Chapter 06 Solved Problems

Problem 6.25

C.V. Nozzle, steady state, 1 inlet and 1 exit flow, insulated so no heat transfer.

$$q + h_i + \mathbf{V}_i^2/2 = h_e + \mathbf{V}_e^2/2,$$

$$q = 0, \quad \mathbf{V}_i = 0$$

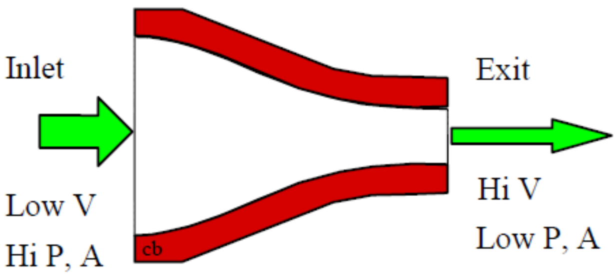
Table B.2.2: $h_i = 1464.9 = h_e + 450^2/(2\times1000) \quad \Rightarrow \quad h_e = 1363.6 \text{ kJ/kg}$

Table B.2.1: $P_e = 300$ kPa Sat. state at –9.2°C :

$$h_e = 1363.6 = 138.0 + x_e \times 1293.8,$$

=> $x_e = \mathbf{0.947}$, $v_e = 0.001536 + x_e \times 0.4064 = 0.3864 \text{ m}^3\text{/kg}$

$$A_e = \dot{m}_e v_e/\mathbf{V}_e = 0.01 \times 0.3864 / 450 = \mathbf{8.56 \times 10^{-6}\ m^2}$$



Problem 6.27

Continuity Eq.6.3: $\dot{m}_i = A_i\mathbf{V}_i/v_i = \dot{m}_e = A_e\mathbf{V}_e/v_e,$

Energy Eq.(per unit mass flow)6.13: $h_i + \frac{1}{2}\mathbf{V}_i^2 = h_e + \frac{1}{2}\mathbf{V}_e^2$

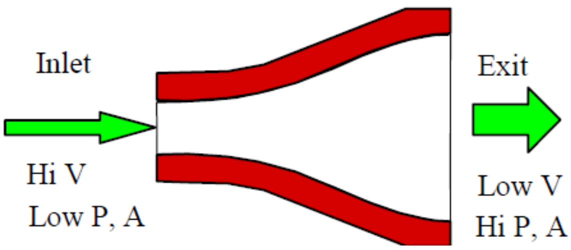
$$h_e - h_i = \frac{1}{2} \times 200^2/1000 - \frac{1}{2} \times 20^2/1000 = 19.8 \text{ kJ/kg}$$

$$T_e = T_i + (h_e - h_i)/C_p = 300 + 19.8/1.004 = \mathbf{319.72\ K}$$

Now use the continuity equation and the ideal gas law

$$v_e = v_i \left(\frac{A_e\mathbf{V}_e}{A_i\mathbf{V}_i}\right) = (RT_i/P_i)\left(\frac{A_e\mathbf{V}_e}{A_i\mathbf{V}_i}\right) = RT_e/P_e$$

$$P_e = P_i \left(\frac{T_e}{T_i}\right)\left(\frac{A_i\mathbf{V}_i}{A_e\mathbf{V}_e}\right) = 100\left(\frac{319.72}{300}\right)\left(\frac{100 \times 200}{860 \times 20}\right) = \mathbf{123.92\ kPa}$$



Problem 6.35

Energy Eq. $h_1 + \frac{1}{2}\mathbf{V}_1^2 + gZ_1 = h_2 + \frac{1}{2}\mathbf{V}_2^2 + gZ_2$

Process: $Z_1 = Z_2$ and $\mathbf{V}_2 = \mathbf{V}_1$

State 1, Table B.5.1: $h_1 = 234.59$ kJ/kg, $v_1 = v_f = 0.000829$ m^3/kg

Use energy eq.: $\Rightarrow h_2 = h_1 = 234.59$ kJ/kg

State 2: P_2 & h_2 $\Rightarrow$ 2 – phase and $T_2 = T_{sat}$ (165 kPa) = **-15°C**

$h_2 = h_f + x_2\, h_{fg} = 234.59$ kJ/kg

$x_2 = (h_2 - h_f) / h_{fg} = (234.59 – 180.19) / 209 = 0.2603$

$v_2 = v_f + x_2 \times v_{fg} = 0.000746 + 0.2603 \times 0.11932 = 0.0318$ m^3/kg

Now the continuity equation with $\mathbf{V}_2 = \mathbf{V}_1$ gives

$$\dot{m} = \rho A\mathbf{V} = A\mathbf{V}/v = A_1\mathbf{V}_1/v_1 = (A_2\,\mathbf{V}_1) / v_2$$

$(A_2 / A_1) = v_2 / v_1 = (D_2 / D_1)^2$

$(D_2/D_1) = (v_2 / v_1)^{0.5} = (0.0318 / 0.000829)^{0.5}$ = **6.19**

Problem 6.42

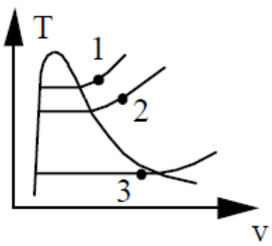
C.V. Throttle, Steady, $q = 0$ and $w = 0$. No change in kinetic or potential energy. The energy equation then reduces to

Energy Eq.6.13: $h_1 = h_2 = 2927.2$ kJ/kg from Table B.1.3

C.V. Turbine, Steady, no heat transfer, specific work: $w = \frac{110}{0.25} = 440$ kJ/kg

Energy Eq.: $h_1 = h_2 = h_3 + w = 2927.2$ kJ/kg

$\Rightarrow h_3 = 2927.2 - 440 = 2487.2$ kJ/kg



State 3: (P, h) Table B.1.2 $h < h_g$

$2487.2 = 191.83 + x_3 \times 2392.8$

$\Rightarrow$ T = **45.8°C** , x_3 = **0.959**

Problem 6.50

C.V. air compressor $q = 0$

Continuity Eq.: $\dot{m}_2 = \dot{m}_1$

Energy Eq.6.13: $h_1 + w_c = h_2$

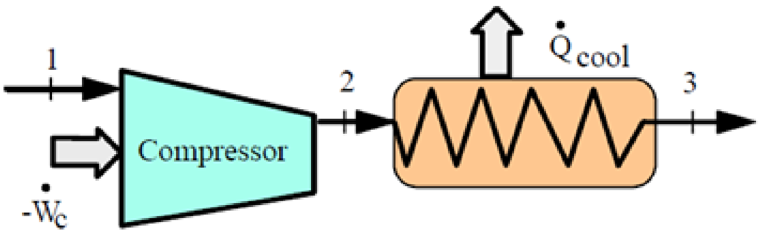


Table A.7:

$w_{c\ in} = h_2 - h_1 = 607.02 - 290.17 = \mathbf{316.85\ kJ/kg}$

C.V. cooler $w = 0$

Continuity Eq.: $\dot{m}_3 = \dot{m}_1$

Energy Eq. $h_2 = q_{out} + h_3$

$q_{out} = h_2 - h_3 = 607.02 - 300.19 = \mathbf{306.83\ kJ/kg}$

Problem 6.55

C.V.: boiler steady single inlet and exit flow, neglect KE, PE energies in flow

Continuity Eq.: $\dot{m}_1 = \dot{m}_2 = \dot{m}_3$

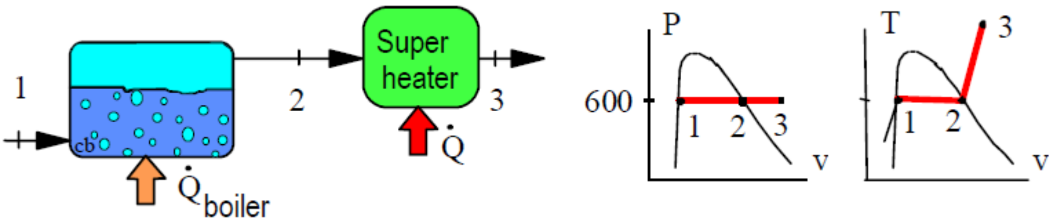


Table B.6.1: $h_1 = -81.469$ kJ/kg, $h_2 = 86.85$ kJ/kg,

Table B.6.2: $h_3 = 289.05$ kJ/kg

Energy Eq. $q_{boiler} = h_2 - h_1 = 86.85 - (-81.469) = 168.32$ kJ/kg

$\dot{Q}_{boiler} = \dot{m}_1 q_{boiler} = 0.005 \times 168.32 = \mathbf{0.842\ kW}$

C.V. Superheater (same approximations as for boiler)

Energy Eq. $q_{sup\ heater} = h_3 - h_2 = 289.05 - 86.85 = 202.2$ kJ/kg

$\dot{Q}_{sup\ heater} = \dot{m}_2 q_{sup\ heater} = 0.005 \times 202.2 = \mathbf{1.01\ kW}$

Problem 6.72

C.V. Turbine Steady state, 1 inlet and 2 exit flows.

Continuity Eq.: $\dot{m}_1 = \dot{m}_2 + \dot{m}_3 \Rightarrow \dot{m}_3 = \dot{m}_1 - \dot{m}_2 = 80$ kg/s

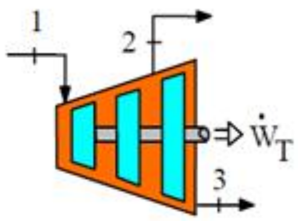
Energy Eq : $\dot{m}_1 h_1 = \dot{W}_T + \dot{m}_2 h_2 + \dot{m}_3 h_3$

Table B.1.3 $h_1 = 3582.3$ kJ/kg,

$h_2 = 3137$ kJ/kg

Table B.1.2 : $h_3 = h_f + x_3 h_{fg} = 384.3 + 0.95 \times 2278.6$

$= 2549.1$ kJ/kg



From the energy equation,

$\Rightarrow \dot{W}_T = \dot{m}_1 h_1 - \dot{m}_2 h_2 - \dot{m}_3 h_3 = \mathbf{91.565\ MW}$

Problem 6.76

C.V. Heat exchanger

Energy Eq. $\dot{m}_{cool}h_{20} + \dot{m}_{H_2O}h_{300} = \dot{m}_{cool}h_{30} + \dot{m}_{H_2O}h_{f,\ 10\ kPa}$

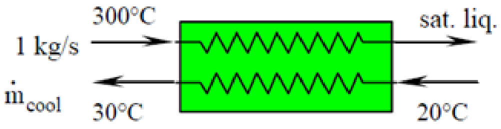


Table B.1.1: $h_{20} = 83.96$ kJ/kg , $h_{30} = 125.79$ kJ/kg

Table B.1.3: $h_{300,\ 10kPa} = 3076.5$ kJ/kg, B.1.2: $h_{f,\ 10\ kPa} = 191.83$ kJ/kg

$$\dot{m}_{cool} = \dot{m}_{H_2O} \frac{h_{300} - h_{f,\ 10kPa}}{h_{30} - h_{20}} = 1 \times \frac{3076.5 - 191.83}{125.79 - 83.96} = \mathbf{69\ kg/s}$$

Problem 6.94

Turbine $A_5 = (\pi/4)(0.2)^2 = 0.031\ 42\ m^2$, $v_5 = 0.06163\ m^3/kg$

$\mathbf{V}_5 = \dot{m}v_5/A_5 = 25\ kg/s \times 0.061\ 63\ m^3/kg\ /\ 0.031\ 42\ m^2 = \mathbf{49\ m/s}$

$h_6 = 191.83 + 0.92 \times 2392.8 = 2393.2$ kJ/kg

$$w_T = h_5 - h_6 + \frac{1}{2}(\mathbf{V}_5^2 - \mathbf{V}_6^2)$$

$$= 3404 - 2393.2 + (49^2 - 200^2)/(2 \times 1000) = 992 \text{ kJ/kg}$$

$\dot{W}_T = \dot{m}w_T = 25 \times 992 = \mathbf{24\ 800\ kW}$

Remark: Notice the kinetic energy change is small relative to enthalpy change.

Condenser $A_7 = (\pi/4)(0.075)^2 = 0.004\ 418\ m^2$, $v_7 = 0.001\ 008\ m^3/kg$

$\mathbf{V}_7 = \dot{m}v_7/A_7 = 25 \times 0.001\ 008\ /\ 0.004\ 418 = 5.7$ m/s

$h_6 = 191.83 + 0.92 \times 2392.8 = 2393.2$ kJ/kg

$$q_{COND} = h_7 - h_6 + \frac{1}{2}(\mathbf{V}_7^2 - \mathbf{V}_6^2)$$

$$= 168 - 2393.2 + (5.7^2 - 200^2)/(2\times1000) = -2245.2 \text{ kJ/kg}$$

$\dot{Q}_{COND} = 25 \times (-2245.2) = \mathbf{-56\ 130\ kW}$

This rate of heat transfer is carried away by the cooling water so

$$-\dot{Q}_{COND} = \dot{m}_{H_2O}(h_{out} - h_{in})_{H_2O} = 56\ 130 \text{ kW}$$

$$\Rightarrow \quad \dot{m}_{H_2O} = \frac{56\ 130}{104.9 - 63.0} = \mathbf{1339.6\ kg/s}$$

Economizer $A_7 = \pi D_7^2/4 = 0.004\ 418\ m^2$, $v_7 = 0.001\ 008\ m^3/kg$

$$\mathbf{V}_2 = \mathbf{V}_7 = \dot{m}v_7/A_7 = 25 \times 0.001\ 008/0.004\ 418 = 5.7\ m/s,$$

$$\mathbf{V}_3 = (v_3/v_2)\mathbf{V}_2 = (0.001\ 118\ /\ 0.001\ 008)\ 5.7 = 6.3\ m/s \approx \mathbf{V}_2$$

so kinetic energy change unimportant

$$q_{ECON} = h_3 - h_2 = 744 - 194 = 550.0\ kJ/kg$$

$$\dot{Q}_{ECON} = \dot{m}q_{ECON} = 25\ (550.0) = \mathbf{13\ 750\ kW}$$

Generator $A_4 = \pi D_4^2/4 = 0.031\ 42\ m^2$, $v_4 = 0.060\ 23\ m^3/kg$

$$\mathbf{V}_4 = \dot{m}v_4/A_4 = 25 \times 0.060\ 23/0.031\ 42 = 47.9\ m/s$$

$$q_{GEN} = 3426 - 744 + (47.9^2 - 6.3^2)/(2 \times 1000) = 2683\ kJ/kg$$

$$\dot{Q}_{GEN} = \dot{m}q_{GEN} = 25 \times (2683) = \mathbf{67\ 075\ kW}$$

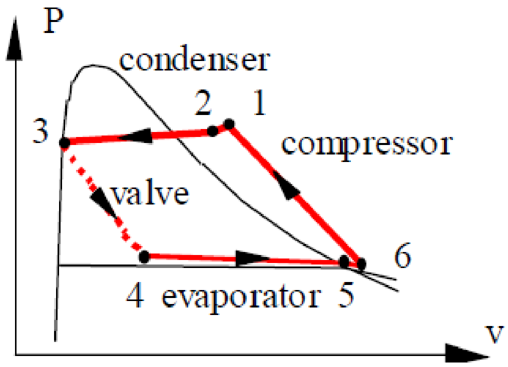
Problem 6.99

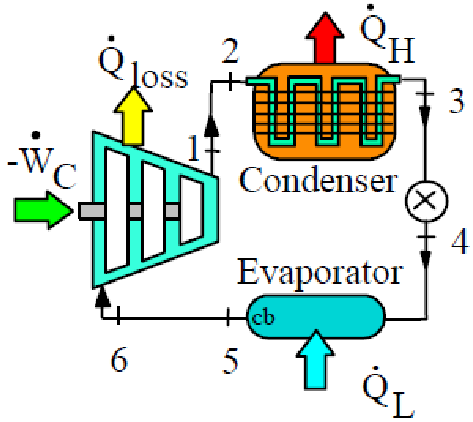
CV: Compressor $\dot{Q}_{COMP} = \dot{m}(h_1 - h_6) + \dot{W}_{COMP} = 0.05\ (377 - 284) - 5.0 = \mathbf{-0.35\ kW}$

CV: Condenser $\dot{Q}_{COND} = \dot{m}(h_3 - h_2) = 0.05\ kg/s\ (134 - 367)\ kJ/kg = \mathbf{-11.65\ kW}$

C.V. Valve: $h_4 = h_3 = 134\ kJ/kg$

CV: Evaporator $\dot{Q}_{EVAP} = \dot{m}\ (h_5 - h_4) = 0.05\ kg/s\ (280 - 134)\ kJ/kg = \mathbf{7.3\ kW}$





Problem 6.100

The compressor, turbine and nozzle are all steady state single flow devices and they are adiabatic.

We will use air properties from table A.7.1:

$h_1 = 260.32$, $h_2 = 800.28$, $h_3 = 1635.80$, $h_4 = 933.15$, $h_5 = 649.53$ kJ/kg

Energy equation for the compressor gives

$$w_{c\ in} = h_2 - h_1 = 800.28 - 260.32 = \mathbf{539.36\ kJ/kg}$$

Energy equation for the turbine gives

$$w_T = h_3 - h_4 = 1635.80 - 933.15 = \mathbf{702.65\ kJ/kg}$$

Energy equation for the nozzle gives

$$h_4 = h_5 + ½\, \mathbf{V}_5^2$$

$$½\, \mathbf{V}_5^2 = h_4 - h_5 = 933.15 - 649.53 = 283.62 \text{ kJ/kg}$$

$$\mathbf{V}_5 = [2(h_4 - h_5)]^{1/2} = (2\times 283.62 \times 1000)^{1/2} = \mathbf{753\ m/s}$$

Problem 6.101

Separation of phases in flash-evaporator constant h in the valve flow so

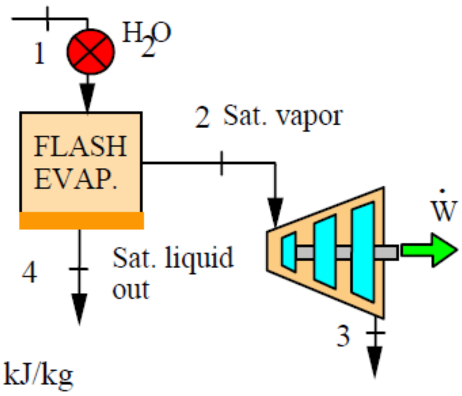


Table B.1.3: $h_1 = 763.5$ kJ/kg

$h_1 = 763.5 = 604.74 + x \times 2133.8$

$\Rightarrow \quad x = 0.07439 = \dot{m}_2/\dot{m}_1$

Table B.1.2: $h_2 = 2738.6$ kJ/kg;

$h_3 = 191.83 + 0.9 \times 2392.8 = 2345.4$ kJ/kg

Energy Eq.6.12 for the turbine

$$\dot{W} = \dot{m}_2(h_2 - h_3) \quad => \quad \dot{m}_2 = \frac{1000}{2738.6 - 2345.4} = 2.543 \text{ kg/s}$$

$$\Rightarrow \quad \dot{m}_1 = \dot{m}_2/x = 34.19 \text{ kg/s} = \mathbf{123\ 075\ kg/h}$$