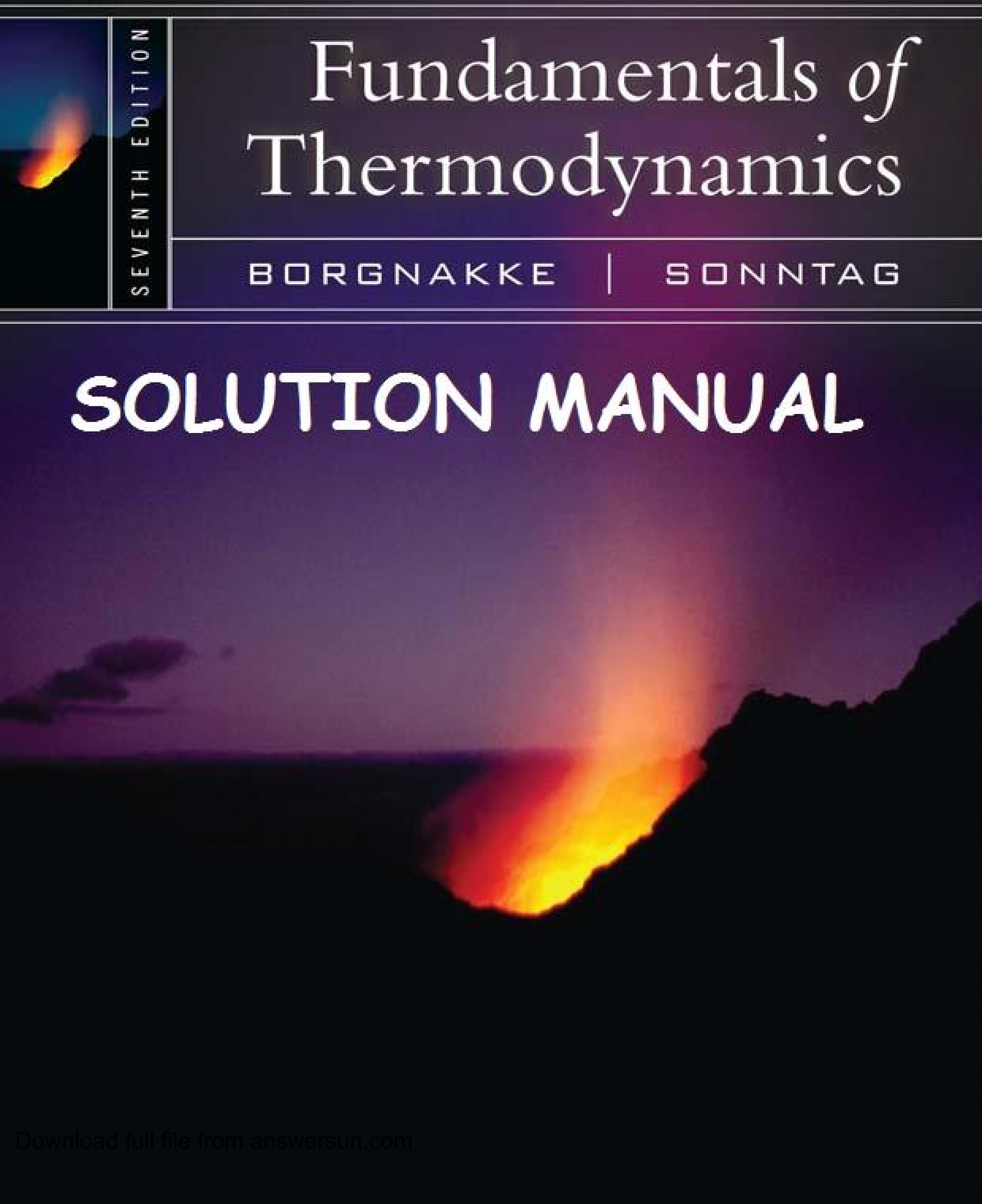
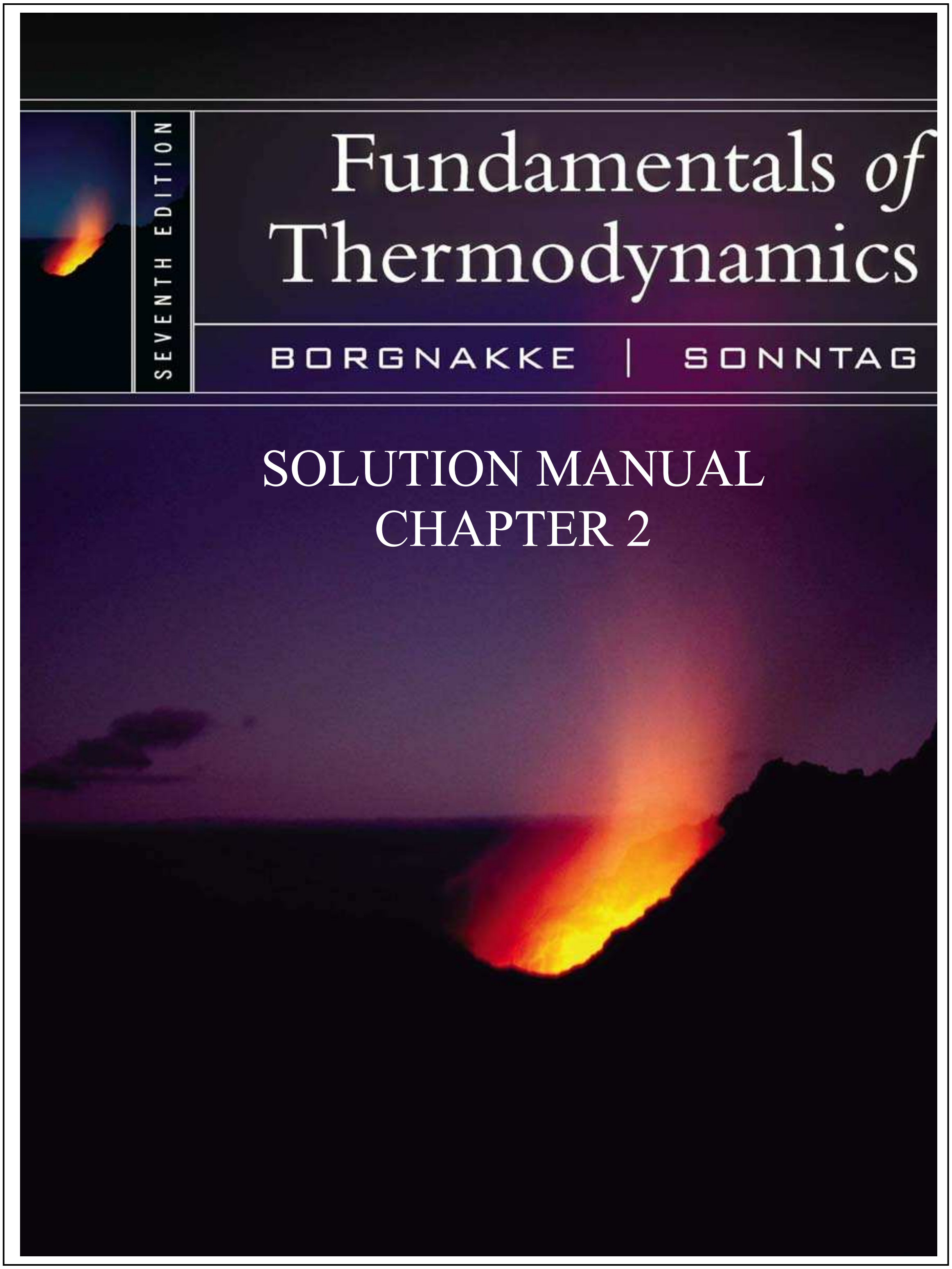

SEVENTH EDITION
Fundamentals of Thermodynamics
BORGNAKKE | SONNTAG
SOLUTION MANUAL


Fundamentals of Thermodynamics
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SOLUTION MANUAL
CHAPTER 2

CONTENT

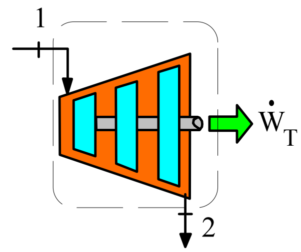
In-Text Concept Questions

2.a

Make a control volume around the turbine in the steam power plant in Fig. 1.1 and list the flows of mass and energy that are there.

Solution:

We see hot high pressure steam flowing in at state 1 from the steam drum through a flow control (not shown). The steam leaves at a lower pressure to the condenser (heat exchanger) at state 2. A rotating shaft gives a rate of energy (power) to the electric generator set.

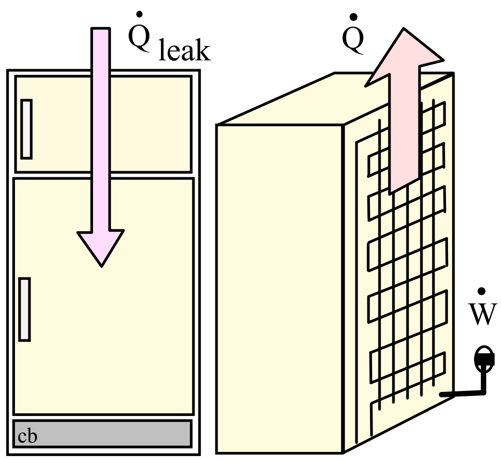


2.b

Take a control volume around your kitchen refrigerator and indicate where the components shown in Figure 1.6 are located and show all flows of energy transfer.

Solution:

The valve and the cold line, the evaporator, is inside close to the inside wall and usually a small blower distributes cold air from the freezer box to the refrigerator room.



The black grille in the back or at the bottom is the condenser that gives heat to the room air.

The compressor sits at the bottom.

2.38

One kilogram of diatomic oxygen (O_2 molecular weight 32) is contained in a 500-L tank. Find the specific volume on both a mass and mole basis (v and $\bar{v}$).

Solution:

From the definition of the specific volume

$$v = \frac{V}{m} = \frac{0.5}{1} = \mathbf{0.5\ m^3/kg}$$

$$\bar{v} = \frac{V}{n} = \frac{V}{m/M} = M\,v = 32 \times 0.5 = \mathbf{16\ m^3/kmol}$$

2.85

A dam retains a lake 6 m deep. To construct a gate in the dam we need to know the net horizontal force on a 5 m wide and 6 m tall port section that then replaces a 5 m section of the dam. Find the net horizontal force from the water on one side and air on the other side of the port.

Solution:

$P_{bot} = P_0 + \Delta P$

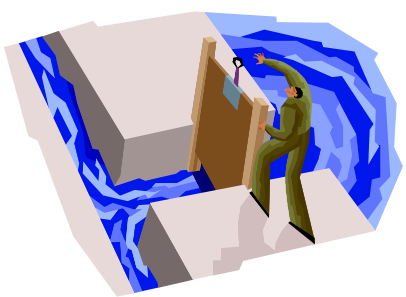
$\Delta P = \rho g h = 997 \times 9.807 \times 6 = 58\ 665 \text{ Pa} = 58.66 \text{ kPa}$

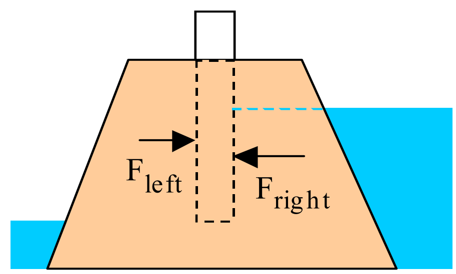
Neglect ΔP in air

$F_{net} = F_{right} - F_{left} = P_{avg}\ A - P_0 A$

$P_{avg} = P_0 + 0.5\ \Delta P$ Since a linear pressure variation with depth.

$F_{net} = (P_0 + 0.5\ \Delta P)A - P_0 A = 0.5\ \Delta P\ A = 0.5 \times 58.66 \times 5 \times 6 =$ **880 kN**





3.83

A cylindrical gas tank 1 m long, inside diameter of 20 cm, is evacuated and then filled with carbon dioxide gas at 20°C. To what pressure should it be charged if there should be 1.2 kg of carbon dioxide?

Solution:

Assume CO_2 is an ideal gas, table A.5: $R = 0.1889$ kJ/kg K

$$V_{cyl} = A \times L = \frac{\pi}{4}(0.2)^2 \times 1 = 0.031416 \text{ m}^3$$

$$P V = mRT \quad => \quad P = \frac{mRT}{V}$$

$$\Rightarrow P = \frac{1.2 \text{ kg} \times 0.1889 \text{ kJ/kg K} \times (273.15 + 20) \text{ K}}{0.031416 \text{ m}^3} = \mathbf{2115 \text{ kPa}}$$

4.34

A cylinder fitted with a frictionless piston contains 5 kg of superheated refrigerant R-134a vapor at 1000 kPa, 140°C. The setup is cooled at constant pressure until the R-134a reaches a quality of 25%. Calculate the work done in the process.

Solution:

Constant pressure process boundary work. State properties from Table B.5.2

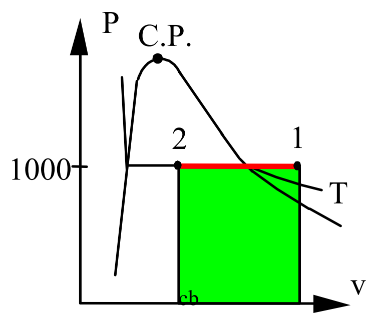
State 1: $v = 0.03150 \text{ m}^3/\text{kg}$,

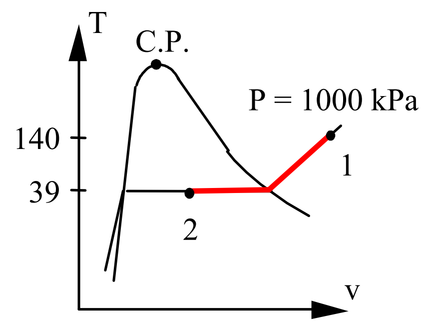
State 2: $v = 0.000871 + 0.25 \times 0.01956 = 0.00576 \text{ m}^3/\text{kg}$

Interpolated to be at 1000 kPa, numbers at 1017 kPa could have been used in which case: $v = 0.00566 \text{ m}^3/\text{kg}$

$${}_1W_2 = \int P\, dV = P\,(V_2\text{-}V_1) = mP\,(v_2\text{-}v_1)$$

$$= 5 \times 1000\,(0.00576 - 0.03150) = \mathbf{-128.7\ kJ}$$

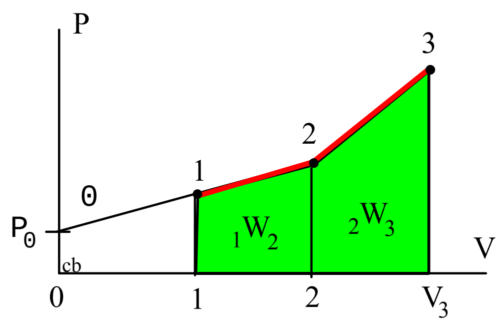




4.129

Two springs with same spring constant are installed in a massless piston/cylinder with the outside air at 100 kPa. If the piston is at the bottom, both springs are relaxed and the second spring comes in contact with the piston at $V = 2$ m^3. The cylinder (Fig. P4.129) contains ammonia initially at -2°C, $x = 0.13$, $V = 1$ m^3, which is then heated until the pressure finally reaches 1200 kPa. At what pressure will the piston touch the second spring? Find the final temperature and the total work done by the ammonia.

Solution :



State 1: P = 399.7 kPa Table B.2.1

$v = 0.00156 + 0.13 \times 0.3106 = 0.0419$

At bottom state 0: 0 m^3, 100 kPa

State 2: V = 2 m^3 and on line 0-1-2

Final state 3: 1200 kPa, on line segment 2.

Slope of line 0-1-2: $\Delta P/\Delta V = (P_1 - P_0)/\Delta V = (399.7-100)/1 = 299.7$ kPa/ m^3

$$P_2 = P_1 + (V_2 - V_1)\Delta P/\Delta V = 399.7 + (2-1)\times 299.7 = \mathbf{699.4\ kPa}$$

State 3: Last line segment has twice the slope.

$$P_3 = P_2 + (V_3 - V_2)2\Delta P/\Delta V \quad \Rightarrow \quad V_3 = V_2 + (P_3 - P_2)/(2\Delta P/\Delta V)$$

$$V_3 = 2 + (1200-699.4)/599.4 = 2.835 \text{ m}^3$$

$$v_3 = v_1 V_3/V_1 = 0.0419 \times 2.835/1 = 0.1188 \quad \Rightarrow \quad T = \mathbf{51°C}$$

$$_1W_3 = {}_1W_2 + {}_2W_3 = \frac{1}{2}(P_1 + P_2)(V_2 - V_1) + \frac{1}{2}(P_3 + P_2)(V_3 - V_2)$$

$$= 549.6 + 793.0 = \mathbf{1342.6\ kJ}$$

5.87

A 1 kg steel pot contains 1 kg liquid water both at 15°C. It is now put on the stove where it is heated to the boiling point of the water. Neglect any air being heated and find the total amount of energy needed.

Solution:

Energy Eq.: $U_2 - U_1 = {}_1Q_2 - {}_1W_2$

The steel does not change volume and the change for the liquid is minimal, so ${}_1W_2 \cong 0$.

State 2: $T_2 = T_{sat}$ (1atm) = 100°C

Tbl B.1.1 : $u_1 = 62.98$ kJ/kg, $u_2 = 418.91$ kJ/kg

Tbl A.3 : $C_{st} = 0.46$ kJ/kg K

Solve for the heat transfer from the energy equation

$${}_1Q_2 = U_2 - U_1 = m_{st}\,(u_2 - u_1)_{st} + m_{H2O}\,(u_2 - u_1)_{H2O}$$
$$= m_{st}C_{st}\ (T_2 - T_1) + m_{H2O}\,(u_2 - u_1)_{H2O}$$

$${}_1Q_2 = 1\text{ kg} \times 0.46\,\frac{\text{kJ}}{\text{kg K}} \times (100 - 15)\text{ K} + 1\text{ kg} \times (418.91 - 62.98)\text{ kJ/kg}$$
$$= 39.1 + 355.93 = \mathbf{395\ kJ}$$

6.i

If you compress air the temperature goes up, why? When the hot air, high P flows in long pipes it eventually cools to ambient T. How does that change the flow?

As the air is compressed, volume decreases so work is done on a mass element, its energy and hence temperature goes up. If it flows at nearly constant P and cools its density increases (v decreases) so it slows down for same mass flow rate ($\dot{m} = \rho A\mathbf{V}$) and flow area.

8.3

CV A is the mass inside a piston/cylinder, CV B is that plus part of the wall out to a source of ${}_1Q_2$ at T_s. Write the entropy equation for the two control volumes assuming no change of state of the piston mass or walls.

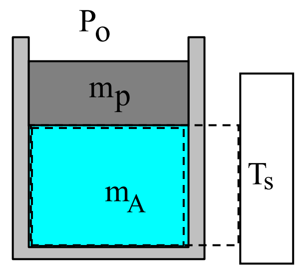


Fig. P8.3

The general entropy equation for a control mass is Eq.8.37

$$S_2 - S_1 = \int_1^2 \frac{dQ}{T} + {}_1S_{2\,\text{gen}}$$

The left hand side is storage so that depends of what is inside the C.V. and the integral is summing the dQ/T that crosses the control volume surface while the process proceeds from 1 to 2.

C.V. A: $\quad m_A (s_2 - s_1) = \int_1^2 \frac{dQ}{T_A} + {}_1S_{2\,\text{gen CV A}}$

C.V. B: $\quad m_A (s_2 - s_1) = \int_1^2 \frac{dQ}{T_s} + {}_1S_{2\,\text{gen CV B}}$

In the first equation the temperature is that of mass m_A which possibly changes from 1 to 2 whereas in the second equation it is the reservoir temperature T_s. The two entropy generation terms are also different the second one includes the first one plus any s generated in the walls that separate the mass m_A from the reservoir and there is a Q over a finite temperature difference. When the storage effect in the walls are neglected the left hand sides of the two equations are equal.

8.98

Argon in a light bulb is at 90 kPa and 20°C when it is turned on and electric input now heats it to 60°C. Find the entropy increase of the argon gas.

Solution:

C.V. Argon gas. Neglect any heat transfer.

Energy Eq.5.11: $m(u_2 - u_1) = {}_1W_{2\text{ electrical in}}$

Entropy Eq.8.37: $s_2 - s_1 = \int dq/T + {}_1s_{2\text{ gen}} = {}_1s_{2\text{ gen}}$

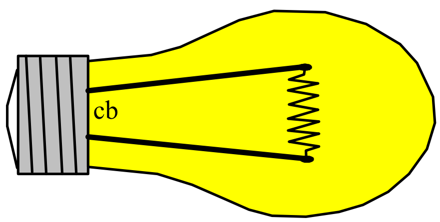
Process: v = constant and ideal gas => $P_2/ P_1 = T_2/T_1$

Evaluate changes in s from Eq.8.16 or 8.17

$$s_2 - s_1 = C_p \ln (T_2/T_1) - R \ln (P_2/ P_1) \qquad \text{Eq.8.16}$$

$$= C_p \ln (T_2/T_1) - R \ln (T_2/ T_1) = C_v \ln(T_2/T_1) \qquad \text{Eq.8.17}$$

$$= 0.312 \text{ kJ/kg-K} \times \ln \left[\frac{60 + 273}{20 + 273} \right] = \mathbf{0.04\ kJ/kg\ K}$$



Since there was no heat transfer but work input all the change in s is generated by the process (irreversible conversion of W to internal energy)

9.89

A condenser in a power plant receives 5 kg/s steam at 15 kPa, quality 90% and rejects the heat to cooling water with an average temperature of 17°C. Find the power given to the cooling water in this constant pressure process and the total rate of enropy generation when condenser exit is saturated liquid.

Solution:

C.V. Condenser. Steady state with no shaft work term.

Energy Eq.6.12: $\dot{m}\, h_i + \dot{Q} = \dot{m} h_e$

Entropy Eq.9.8: $\dot{m}\, s_i + \dot{Q}/T + \dot{S}_{gen} = \dot{m}\, s_e$

Properties are from Table B.1.2

$h_i = 225.91 + 0.9 \times 2373.14 = 2361.74$ kJ/kg , $h_e = 225.91$ kJ/kg

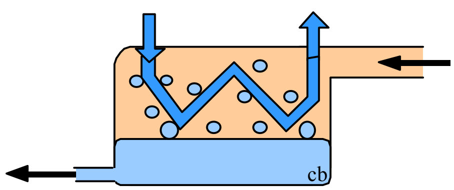
$s_i = 0.7548 + 0.9 \times 7.2536 = 7.283$ kJ/kg K, $s_e = 0.7548$ kJ/kg K

$\dot{Q}_{out} = -\dot{Q} = \dot{m}\,(h_i - h_e) = 5(2361.74 - 225.91) = \mathbf{10679\ kW}$

$\dot{S}_{gen} = \dot{m}\,(s_e - s_i) + \dot{Q}_{out}/T$

$= 5(0.7548 - 7.283) + 10679/(273 + 17)$

$= -32.641 + 36.824 = \mathbf{4.183\ kW/K}$



Often the cooling media flows inside a long pipe carrying the energy away.

Closed Feedwater Heaters

14.64

Solve the previous Problem with Table B.3 values and find the compressibility of the carbon dioxide at that state.

B.3: $v = 0.05236\ m^3/kg$, $u = 327.27\ kJ/kg$, A5: $R = 0.1889\ kJ/kg\text{-}K$

$$Z = \frac{Pv}{RT} = \frac{1000 \times 0.05236}{0.1889 \times 293.15} = 0.9455 \qquad \text{close to ideal gas}$$

To get u^* let us look at the lowest pressure 400 kPa, 20^oC: $v = 0.13551\ m^3/kg$ and $u = 331.57\ kJ/kg$.

$$Z = Pv/RT = 400 \times 0.13551/(0.1889 \times 293.15) = 0.97883$$

It is not very close to ideal gas but this is the lowest P in the printed table.

$$u - u^* = 327.27 - 331.57 = \mathbf{-4.3\ kJ/kg}$$

16.26

Find K for: $CO_2 \Leftrightarrow CO + 1/2O_2$ at 3000 K using A.11

The elementary reaction in A.11 is : $2CO_2 \Leftrightarrow 2CO + O_2$
so the wanted reaction is (1/2) times that so

$$K = K_{A.11}^{1/2} = \sqrt{\exp(-2.217)} = \sqrt{0.108935} = 0.33$$

or

$$\ln K = 0.5 \ln K_{A.11} = 0.5\ (-2.217) = -1.1085$$
$$K = \exp(-1.1085) = 0.33$$