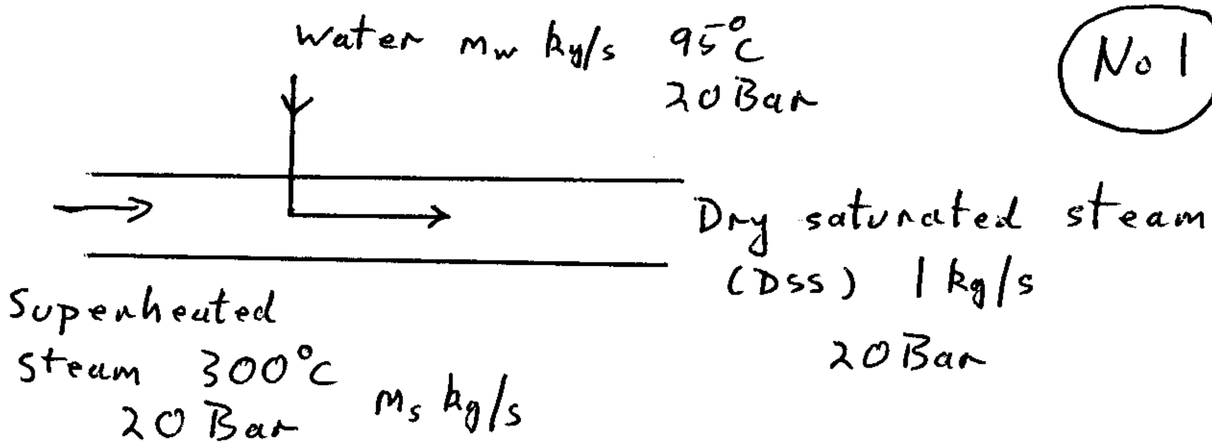
Thermodynamics Tutorial Sheet 3

Worked examples

Answers are given for questions 1, 2 and 3

Questions 4 and 5 are variations on question 3



No 1

A 'desuperheater' is a device where water is sprayed into superheated steam, to generate more steam but with less (or zero) superheat.

mass balance: $m_s + m_w = 1$

enthalpy balance: $m_s h_s + m_w h_w = 1 . h_{DSS}$

At 20 Bar, from superheat tables for steam.
$h_s = 3025$ kJ/kg

At 20 Bar, at saturation $h_{DSS} = 2799$ kJ/kg

At 20 Bar, at saturation, $h_f = 920$ kJ/kg
and $T_{sat} = 215$C

$$\text{So } h_w = 920 - 4.18(215 - 95)$$
$$= 418.4 \text{ kJ/kg}$$

$$3025\, m_s + 418.4\, m_w = 2799$$

$$3025\, m_s + 418.4(1 - m_s) = 2799$$

$$m_s = 0.913 \text{ kg/s} \quad (3286.8 \text{ kg/hr})$$

$$m_w = 0.087 \text{ kg/s} \quad (313.2 \text{ kg/hr})$$

Under the given superheat conditions:

$$v = 0.1255 \text{ m}^3/\text{kg}$$

Volumetric superheated steam rate

$$= 0.913 \times 0.1255 \quad \frac{\text{kg}}{\text{s}} \times \frac{\text{m}^3}{\text{kg}}$$

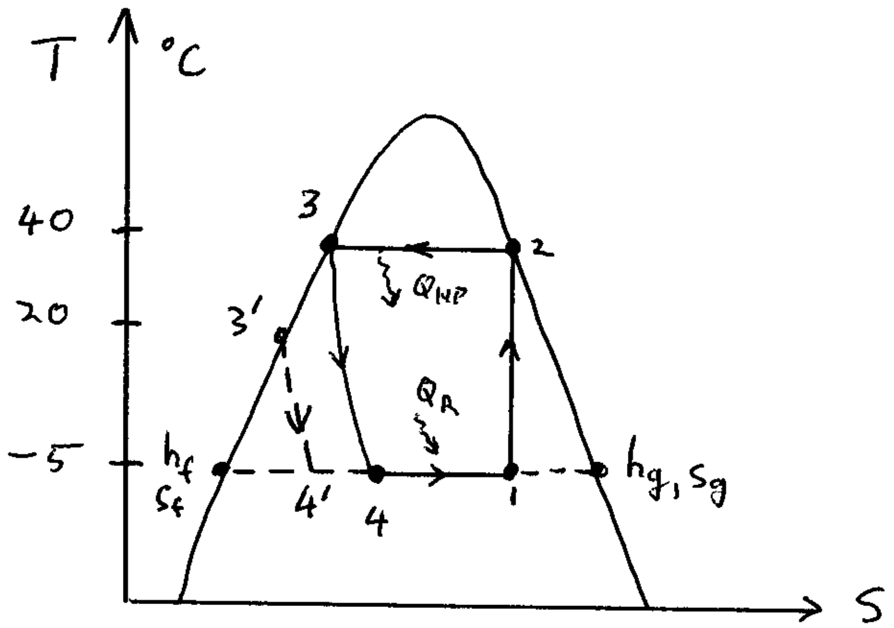
$$= 0.1146 \text{ m}^3/\text{s}$$

$$= 25 \frac{\text{m}}{\text{s}} \times \frac{\pi D^2}{4} \text{ m}^2$$

$$\Rightarrow D = 0.076 \text{ m}$$

Required pipe diameter $\geqslant 0.076$ m

No 2



Refrigeration effect = $h_1 - h_4$

Compressor work (assuming isentropic compression) = $h_2 - h_1$

CoP(refrig) = $(h_1 - h_4) / (h_2 - h_1)$

Dryness fraction at ①:

$$S_2 = S_1$$

$$(1 - x) S_f + x S_g = S_1 = S_2$$

$$0{\cdot}125\,(1 - x) + 0{\cdot}699\,x = S_1 = 0{\cdot}6825 \text{ kJ/kg C}$$

Data from tables for Freon 12

$$\underline{x = 0{\cdot}97}$$

Enthalpies:

$$h_1 = (1 - x)\,h_f + x\,h_g$$

$$= (1 - x)\cdot 31{\cdot}45 + 185{\cdot}38\,x$$

$$= \underline{180{\cdot}8 \text{ kJ/kg}}$$

$h_4 = h_3$ (isenthalpic expansion)

$= 74.6$ kJ/kg — liquid satn. enthalpy at 40°C

$h_2 = 203.2$ kJ/kg — vapour satn. enthalpy at 40°C

Refrigeration effect $= h_1 - h_4 = 106.2$ kJ/kg

CoP $= (h_1 - h_4)/(h_2 - h_1) = 4.74$

With sub cooling to 20°C,

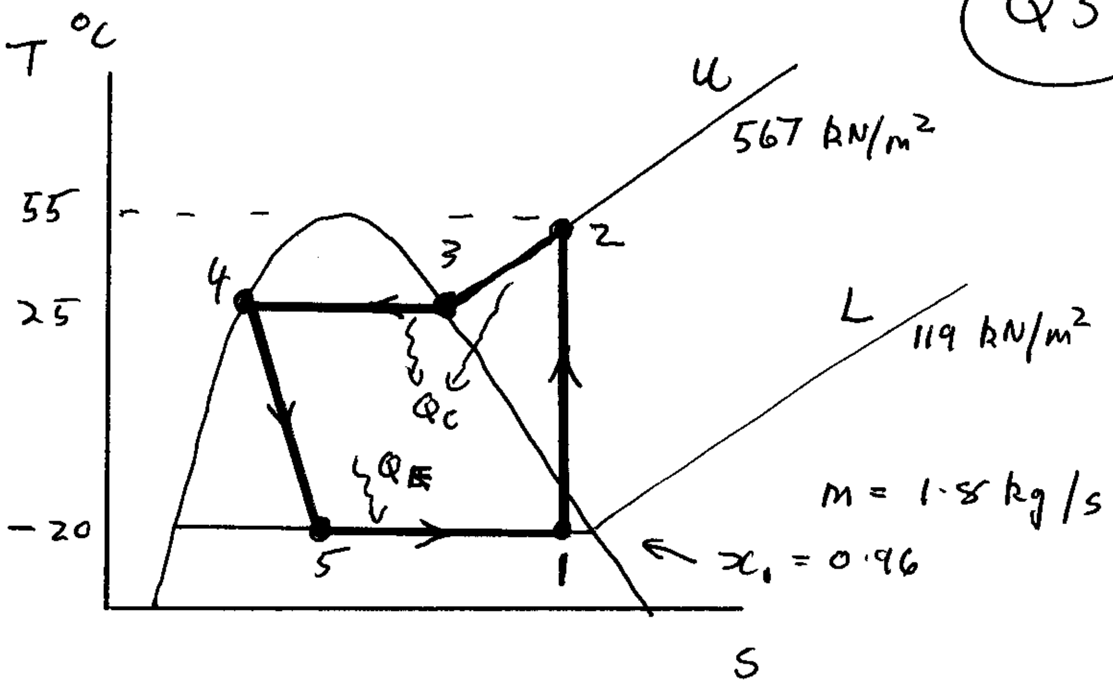
$h_{3'} = 54.9$ kJ/kg ($\simeq$ liquid satn. at 20°C)

So $h_4' = 54.9$

$\Rightarrow$ RE $= 125.9$ kJ/kg

CoP $= 5.62$

Q3



$$CoP = \frac{h_1 - h_5}{h_2 - h_1}$$

$$Q_{COND} = h_2 - h_4$$

$$Q_{EVAP} = h_1 - h_5$$

4 → 5 ISENTHALPIC, 1 → 2 ISENTROPIC

$$h_1 = x h_{g_L} + (1-x) h_{f_L} = 0.96 \times 455.2 + 0.04 \times 30.1$$

$$= \underline{438.19 \text{ kJ/kg}}$$

$$h_5 = h_4 = \underline{100.5 \text{ kJ/kg}}$$

$$s_1 = x s_{g_L} + (1-x) s_{f_L} = 0.96 \times 1.803 + 0.04 \times 0.124$$

$$= 1.736 \text{ kJ/kg C}$$

$$= s_2$$

Assume vapour is ideal

$$s_2 - s_3 = C_p \ln \frac{T_2}{T_3} - R \ln \frac{P_2}{P_3}$$

$$= C_p \ln \frac{T_2}{T_3} \quad \text{since } P_2 = P_3$$

$$1.736 - 1.642 = C_p \ln \frac{55+273}{25+273}$$

$$\underline{C_p = 0.98 \text{ kJ/kg C}}$$

$$h_2 - h_3 = C_p (T_2 - T_3)$$

$$h_2 = 476.8 + 0.98(55-25)$$

$$= \underline{506.2 \text{ kJ/kg}}$$

$$\underline{\underline{CoP = h_1 - h_5 / h_2 - h_1 = 4.97}}$$

$$Q_{COND} = h_2 - h_4 = 405.7 \text{ kJ/kg}$$

$$\text{Condensor heat load} = \frac{1.8}{60} \times 405.7$$

$$= 12.17 \text{ kJ/s}$$

$$= m_w S_w \Delta T_w$$

$$12.17 = \frac{960}{3600} \times 4.187 \times \Delta T_w$$

$$\underline{\underline{\Delta T_w = 10.9\,°C}}$$

$$Q_{EVAP} = h_1 - h_5 = 337.69 \text{ kJ/kg}$$

EVAPORATOR heat load $= \frac{1.8}{60} \times 337.69$

$$= 10.13 \text{ kJ/s}$$

$$= m_{ice} \lambda + m_{ice} \times S_w \times (15-0)$$

$$10.13 = m_{ice} (336 + 4.187 \times 15)$$

$$m_{ice} = 0.0254 \text{ kg/s}$$

$$= \underline{\underline{91.4 \text{ kg/hr}}}$$