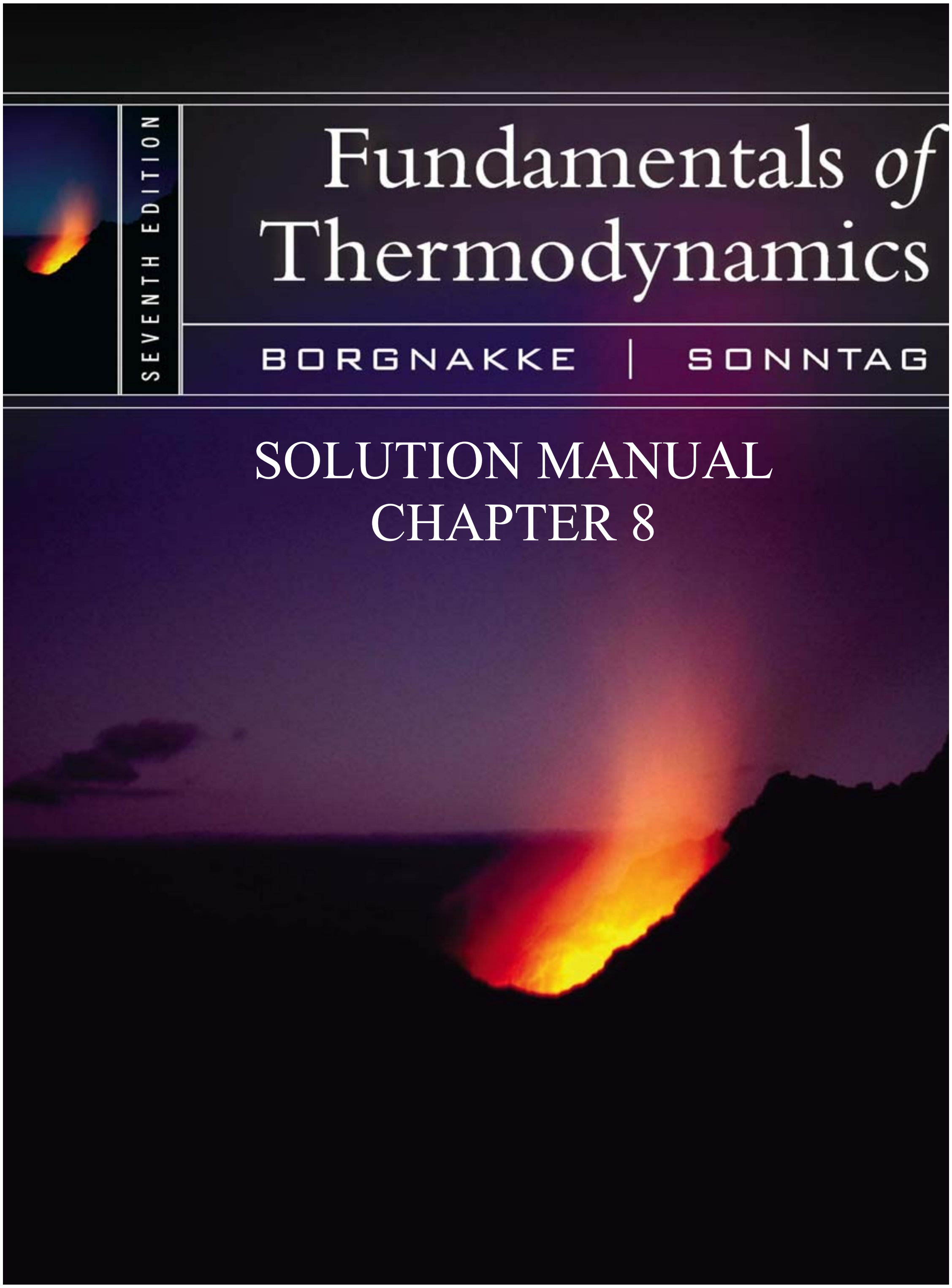

SEVENTH EDITION

Fundamentals of Thermodynamics

BORGNAKKE | SONNTAG

SOLUTION MANUAL
CHAPTER 8

CONTENT

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In-Text Concept Questions

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8.a

Does Clausius say anything about the sign for $\oint dQ$?

No.

The total (net) heat transfer can be coming in like in a heat engine ($W_{out} = Q_H - Q_L$) in which case it is positive. It can also be net going out like in a refrigerator or heat pump ($W_{in} = Q_H - Q_L$) in which case the sign is negative. Finally if you look at a transmission gearbox there could be no heat transfer (first approximation) in which case the integral is zero.

8.b

Does the statement of Clausius require a constant T for the heat transfer as in a Carnot cycle?

No.

The statement for a cycle involves an integral of dQ/T so T can vary, which it does during most processes in actual devices. This just means that you cannot that easily get a closed expression for the integral.

8.c

How can you change s of a substance going through a reversible process?

From the definition of entropy

$$ds = \frac{dq}{T}$$

for a reversible process. Thus only heat transfer gives a change in s, expansion/compression involving work does not give such a contribution.

8.d

A reversible process adds heat to a substance. If T is varying does that influence the change in s?

Yes.

$$\text{Reversible:} \qquad ds = \frac{dq}{T}$$

So if T goes up it means that s changes less per unit of dq, and the opposite if T decreases then s changes more per unit of dq.

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8.e

Water at 100 kPa, 150^{o}C receives 75 kJ/kg in a reversible process by heat transfer. Which process changes s the most: constant T, constant v or constant P?

$$ds = \frac{dq}{T}$$

Look at the constant property lines in a T-s diagram, Fig. 8.5. The constant v line has a higher slope than the constant P line also at positive slope. Thus both the constant P and v processes have an increase in T. As T goes up the change in s is smaller.

The constant T (isothermal) process therefore changes s the most.

8.f

A liquid is compressed in a reversible adiabatic process. What is the change in T?

If the process is reversible then s is constant, $ds = \frac{dq}{T} = 0$

Change in s for a liquid (an incompressible substance) is

Eq. 8.10: $ds = \frac{C}{T} dT$

From this it follows that if ds = 0 then **T is constant**.

8.g

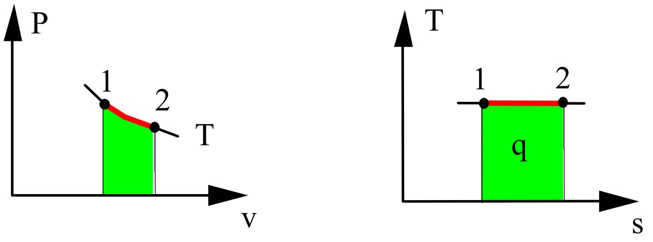
An ideal gas goes through a constant T reversible heat addition process. How do the properties (v, u, h, s, P) change (up, down or constant)?

Ideal gas: u(T), h(T) so they are both constant

Eq. 8.11 gives: $ds = dq/T + ds_{gen} = dq/T + 0 > 0$ so s goes up by q/T

Eq. 8.21 gives: $ds = (R/v)\, dv$ so v increases

Eq. 8.23 gives: $ds = -(R/P)\, dP$ so P decreases



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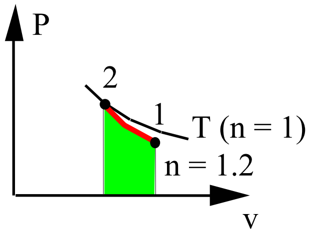
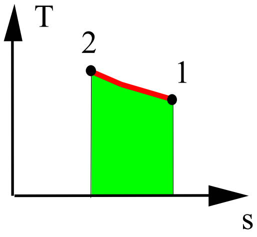
8.h

Carbon dioxide is compressed to a smaller volume in a polytropic process with $n = 1.2$. How do the properties (u, h, s, P, T) change (up, down or constant)?

For carbon dioxide Table A.5 $k = 1.289$ so we have $n < k$ and the process curve can be recognized in Figure 8.18. From this we see a smaller volume means moving to the left in the P-v diagram and thus also up.

From P-v diagram: P up, T up
From T-s diagram Since T is up then s down.
As T is up so is h and u.





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8.i

A substance has heat transfer out. Can you say anything about changes in s if the process is reversible? If it is irreversible?

Reversible: $ds = \frac{dq}{T} < 0$ since $dq < 0$

Irreversible: $ds = \frac{dq}{T} + ds_{gen} = ?$ $dq < 0$ but $ds_{gen} > 0$

You cannot say, ds depends on the magnitude of dq/T versus ds_{gen}

8.j

A substance is compressed adiabatically so P and T go up. Does that change s?

If the process is reversible then s is constant, $ds = \frac{dq}{T} = 0$

If the process is irreversible then s goes up, $ds = \frac{dq}{T} + ds_{gen} = ds_{gen} > 0$

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Concept Problems

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8.1

When a substance has completed a cycle, v, u, h, and s are unchanged. Did anything happen? Explain.

Yes.

During various parts of the cycle work and heat transfer may be transferred. That happens at different P and T. The net work out equals the net heat transfer in (energy conservation) so dependent upon the sign it is a heat engine or a heat pump (refrigerator). The net effect is thus a conversion of energy from one storage location to another and it may also change nature (some Q was changed to W or the opposite)

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8.2

Assume a heat engine with a given Q_H. Can you say anything about Q_L if the engine is reversible? If it is irreversible?

For a reversible heat engine it must be that:

$$\oint \frac{dQ}{T} = 0 = \frac{Q_H}{T_H} - \frac{Q_L}{T_L} \qquad \text{or integrals if T not constant}$$

So as T_L is lower than T_H then Q_L must be correspondingly lower than Q_H to obtain the net zero integral.

For an irreversible heat engine we have

$$\oint \frac{dQ}{T} = \frac{Q_H}{T_H} - \frac{Q_L}{T_L} < 0$$

This means that Q_L is larger than before (given Q_H and the T's). The irreversible heat engine rejects more energy and thus gives less out as work.

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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.

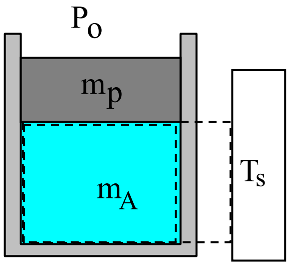

Fig. P8.3

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.

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

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

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.

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8.4

Consider the previous set-up with the mass m_A and the piston cylinder of mass m_p starting out at two different temperatures. After a while the temperature becomes uniform without any external heat transfer. Write the entropy equation storage term $(S_2 - S_1)$ for the total mass.

In this case the storage effect must be summed up over all the mass inside the control volume.

$$S_2 - S_1 = m_A\,(s_2 - s_1)_A + m_P\,(s_2 - s_1)_P$$

$$\approx m_A\,(s_2 - s_1)_A + m_P\,C_P \ln\left(\frac{T_2}{T_{1\,P}}\right)$$

The last equation assumed a constant specific heat for the solid material of the piston, a common assumption. There is only a single temperature T_2, but there are two different temperatures for state 1 $T_{1\,A}$ and $T_{1\,P}$. The temperature T_2 would be found from the energy equation.

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8.5

Water at 100^{o}C, quality 50% in a rigid box is heated to 110^{o}C. How do the properties (P, v, x, u and s) change? (increase, stay about the same, or decrease)

A fixed mass in a rigid box give a constant v process. So

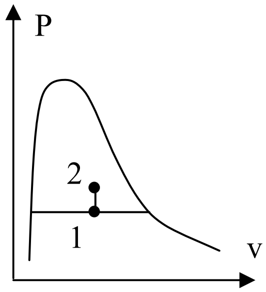
P goes up (in the two-phase region P = P_{sat} at given T)

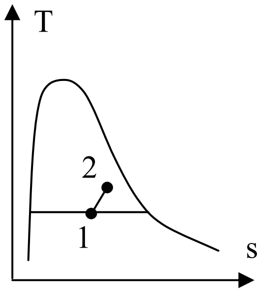
v stays constant.

x goes up (we get closer to the saturated vapor state see P-v diagram)

u goes up (Q in and no work)

s goes up (Q in)





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8.6

Liquid water at 20$^{\mathrm{o}}$C, 100 kPa is compressed in a piston/cylinder without any heat transfer to a pressure of 200 kPa. How do the properties (T, v, u, and s) change? (increase, stay about the same, or decrease)

Adiabatic dq = 0: dq = T ds = 0;
Incompressible dv = 0: dw = P dv = 0

(T, v, u, and s) they are all constant.
Only the pressure and enthalpy goes up.

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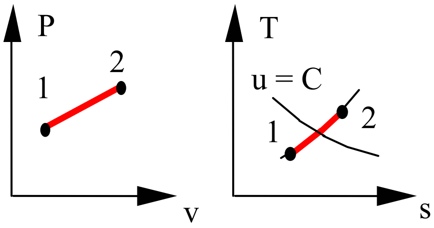
8.7

A reversible process in a piston/cylinder is shown in Fig. P8.7. Indicate the storage change $u_2 - u_1$ and transfers ${}_1w_2$ and ${}_1q_2$ as positive, zero, or negative



$${}_1w_2 = \int P\,dv > 0\,; \qquad {}_1q_2 = \int T\,ds > 0$$

$u_2 - u_1 > 0$ from general shape of the constant u curves. Further out in the ideal gas region the constant u curve become horizontal (u = fct(T) only).

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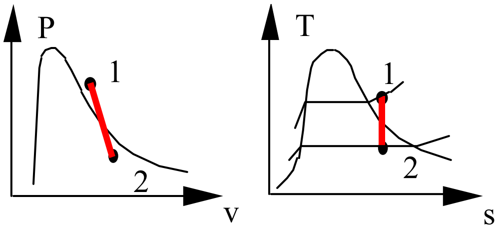
8.8

A reversible process in a piston/cylinder is shown in Fig. P8.8. Indicate the storage change $u_2 - u_1$ and transfers ${}_1w_2$ and ${}_1q_2$ as positive, zero, or negative



$${}_1w_2 = \int P\, dv > 0 \; ; \qquad {}_1q_2 = \int T\, ds = 0$$

$$u_2 - u_1 = {}_1q_2 - {}_1w_2 < 0$$

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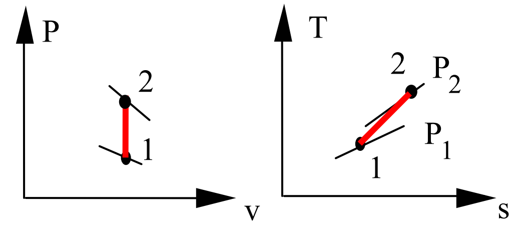
8.9

Air at 290 K, 100 kPa in a rigid box is heated to 325 K. How do the properties (P, v, u and s) change? (increase, stay about the same, or decrease)

Rigid box: v = constant, (P, u, and s) all increases.



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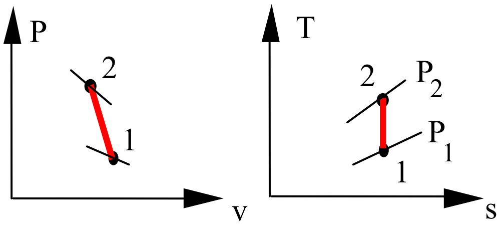
8.10

Air at 20^{o}C, 100 kPa is compressed in a piston/cylinder without any heat transfer to a pressure of 200 kPa. How do the properties (T, v, u and s) change? (increase, about the same or decrease)

T goes up,
v goes down
u goes up (work in, q = 0)
s = constant



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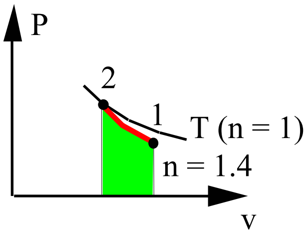
8.11

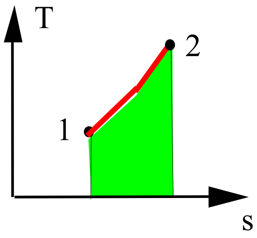
Carbon dioxide is compressed to a smaller volume in a polytropic process with n = 1.4. How do the properties (u, h, s, P, T) change (up, down or constant)?

For carbon dioxide Table A.5 k = 1.289 so we have n > k and the process curve can be recognized in Figure 8.18. From this we see a smaller volume means moving to the left in the P-v diagram and thus also up.

P up, T up. As T is up so is h and u.

From the T-s diagram as n > k then we move to larger T means s is up.





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8.12

Process A: Air at 300 K, 100 kPa is heated to 310 K at constant pressure.
Process B: Heat air at 1300 K to 1310 K at constant 100 kPa.
Use the table below to compare the property changes.

	Property	$\Delta_A > \Delta_B$	$\Delta_A \approx \Delta_B$	$\Delta_A < \Delta_B$
a	$\Delta = v_2 - v_1$		√	
b	$\Delta = h_2 - h_1$			√
c	$\Delta = s_2 - s_1$	√		

a. Ideal gas $Pv = RT$ so v goes with absolute T
$\Delta v = (R/P)\ \Delta T$ thus the same

b. Since $dh = C_P\ dT$ and C_P increases with T

c. At constant P: $ds = (C_P/T)\ dT$
C_P is only 15% higher at 1300 K compared to 300 K (see Fig. 5.11)

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8.13

Why do we write ΔS or $S_2 - S_1$ whereas we write $\int dQ/T$ and ${}_1S_{2\ gen}$?

This is similar to the terms in the continuity equation $m_2 - m_1$ versus m_i, m_e and the energy equation $E_2 - E_1$ versus ${}_1Q_2$, ${}_1W_2$. The first part is the **change in the storage** $S_2 - S_1$ of entropy in the mass and the second part is the transfer or generation during the process from 1 to 2. The storage terms correspond to the left hand side of the balance equation for entropy. The integral $\int dQ/T$ represents a **transfer** of entropy **across the control volume surface** during the process from 1 to 2 and the ${}_1S_{2\ gen}$ expresses the total amount of entropy being generated **inside** the control volume and both are on the right hand side of the balance equation.

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8.14

A reversible heat pump has a flux of s entering as $\dot{Q}_L/T_L$. What can you say about the exit flux of s at T_H?

For the entropy equation 8.3 and 8.42, the rate of storage is zero and the generation term is zero. Thus the entropy equation becomes

$$0 = \frac{\dot{Q}_L}{T_L} - \frac{\dot{Q}_H}{T_H} + 0$$

So: $$\frac{\dot{Q}_L}{T_L} = \frac{\dot{Q}_H}{T_H} = \text{flux of s}$$

We have the same flux of s in as out matching the result in chapter 7.

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8.15

An electric baseboard heater receives 1500 W of electrical power that heats the room air which loses the same amount out through the walls and windows. Specify exactly where entropy is generated in that process.

a Electrical heating wire (electrical work turned into internal energy, leaving as heat transfer).
b Heat transfer from hot wire to cooler room air, i.e. in the wire coverings
c Room air to walls
d Inside walls and windows, heat transfer over a finite ΔT
e from outside wall surface to ambient T

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8.16

A 500 W electric space heater with a small fan inside heats air by blowing it over a hot electrical wire. For each control volume: a) wire at T_{wire} only b) all the room air at T_{room} and c) total room plus the heater, specify the storage, entropy transfer terms and entropy generation as rates (neglect any $\dot{Q}$ through the room walls or windows).

	Storage	$\dot{Q}/T$	$\dot{S}_{gen}$
C.V. Wire only	0	$\frac{-500\text{ W}}{T_{wire}}$	$\frac{500\text{ W}}{T_{wire}}$
C.V. Room air	$\frac{500\text{ W}}{T_{room}}$	$\frac{500\text{ W}}{T_{wire}}$	$500\text{ W}\left(\frac{1}{T_{room}} - \frac{1}{T_{wire}}\right)$
C.V. Total room	$\frac{500\text{ W}}{T_{room}}$	0	$\frac{500\text{ W}}{T_{room}}$

Remark: Room only receives the electrical power input of 500 W.

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Inequality of Clausius

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8.17

Consider the steam power plant in Example 6.9 and assume an average T in the line between 1 and 2. Show that this cycle satisfies the inequality of Clausius.

Solution:

Show Clausius: $\int \frac{dQ}{T} \leq 0$

For this problem we have three heat transfer terms:

$q_b = 2831$ kJ/kg, $q_{loss} = 21$ kJ/kg, $q_c = 2173.3$ kJ/kg

$$\int \frac{dq}{T} = \frac{q_b}{T_b} - \frac{q_{loss}}{T_{avg\ 1\text{-}2}} - \frac{q_c}{T_c}$$

$$= \frac{2831}{573} - \frac{21}{568} - \frac{2173.3}{318}$$

$$= -1.93 \text{ kJ/kg K} < 0 \quad \textbf{OK}$$

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8.18

A heat engine receives 6 kW from a 250°C source and rejects heat at 30°C. Examine each of three cases with respect to the inequality of Clausius.

a. $\dot{W} = 6$ kW b. $\dot{W} = 0$ kW c. Carnot cycle

Solution:

$T_H = 250 + 273 = 523$ K ; $T_L = 30 + 273 = 303$ K

Case a) $$\int \frac{d\dot{Q}}{T} = \frac{6000}{523} - \frac{0}{303} = 11.47 \text{ kW/K} > 0 \quad \textbf{Impossible}$$

b) $$\int \frac{d\dot{Q}}{T} = \frac{6000}{523} - \frac{6000}{303} = -8.33 \text{ kW/K} < 0 \quad \textbf{OK}$$

c) $$\int \frac{d\dot{Q}}{T} = 0 = \frac{6000}{523} - \frac{\dot{Q}_L}{303} \quad \Rightarrow$$

$$\dot{Q}_L = \frac{303}{523} \times 6 \text{ kW} = 3.476 \text{ kW}$$

$$\dot{W} = \dot{Q}_H - \dot{Q}_L = 2.529 \text{ kW}$$

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8.19

Use the inequality of Clausius to show that heat transfer from a warm space towards a colder space without work is a possible process i.e. a heat engine with no work output.

$$\text{Clausius:} \quad \int \frac{dQ}{T} \le 0 \qquad \text{or} \qquad \int \frac{d\dot{Q}}{T} \le 0$$

Take C.V. as the space separating the warm and cold space. It is the same Q that crosses each surface (from energy equation) so

$$\int \frac{dQ}{T} = \frac{Q}{T_{warm}} - \frac{Q}{T_{cold}} = Q\,\left(\frac{1}{T_{warm}} - \frac{1}{T_{cold}}\right) < 0 \qquad \text{OK}$$

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8.20

Use the inequality of Clausius to show that heat transfer from a cold space towards a warmer space without work is an impossible process i.e. a heat pump with no work input.

Clausius: $\int \frac{dQ}{T} \leq 0$ or $\int \frac{d\dot{Q}}{T} \leq 0$

Take C.V. as the space separating the warm and cold space. It is the same Q that crosses each surface (from energy equation) so

$$\int \frac{dQ}{T} = \frac{Q}{T_{cold}} - \frac{Q}{T_{warm}} = Q \left(\frac{1}{T_{cold}} - \frac{1}{T_{warm}}\right) > 0 \quad \text{Impossible!}$$

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8.21

Assume the heat engine in Problem 7.32 has a high temperature of 1200 K and a low temperature of 400 K. What does the inequality of Clausius say about each of the four cases?

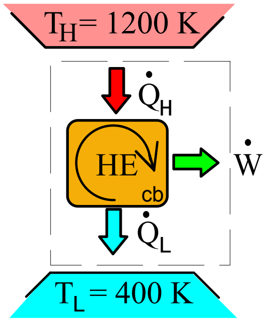
Solution:

Cases a) $\int \frac{d\dot{Q}}{T} = \frac{6}{1200} - \frac{4}{400} = -\ 0.005 \text{ kW/K} < 0$ **OK**

b) $\int \frac{d\dot{Q}}{T} = \frac{6}{1200} - \frac{0}{400} = 0.005 \text{ kW/K} > 0$ **Impossible**

c) $\int \frac{d\dot{Q}}{T} = \frac{6}{1200} - \frac{2}{400} = 0 \text{ kW/K}$ **Possible if reversible**

d) $\int \frac{d\dot{Q}}{T} = \frac{6}{1200} - \frac{6}{400} = -\ 0.001 \text{ kW/K} < 0$ **OK**



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8.22

Let the steam power plant in Problem 7.35 have 700°C in the boiler and 40°C during the heat rejection in the condenser. Does that satisfy the inequality of Clausius? Repeat the question for the cycle operated in reverse as a refrigerator.

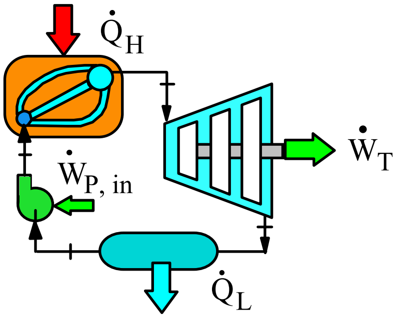
Solution:

$$\dot{Q}_H = 1 \text{ MW} \qquad \dot{Q}_L = 0.58 \text{ MW}$$

$$\int \frac{d\dot{Q}}{T} = \frac{1000}{973} - \frac{580}{313} = -0.82 \text{ kW/K} < 0$$ **OK**

Refrigerator

$$\int \frac{d\dot{Q}}{T} = \frac{580}{313} - \frac{1000}{973} = 0.82 > 0$$ **Cannot be possible**



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8.23

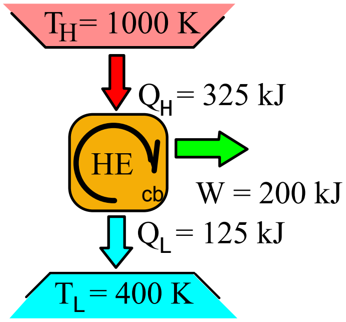
Examine the heat engine given in Problem 7.54 to see if it satisfies the inequality of Clausius.

Solution:

$Q_H = 325$ kJ at $T_H = 1000$ K

$Q_L = 125$ kJ at $T_L = 400$ K

$$\int \frac{dQ}{T} = \frac{325}{1000} - \frac{125}{400} = 0.0125 \text{ kJ/K} > 0$$ **Impossible**



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Entropy of a pure substance

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8.24

Find the missing properties of T, P, s and x for water at:

a. $P = 25$ kPa, $s = 7.7$ kJ/kgK

b. $P = 10$ MPa, $u = 3400$ kJ/kg

c. $T = 150^oC$, $s = 7.4$ kJ/kgK

Solution:

a) Table B.1.2 $s_f < s < s_g$ so two-phase and $T = T_{sat}(P) = 64.97°C$

$$x = (s - s_f)/s_{fg} = \frac{7.70 - 0.893}{6.9383} = 0.981$$

$$h = 271.9 + 0.981 \times 2346.3 = 2573.8 \text{ kJ/kg}$$

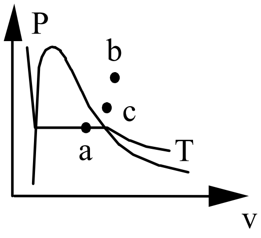
b) Table B.1.2 $u > u_g$ => Superheated vapor Table B.1.3, x = undefined

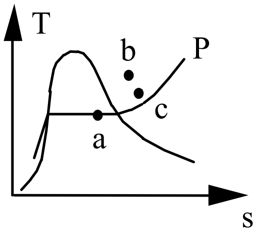
$$T \cong 682°C, \quad s \cong 7.1223 \text{ kJ/kg K}$$

c) Table B.1.1 $s > s_g$ so superheated vapor. Table B.1.3, x = undefined

State is located between 100 and 200 kPa, so interpolate

$$P = 100 \text{ kPa} + 100 \text{ kPa} \times \frac{7.40 - 7.6133}{7.2795 - 7.6133} = 163.9 \text{ kPa}$$





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8.25

Determine the missing property among P, T, s, and x for R-410a at:

a. $T = -20^{o}C$, $v = 0.1377\ m^3/kg$
b. $T = 20^{o}C$, $v = 0.01377\ m^3/kg$
c. $P = 200$ kPa, $s = 1.409$ kJ/kgK

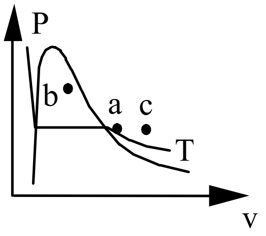
a) B.4.1: $v > v_g = 0.0648\ m^3/kg$ =>
B.4.2 superheated vapor so x is undefined
very close to 200 kPa, $s = 1.1783$ kJ/kg-K

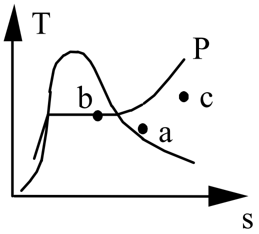
b) B.4.1: $0.000923 = v_f < v < v_g = 0.01758\ m^3/kg$ => Two-phase
$P = P_{sat} = 1444.2$ kPa

$$x = (v - v_f)/v_{fg} = \frac{0.01377 - 0.000923}{0.01666} = 0.77113$$

$s = s_f + x\ s_{fg} = 0.3357 + 0.77113 \times 0.6627 = 0.8467$ kJ/kg-K

c) Table B.4.2 at 200 kPa, $s > s_g$ so superheated vapor,
x is undefined, and we find the state at $T = 60^{o}C$.





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8.26

Find the missing properties and give the phase of the ammonia, NH_3.

a. $T = 65°C, P = 600$ kPa $s = ?\ v = ?$

b. $T = 20°C, P = 100$ kPa $v = ?\ s = ?\ x = ?$

c. $T = 50°C, v = 0.1185\ m^3/kg$ $s = ?\ x = ?\ P = ?$

a) B.2.2 average between 60°C and 70°C

$v = (0.25981 + 0.26999)/2 = 0.26435\ m^3/kg$

$s = (5.6383 + 5.7094)/2 = 5.6739$ kJ/kgK

b) B.2.1: $P < P_{sat} = 857.5$ kPa =>

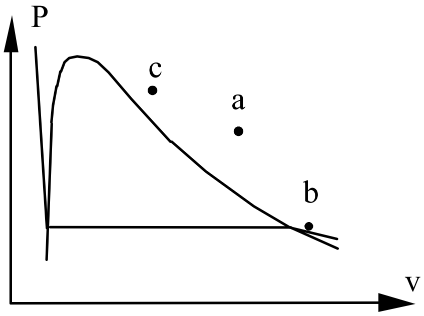
B.2.2 superheated vapor so x is undefined

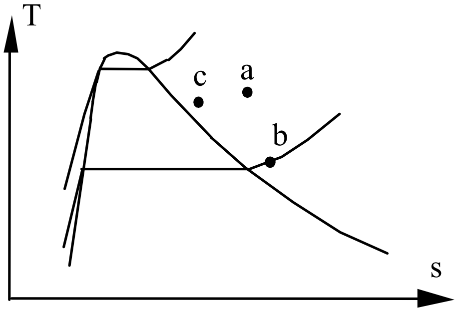
$v = 1.4153\ m^3/kg$, $s = 6.2826$ kJ/kgK

c) B.2.1: $v > v_g = 0.06337\ m^3/kg$ =>

B.2.2 superheated vapor so x is undefined

very close to 1200 kPa, $s = 5.1497$ kJ/kgK





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8.27

Find the entropy for the following water states and indicate each state on a T-s diagram relative to the two-phase region.

a. 250°C, v = 0.02 m^3/kg

b. 250°C, 2000 kPa

c. –2°C, 100 kPa

Solution:

a) Table B.1.1: $0.001251 = v_f < v < v_g = 0.05013\ m^3/kg$ => Two-phase

$$x = \frac{0.02 - 0.001251}{0.04887} = 0.38365$$

$s = s_f + x\, s_{fg} = 2.7927 + 0.38365 \times 3.2802 =$ **4.05 kJ/kg K**

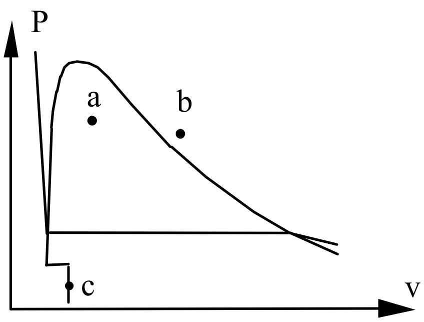
b) Table B.1.1: $P < P_{sat} = 3973$ kPa => superheated vapor B.1.3

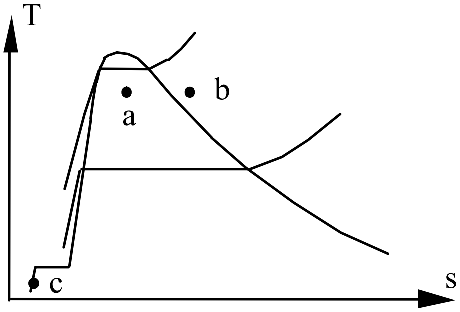
s = 6.5452 kJ/kg K

c) Table B.1.1 $T < T_{tripple} = 0.01°C$ so goto B.1.5

Table B.1.5: $P > P_{sat} = 0.5177$ kPa so compressed solid

s = –1.2369 kJ/kg K





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8.28

Find the entropy for the following water states and indicate each state on a T-s diagram relative to the two-phase region.

a. 20^{o}C, 100 kPa

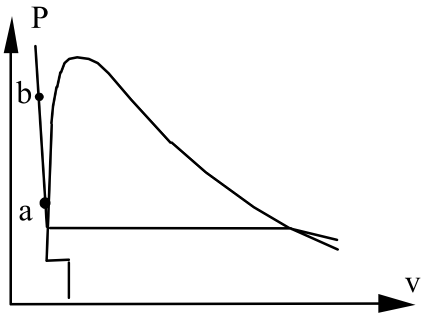
b. 20^{o}C, 10 000 kPa

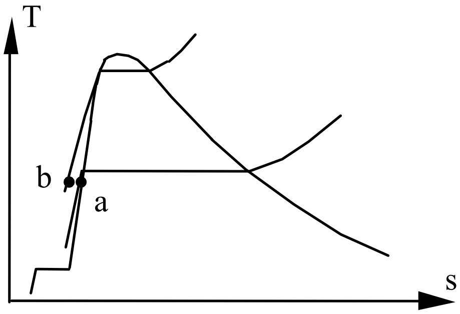
Solution:

Both states are compressed liquid states $P > P_{sat} = 2.34$ kPa from B.1.1

a) Table B.1.1: **s = 0.2966 kJ/kg K** (saturated liquid same T)

b) Table B.1.4 **s = 0.2945 kJ/kg K**





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8.29

Determine the missing property among P, T, s, and x for CO_2 at:

a. $P = 1000$ kPa, $v = 0.05$ m^3/kg

b. $T = 0^oC$, $s = 1$ kJ/kgK

c. $T = 60^oC$, $s = 1.8$ kJ/kgK

a) Table B.3.1 at 1004 kPa: $v > v_g = 0.03828$ m^3/kg => Superheated vapor

B.3.2: $$T = 0 + 20 \frac{0.05 - 0.048}{0.0524 - 0.048} = 20 \times 0.4545 = 9.09^oC$$

$$s = 1.5371 + (1.6025 - 1.5371) \times 0.4545 = 1.5514 \text{ kJ/kg-K}$$

b) Table B.3.1: $0.3344 = s_f < s < s_g = 1.1797$ kJ/kg-K => Two-phase

$$P = P_{sat} = 3485 \text{ kPa}$$

$$x = \frac{s - s_f}{s_{fg}} = \frac{1 - 0.3344}{0.8453} = 0.7874$$

c) Table B.3.1: $T > T_{critical} = 31^oC$ so superheated vapor or dense fluid.

Table B.3.2: Start at 1000 kPa, we see s = 1.72 is too low, so lower P.
State is between 400 and 800 kPa at 60°C, interpolate

$$P = 400 \text{ kPa} + 400 \text{ kPa} \times \frac{1.8 - 1.9033}{1.7660 - 1.9033} = 300.95 \text{ kPa}$$

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8.30

Two kg water at 120°C with a quality of 25% has its temperature raised 20°C in a constant volume process. What are the new quality and specific entropy?

Solution:

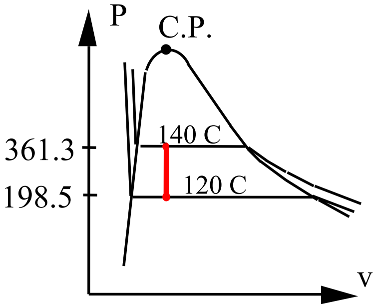
State 1 from Table B.1.1 at 120°C

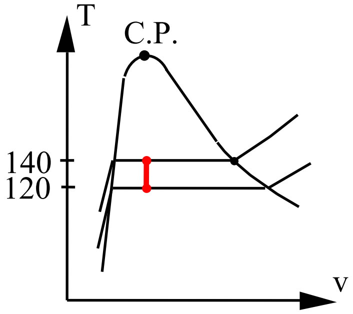
$$v = v_f + x\, v_{fg} = 0.001060 + 0.25 \times 0.8908 = 0.22376 \text{ m}^3\text{/kg}$$

State 2 has same v at 140°C also from Table B.1.1

$$x = \frac{v - v_f}{v_{fg}} = \frac{0.22376 - 0.00108}{0.50777} = \mathbf{0.4385}$$

$$s = s_f + x\, s_{fg} = 1.739 + 0.4385 \times 5.1908 = \mathbf{4.015\ kJ/kg\ K}$$





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8.31

Two kg water at 200 kPa with a quality of 25% has its temperature raised 20^{o}C in a constant pressure process. What is the change in entropy?

Solution:

State 1 from Table B.1.2 at 200 kPa

$$s = s_f + x\, s_{fg} = 1.53 + 0.25 \times 5.597 = 2.9293 \text{ kJ/kg}$$

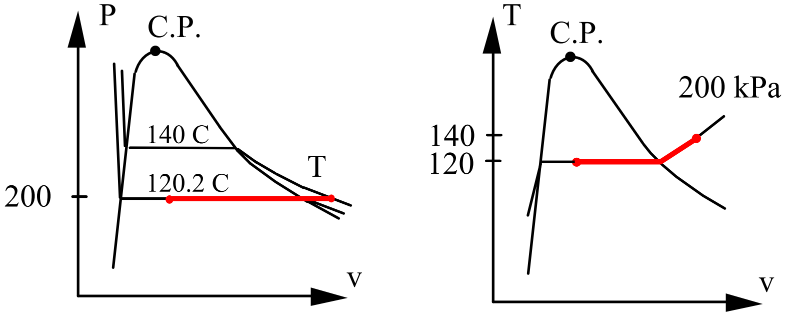
State 2 has same P from Table B.1.2 at 200 kPa

$$T_2 = T_{sat} + 20 = 120.23 + 20 = 140.23^{o}\text{C}$$

so state 2 is superheated vapor (x = undefined) from Table B.1.3

$$s_2 = 7.1271 + (7.2795 - 7.1271)\frac{20}{150 - 120.23} = 7.2295 \text{ kJ/kgK}$$

$$s_2 - s_1 = 7.2295 - 2.9293 = \mathbf{4.3002\ kJ/kgK}$$



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8.32

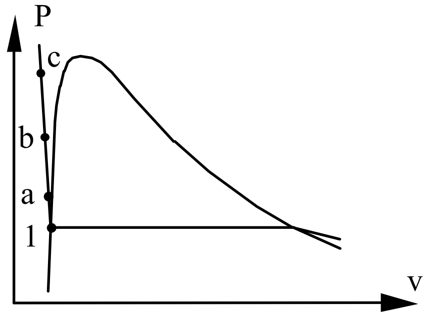
Saturated liquid water at 20^{o}C is compressed to a higher pressure with constant temperature. Find the changes in u and s when the final pressure is

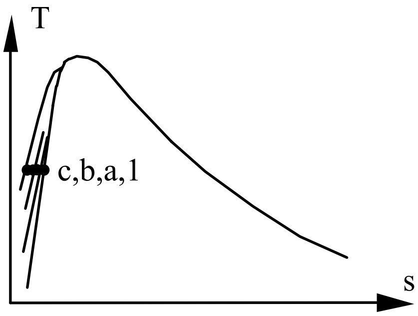
a. 500 kPa b. 2000 kPa c. 20 000 kPa

Solution:

	kJ/kg	kJ/kg K		
B.1.1:	$u_1 = 83.94$	$s_1 = 0.2966$		
B.1.4:	$u_a = 83.91$	$s_a = 0.2965$	$\Delta u = -0.03$	$\Delta s = -0.0001$
B.1.4:	$u_b = 83.82$	$s_b = 0.2962$	$\Delta u = -0.12$	$\Delta s = -0.0004$
B.1.4:	$u_c = 82.75$	$s_c = 0.2922$	$\Delta u = -1.19$	$\Delta s = -0.0044$

Nearly constant u and s, incompressible media





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8.33

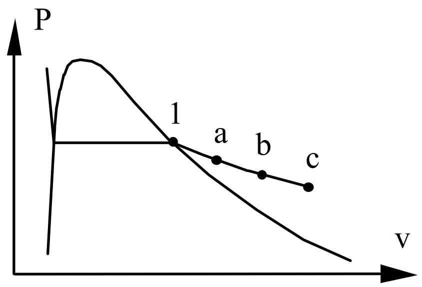
Saturated vapor water at 150^{o}C is expanded to a lower pressure with constant temperature. Find the changes in u and s when the final pressure is

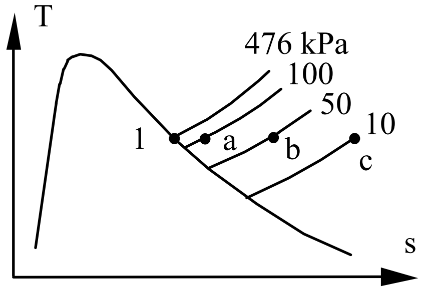
a. 100 kPa b. 50 kPa c. 10 kPa

Solution:

Table B.1.1 for the first state then B.1.3 for the a, b and c states.

kJ/kg	kJ/kg K	kJ/kg	kJ/kg K
u_1= 2559.54	s_1= 6.8378		
u_a = 2582.75	s_a = 7.6133	Δu = 23.21	Δs = 0.7755
u_b = 2585.61	s_b = 7.94	Δu = 26.07	Δs = 1.1022
u_c = 2587.86	s_c = 8.6881	Δu = 28.32	Δs = 1.8503





Remark: You approach ideal gas as P drops so u is u(T) but s is still s(T,P).

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8.34

Determine the missing property among *P, T, s, x* for the following states:

a. Ammonia 25°C, v = 0.10 m^3/kg
b. Ammonia 1000 kPa, s = 5.2 kJ/kg K
c. R-134a 5°C, s = 1.7 kJ/kg K
d. R-134a 50°C, s = 1.9 kJ/kg K

Solution:

	Table	**P kPa**	**T °C**	**s kJ/kg K**	**x**
a)	B2.1	1003	25	4.1601	0.7776
b)	B2.2	1000	42.53	5.2	-----
c)	B5.1	350.9	5	1.7	0.96598
d)	B5.2	232.3	50	1.9	-----

a) $x = (0.1 - 0.001658)/0.12647 = \mathbf{0.7776}$

$s = s_f + x\, s_{fg} = 1.121 + x \times 3.9083 = \mathbf{4.1601\ kJ/kg\ K}$

b) $T = 40 + 10 \times (5.2 - 5.1778)/(5.2654 - 5.1778) = \mathbf{42.53^oC}$

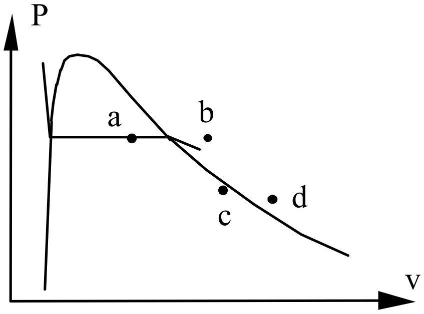
superheated vapor so x is undefined

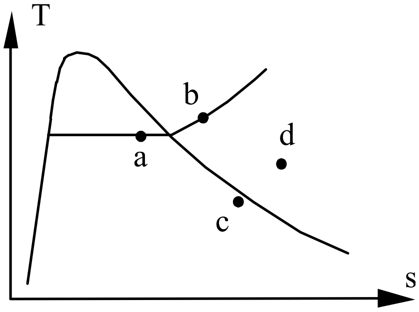
c) $x = (1.7 - 1.0243)/0.6995 = \mathbf{0.96598}$

$P = P_{sat} = \mathbf{350.9\ kPa}$

d) superheated vapor between 200 and 300 kPa

$P = 200 + 100 \times (1.9 - 1.9117)/(1.8755 - 1.9117) = \mathbf{232.3\ kPa}$





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Reversible processes

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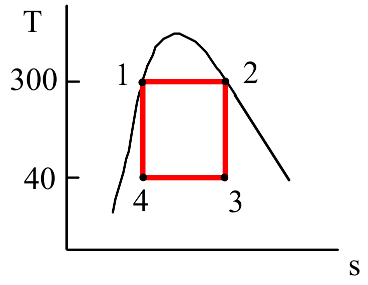
8.35

Consider a Carnot-cycle heat engine with water as the working fluid. The heat transfer to the water occurs at 300°C, during which process the water changes from saturated liquid to saturated vapor. The heat is rejected from the water at 40°C. Show the cycle on a *T–s* diagram and find the quality of the water at the beginning and end of the heat rejection process. Determine the net work output per kilogram of water and the cycle thermal efficiency.

Solution:

From the definition of the Carnot cycle, two constant s and two constant T processes.



From table B.1.1
State 2 is saturated vapor so

$$s_3 = s_2 = 5.7044 \text{ kJ/kg K}$$
$$= 0.5724 + x_3(7.6845)$$

$$x_3 = \mathbf{0.6678}$$

State 1 is saturated liquid so

$$s_4 = s_1 = 3.2533 \text{ kJ/kg K} = 0.5724 + x_4(7.6845)$$

$$x_4 = \mathbf{0.3489}$$

$$\eta_{TH} = \frac{w_{NET}}{q_H} = \frac{T_H - T_L}{T_H} = \frac{260}{573.2} = \mathbf{0.4536}$$

$$q_H = T_H(s_2 - s_1) = 573.2 \text{ K } (5.7044 - 3.2533) \text{ kJ/kg K} = 1405.0 \text{ kJ/kg}$$

$$w_{NET} = \eta_{TH} \times q_H = \mathbf{637.3 \text{ kJ/kg}}$$

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8.36

A piston cylinder compresses R-410a at 200 kPa, -20°C to a pressure of 1200 kPa in a reversible adiabatic process. Find the final temperature and the specific compression work?

C.V. The R-410a

Energy Eq.: $u_2 - u_1 = {}_1q_2 - {}_1w_2 = - {}_1w_2$

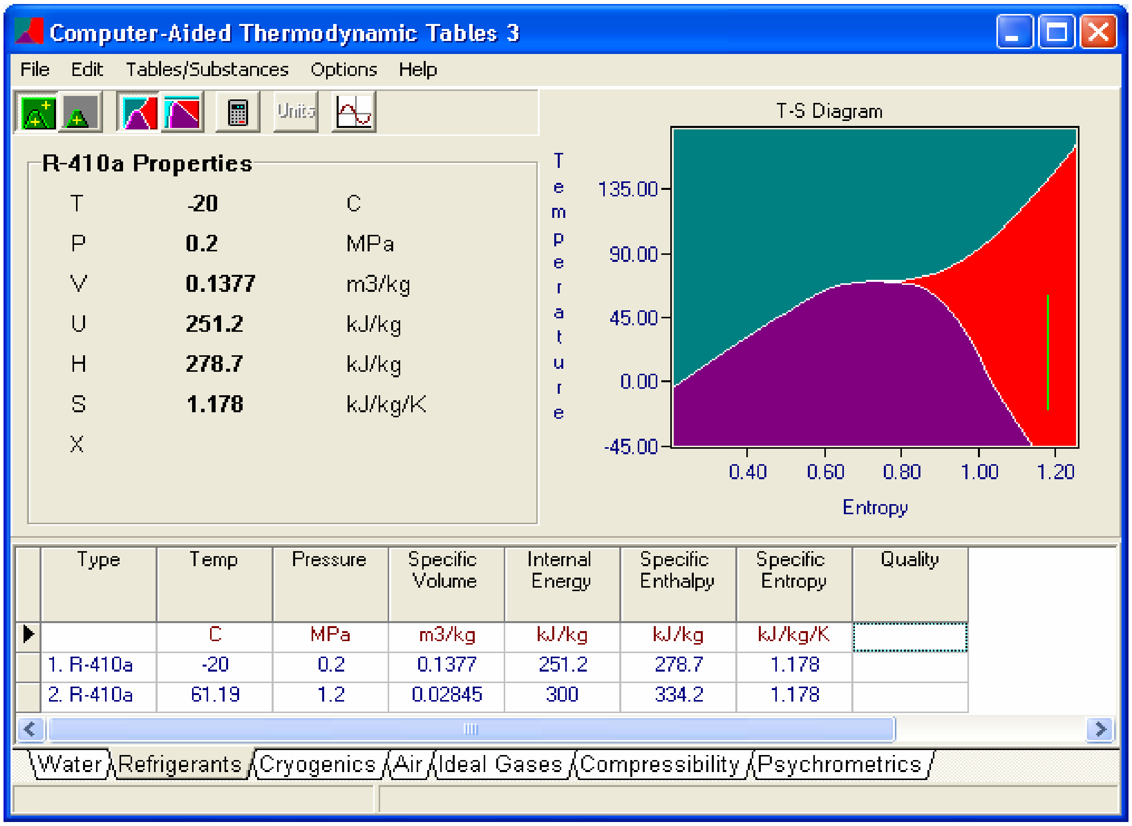
Entropy Eq.: $s_2 - s_1 = \int dq/T + 0 = 0 \quad \Rightarrow \quad s_2 = s_1$

State 1: Sup. vapor $u_1 = 251.18$ kJ/kg, $s_1 = 1.1783$ kJ/kgK

State 2: (P_2, s_2) $u_2 = 300.05$ kJ/kg (same interpolation as for T),

$$T_2 = 60 + 20 \frac{1.1783 - 1.1747}{1.2331 - 1.1747} = \mathbf{61.2^oC}$$

$${}_1w_2 = u_1 - u_2 = 251.18 - 300.05 = \mathbf{-48.87\ kJ/kg}$$



R-410a Properties

T	-20	C
P	0.2	MPa
V	0.1377	m3/kg
U	251.2	kJ/kg
H	278.7	kJ/kg
S	1.178	kJ/kg/K
X		

Type	Temp	Pressure	Specific Volume	Internal Energy	Specific Enthalpy	Specific Entropy	Quality
	C	MPa	m3/kg	kJ/kg	kJ/kg	kJ/kg/K	
1. R-410a	-20	0.2	0.1377	251.2	278.7	1.178	
2. R-410a	61.19	1.2	0.02845	300	334.2	1.178	

Process line shown by CATT3 program in T-s diagram

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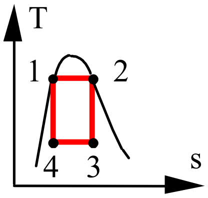
8.37

In a Carnot engine with ammonia as the working fluid, the high temperature is 60°C and as Q_H is received, the ammonia changes from saturated liquid to saturated vapor. The ammonia pressure at the low temperature is 190 kPa. Find T_L, the cycle thermal efficiency, the heat added per kilogram, and the entropy, *s*, at the beginning of the heat rejection process.

Solution:



Constant T $\Rightarrow$ constant P from 1 to 2, Table B.2.1

$$q_H = \int T ds = T (s_2 - s_1) = T s_{fg}$$

$$= h_2 - h_1 = h_{fg} = \mathbf{997.0\ kJ/kg}$$

States 3 & 4 are two-phase, Table B.2.1

$$\Rightarrow \quad T_L = T_3 = T_4 = T_{sat}(P) = \mathbf{-20°C}$$

$$\eta_{cycle} = 1 - \frac{T_L}{T_H} = 1 - \frac{253.2}{333.2} = \mathbf{0.24}$$

Table B.2.1: $s_3 = s_2 = s_g(60°C) = \mathbf{4.6577\ kJ/kg\ K}$

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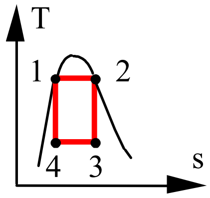
8.38

Water is used as the working fluid in a Carnot cycle heat engine, where it changes from saturated liquid to saturated vapor at 200°C as heat is added. Heat is rejected in a constant pressure process (also constant T) at 20 kPa. The heat engine powers a Carnot cycle refrigerator that operates between –15°C and +20°C. Find the heat added to the water per kg water. How much heat should be added to the water in the heat engine so the refrigerator can remove 1 kJ from the cold space?

Solution:

Carnot cycle heat engine:



Constant T $\Rightarrow$ constant P from 1 to 2, Table B.2.1

$$q_H = \int T ds = T\,(s_2 - s_1) = T\,s_{fg} = h_{fg}$$

$$= 473.15\,(4.1014) = \mathbf{1940\ kJ/kg}$$

States 3 & 4 are two-phase, Table B.2.1

$$\Rightarrow \quad T_L = T_3 = T_4 = T_{sat}(P) = 60.06^oC$$

Carnot cycle refrigerator (T_L and T_H are different from above):

$$\beta_{ref} = \frac{Q_L}{W} = \frac{T_L}{T_H - T_L} = \frac{273 - 15}{20 - (-15)} = \frac{258}{35} = 7.37$$

$$W = \frac{Q_L}{\beta} = \frac{1}{7.37} = 0.136\ kJ$$

The needed work comes from the heat engine

$$W = \eta_{HE}\, Q_{H\,H2O}\ ; \qquad \eta_{HE} = 1 - \frac{T_L}{T_H} = 1 - \frac{333}{473} = 0.296$$

$$Q_{H\,H2O} = \frac{W}{\eta_{HE}} = \frac{0.136}{0.296} = \mathbf{0.46\ kJ}$$

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8.39

Water at 200 kPa, x = 1.0 is compressed in a piston/cylinder to 1 MPa, 250°C in a reversible process. Find the sign for the work and the sign for the heat transfer.

Solution:

The process is not specified, but the beginning and end states are

State 1: Table B.1.1:

$$v_1 = 0.8857\ \text{m}^3\text{/kg};\quad u_1 = 2529.5\ \text{kJ/kg};\quad s_1 = 7.1271\ \text{kJ/kg K}$$

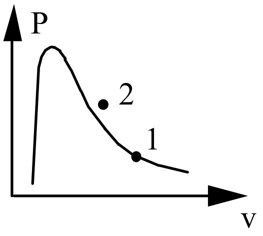
State 2: Table B.1.3:

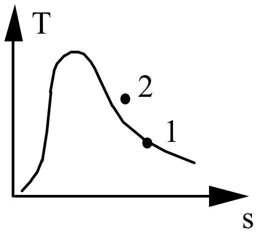
$$v_2 = 0.23268\ \text{m}^3\text{/kg};\quad u_2 = 2709.9\ \text{kJ/kg};\quad s_2 = 6.9246\ \text{kJ/kg K}$$

Reversible process: $dw = P\,dv$ $\quad dq = T\,ds$

$v_2 < v_1 \quad \Rightarrow \quad {}_1w_2 = \int P\,dv < 0$

$s_2 < s_1 \quad \Rightarrow \quad {}_1q_2 = \int T\,ds < 0$





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8.40

Water at 200 kPa, x = 1.0 is compressed in a piston/cylinder to 1 MPa, 350°C in a reversible process. Find the sign for the work and the sign for the heat transfer.

Solution**:**

$_1w_2 = \int P\, dv$ so sign dv

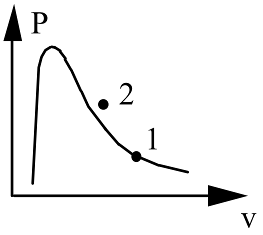
$_1q_2 = \int T\, ds$ so sign ds

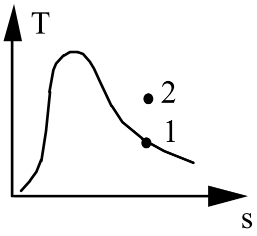
B1.2 $v_1 = 0.88573\ m^3/kg$ $s_1 = 7.1271\ kJ/kg\ K$

B1.3 $v_2 = 0.28247\ m^3/kg$ $s_2 = 7.301\ kJ/kg\ K$

$dv < 0$ => **w is negative**

$ds > 0$ => **q is positive**





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8.41

R-410a at 1 MPa and 60°C is expanded in a piston cylinder to 500 kPa, 20°C in a reversible process. Find the sign for both the work and the heat transfer for this process.

Solution:

$_1w_2 = \int P\, dv$ so sign dv

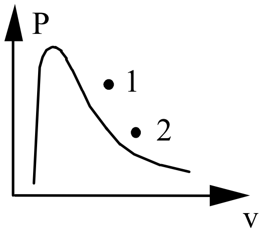
$_1q_2 = \int T\, ds$ so sign ds

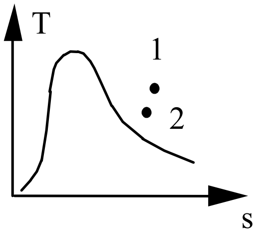
B.4.2 $v_1 = 0.03470\ m^3/kg$ $s_1 = 1.2019$ kJ/kg K

B.4.2 $v_2 = 0.06231\ m^3/kg$ $s_2 = 1.1803$ kJ/kg K

$dv > 0$ => **w is positive**

$ds < 0$ => **q is negative**





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8.42

A piston cylinder maintaining constant pressure contains 0.1 kg saturated liquid water at 100°C. It is now boiled to become saturated vapor in a reversible process. Find the work term and then the heat transfer from the energy equation. Find the heat transfer from the entropy equation, is it the same?

Energy Eq.: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.: $m(s_2 - s_1) = \int \frac{dq}{T} + 0 = \frac{{}_1Q_2}{T}$

Process: $P = C \Rightarrow {}_1W_2 = m\,P(v_2 - v_1) = m\,P\,v_{fg}$

$$= 0.1 \text{ kg} \times 101.3 \text{ kPa} \times 1.67185 \text{ m}^3/\text{kg} = \mathbf{16.936\ kJ}$$

From the energy equation we get

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = m\,u_{fg} + {}_1W_2$$

$$= 0.1 \times 2087.58 + 16.936 = 225.7 \text{ kJ}$$

$$\text{or} \quad = m(h_2 - h_1) = m\,h_{fg} = 0.1 \times 2257.03 = \mathbf{225.7\ kJ}$$

From the entropy equation we can get

$${}_1Q_2 = mT(s_2 - s_1) = m\,T\,s_{fg} = 0.1 \times 373.15 \times 6.048 = \mathbf{225.68\ kJ}$$

So they are equal to within round off errors.

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8.43

Consider a Carnot-cycle heat pump with R-410a as the working fluid. Heat is rejected from the R-410a at 40°C, during which process the R-410a changes from saturated vapor to saturated liquid. The heat is transferred to the R-410a at -5°C.

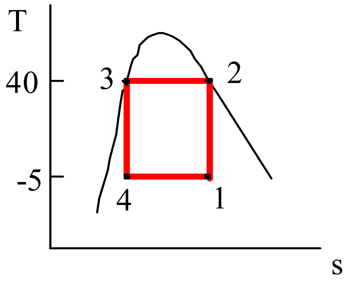
a. Show the cycle on a *T–s* diagram.

b. Find the quality of the R-410a at the beginning and end of the isothermal heat addition process at -5°C.

c. Determine the coefficient of performance for the cycle.

Solution:

a)



b) From Table B.4.1, state 3 is saturated liquid

$$s_4 = s_3 = 0.4473 \text{ kJ/kg K}$$
$$= 0.1989 + x_4(0.8477)$$
$$\Rightarrow \quad x_4 = \mathbf{0.293}$$

State 2 is saturated vapor so from Table B.4.1

$$s_1 = s_2 = 0.9552 \text{ kJ/kg K} = 0.1989 + x_1(0.8477)$$
$$\Rightarrow \quad x_1 = \mathbf{0.892}$$

c) $$\beta' = \frac{q_H}{w_{IN}} = \frac{T_H}{T_H - T_L} = \frac{313.2}{45} = \mathbf{6.96}$$

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8.44

Do Problem 8.43 using refrigerant R-134a instead of R-410a.
Consider a Carnot-cycle heat pump with R-410a as the working fluid. Heat is rejected from the R-410a at 40°C, during which process the R-410a changes from saturated vapor to saturated liquid. The heat is transferred to the R-410a at -5°C.

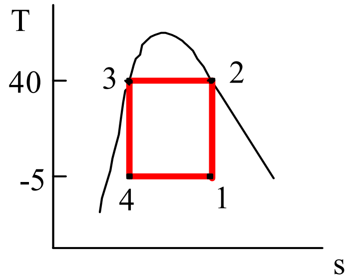
a. Show the cycle on a *T–s* diagram.

b. Find the quality of the R-410a at the beginning and end of the isothermal heat addition process at -5°C.

c. Determine the coefficient of performance for the cycle.

Solution:

a)



b) From Table B.5.1, state 3 is saturated liquid

$$s_4 = s_3 = 1.1909 \text{ kJ/kg K} = 0.9755 + x_4(0.7534)$$

$$\Rightarrow \quad x_4 = \mathbf{0.2859}$$

State 2 is saturated vapor so from Table B.5.1

$$s_1 = s_2 = 1.7123 \text{ kJ/kg K} = 0.9755 + x_1(0.7534)$$

$$\Rightarrow \quad x_1 = \mathbf{0.978}$$

c)

$$\beta' = \frac{q_H}{w_{IN}} = \frac{T_H}{T_H - T_L} = \frac{313.2}{45} = \mathbf{6.96}$$

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8.45

One kilogram of ammonia in a piston/cylinder at 50°C, 1000 kPa is expanded in a reversible isobaric process to 140°C. Find the work and heat transfer for this process.

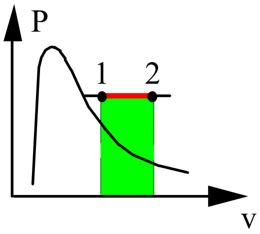
Solution:

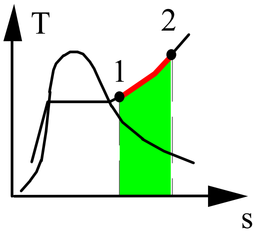
Control mass.

$m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: $P = \text{constant}$

$\Rightarrow\ {}_1W_2 = mP(v_2 - v_1)$





State 1: Table B.2.2 $v_1 = 0.145\ \text{m}^3/\text{kg}$, $u_1 = 1391.3\ \text{kJ/kg}$

State 2: Table B.2.2 $v_2 = 0.1955\ \text{m}^3/\text{kg}$, $u_2 = 1566.7\ \text{kJ/kg}$

${}_1W_2 = 1 \times 1000(0.1955 - 0.145) = \mathbf{50.5\ kJ}$

${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 1 \times (1566.7 - 1391.3) + 50.5 = \mathbf{225.9\ kJ}$

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8.46

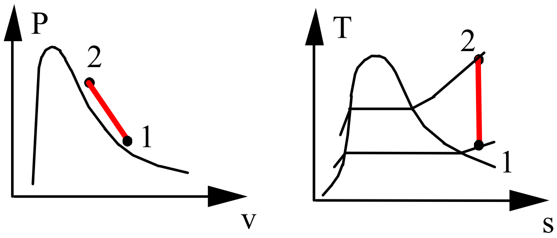
A piston cylinder contains 0.25 kg of R-134a at 100 kPa. It will be compressed in an adiabatic reversible process to 400 kPa and should be 70^{o}C. What should the initial temperature be?

C.V. R-134a which is a control mass.

Entropy Eq.8.3: $m(s_2 - s_1) = \int dQ/T = 0$

State 2: $s_2 = s_1 = 1.9051$ kJ/kgK

Work backwards from state 2 to state 1
State 1: 100 kPa & s_1 => $T_1 =$ **26.4°C**



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8.47

Compression and heat transfer brings carbon dioxide in a piston/cylinder from 1400 kPa, 20^{o}C to saturated vapor in an isothermal process. Find the specific heat transfer and the specific work.

Solution:

m = constant

Energy Eq.5.11: $u_2 - u_1 = {}_1q_2 - {}_1w_2$

Entropy Eq.8.3: $s_2 - s_1 = \int dq/T = {}_1q_2 / T$

Process: T = C and assume reversible ⇒ $_1q_2 = T\,(s_2 - s_1)$

State 1: Table B.4.2:

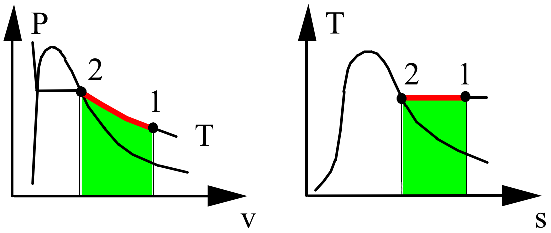
$u_1 = 259.18$ kJ/kg,

$s_1 = 1.0057$ kJ/kg K

State 2: Table B.4.1

$u_2 = 258.16$ kJ/kg,

$s_2 = 0.9984$ kJ/kg K



$_1q_2 = (273 + 20) \times (0.9984 - 1.0057) = \mathbf{-2.14\ kJ/kg}$

$_1w_2 = {}_1q_2 + u_1 - u_2 = -2.14 + 259.18 - 258.16$

$= \mathbf{-1.12\ kJ/kg}$

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8.48

One kilogram of carbon dioxide in a piston/cylinder at 120°C, 1400 kPa, shown in Fig. P8.48, is expanded to 800 kPa in a reversible adiabatic process. Find the work and heat transfer.

Solution:

Control mass: Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

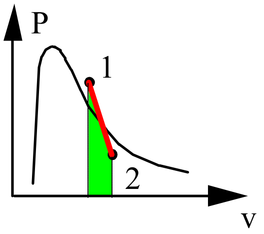
Entropy Eq.8.3: $m(s_2 - s_1) = \int dQ/T$ (= since reversible)

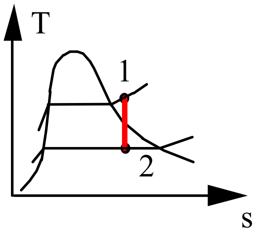
Process: $\mathbf{{}_1Q_2 = 0}$ $\Rightarrow$ $s_2 = s_1$

State 1: (P, T) Table B.3.2, $u_1 = 398.83$ kJ/kg, $s_1 = 1.8093$ kJ/kg K

State 2: P_2 , s_2 $\Rightarrow$ superheated vapor, $u_2 = 368.52$ kJ/kg

$${}_1W_2 = 1 \times (398.83 - 368.52) = \mathbf{30.3\ kJ}$$





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8.49

A cylinder fitted with a piston contains ammonia at 50°C, 20% quality with a volume of 1 L. The ammonia expands slowly, and during this process heat is transferred to maintain a constant temperature. The process continues until all the liquid is gone. Determine the work and heat transfer for this process.

Solution:

C.V. Ammonia in the cylinder.

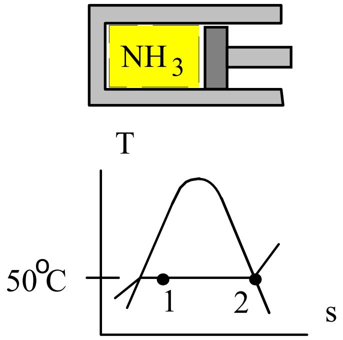

Table B.2.1: $T_1 = 50°C$, $x_1 = 0.20$, $V_1 = 1$ L

$v_1 = 0.001777 + 0.2 \times 0.06159 = 0.014095\ m^3/kg$

$s_1 = 1.5121 + 0.2 \times 3.2493 = 2.1620$ kJ/kg K

$m = V_1/v_1 = 0.001/0.014095 = 0.071$ kg

$v_2 = v_g = 0.06336\ m^3/kg$,

$s_2 = s_g = 4.7613$ kJ/kg K

Process: T = constant to $x_2 = 1.0$, P = constant = 2.033 MPa

From the constant pressure process

${}_1W_2 = \int PdV = Pm(v_2 - v_1) = 2033 \times 0.071 \times (0.06336 - 0.014095) = \mathbf{7.11\ kJ}$

From the second law Eq.8.3 with constant T

${}_1Q_2 = \int TdS = Tm(s_2 - s_1) = 323.2 \times 0.071(4.7613 - 2.1620) = \mathbf{59.65\ kJ}$

or ${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = m(h_2 - h_1)$

$h_1 = 421.48 + 0.2 \times 1050.01 = 631.48$ kJ/kg, $h_2 = 1471.49$ kJ/kg

${}_1Q_2 = 0.071(1471.49 - 631.48) = \mathbf{59.65\ kJ}$

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8.50

Water in a piston/cylinder at 400^{o}C, 2000 kPa is expanded in a reversible adiabatic process. The specific work is measured to be 415.72 kJ/kg out. Find the final P and T and show the P-v and the T-s diagram for the process.

Solution:

C.V. Water, which is a control mass. Adiabatic so: $_1q_2 = 0$

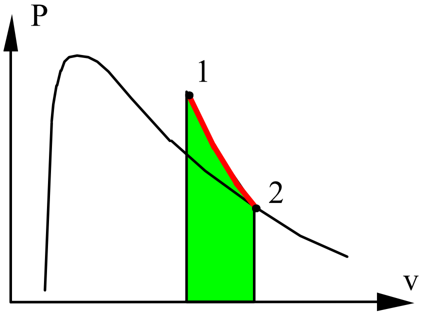
Energy Eq.5.11: $u_2 – u_1 = {_1q_2} – {_1w_2} = -{_1w_2}$

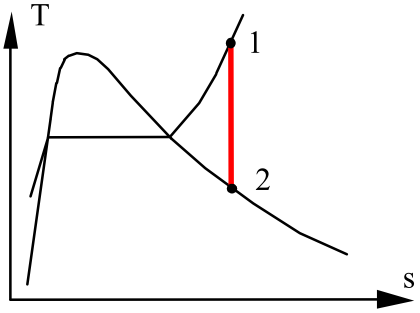
Entropy Eq.8.3: $s_2 - s_1 = \int dq/T = 0$ (= since reversible)

State 1: Table B.1.3 $u_1 = 2945.21$ kJ/kg; $s_1 = 7.127$ kJ/kg K

State 2: (s, u): $u_2 = u_1 - {_1w_2} = 2945.21 – 415.72 = 2529.49$ kJ/kg

=> **sat. vapor 200 kPa, T = 120.23°C**





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8.51

A piston cylinder has R-134a at –20^{o}C, 100 kPa which is compressed to 500 kPa in a reversible adiabatic process. Find the final temperature and the specific work.

Solution:

C.V. R-134a, Control mass of unknown size, adiabatic $_1q_2 = 0$

Energy Eq.5.11: $u_2 - u_1 = {}_1q_2 - {}_1w_2 = - {}_1w_2$

Entropy Eq.8.3: $s_2 - s_1 = \int dq/T$

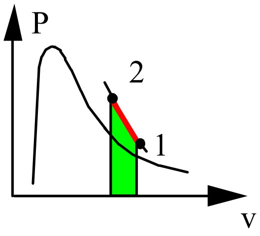
Process: Adiabatic and reversible => $s_2 = s_1$

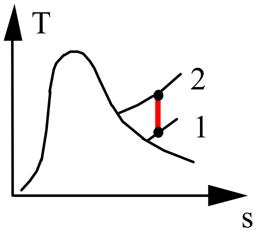
State 1: (T, P) B.5.2 $u_1 = 367.36$ kJ/kg, $s_1 = 1.7665$ kJ/kg K

State 2: (P, s) B.5.2 $P_2 = 500$ kPa, $s_2 = s_1 = 1.7665$ kJ/kg K

very close at 30^{o}C $u_2 = 398.99$ kJ/kg

$_1w_2 = u_2 - u_1 = 367.36 – 398.99 =$ **-31.63 kJ/kg**





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8.52

A piston/cylinder has 2 kg water at 1000 kPa, 250°C which is now cooled with a constant loading on the piston. This isobaric process ends when the water has reached a state of saturated liquid. Find the work and heat transfer and sketch the process in both a P-v and a T-s diagram.

Solution:

C.V. H_2O

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.3: $m(s_2 - s_1) = \int dQ/T$

Process: $P = C \;\; \Rightarrow \;\; W = \int P\, dV = P(V_2 - V_1)$

State 1: B.1.3 $v_1 = 0.23268\ \mathrm{m^3/kg}$, $s_1 = 6.9246\ \mathrm{kJ/kg\ K}$, $u_1 = 2709.91\ \mathrm{kJ/kg}$

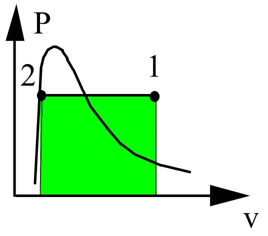
State 2: B.1.2 $v_2 = 0.001127\ \mathrm{m^3/kg}$, $s_2 = 2.1386\ \mathrm{kJ/kg\ K}$, $u_2 = 761.67\ \mathrm{kJ/kg}$

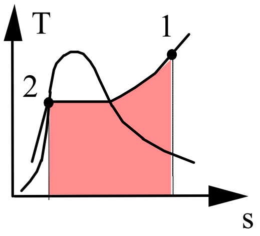
From the process equation

$${}_1W_2 = m\,P\,(v_2 - v_1) = 2 \times 1000\,(0.001127 - 0.23268) = \mathbf{-463.1\ kJ}$$

From the energy equation we get

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 2\,(761.67 - 2709.91) - 463.1 = \mathbf{-4359.6\ kJ}$$





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8.53

One kilogram of water at 300°C expands against a piston in a cylinder until it reaches ambient pressure, 100 kPa, at which point the water has a quality of 90.2%. It may be assumed that the expansion is reversible and adiabatic. What was the initial pressure in the cylinder and how much work is done by the water?

Solution:

C.V. Water. Process: Rev., $Q = 0$

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2 = -\,{}_1W_2$

Entropy Eq.8.3: $m(s_2 - s_1) = \int dQ/T$

Process: Adiabatic $Q = 0$ and reversible => $s_2 = s_1$

State 2: $P_2 = 100$ kPa, $x_2 = 0.902$ from Table B.1.2

$s_2 = 1.3026 + 0.902 \times 6.0568 = 6.7658$ kJ/kg K

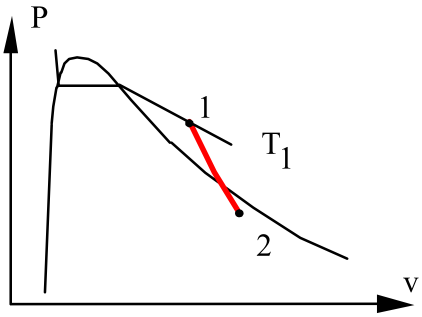
$u_2 = 417.36 + 0.902 \times 2088.7 = 2301.4$ kJ/kg

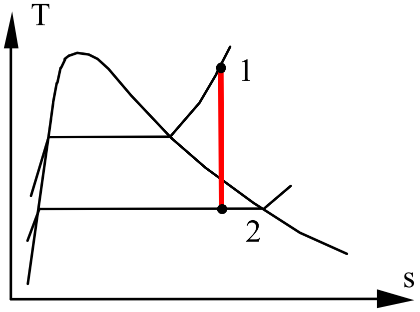
State 1 At $T_1 = 300°C$, $s_1 = 6.7658$ Find it in Table B.1.3

$\Rightarrow$ $P_1 =$ **2000 kPa,** $u_1 = 2772.6$ kJ/kg

From the energy equation

${}_1W_2 = m(u_1 - u_2) = 1(2772.6 - 2301.4) =$ **471.2 kJ**





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8.54

Water at 1000 kPa, 250°C is brought to saturated vapor in a rigid container, shown in Fig. P8.54. Find the final T and the specific heat transfer in this isometric process.

Solution:

Energy Eq.5.11: $u_2 - u_1 = {}_1q_2 - {}_1w_2$

Entropy Eq.8.3: $s_2 - s_1 = \int dq/T$

Process: $v = \text{constant} \quad \Rightarrow \quad {}_1w_2 = 0$

State 1: (T, P) Table B.1.3 $u_1 = 2709.91$ kJ/kg, $v_1 = 0.23268\ \text{m}^3/\text{kg}$

State 2: $x = 1$ and $v_2 = v_1$ so from Table B.1.1 we see $P_2 \cong 800$ kPa

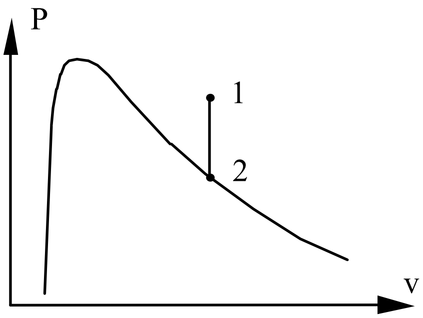
$$T_2 = 170 + 5 \times (0.23268 - 0.24283)/(0.2168 - 0.24283)$$

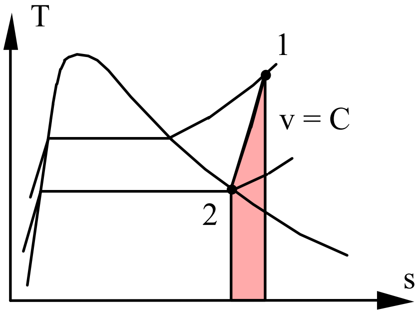
$$= 170 + 5 \times 0.38993 = \mathbf{171.95°C}$$

$$u_2 = 2576.46 + 0.38993 \times (2580.19 - 2576.46) = 2577.9 \text{ kJ/kg}$$

From the energy equation

$${}_1q_2 = u_2 - u_1 = 2577.9 - 2709.91 = \mathbf{-132\ kJ/kg}$$





Notice to get ${}_1q_2 = \int T\, ds$ we must know the function T(s) which we do not readily have for this process.

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8.55

Estimate the specific heat transfer from the area in the T-s diagram and compare it to the correct value for the states and process in Problem 8.54.

Solution:

Energy Eq.5.11: $u_2 - u_1 = {}_1q_2 - {}_1w_2$

Entropy Eq.8.3: $s_2 - s_1 = \int dq/T$

Process: v = constant => ${}_1w_2 = 0$

State 1: (T, P) Table B.1.3 $u_1 = 2709.91$ kJ/kg, $v_1 = 0.23268$ m^3/kg,

$s_1 = 6.9246$ kJ/kg K

State 2: $x = 1$ and $v_2 = v_1$ so from Table B.1.1 we see $P_2 \cong 800$ kPa

$$T_2 = 170 + 5 \times (0.23268 - 0.24283)/(0.2168 - 0.24283)$$

$$= 170 + 5 \times 0.38993 = \mathbf{171.95°C}$$

$$u_2 = 2576.46 + 0.38993 \times (2580.19 - 2576.46) = 2577.9 \text{ kJ/kg}$$

$$s_2 = 6.6663 + 0.38993\ (6.6256 - 6.6663) = 6.6504 \text{ kJ/kg K}$$

From the energy equation

$${}_1q_{2\text{ actual}} = u_2 - u_1 = 2577.9 - 2709.91 = \mathbf{-132\ kJ/kg}$$

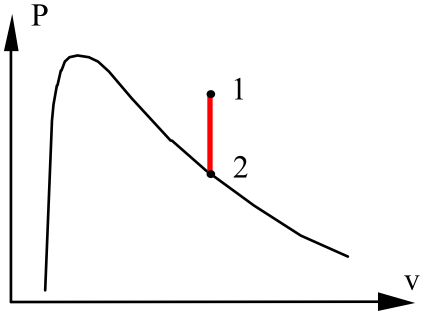
Assume a linear variation of T versus s.

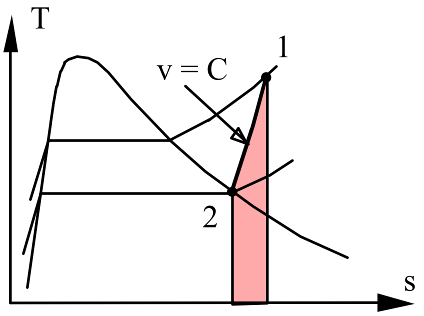
$${}_1q_2 = \int T\, ds = \text{area} \cong \frac{1}{2}(T_1 + T_2)(s_2 - s_1)$$

$$= \frac{1}{2}(171.95 + (2 \times 273.15) + 250)(6.6504 - 6.9246)$$

$$= \mathbf{-132.74\ kJ/kg}$$

very close i.e. the v = C curve is close to a straight line in the T-s diagram. Look at the constant v curves in Fig. E.1. In the two-phase region they curve slightly and more so in the region above the critical point.





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8.56

An insulated cylinder fitted with a piston contains 0.1 kg of water at 100°C, 90% quality. The piston is moved, compressing the water until it reaches a pressure of 1.2 MPa. How much work is required in the process?

Solution:

C.V. Water in cylinder.

Energy Eq.5.11: $_1Q_2 = 0 = m(u_2 - u_1) + {_1W_2}$

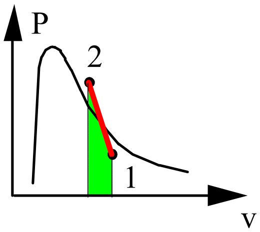
Entropy Eq.8.3: $m(s_2 - s_1) = \int dQ/T = 0$ (assume reversible)

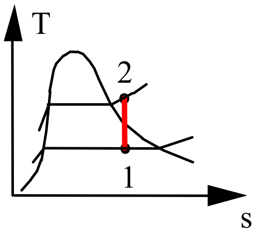
State 1: 100°C, $x_1 = 0.90$:

Table B.1.1,

$s_1 = 1.3068 + 0.90 \times 6.048$

$= 6.7500$ kJ/kg K





$u_1 = 418.91 + 0.9 \times 2087.58 = 2297.7$ kJ/kg

State 2: Given by (P, s) B.1.3 $\left.\begin{array}{l} s_2 = s_1 = 6.7500 \\ P_2 = 1.2 \text{ MPa} \end{array}\right\} \Rightarrow \left\{\begin{array}{l} T_2 = 232.3°\text{C} \\ u_2 = 2672.9 \end{array}\right.$

$_1W_2 = -m(u_2 - u_1) = -0.1(2672.9 - 2297.7) = \mathbf{-37.5\ kJ}$

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8.57

A closed tank, *V* = 10 L, containing 5 kg of water initially at 25°C, is heated to 175°C by a heat pump that is receiving heat from the surroundings at 25°C. Assume that this process is reversible. Find the heat transfer to the water and the change in entropy.

Solution:

C.V.: Water from state 1 to state 2.

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.3: $m(s_2 - s_1) = \int dQ/T$

Process: constant volume (reversible isometric) so ${}_1W_2 = 0$

State 1: $v_1 = V/m = 0.002$ from Table B.1.1

$x_1 = (0.002 - 0.001003)/43.358 = 0.000023$

$u_1 = 104.86 + 0.000023 \times 2304.9 = 104.93$ kJ/kg

$s_1 = 0.3673 + 0.000023 \times 8.1905 = 0.36759$ kJ/kg K

Continuity eq. (same mass) and V = C fixes v_2

State 2: T_2, $v_2 = v_1$ so from Table B.1.1

$x_2 = (0.002 - 0.001121)/0.21568 = 0.004075$

$u_2 = 740.16 + 0.004075 \times 1840.03 = 747.67$ kJ/kg

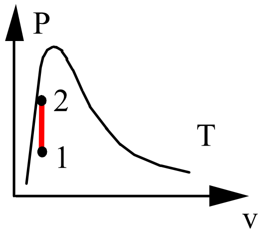
$s_2 = 2.0909 + 0.004075 \times 4.5347 = 2.1094$ kJ/kg K

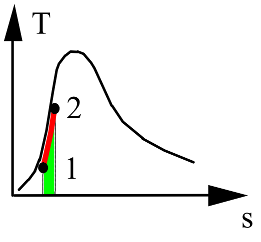
Energy eq. has W = 0, thus provides heat transfer as

${}_1Q_2 = m(u_2 - u_1) = 3213.7$ kJ

The entropy change becomes

$m(s_2 - s_1) = 5(2.1094 – 0.36759) =$ **8.709 kJ/K**





Notice we do not perform the integration $\int dQ/T$ to find change in s as the equation for the dQ as a function of T is not known.

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8.58

A piston/cylinder has 2 kg of R-410a at 60°C, 100 kPa which is compressed to 1000 kPa. The process happens so slowly that the temperature is constant. Find the heat transfer and work for the process assuming it to be reversible.

Solution:

CV : R-410a Control Mass

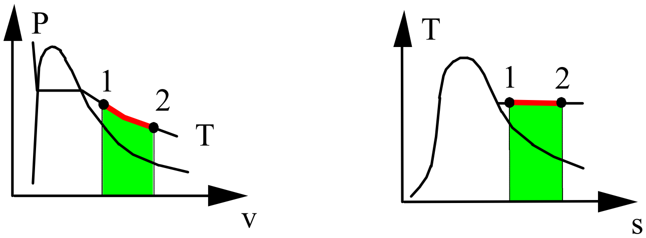
Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$;

Entropy Eq.8.3: $m(s_2 - s_1) = \int dQ/T$

Process: T = constant and assume reversible process

1: (T,P), Table B.4.2: $v_1 = 0.37833\ \mathrm{m^3/kg}$, $u_1 = 309.4$ kJ/kg, $s_1 = 1.4910$ kJ/kg K

2: (T,P), Table B.4.2: $v_2 = 0.03470\ \mathrm{m^3/kg}$, $u_2 = 301.04$ kJ/kg, $s_2 = 1.2019$ kJ/kg K



From the entropy equation (2nd law)

$${}_1Q_2 = mT(s_2 - s_1) = 2 \times 333.15\ (1.2019 - 1.4910) = \mathbf{-192.63\ kJ}$$

From the energy equation

$${}_1W_2 = {}_1Q_2 - m(u_2 - u_1) = -192.63 - 2(301.04 - 309.4) = \mathbf{-175.9\ kJ}$$

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8.59

A heavily-insulated cylinder fitted with a frictionless piston, as shown in Fig. P8.59 contains ammonia at 5°C, 92.9% quality, at which point the volume is 200 L. The external force on the piston is now increased slowly, compressing the ammonia until its temperature reaches 50°C. How much work is done by the ammonia during this process?

Solution:

C.V. ammonia in cylinder, insulated so assume adiabatic $Q = 0$.

Cont.Eq.: $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.3: $m(s_2 - s_1) = \int dQ/T$

State 1: $T_1 = 5^oC$, $x_1 = 0.929$, $V_1 = 200\ L = 0.2\ m^3$

Table B.2.1 saturated vapor, $P_1 = P_g = 515.9$ kPa

$v_1 = v_f + x_1v_{fg} = 0.001583 + 0.929 \times 0.2414 = 0.2258\ m^3/kg$,

$u_1 = u_f + x_1u_{fg} = 202.8 + 0.929 \times 1119.2 = 1242.5$ kJ/kg

$s_1 = s_f + x_1s_{fg} = 0.7951 + 0.929 \times 4.44715 = 4.9491$ kJ/kg K,

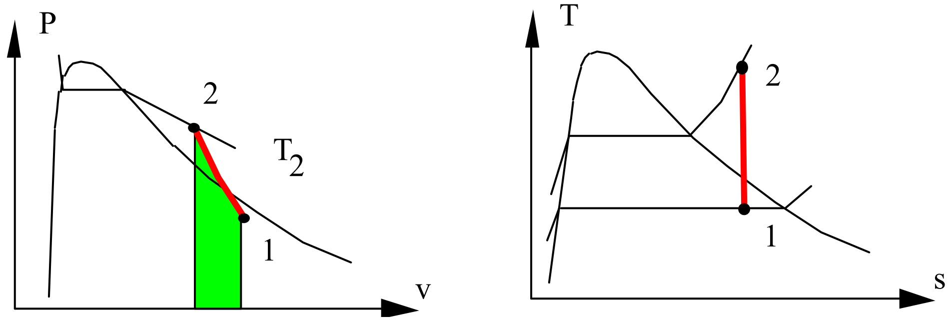
$m_1 = V_1/v_1 = 0.2 / 0.2258 = 0.886$ kg

Process: $1 \rightarrow 2$ Adiabatic ${}_1Q_2 = 0$ & Reversible => $s_1 = s_2$

State 2: $T_2 = 50^oC$, $s_2 = s_1 = 4.9491$ kJ/kg K

superheated vapor, interpolate in Table B.2.2 =>

$P_2 = 1600$ kPa, $u_2 = 1364.9$ kJ/kg



Energy equation gives the work as

${}_1W_2 = m(u_1 - u_2) = 0.886\ (\ 1242.5 – 1364.9) = $ **–108.4 kJ**

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8.60

A heavily insulated cylinder/piston contains ammonia at 1200 kPa, 60°C. The piston is moved, expanding the ammonia in a reversible process until the temperature is −20°C. During the process 600 kJ of work is given out by the ammonia. What was the initial volume of the cylinder?

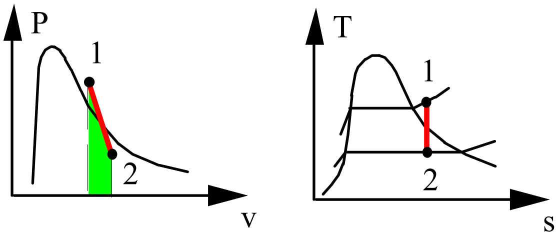
C.V. ammonia. Control mass with no heat transfer.

State 1: Table B.2.2 $v_1 = 0.1238\ \text{m}^3/\text{kg}$, $s_1 = 5.2357\ \text{kJ/kg K}$

$$u_1 = h - Pv = 1553.3 - 1200\times0.1238 = 1404.9\ \text{kJ/kg}$$

Entropy Eq.: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\ \text{gen}}$

Process: reversible (${}_1S_{2\ \text{gen}} = 0$) and adiabatic ($dQ = 0$) => $s_2 = s_1$



State 2: $T_2, s_2 \Rightarrow x_2 = (5.2357 - 0.3657)/5.2498 = 0.928$

$$u_2 = 88.76 + 0.928\times1210.7 = 1211.95\ \text{kJ/kg}$$

$${}_1Q_2 = 0 = m(u_2 - u_1) + {}_1W_2 = m(1211.95 - 1404.9) + 600$$

$$\Rightarrow\ m = 3.110\ \text{kg}$$

$V_1 = mv_1 = 3.11 \times 0.1238 =$ $\mathbf{0.385\ m^3}$

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8.61

Water at 1000 kPa, 250°C is brought to saturated vapor in a piston/cylinder with an isothermal process. Find the specific work and heat transfer. Estimate the specific work from the area in the P-v diagram and compare it to the correct value.

Solution:

Continuity Eq.: $m_2 = m_1 = m$;

Energy Eq.:5.11 $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.3: $m(s_2 - s_1) = \int dQ/T$

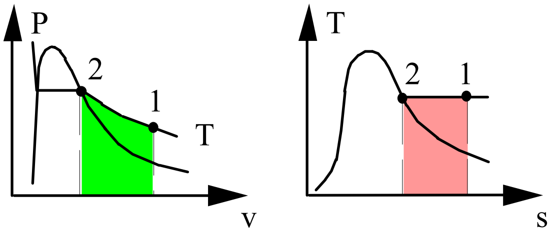
Process: T = constant, reversible

State 1: Table B.1.3:

$v_1 = 0.23268\ m^3/kg;\quad u_1 = 2709.91\ kJ/kg;\ s_1 = 6.9246\ kJ/kg\ K$

State 2: (T, x) Table B.1.1 $P_2 = 3973$ kPa

$v_2 = 0.05013\ m^3/kg,\ \ u_2 = 2602.37\ kJ/kg,\quad s_2 = 6.0729\ kJ/kg\ K$



From the entropy equation

${}_1q_2 = \int T\,ds = T(s_2 - s_1) = (250 + 273)\ (6.0729 - 6.9246) =$ **-445.6 kJ/kg**

From the energy equation

${}_1w_2 = {}_1q_2 + u_1 - u_2 = -445.6 + 2709.91 - 2602.37 =$ **-338 kJ/kg**

Estimation of the work term from the area in the P-v diagram

$${}_1w_{2\ area} \cong \frac{1}{2}\,(P_1+P_2)(v_2 - v_1) = \frac{1}{2}(1000 + 3973)(0.05013 - 0.23268)$$

$$= -454\ kJ/kg$$

Not extremely accurate estimate; P-v curve not linear more like Pv = constant as curve has positive curvature the linear variation over-estimates area.

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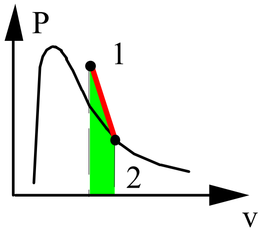
8.62

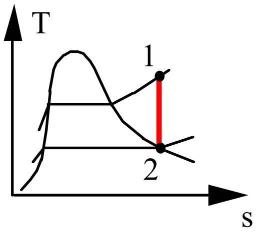
A rigid, insulated vessel contains superheated vapor steam at 3 MPa, 400°C. A valve on the vessel is opened, allowing steam to escape. The overall process is irreversible, but the steam remaining inside the vessel goes through a reversible adiabatic expansion. Determine the fraction of steam that has escaped, when the final state inside is saturated vapor.

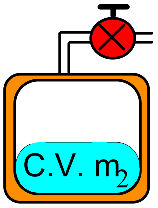
C.V.: steam remaining inside tank. Rev. & Adiabatic (inside only)

Cont.Eq.: $m_2 = m_1 = m$; Energy Eq.: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\ gen}$







Rev (${}_1S_{2\ gen} = 0$) Adiabatic ($Q = 0$) => $s_2 = s_1 = 6.9212 = s_G$ at T_2

$\Rightarrow$ $T_2 = 141°C$, $v_2 = v_{g\ at\ T_2} = 0.4972\ m^3/kg$

$$\frac{m_e}{m_1} = \frac{m_1\text{-}m_2}{m_1} = 1 - \frac{m_2}{m_1} = 1 - \frac{v_1}{v_2} = 1 - \frac{0.09936}{0.4972} = \mathbf{0.80}$$

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8.63

A cylinder containing R-134a at 10°C, 150 kPa, has an initial volume of 20 L. A piston compresses the R-134a in a reversible, isothermal process until it reaches the saturated vapor state. Calculate the required work and heat transfer to accomplish this process.

Solution:

C.V. R-134a.

Cont.Eq.: $m_2 = m_1 = m$;

Energy Eq.:5.11 $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

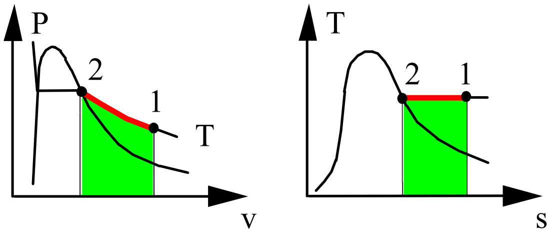
Entropy Eq.8.3: $m(s_2 - s_1) = \int dQ/T$

Process: T = constant, reversible

State 1: (T, P) Table B.5.2 $u_1 = 388.36$ kJ/kg, $s_1 = 1.822$ kJ/kg K

$m = V/v_1 = 0.02/0.148283 = 0.1349$ kg

State 2: (10°C, sat. vapor)
Table B.5.1
$u_2 = 383.67$ kJ/kg,
$s_2 = 1.7218$ kJ/kg K



As T is constant we can find Q by integration as

$${}_1Q_2 = \int T ds = mT(s_2 - s_1) = 0.1349 \times 283.15 \times (1.7218 - 1.822) = \mathbf{-3.83\ kJ}$$

The work is then from the energy equation

$${}_1W_2 = m(u_1 - u_2) + {}_1Q_2 = 0.1349 \times (388.36 - 383.67) - 3.83 = \mathbf{-3.197\ kJ}$$

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8.64

Water at 1000 kPa, 250°C is brought to saturated vapor in a piston/cylinder with an adiabatic process. Find the final T and the specific work. Estimate the specific work from the area in the P-v diagram and compare it to the correct value.

Solution:

C.V. Water, which is a control mass with unknown size.

Energy Eq.5.11: $u_2 - u_1 = 0 - {}_1w_2$

Entropy Eq.8.3: $s_2 - s_1 = \int dq/T = 0$

Process: Adiabatic ${}_1q_2 = 0$ and reversible as used above

State 1: Table B.1.3 $v_1 = 0.23268 \text{ m}^3/\text{kg}$, $u_1 = 2709.91 \text{ kJ/kg}$,

$s_1 = 6.9246 \text{ kJ/kg K}$

State 2: Table B.1.1 $x = 1$ and $s_2 = s_1 = 6.9246 \text{ kJ/kg K}$

=> $T_2 \cong 140.56°\text{C}$, $P_2 \cong 367.34 \text{ kPa}$, $v_2 = 0.50187 \text{ m}^3/\text{kg}$,

$u_2 \cong 2550.56 \text{ kJ/kg}$

From the energy equation

$${}_1w_2 = u_1 - u_2 = 2709.91 - 2550.56 = 159.35 \text{ kJ/kg}$$

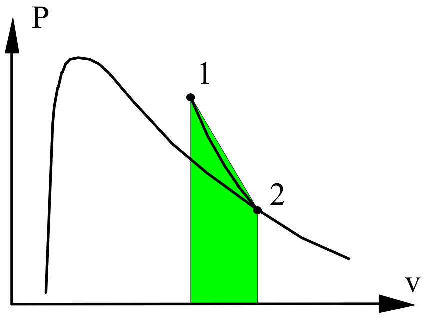
Now estimate the work term from the area in the P-v diagram

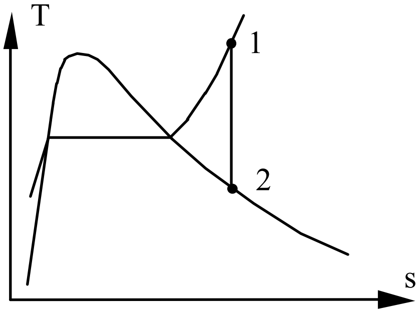
$${}_1w_2 \cong \frac{1}{2}(P_1 + P_2)(v_2 - v_1)$$

$$= \frac{1}{2}(1000 + 367.34)(0.50187 - 0.23268)$$

$$= \mathbf{184 \text{ kJ/kg}}$$

The s = constant curve is <u>not</u> a straight line in the the P-v diagram, notice the straight line overestimates the area slightly.





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8.65

A piston/cylinder contains 2 kg water at 200°C, 10 MPa. The piston is slowly moved to expand the water in an isothermal process to a pressure of 200 kPa. Any heat transfer takes place with an ambient at 200°C and the whole process may be assumed reversible. Sketch the process in a P-V diagram and calculate both the heat transfer and the total work.

Solution:

C.V. Water.

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.3: $m(s_2 - s_1) = \int dQ/T = {}_1Q_2 / T$

Process: T = C and reversible as used in entropy equation

State 1: Table B.1.4 : $v_1 = 0.001148 \text{ m}^3/\text{kg}$, $u_1 = 844.49 \text{ kJ/kg}$,

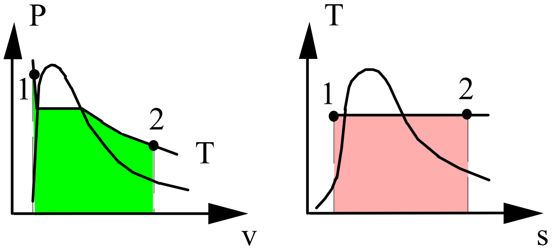
$s_1 = 2.3178 \text{ kJ/kg K}$,

$V_1 = mv_1 = 0.0023 \text{ m}^3$

State 2: Table B.1.3 : $v_2 = 1.08034 \text{ m}^3/\text{kg}$, $u_2 = 2654.4 \text{ kJ/kg}$

$s_2 = 7.5066 \text{ kJ/kg K}$

$V_2 = mv_2 = 2.1607 \text{ m}^3$,



From the entropy equation and the process equation

$${}_1Q_2 = mT(s_2 - s_1) = 2 \times 473.15\ (7.5066 - 2.3178) = \mathbf{4910\ kJ}$$

From the energy equation

$${}_1W_2 = {}_1Q_2 - m(u_2 - u_1) = \mathbf{1290.3\ kJ}$$

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8.66

Water at 1000 kPa, 250°C is brought to saturated vapor in a piston/cylinder with an isobaric process. Find the specific work and heat transfer. Estimate the specific heat transfer from the area in the T-s diagram and compare it to the correct value.

Solution:

C.V. H_2O

Energy Eq.5.11: $u_2 - u_1 = {}_1q_2 - {}_1w_2$

Entropy Eq.8.3: $s_2 - s_1 = \int dq/T$

Process: $P = C \quad => \quad w = \int P\,dv = P(v_2 - v_1)$

1: B1.3 $v_1 = 0.23268\ m^3/kg$, $s_1 = 6.9246\ kJ/kgK$, $u_1 = 2709.91\ kJ/kg$

2: B1.3 $v_2 = 0.19444\ m^3/kg$, $s_2 = 6.5864\ kJ/kg\ K$, $u_2 = 2583.64\ kJ/kg$, $T_2 = 179.91°C$

From the process equation

$${}_1w_2 = P\,(v_2 - v_1) = 1000\,(0.1944 - 0.23268) = \mathbf{-38.28\ kJ/kg}$$

From the energy equation

$${}_1q_2 = u_2 - u_1 + {}_1w_2 = 2583.64 - 2709.91 - 38.28 = \mathbf{-164.55\ kJ/kg}$$

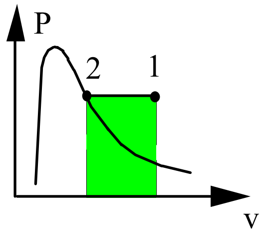
Now estimate the heat transfer from the T-s diagram.

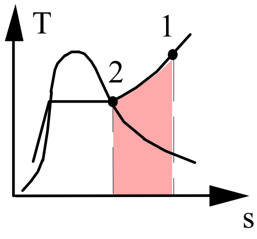
$${}_1q_2 = \int T\,ds = \text{AREA} \cong \frac{1}{2}(T_1 + T_2)(s_2 - s_1)$$

$$= \frac{1}{2}(250 + 179.91 + 2 \times 273.15)(6.5864 - 6.9246)$$

$$= 488.105 \times (-0.3382) = \mathbf{-165.1\ kJ/kg}$$

very close approximation. The P = C curve in the T-s diagram is nearly a straight line. Look at the constant P curves on Fig.E.1. Up over the critical point they curve significantly.





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Entropy of a liquid or a solid

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8.67

Two 5 kg blocks of steel, one at 250°C the other at 25°C, come in thermal contact. Find the final temperature and the change in entropy of the steel?

C.V. Both blocks, no external heat transfer, C from Table A.3.

Energy Eq.: $U_2 - U_1 = m_A(u_2 - u_1)_A + m_B(u_2 - u_1)_B = 0 - 0$

$$= m_A C(T_2 - T_{A1}) + m_B C(T_2 - T_{B1})$$

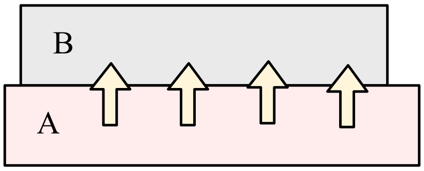
$$T_2 = \frac{m_A T_{A1} + m_B T_{B1}}{m_A + m_B} = \frac{1}{2} T_{A1} + \frac{1}{2} T_{B1} \ \mathbf{= 137.5^oC}$$

Entropy Eq.8.39: $S_2 - S_1 = m_A(s_2 - s_1)_A + m_B(s_2 - s_1)_B = {}_1S_{2\ gen}$

$$S_2 - S_1 = m_A C \ln \frac{T_2}{T_{A1}} + m_B C \ln \frac{T_2}{T_{B1}}$$

$$= 5 \times 0.46 \ln \frac{137.5 + 273.15}{250 + 273.15} + 5 \times 0.46 \ln \frac{137.5 + 273.15}{298.15}$$

$$= -0.5569 + 0.7363 = \mathbf{0.1794\ kJ/K}$$



Heat transfer over a finite temperature difference is an irreversible process

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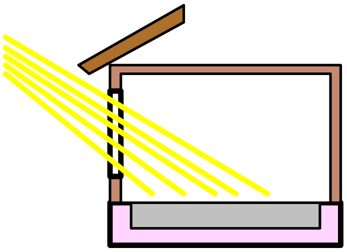
8.68

A large slab of concrete, 5 × 8 × 0.3 m, is used as a thermal storage mass in a solar-heated house. If the slab cools overnight from 23°C to 18°C in an 18°C house, what is the net entropy change associated with this process?

Solution:

C.V.: Control mass concrete.



$$V = 5 \times 8 \times 0.3 = 12 \text{ m}^3$$

$$m = \rho V = 2200 \times 12 = 26\,400 \text{ kg}$$

Energy Eq.: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.: $m(s_2 - s_1) = \frac{{}_1Q_2}{T_0} + {}_1S_{2\text{ gen}}$

Process: V = constant so ${}_1W_2 = 0$

Use heat capacity (Table A.3) for change in u of the slab

$${}_1Q_2 = mC\Delta T = 26400 \text{ kg} \times 0.88 \text{ kJ/kg-K} \times (-5) \text{ K} = -116\,160 \text{ kJ}$$

We add all the storage changes as in Eq.8.39:

$$\Delta S_{\text{slab}} = m(s_2 - s_1) = m\,C \ln\frac{T_2}{T_1}$$

$$= 26400 \text{ kg} \times 0.88 \text{ kJ/kg-K} \times \ln\frac{291.2}{296.2} = -395.5 \text{ kJ/K}$$

$$\Delta S_{\text{SURR}} = \frac{-{}_1Q_2}{T_0} = \frac{+116\,160}{291.2} = +398.9 \text{ kJ/K}$$

$\Delta S_{\text{NET}} = -395.5 + 398.9 =$ **+3.4 kJ/K**

$$= m(s_2 - s_1) - \frac{{}_1Q_2}{T_0} = {}_1S_{2\text{ gen}}$$

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8.69

A piston cylinder has constant pressure of 2000 kPa with water at 20°C. It is now heated up to 100°C. Find the heat transfer and the entropy change using the steam tables. Repeat the calculation using constant heat capacity and incompressibility.

Solution:

C.V. Water. Constant pressure heating.

Energy Eq.5.11: $u_2 - u_1 = {}_1q_2 - {}_1w_2$

Entropy Eq.8.3: $s_2 - s_1 = {}_1q_2 / T_{SOURCE} + {}_1s_{2\ gen}$

Process: $P = P_1 \quad => \quad {}_1w_2 = P(v_2 - v_1)$

The energy equation then gives the heat transfer as

$${}_1q_2 = u_2 - u_1 + {}_1w_2 = h_2 - h_1$$

Steam Tables B.1.4: $h_1 = 85.82$ kJ/kg; $s_1 = 0.2962$ kJ/kg K

$h_2 = 420.45$ kJ/kg; $s_2 = 1.3053$ kJ/kg K

$${}_1q_2 = h_2 - h_1 = -85.82 + 420.45 = \mathbf{334.63\ kJ/kg}$$

$$s_2 - s_1 = 1.3053 - 0.2962 = \mathbf{1.0091\ kJ/kg\ K}$$

Now using values from Table A.4: Liquid water $C_p = 4.18$ kJ/kg K

$$h_2 - h_1 \cong C_p(T_2 - T_1) = 4.18 \times 80 = \mathbf{334.4\ kJ/kg}$$

$$s_2 - s_1 \cong C_p \ln(T_2/T_1) = 4.18 \ln \frac{373.15}{293.15} = \mathbf{1.0086\ kJ/kg\ K}$$

Approximations are very good

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8.70

A 4 L jug of milk at 25°C is placed in your refrigerator where it is cooled down to the refrigerators inside constant temperature of 5°C. Assume the milk has the property of liquid water and find the entropy change of the milk.

Solution:

C.V. Jug of milk. Control mass at constant pressure.

Continuity Eq.: $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.37: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\ gen}$

State 1: Table B.1.1: $v_1 \cong v_f = 0.001003\ m^3/kg$, $s_f = 0.3673$ kJ/kg K

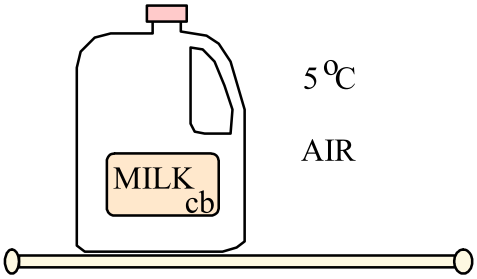
$$m = V/v = 0.004\ m^3/\ 0.001003\ (m^3/kg) = 3.988\ kg$$

State 2: Table B.1.1: $s = s_f = 0.0761$ kJ/kg K

The change of entropy becomes

$$S_2 - S_1 = m(s_2 - s_1) = 3.988\ (0.0761 - 0.3673)$$

$$= \mathbf{-\ 1.1613\ kJ/K}$$



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8.71

A foundry form box with 25 kg of 200°C hot sand is dumped into a bucket with 50 L water at 15°C. Assuming no heat transfer with the surroundings and no boiling away of liquid water, calculate the net entropy change for the process.

Solution:

C.V. Sand and water, constant pressure process

$$m_{sand}(u_2 - u_1)_{sand} + m_{H_2O}(u_2 - u_1)_{H_2O} = -P(V_2 - V_1)$$

$$\Rightarrow \; m_{sand}\Delta h_{sand} + m_{H_2O}\Delta h_{H_2O} = 0$$

For this problem we could also have said that the work is nearly zero as the solid sand and the liquid water will not change volume to any measurable extent. Now we get changes in u's instead of h's. For these phases $C_V = C_P = C$ which is a consequence of the incompressibility. Now the energy equation becomes

$$m_{sand}C_{sand}\Delta T_{sand} + m_{H_2O}C_{H_2O}\Delta T_{H_2O} = 0$$

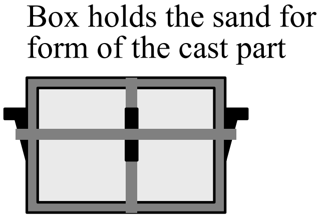
$$25 \times 0.8\times(T_2 - 200) + (50\times10^{-3}/0.001001) \times 4.184 \times (T_2 - 15) = 0$$

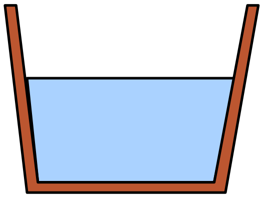
$$T_2 = 31.2°\text{C}$$

$$\Delta S = m_{sand}(s_2 - s_1) + m_{H2O} (s_2 - s_1)$$

$$= m_{sand}\, C_{sand} \ln(T_2/T_1) + m_{H2O}\, C_{H2O} \ln(T_2/T_1)$$

$$= 25 \times 0.8 \ln\left(\frac{304.3}{473.15}\right) + 49.95 \times 4.184 \ln\left(\frac{304.3}{288.15}\right) = \mathbf{2.57\ kJ/K}$$





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8.72

In a sink 5 liters of water at 70°C is combined with 1 kg aluminum pots, 1 kg of flatware (steel) and 1 kg of glass all put in at 20°C. What is the final uniform temperature and change in stored entropy neglecting any heat loss and work?

Energy Eq.: $U_2 - U_1 = \sum m_i(u_2 - u_1)_i = {}_1Q_2 - {}_1W_2 = 0$

Entropy Eq.: $S_2 - S_1 = \int dQ/T + {}_1S_{2\ gen}$

For the water: $v_f = 0.001023\ m^3/kg$, $V = 5\ L = 0.005\ m^3$; $m = V/v = 4.8876\ kg$

For the liquid and the metal masses we will use the specific heats (Tbl A.3, A.4) so

$$\sum m_i(u_2 - u_1)_i = \sum m_i C_{v\,i}\,(T_2 - T_1)_i = T_2 \sum m_i C_{v\,i} - \sum m_i C_{v\,i} T_{1\,i}$$

noticing that all masses have the same T_2 but not same initial T.

$$\sum m_i C_{v\,i} = 4.8876 \times 4.18 + 1 \times 0.9 + 1 \times 0.46 + 1 \times 0.8 = 22.59\ kJ/K$$

Energy Eq.: $22.59\ T_2 = 4.8876 \times 4.18 \times 70 + (1\times 0.9 + 1\times 0.46 + 1\times 0.8) \times 20$

$$= 1430.11 + 43.2$$

$$T_2 = \mathbf{65.2^oC}$$

$$S_2 - S_1 = \sum m_i(s_2 - s_1)_i = \sum m_i\, C_i \ln \frac{T_2}{T_{i1}}$$

$$= 4.8876 \times 4.18 \times \ln \frac{65.22 + 273.15}{70 + 273.15}$$

$$+ 1 \times (0.9 + 0.46 + 0.8) \ln \frac{65.22 + 273.15}{20 + 273.15}$$

$$= -0.28659 + 0.30986 = \mathbf{0.02327\ kJ/K}$$

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8.73

A 5-kg steel container is cured at 500°C. An amount of liquid water at 15°C, 100 kPa is added to the container so a final uniform temperature of the steel and the water becomes 75°C. Neglect any water that might evaporate during the process and any air in the container. How much water should be added and how much was the entropy changed?

CV. The steel and the water no external heat transfer nor any work.

Energy Eq.: $m_{H2O}(u_2 - u_1)_{H2O} + m_{st}(u_2 - u_1) = 0$

$m_{H2o}(313.87 - 62.98) + m_{st}C (T_2 - T_1) = 0$

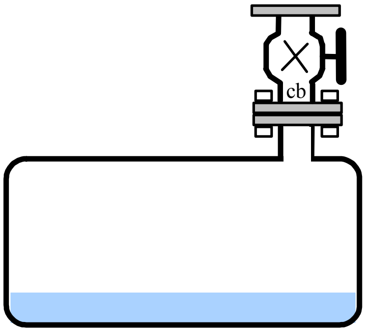
$m_{H2O} \times 250.89 + 5 \times 0.46 \times (75 - 500) = 0$

$m_{H2O} = 977.5/250.89 = \mathbf{3.896\ kg}$

Entropy Eq. 8.37: $m_{H2O} (s_2\text{-}s_1) + m_{st}(s_2 - s_1) = \varnothing + {}_1S_{2\ gen}$

$$S_2 - S_1 = 3.896\ (1.0154 - 0.2245) + 5 \times 0.46 \ln \frac{75 + 273}{773}$$

$$= 3.0813 - 1.8356 = \mathbf{1.246\ kJ/K}$$



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8.74

A pan in an autoshop contains 5 L of engine oil at 20°C, 100 kPa. Now 2 L of hot 100°C oil is mixed into the pan. Neglect any work term and find the final temperature and the entropy change.

Solution:

Since we have no information about the oil density, we assume the same for both from Table A.4: $\rho = 885 \text{ kg/m}^3$

Energy Eq.: $m_2u_2 - m_Au_A - m_Bu_B \cong 0 - 0$

$\Delta u \cong C_v\Delta T$ so same $C_v = 1.9$ kJ/kg K for all oil states.

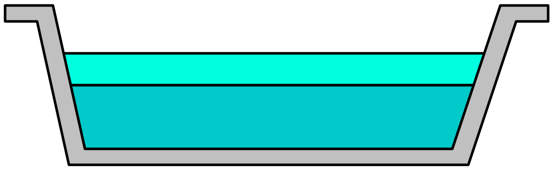
$$T_2 = \frac{m_A}{m_2} T_A + \frac{m_B}{m_2} T_B = \frac{5}{7} \times 20 + \frac{2}{7} \times 100 = 42.868^{\circ}\text{C} = \mathbf{316.02\ K}$$

$$S_2 - S_1 = m_2s_2 - m_As_A - m_Bs_B = m_A(s_2 - s_A) + m_B(s_2 - s_B)$$

$$= 0.005 \times 885 \times 1.9 \ln \frac{316.02}{293.15} + 0.002 \times 885 \times 1.9 \ln \frac{316.02}{373.15}$$

$$= 0.6316 - 0.5588 = \mathbf{+\ 0.0728\ kJ/K}$$

Entropy generation is the total change in S, recall Eq.8.39, no external Q



Oils shown before mixed to final uniform state.

8.75

A computer CPU chip consists of 50 g silicon, 20 g copper, 50 g polyvinyl chloride (plastic). It heats from 15°C to 70°C as the computer is turned on. How much did the entropy increase?

C.V. CPU chip. The process has electrical work input and no heat transfer.

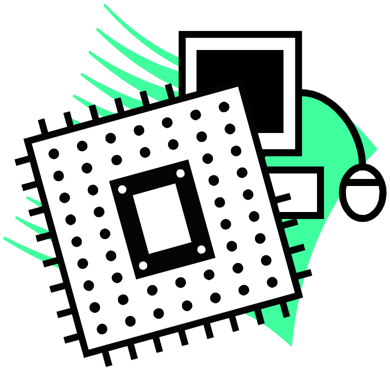
Entropy Eq.: $S_2 - S_1 = \sum m_i(s_2 - s_1)_i = \int dQ/T + {}_1S_{2\,gen} = {}_1S_{2\,gen}$

For the solid masses we will use the specific heats, Table A.3, and they all have the same temperature so

$$\sum m_i(s_2 - s_1)_i = \sum m_iC_i \ln(T_2 / T_1)_i = \ln (T_2/T_1) \sum m_iC_i$$

$$\sum m_iC_i = 0.05 \times 0.7 + 0.02 \times 0.42 + 0.05 \times 0.96 = 0.0914 \text{ kJ/K}$$

$$S_2 - S_1 = 0.0914 \times \ln (343.15 / 288.15) = \mathbf{0.016\ kJ/K}$$



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8.76

A 12 kg steel container has 0.2 kg superheated water vapor at 1000 kPa, both at 200°C. The total mass is now cooled to ambient temperature 30°C. How much heat transfer was taken out and what is the steel-water entropy change?

Solution:

C.V.: Steel and the water, control mass of constant volume.

Energy Eq.5.11: $U_2 - U_1 = {}_1Q_2 - {}_1W_2$

Process: V = constant => ${}_1W_2 = 0$

State 1: H_20 Table B.1.3: $u_1 = 2621.9$ kJ/kg, $v_1 = 0.20596\ m^3/kg$,
$s_1 = 6.6939$ kJ/kg K

State 2: H_20: T_2 , $v_2 = v_1$ => from Table B.1.1

$$x_2 = \frac{v - v_f}{v_{fg}} = \frac{0.20596 - 0.001004}{32.8922} = 0.006231$$

$$u_2 = 125.77 + x_2 \times 2290.81 = 140.04 \text{ kJ/kg}$$

$$s_2 = 0.4369 + x_2 \times 8.0164 = 0.48685 \text{ kJ/kg K}$$

$$ {}_1Q_2 = m(u_2 - u_1) = m_{steel}C_{steel} (T_2 - T_1) + m_{H2O} (u_2 - u_1)_{H2O}$$

$$= 12 \times 0.46 (30 - 200) + 0.2 (140.04 - 2621.9)$$

$$= \mathbf{-1434.8\ kJ}$$

Entropy changes from Eq.8.11 and the water tables

$$S_2 - S_1 = m_2 s_2 - m_1 s_1 = m_{steel}C_{steel} \ln \left(\frac{T_2}{T_1}\right) + m_{H2O} (s_2 - s_1)_{H2O}$$

$$=12 \times 0.46 \ln \left(\frac{303.15}{473.15}\right) + 0.2 (0.48685 - 6.6939)$$

$$= -2.4574 - 1.2414$$

$$= \mathbf{-3.699\ kJ/K}$$

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8.77

Two kg of liquid lead initially at 500°C are poured into a form. It then cools at constant pressure down to room temperature of 20°C as heat is transferred to the room. The melting point of lead is 327°C and the enthalpy change between the phases, h_{if} , is 24.6 kJ/kg. The specific heats are in Tables A.3 and A.4. Calculate the net entropy change for this process.

Solution:

C.V. Lead, constant pressure process

$$m_{Pb}(u_2 - u_1)_{Pb} = {}_1Q_2 - P(V_2 - V_1)$$

We need to find changes in enthalpy (u + Pv) for each phase separately and then add the enthalpy change for the phase change.

Consider the process in several steps:

Cooling liquid to the melting temperature

Solidification of the liquid to solid

Cooling of the solid to the final temperature

$$_1Q_2 = m_{Pb}(h_2 - h_1) = m_{Pb}(h_2 - h_{327,sol} - h_{if} + h_{327,f} - h_{500})$$

$$= 2 \times (0.138 \times (20 - 327) - 24.6 + 0.155 \times (327 - 500))$$

$$= -84.732 - 49.2 - 53.63 = -187.56 \text{ kJ}$$

$$\Delta S_{CV} = m_{Pb}[C_{p\ sol}\ln(T_2/600) - (h_{if}/600) + C_{P\ liq}\ln(600/T_1)]$$

$$= 2 \times \left[0.138 \ln \frac{293.15}{600} - \frac{24.6}{600} + 0.155 \ln \frac{600}{773.15}\right] = -0.358 \text{ kJ/K}$$

$$\Delta S_{SUR} = -{}_1Q_2/T_0 = 187.56/293.15 = 0.64 \text{ kJ/K}$$

The net entropy change from Eq.8.39 is equivalent to total entropy generation

$$\Delta S_{net} = \Delta S_{CV} + \Delta S_{SUR} = \mathbf{0.282\ kJ/K}$$

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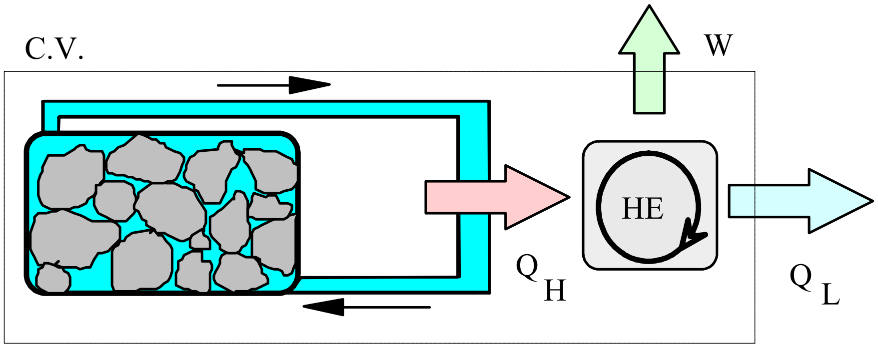
8.78

Find the total work the heat engine can give out as it receives energy from the rock bed as described in Problem 7.65 (see Fig.P 8.78). Hint: write the entropy balance equation for the control volume that is the combination of the rock bed and the heat engine.

Solution:

To get the work we must integrate over the process or do the 2nd law for a control volume around the whole setup out to T_0

C.V. Heat engine plus rock bed out to T_0. W and Q_L goes out.



Energy Eq.5.11: $(U_2 - U_1)_{rock} = - Q_L - W$

Entropy Eq.8.3: $(S_2 - S_1)_{rock} = - \frac{Q_L}{T_0} = mC \ \ln\left(\frac{T_2}{T_1}\right)$

$$= 5500 \times 0.89 \ln \frac{290}{400} = -1574.15 \text{ kJ/K}$$

$$Q_L = -T_0 (S_2 - S_1)_{rock} = -290 (-1574.15) = 456\,504 \text{ kJ}$$

The energy drop of the rock $-(U_2 - U_1)_{rock}$ equals Q_H into heat engine

$$(U_2 - U_1)_{rock} = mC (T_2 - T_1) = 5500 \times 0.89 (290 - 400) = -538\,450 \text{ kJ}$$

$$W = -(U_2 - U_1)_{rock} - Q_L = 538450 - 456504 = \mathbf{81\,946\ kJ}$$

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8.79

A 5-kg aluminum radiator holds 2 kg of liquid R-134a at -10C. The setup is brought indoors and heated with 220 kJ. Find the final temperature and the change in entropy of all the mass.

Solution:

C.V. The aluminum radiator and the R-134a.

Energy Eq.5.11: $m_2u_2 - m_1u_1 = {}_1Q_2 - 0$

Process: No change in volume so no work as used above.

The energy equation now becomes (summing over the mass)

$$m_{al}\,(u_2 - u_1)_{al} + m_{R134a}\,(u_2 - u_1)_{R134a} = {}_1Q_2$$

Use specific heat from Table A.3 and A.4

$$m_{al}C_{al}\,(T_2 - T_1) + m_{R134a}C_{R134a}\ln\,(T_2 - T_1) = {}_1Q_2$$

$$T_2 - T_1 = {}_1Q_2 / [m_{al}C_{al} + m_{R134a}C_{R134a}]$$

$$= 220 / [5 \times 0.9 + 2 \times 1.43] = 29.89^{o}C$$

$$T_2 = -10 + 29.89 = 19.89^{o}C$$

Entropy change for solid (A.3) and liquid (A.4) from Eq.8.11

$$S_2 - S_1 = m_{al}\,(s_2 - s_1)_{al} + m_{R134a}\,(s_2 - s_1)_{R134a}$$

$$= m_{al}C_{al}\ln\,(T_2/T_1) + m_{R134a}C_{R134a}\ln\,(T_2/T_1)$$

$$= (5 \times 0.9 + 2 \times 1.43)\ln\frac{(19.89 + 273.15)}{-10 + 273.15}$$

$$= \mathbf{0.792\ kJ/K}$$

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Entropy of ideal gases

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8.80

Air inside a rigid tank is heated from 300 to 350 K. Find the entropy increase s_2 - s_1? What if it is from 1300 to 1350 K?

Process: V = C $\rightarrow$ ${}_1W_2 = \emptyset$

Entropy change from Eq.8.17:

a) $s_2 - s_1 = C_{vo} \ln \left(\frac{T_2}{T_1}\right) = 0.717 \ln \left(\frac{350}{300}\right) = \mathbf{0.1105\ kJ/kgK}$

b) $s_2 - s_1 = C_{vo} \ln \left(\frac{T_2}{T_1}\right) = 0.717 \ln \left(\frac{1350}{1300}\right) = \mathbf{0.02706\ kJ/kgK}$

From A.7:

case a) $C_v \approx \Delta u / \Delta T = 36/50 = 0.72$ kJ/kg K , see A.5

case b) $C_v \approx \Delta u / \Delta T = 45.2/50 = 0.904$ kJ/kg K (25 % higher)
so result should have been 0.0341 kJ/kgK

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8.81

A piston/cylinder setup contains air at 100 kPa, 400 K which is compressed to a final pressure of 1000 kPa. Consider two different processes (i) a reversible adiabatic process and (ii) a reversible isothermal process. Show both processes in P-v and a T-s diagram. Find the final temperature and the specific work for both processes.

Solution:

C.V. Air, control mass of unknown size and mass.

Energy Eq.5.11: $u_2 - u_1 = {}_1q_2 - {}_1w_2$

Entropy Eq.8.14: $s_2 - s_1 = \int dq/T + {}_1s_{2\,gen}$

Process: Reversible ${}_1s_{2\,gen} = 0$

i) $dq = 0$ so ${}_1q_2 = 0$

ii) $T = C$ so $\int dq/T = {}_1q_2/T$

i) For this process the entropy equation reduces to:

$s_2 - s_1 = 0 + 0$ so we have constant s, an isentropic process.

The relation for an ideal gas, constant s and k becomes Eq.8.32

$$T_2 = T_1(\,P_2 / P_1)^{\frac{k-1}{k}} = 400\left(\frac{1000}{100}\right)^{\frac{0.4}{1.4}} = 400 \times 10^{0.28575} = \mathbf{772\ K}$$

From the energy equation we get the work term

$${}_1w_2 = u_1 - u_2 = C_v(T_1 - T_2) = 0.717(400 - 772) = \mathbf{-266.7\ kJ/kg}$$

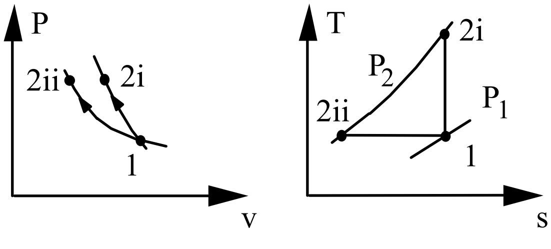
ii) For this process $T_2 = T_1$ so since ideal gas we get

$$u_2 = u_1 \text{ also } s^o_{T2} = s^o_{T1} \quad => \quad \text{Energy Eq.: } {}_1w_2 = {}_1q_2$$

Now from the entropy equation we solve for ${}_1q_2$

$${}_1w_2 = {}_1q_2 = T(s_2 - s_1) = T[s^o_{T2} - s^o_{T1} - R \ln \frac{P_2}{P_1}] = -RT \ln \frac{P_2}{P_1}$$

$$= -\,0.287 \times 400 \ln 10 = \mathbf{-264\ kJ/kg}$$



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8.82

Prove that the two relations for changes in s, Eqs.8.16 and 8.17 are equivalent once we assume constant specific heat. Hint: recall the relation for specific heat in Eq. 5.27.

From Eq. 5.27: $C_{po} = C_{vo} + R$

Start with Eq.8.16: $s_2 - s_1 = C_{po} \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$

Now substitute Eq.5.27 to get:

$$\begin{aligned} s_2 - s_1 &= (C_{vo} + R) \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} \\ &= C_{vo} \ln \frac{T_2}{T_1} - R \left[\ln \frac{P_2}{P_1} - \ln \frac{T_2}{T_1} \right] \\ &= C_{vo} \ln \frac{T_2}{T_1} - R \ln \left(\frac{P_2}{P_1} \frac{T_1}{T_2} \right) \end{aligned}$$

Use the ideal gas law $Pv = RT$ for both states to get the ratio

$$\frac{P_2 v_2}{RT_2} = \frac{P_1 v_1}{RT_1} \quad \Rightarrow \quad \frac{P_2}{P_1} \frac{T_1}{T_2} = \frac{v_1}{v_2}$$

so then we get to Eq. 8.17 as

$$\begin{aligned} s_2 - s_1 &= C_{vo} \ln \frac{T_2}{T_1} - R \ln \frac{v_1}{v_2} \\ &= C_{vo} \ln \frac{T_2}{T_1} + \ln \frac{v_2}{v_1} \end{aligned}$$

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8.83

Assume an ideal gas with constant specific heats. Show the functions T(s, P = C) and T(s, v = C) mathematically and sketch them in a T-s diagram.

From Eq 8.17 when $P_2 = P_1$

$$s_2 - s_1 = C_{po} \ln \frac{T_2}{T_1}$$

so we can solve for T_2 as a function of s_2 as

$$T_2 = T_1 \exp \left[\frac{s_2 - s_1}{C_{po}} \right]$$

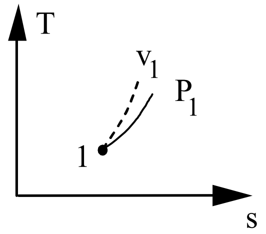
and it is an exponential function. For the other function use Eq.8.16 with $v_2 = v_1$

$$s_2 - s_1 = C_{vo} \ln \frac{T_2}{T_1}$$

so we can solve for T_2 as a function of s_2 as

$$T_2 = T_1 \exp \left[\frac{s_2 - s_1}{C_{vo}} \right]$$

which is also an exponential function. Since C_{po} is larger than C_{vo} the slope of the first function is lower than the slope of the second function.



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8.84

Water at 150°C, 400 kPa, is brought to 1200°C in a constant pressure process. Find the change in the specific entropy, using a) the steam tables, b) the ideal gas water Table A.8, and c) the specific heat from A.5.

Solution:

a)

State 1: Table B.1.3 Superheated vapor $s_1 = 6.9299$ kJ/kgK

State 2: Table B.1.3 $s_2 = 9.7059$ kJ/kgK

$$s_2 - s_1 = 9.7059 - 6.9299 = \mathbf{2.776\ kJ/kgK}$$

b)

Table A.8 at 423.15 K: $s^o_{T1} = 11.13891$ kJ/kgK

Table A.8 at 1473.15 K: $s^o_{T2} = 13.86383$ kJ/kgK

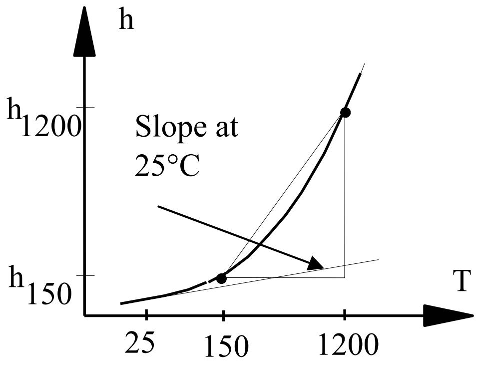
$$s_2 - s_1 = s^o_{T2} - s^o_{T1} - R \ln \frac{P_2}{P_1} = s^o_{T2} - s^o_{T1}$$

$$s^o_{T2} - s^o_{T1} = 13.86383 - 11.13891 = \mathbf{2.72492\ kJ/kgK}$$

c) Table A.5: $C_{po} = 1.872$ kJ/kgK

$$s_2 - s_1 \approx C_{po} \ln \left(\frac{T_2}{T_1}\right) = 1.872 \ln \left(\frac{1473.15}{423.15}\right) = \mathbf{2.3352\ kJ/kgK}$$

Notice how the average slope from 150°C to 1200°C is higher than the one at 25°C (= C_{po})



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8.85

R-410a at 400 kPa is brought from 20°C to 120°C in a constant pressure process. Evaluate the change in specific entropy using Table B.4 and using ideal gas with $C_p = 0.81$ kJ/kgK.

Table B.4.2 $\quad s_1 = 1.2108$ kJ/kg-K, $\quad s_2 = 1.4788$ kJ/kg-K

$s_2 - s_1 = 1.4788 - 1.2108 =$ **0.268 kJ/kg-K**

Eq. 8.17: $\quad s_2 - s_1 \approx C_{po} \ln \frac{T_2}{T_1} = 0.81 \ln \frac{393.15}{293.15} =$ **0.238 kJ/kg-K**

Two explanations for the difference are as the average temperature is higher than 25°C we could expect a higher value of the specific heat and secondly it is not an ideal gas (if you calculate $Z = Pv/RT = 0.94$).

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8.86

R-410a at 300 kPa, 20^{o}C is brought to 500 kPa, 200^{o}C in a constant volume process. Evaluate the change in specific entropy using Table B.4 and using ideal gas with $C_v = 0.695$ kJ/kgK.

Table B.4.2 $s_1 = 1.2485$ kJ/kg-K, $v_1 = 0.10720$ m^3/kg

$s_2 = 1.6413$ kJ/kg-K, $v_2 = 0.10714$ m^3/kg (very close to v_1)

$s_2 - s_1 = 1.6413 - 1.2485 =$ **0.3928 kJ/kg-K**

Eq. 8.16: $$s_2 - s_1 \approx C_{vo} \ln \frac{T_2}{T_1} = 0.695 \ln \frac{473.15}{293.15} = \mathbf{0.333\ kJ/kg\text{-}K}$$

Two explanations for the difference are as the average temperature is higher than 25^{o}C we could expect a higher value of the specific heat and secondly it is not an ideal gas (if you calculate $Z = Pv/RT = 0.96$).

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8.87

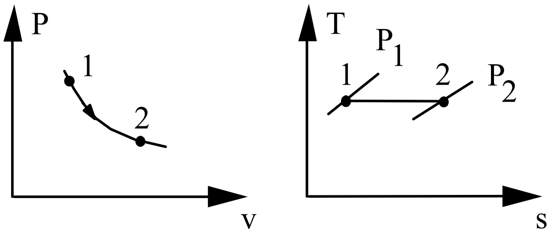
A mass of 1 kg of air contained in a cylinder at 1.5 MPa, 1000 K, expands in a reversible isothermal process to a volume 10 times larger. Calculate the heat transfer during the process and the change of entropy of the air.

Solution:

C.V. Air, control mass.

Energy Eq. 5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2 = 0$

Process: T = constant so with ideal gas => $u_2 = u_1$



From the process equation and ideal gas law

$$PV = mRT = \text{constant}$$

we can calculate the work term as in Eq.4.5

$${}_1Q_2 = {}_1W_2 = \int P dV = P_1V_1 \ln (V_2/V_1) = mRT_1 \ln (V_2/V_1)$$

$$= 1 \times 0.287 \times 1000 \ln (10) = \mathbf{660.84\ kJ}$$

The change of entropy from Eq.8.3 is

$$\Delta S_{air} = m(s_2 - s_1) = {}_1Q_2/T = 660.84/1000 = \mathbf{0.661\ kJ/K}$$

If instead we use Eq.8.17 we would get

$$\Delta S_{air} = m(s_2 - s_1) = m(C_{vo} \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1})$$

$$= 1 [0 + 0.287 \ln(10)] = 0.661 \text{ kJ/K}$$

consistent with the above result.

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8.88

Consider a small air pistol with a cylinder volume of 1 cm^3 at 250 kPa, 27°C. The bullet acts as a piston initially held by a trigger. The bullet is released so the air expands in an adiabatic process. If the pressure should be 100 kPa as the bullet leaves the cylinder find the final volume and the work done by the air.

Solution:

C.V. Air. Assume a reversible, adiabatic process.

Energy Eq.5.11: $u_2 - u_1 = 0 - {}_1w_2$;

Entropy Eq.8.37: $s_2 - s_1 = \int dq/T + {}_1s_{2\ gen} = 0$

State 1: (T_1,P_1) State 2: $(P_2, ?)$

So we realize that one piece of information is needed to get state 2.

Process: Adiabatic ${}_1q_2 = 0$ Reversible ${}_1s_{2\ gen} = 0$

With these two terms zero we have a zero for the entropy change. So this is a constant s (isentropic) expansion process giving $s_2 = s_1$. From Eq.8.23

$$T_2 = T_1(P_2 / P_1)^{\frac{k-1}{k}} = 300 \left(\frac{100}{250}\right)^{\frac{0.4}{1.4}} = 300 \times 0.4^{0.28575} = 230.9 \text{ K}$$

The ideal gas law PV = mRT at both states leads to

$$V_2 = V_1 P_1 T_2/P_2 T_1 = 1 \times 250 \times 230.9/100 \times 300 = \mathbf{1.92\ cm^3}$$

The work term is from Eq.8.29 or Eq.4.4 with polytropic exponent n = k

$${}_1W_2 = \frac{1}{1 - k}(P_2V_2 - P_1V_1) = \frac{1}{1 - 1.4}(100 \times 1.92 - 250 \times 1) \times 10^{-6}$$

$$= \mathbf{0.145\ J}$$

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8.89

Oxygen gas in a piston cylinder at 300 K, 100 kPa with volume 0.1 m^3 is compressed in a reversible adiabatic process to a final temperature of 700 K. Find the final pressure and volume using Table A.5.

Solution:

C.V. Air. Assume a reversible, adiabatic process.

Energy Eq.5.11: $u_2 - u_1 = 0 - {}_1w_2$;

Entropy Eq.8.37: $s_2 - s_1 = \int dq/T + {}_1s_{2\ gen} = 0$

Process: Adiabatic ${}_1q_2 = 0$ Reversible ${}_1s_{2\ gen} = 0$

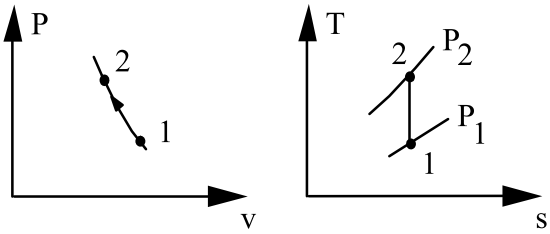
Properties: Table A.5: $k = 1.393$

With these two terms zero we have a zero for the entropy change. So this is a constant s (isentropic) expansion process. From Eq.8.23

$$P_2 = P_1(T_2 / T_1)^{\frac{k}{k-1}} = \mathbf{2015\ kPa}$$

Using the ideal gas law to eliminate P from this equation leads to Eq.8.24

$$V_2 = V_1(T_2 / T_1)^{\frac{1}{1-k}} = 0.1 \times \left(\frac{700}{300}\right)^{\frac{1}{1-1.393}} = \mathbf{0.0116\ m^3}$$



8.90

Oxygen gas in a piston cylinder at 300 K, 100 kPa with volume 0.1 m^3 is compressed in a reversible adiabatic process to a final temperature of 700 K. Find the final pressure and volume using constant heat capacity from Table A.8.

Solution:

C.V. Air. Assume a reversible, adiabatic process.

Energy Eq.5.11: $u_2 - u_1 = 0 - {}_1w_2$;

Entropy Eq.8.37: $s_2 - s_1 = \int dq/T + {}_1s_{2\,gen} = 0$

Process: Adiabatic ${}_1q_2 = 0$ Reversible ${}_1s_{2\,gen} = 0$

With these two terms zero we have a zero for the entropy change. So this is a constant s (isentropic) expansion process. From Eq.8.19

$$s^o_{T2} - s^o_{T1} = R \ln \frac{P_2}{P_1}$$

Properties: Table A.8: $s^o_{T1} = 6.4168$, $s^o_{T2} = 7.2336$ kJ/kg K

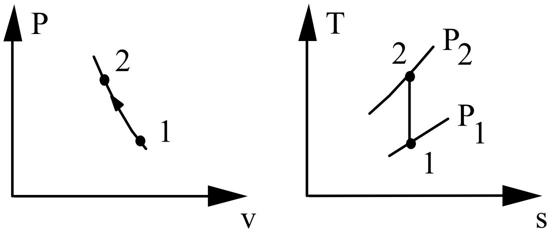
$$\frac{P_2}{P_1} = \exp\,[(s^o_{T2} - s^o_{T1})/R] = \exp\left(\frac{7.2336 - 6.4168}{0.2598}\right) = 23.1955$$

$$P_2 = 100 \times 23.1955 = \mathbf{2320\ kPa}$$

Ideal gas law: $P_1V_1 = mRT_1$ and $P_2V_2 = mRT_2$

Take the ratio of these so mR drops out to give

$$V_2 = V_1 \times (T_2 / T_1) \times (P_1 / P_2) = 0.1 \times \left(\frac{700}{300}\right) \times \left(\frac{100}{2320}\right) = \mathbf{0.01\ m^3}$$



8.91

A rigid tank contains 1 kg methane at 500 K, 1500 kPa. It is now cooled down to 300 K. Find the heat transfer and the change in entropy using ideal gas.

Ideal gas, constant volume so there is no work.

Energy Eq. 5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2 = {}_1Q_2$

Use specific heat from Table A.5

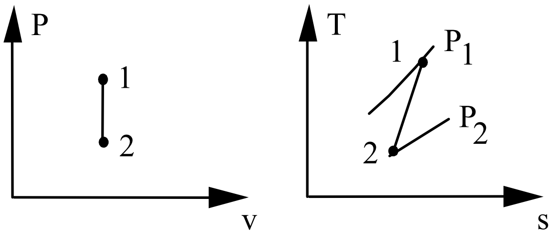
$$u_2 - u_1 = C_v (T_2 - T_1) = 1.736 (300 - 500) = -347.2 \text{ kJ/kg}$$

$${}_1Q_2 = m(u_2 - u_1) = 1 (-347.2) = \mathbf{-347.2 \text{ kJ}}$$

The change in s for an ideal gas, Eqs.8.16-17 and $v_2 = v_1$ gives

$$m(s_2 - s_1) = m \left[C_{vo} \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1} \right] = m\, C_{vo} \ln \frac{T_2}{T_1}$$

$$= 1 \times 1.736 \ln \frac{300}{500} = \mathbf{-\ 0.8868 \text{ kJ/K}}$$



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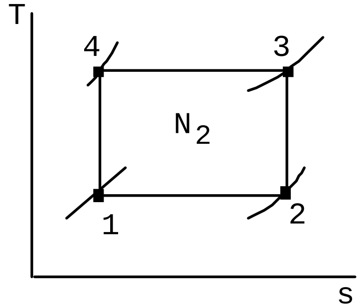
8.92

Consider a Carnot-cycle heat pump having 1 kg of nitrogen gas in a cylinder/piston arrangement. This heat pump operates between reservoirs at 300 K and 400 K. At the beginning of the low-temperature heat addition, the pressure is 1 MPa. During this process the volume triples. Analyze each of the four processes in the cycle and determine

a. The pressure, volume, and temperature at each point

b. The work and heat transfer for each process

Solution:



$T_1 = T_2 =$ **300 K**, $T_3 = T_4 =$ **400 K**,

$P_1 =$ **1 MPa**, $V_2 = 3 \times V_1$

a) $P_2V_2 = P_1V_1 \Rightarrow P_2 = P_1/3 = \mathbf{0.3333\ MPa}$

$$V_1 = \frac{mRT_1}{P_1} = \frac{1 \times 0.2968 \times 300}{1000} = \mathbf{0.08904\ m^3}$$

$V_2 = \mathbf{0.26712\ m^3}$

$$P_3 = P_2(T_3/T_2)^{\frac{k}{k-1}} = 0.3333\left(\frac{400}{300}\right)^{3.5} = \mathbf{0.9123\ MPa}$$

$$V_3 = V_2 \times \frac{P_2}{P_3} \times \frac{T_3}{T_2} = 0.26712 \times \frac{0.3333}{0.9123} \times \frac{400}{300} = \mathbf{0.1302\ m^3}$$

$$P_4 = P_1(T_3/T_1)^{\frac{k}{k-1}} = 1\left(\frac{400}{300}\right)^{3.5} = \mathbf{2.73707\ MPa}$$

$$V_4 = V_1 \times \frac{P_1}{P_4} \times \frac{T_4}{T_1} = 0.08904 \times \frac{1}{2.737} \times \frac{400}{300} = \mathbf{0.04337\ m^3}$$

b) $_1W_2 = {}_1Q_2 = mRT_1 \ln(P_1/P_2)$

$= 1 \times 0.2968 \times 300 \ln(1/0.333) = \mathbf{97.82\ kJ}$

$_3W_4 = {}_3Q_4 = mRT_3 \ln(P_3/P_4)$

$= 1 \times 0.2968 \times 400 \ln(0.9123/2.737) = \mathbf{-130.43\ kJ}$

$_2W_3 = -mC_{v0}(T_3 - T_2) = -1 \times 0.7448(400 - 300) = \mathbf{-74.48\ kJ}$

$_4W_1 = -mC_{v0}(T_1 - T_4) = -1 \times 0.7448(300 - 400) = \mathbf{+74.48\ kJ}$

$_2Q_3 = \mathbf{0}$, $_4Q_1 = \mathbf{0}$

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8.93

A hydrogen gas in a piston/cylinder assembly at 280 K, 100 kPa with a volume of 0.1 m^3 is now compressed to a volume of 0.01 m^3 in a reversible adiabatic process. What is the new temperature and how much work is required?

Entropy Eq.8.37: $s_2 - s_1 = \int dq/T + {}_1s_{2\ gen} = 0 + 0 = 0$

For an isentropic process and constant heat capacity we have Eq.8.24

From Eq.8.24: $T_2 = T_1(v_2 / v_1)^{1-k} = 280\ (0.01/0.1)^{1-1.409} = \mathbf{718\ K}$

From Eq.8.39: ${}_1w_2 = \frac{R}{1-k}(T - T) = \frac{4.1243}{1-1.409}(718 - 280) = \mathbf{-4417\ kJ/kg}$

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8.94

A handheld pump for a bicycle has a volume of 25 cm^3 when fully extended. You now press the plunger (piston) in while holding your thumb over the exit hole so that an air pressure of 300 kPa is obtained. The outside atmosphere is at P_0, T_0. Consider two cases: (1) it is done quickly (~1 s), and (2) it is done very slowly (~1 h).

a. State assumptions about the process for each case.

b. Find the final volume and temperature for both cases.

Solution:

C.V. Air in pump. Assume that both cases result in a reversible process.

State 1: P_0, T_0 State 2: 300 kPa, ?

One piece of information must resolve the ? for a state 2 property.

Case I) Quickly means no time for heat transfer

Q = 0, so a reversible adiabatic compression.

$$u_2 - u_1 = -{}_1w_2 \;;\quad s_2 - s_1 = \int dq/T + {}_1s_{2\,gen} = 0$$

With constant s and constant heat capacity we use Eq.8.23

$$T_2 = T_1(\,P_2 / P_1)^{\frac{k-1}{k}} = 298 \left(\frac{300}{101.325}\right)^{\frac{0.4}{1.4}} = \mathbf{405.3\ K}$$

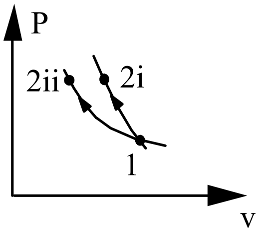
Use ideal gas law PV = mRT at both states so ratio gives

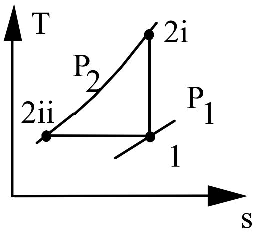
$$\Rightarrow \quad V_2 = P_1V_1T_2/T_1P_2 = \mathbf{11.48\ cm^3}$$

Case II) Slowly, time for heat transfer so T = constant = T_0.

The process is then a reversible isothermal compression.

$$T_2 = T_0 = \mathbf{298\ K} \qquad \Rightarrow \qquad V_2 = V_1P_1/P_2 = \mathbf{8.44\ cm^3}$$





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8.95

An insulated piston/cylinder setup contains carbon dioxide gas at 400 kPa, 300 K which is then compressed to 3 MPa in a reversible adiabatic process. Calculate the final temperature and the specific work using a) ideal gas tables A.8 and b) using constant specific heats A.5.

Solution:

C.V. CO_2, a control mass undergoing a reversible, adiabatic process.

Energy Eq.5.11: $u_2 - u_1 = 0 - {}_1w_2$;

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

Process: Adiabatic ${}_1q_2 = 0$ Reversible ${}_1s_{2\,gen} = 0$

State 1: (300 K, 400 kPa) State 2: (3000 kPa, ?)

With two terms zero in the entropy equation we have a zero for the entropy change. So this is a constant s (isentropic) expansion process, $s_2 = s_1$.

a) Table A.8 for CO_2 and Eq.8.19

$$s_2 - s_1 = 0 = s^o_{T2} - s^o_{T1} - R \ln(P_2/P_1)$$

$$s^o_{T2} = s^o_{T1} + R \ln \frac{P_2}{P_1} = 4.8631 + 0.1889 \ln \frac{3000}{400} = 5.2437 \text{ kJ/kg-K}$$

Now interpolate in A.8 to find T_2

$$T_2 = 450 + 50\,(5.2437 - 5.2325)/(5.3375 - 5.2325) = \mathbf{455.3\ K}$$

$${}_1w_2 = -(u_2 - u_1) = -(271 - 157.7) = \mathbf{-113.3\ kJ/kg}$$

b) Table A.5: $k = 1.289$, $C_{Vo} = 0.653$ kJ/kg K and now Eq.8.23

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = 300 \left(\frac{3000}{400}\right)^{0.224} = \mathbf{471.1\ K}$$

$${}_1w_2 = -C_{Vo}(T_2 - T_1) = -0.653\,(471.1 - 300) = \mathbf{-111.7\ kJ/kg}$$

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8.96

Extend the previous problem to also solve using a constant specific heat at an average temperature from A.6 and resolve using Table B.3.

C.V. CO_2, a control mass undergoing a reversible, adiabatic process.

Energy Eq.5.11: $u_2 - u_1 = 0 - {}_1w_2$;

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

Process: Adiabatic ${}_1q_2 = 0$ Reversible ${}_1s_{2\ gen} = 0$

State 1: (300 K, 400 kPa) State 2: (3000 kPa, ?)

With two terms zero in the entropy equation we have a zero for the entropy change. So this is a constant s (isentropic) expansion process, $s_2 = s_1$.

Find a heat capacity at an average temperature from Table A.6.

Estimate $T_2 \sim 500$ K giving $T_{AVE} \sim 400$ K => $\theta = 0.4$

$$C_{Po} = 0.45 + 1.67 \times 0.4 - 1.27 \times 0.4^2 + 0.39 \times 0.4^3 = 0.9398 \text{ kJ/kg K}$$

$$C_{Vo} = C_{Po} - R = 0.9398 - 0.1889 = 0.7509, \quad k = C_{Po}/C_{Vo} = 1.2516$$

Eq.8.32: $$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = 300 \left(\frac{3000}{400}\right)^{0.201} = \mathbf{449.8\ K}$$

$${}_1w_2 = -C_{Vo}(T_2 - T_1) = -0.7509\ (449.8 - 300) = \mathbf{-112.5\ kJ/kg}$$

From Table B.3.2: $s_1 = 1.8102$ kJ/kg-K, $u_1 = 336.2$ kJ/kg

$T_2 = 186.7^{o}C =$ **459.8 K**, $u_2 = 446.9$ kJ/kg

$${}_1w_2 = -(u_2 - u_1) = -(446.9 - 336.2) = \mathbf{-110.7\ kJ/kg}$$

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8.97

A piston/cylinder, shown in Fig. P8.97, contains air at 1380 K, 15 MPa, with V_1 = 10 cm^3, A_{cyl} = 5 cm^2. The piston is released, and just before the piston exits the end of the cylinder the pressure inside is 200 kPa. If the cylinder is insulated, what is its length? How much work is done by the air inside?

Solution:

C.V. Air, Cylinder is insulated so adiabatic, Q = 0.

Continuity Eq.: $m_2 = m_1 = m,$

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2 = - {}_1W_2$

Entropy Eq.8.37: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\,gen} = 0 + {}_1S_{2\,gen}$

State 1: (T_1, P_1) State 2: $(P_2, ?)$

So one piece of information is needed for the ?, assume reversible process.

$${}_1S_{2\,gen} = 0 \quad => \quad s_2 - s_1 = 0$$

State 1: Table A.7: $u_1 = 1095.2$ kJ/kg, $s^o_{T1} = 8.5115$ kJ/kg K

$$m = P_1V_1/RT_1 = \frac{15000 \times 10\times10^{-6}}{0.287 \times 1380} = 0.000379 \text{ kg}$$

State 2: P_2 and from Entropy eq.: $s_2 = s_1$ so from Eq.8.19

$$s^o_{T2} = s^o_{T1} + R \ln\frac{P_2}{P_1} = 8.5115 + 0.287 \ln(\frac{200}{15000}) = 7.2724 \text{ kJ/kg K}$$

Now interpolate in Table A.7 to get T_2

$$T_2 = 440 + 20\,(7.2724 - 7.25607)/(7.30142 - 7.25607) = 447.2 \text{ K}$$

$$u_2 = 315.64 + (330.31 - 315.64)\,0.36 = 320.92 \text{ kJ/kg}$$

$$V_2 = V_1 \frac{T_2\,P_1}{T_1P_2} = \frac{10 \times 447.2 \times 15000}{1380 \times 200} = 243 \text{ cm}^3$$

$$\Rightarrow \quad L_2 = V_2 / A_{cyl} = 243/5 = \mathbf{48.6\ cm}$$

$${}_1w_2 = u_1 - u_2 = 774.3 \text{ kJ/kg}, \qquad {}_1W_2 = m_1w_2 = \mathbf{0.2935\ kJ}$$

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8.98

Argon in a light bulb is at 90 kPa and 20^oC when it is turned on and electric input now heats it to 60^oC. 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: $s_2 - s_1 = \int dq/T + {}_1s_{2\ \text{gen}} = {}_1s_{2\ \text{gen}}$

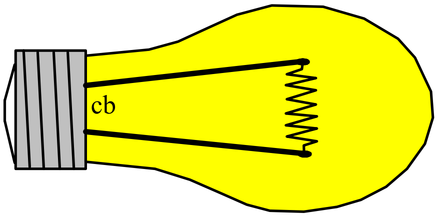
Process: $v = \text{constant and ideal gas} \Rightarrow P_2/P_1 = T_2/T_1$

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)

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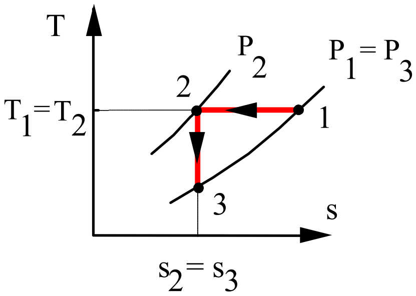
8.99

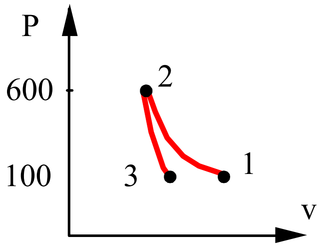
We wish to obtain a supply of cold helium gas by applying the following technique. Helium contained in a cylinder at ambient conditions, 100 kPa, 20°C, is compressed in a reversible isothermal process to 600 kPa, after which the gas is expanded back to 100 kPa in a reversible adiabatic process.

a. Show the process on a *T–s* diagram.
b. Calculate the final temperature and the net work per kilogram of helium.

Solution:

a)





b) The adiabatic reversible expansion gives constant s from the entropy equation Eq.8.37. With ideal gas and constant specific heat this gives relation in Eq.8.23

$$T_3 = T_2(P_3/P_2)^{\frac{k-1}{k}} = 293.15\ (100/600)^{0.4} = \mathbf{143.15\ K}$$

The net work is summed up over the two processes. The isothermal process has work as Eq.8.31

$${}_1w_2 = -RT_1 \ln(P_2/P_1) = -2.0771 \times 293.15 \times \ln(600/100) = -1091.0 \text{ kJ/kg}$$

The adiabatic process has a work term from energy equation with no q

$${}_2w_3 = C_{Vo}(T_2 - T_3) = 3.116\ (293.15 - 143.15) = +467.4 \text{ kJ/kg}$$

The net work is the sum

$$w_{NET} = -1091.0 + 467.4 = \mathbf{-623.6\ kJ/kg}$$

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8.100

A 1-m^3 insulated, rigid tank contains air at 800 kPa, 25°C. A valve on the tank is opened, and the pressure inside quickly drops to 150 kPa, at which point the valve is closed. Assuming that the air remaining inside has undergone a reversible adiabatic expansion, calculate the mass withdrawn during the process.

Solution:

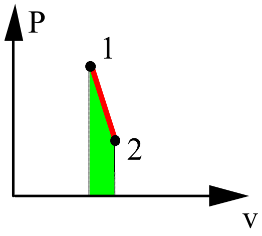
C.V.: Air remaining inside tank, m_2.

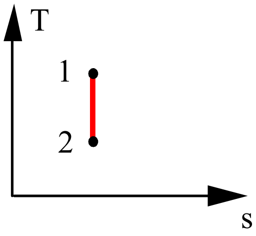
Cont.Eq.: $m_2 = m$;

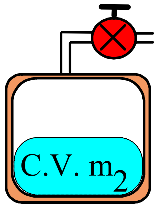
Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.37: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\ gen}$

Process: adiabatic ${}_1Q_2 = 0$ and reversible ${}_1S_{2\ gen} = 0$







Entropy eq. then gives $s_2 = s_1$ and ideal gas gives the relation in Eq.8.23

$$T_2 = T_1(P_2/P_1)^{\frac{k-1}{k}} = 298.2(150/800)^{0.286} = \mathbf{184.8\ K}$$

$m_1 = P_1V/RT_1 = (800\text{ kPa} \times 1\text{ m}^3)/(0.287\text{ kJ/kgK} \times 298.2\text{ K}) = 9.35\text{ kg}$

$m_2 = P_2V/RT_2 = (150\text{ kPa} \times 1\text{ m}^3)/(0.287\text{ kJ/kgK} \times 184.8\text{ K}) = 2.83\text{ kg}$

$m_e = m_1 - m_2 =$ **6.52 kg**

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8.101

Two rigid tanks, shown in Fig. P8.101, each contain 10 kg N_2 gas at 1000 K, 500 kPa. They are now thermally connected to a reversible heat pump, which heats one and cools the other with no heat transfer to the surroundings. When one tank is heated to 1500 K the process stops. Find the final (*P*, *T*) in both tanks and the work input to the heat pump, assuming constant heat capacities.

Solution:

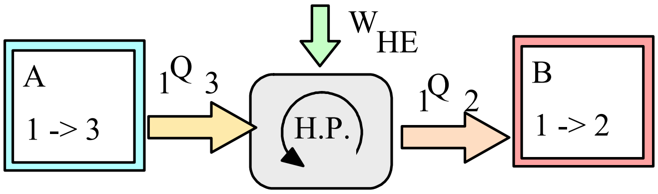
Control volume of hot tank B,

Process = constant volume & mass so no work

Energy equation Eq.5.11 and specific heat in Eq.5.20 gives

$$U_2 - U_1 \cong mC_v(T_2 - T_1) = {}_1Q_2 = 10 \times 0.7448 \times 500 = 3724 \text{ kJ}$$

$$P_2 = P_1T_2/T_1 = 1.5(P_1) = \mathbf{750\ kPa}$$



State: 1 = initial,
2 = final hot
3 = final cold

To fix temperature in cold tank, C.V.: total

For this CV only W_{HP} cross the control surface no heat transfer. The entropy equation Eq.8.37 for a reversible process becomes

$$(S_2 - S_1)_{tot} = 0 = m_{hot}(s_2 - s_1) + m_{cold}(s_3 - s_1)$$

Use specific heats to evaluate the changes in s from Eq.8.25 and division by m

$$C_{p,hot} \ln(T_2 / T_1) - R \ln(P_2 / P_1) + C_{p,cold} \ln(T_3 / T_1) - R \ln(P_3 / P_1) = 0$$

$$P_3 = P_1T_3/T_1 \quad \text{and} \quad P_2 = P_1T_2/T_1$$

Now everything is in terms of T and $C_p = C_v + R$, so

$$C_{v,hot} \ln(T_2/T_1) + C_{v,cold} \ln(T_3/T_1) = 0$$

same C_v: $T_3 = T_1(T_1/T_2) = \mathbf{667\ K}$, $P_3 = \mathbf{333\ kPa}$

$Q_{cold} = -{}_1Q_3 = m\,C_v\,(T_3 - T_1) = -2480$ kJ,

$W_{HP} = {}_1Q_2 + Q_{cold} = {}_1Q_2 - {}_1Q_3 = \mathbf{1244\ kJ}$

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8.102

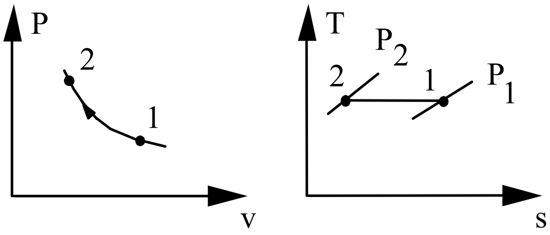
A hydrogen gas in a piston/cylinder assembly at 300 K, 100 kPa with a volume of 0.1 m^3 is now slowly compressed to a volume of 0.01 m^3 while cooling it in a reversible isothermal process. What is the final pressure, the heat transfer and the change in entropy?

Solution:

C.V. Hydrogen, control mass.

Energy Eq. 5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: T = constant so with ideal gas => $u_2 = u_1$



From the process equation ($T_2 = T_1$) and ideal gas law we get

$$P_2 = P_1\ (V_1/V_2) = 10\ P_1 = \mathbf{1000\ kPa}$$

we can calculate the work term as in Eq.4.5

$${}_1Q_2 = {}_1W_2 = \int PdV = P_1V_1 \ln (V_2/V_1)$$

$$= 100 \times 0.1 \times \ln (1/10) = \mathbf{-23.0\ kJ}$$

The change of entropy from the entropy equation Eq.8.3 is

$$m(s_2 - s_1) = {}_1Q_2/T_1 = \frac{-23}{300} = \mathbf{-0.07667\ kJ/K}$$

If instead we use Eq.8.17 we would get

$$\Delta S = m(s_2 - s_1) = m(C_{vo} \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}) = m\ R \ln \frac{v_2}{v_1}$$

$$= (P_1V_1/T_1) \ln (\frac{v_2}{v_1}) = {}_1Q_2/T_1$$

consistent with the above result.

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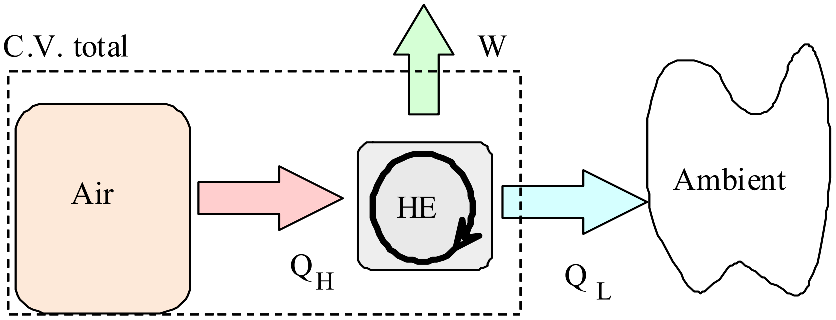
8.103

A rigid tank contains 4 kg air at 200^{o}C, 4 MPa which acts as the hot energy reservoir for a heat engine with its cold side at 20^{o}C shown in Fig. P.8.103. Heat transfer to the heat engine cools the air down in a reversible process to a final 20^o C and then stops. Find the final air pressure and the work output of the heat engine.



Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.3: $m(s_2 - s_1) = \int dQ/T$ (T not constant)

Process: v = constant ⇒ ${}_1W_2 = 0$

State 2: T_2 and $v_2 = v_1$,

$$P_2 = P_1T_2/T_1 = 4000 \times 293.15/473.15 = \mathbf{2478.3\ kPa}$$

From the energy equation

$$Q_H = -{}_1Q_2 = -m(u_2 - u_1) = -m\ C_{vo}\ (T_2 - T_1)$$

$$= -4 \times 0.717\ (293.15 - 473.15) = \mathbf{516.2\ kJ}$$

Take now CV total as the air plus heat engine out to ambient

Entropy Eq.8.3: $m(s_2 - s_1) = -\frac{Q_L}{T_{amb}}$ ⇒

$$Q_L = -mT_{amb}\ (s_2 - s_1) = -mT_{amb}\ C_{vo}\ \ln\frac{T_2}{T_1}$$

$$= -\ 4 \times 293.15 \times 0.717\ \ln(293.15/473.15) = 402.5\ \text{kJ}$$

Now the CV heat engine can give the engine work from the energy equation

Energy H.E.: $W_{HE} = Q_H - Q_L = 516.2 - 402.5 = \mathbf{113.7\ kJ}$

Notice to get ${}_1q_2 = \int T\ ds$ we must know the function T(s) which we do not readily have for this process.

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Polytropic processes

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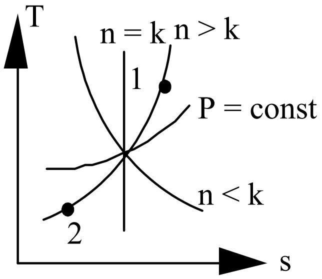
8.104

An ideal gas having a constant specific heat undergoes a reversible polytropic expansion with exponent, *n* = 1.4. If the gas is carbon dioxide will the heat transfer for this process be positive, negative, or zero?

Solution:



CO_2: Table A.5 $k = 1.289 < n$

Since $n > k$ and $P_2 < P_1$

it follows that $s_2 < s_1$ and thus Q flows out.

$\mathbf{{}_1Q_2 < 0}$

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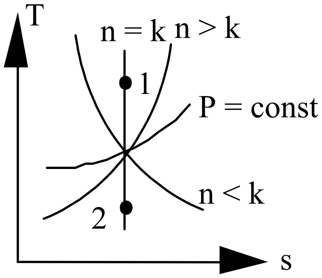
8.105

Repeat the previous problem for the gas carbon monoxide, CO.

Solution:



CO: Table A.5 $k = 1.399 = n$

Since $n \approx k$ and $P_2 < P_1$

it follows that $s_2 \approx s_1$ and thus adiabatic.

$$\mathbf{{}_1Q_2 \approx 0}$$

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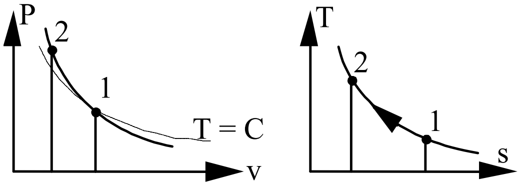
8.106

Neon at 400 kPa, 20°C is brought to 100°C in a polytropic process with $n = 1.4$. Give the sign for the heat transfer and work terms and explain.

Solution:



Neon Table A.5

$k = \gamma = 1.667$ so $n < k$
$C_v = 0.618$, $R = 0.412$

From definition Eq.8.2 $ds = dq/T$ so $dq = T\,ds$
From work term $dw = P\,dv$

From figures: v goes down so work in (**$W < 0$**);
s goes down so Q out (**$Q < 0$**)

We can also calculate the actual specific work from Eq.8.29 and heat transfer from the energy equation as:

$${}_1w_2 = [R/(1-n)](T_2 - T_1) = -82.39 \text{ kJ/kg}$$

$$u_2 - u_1 = C_v(T_2 - T_1) = 49.432, \quad {}_1q_2 = \Delta u + {}_1w_2 = -32.958$$

${}_1W_2$ Negative and **${}_1Q_2$ Negative**

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8.107

A piston/cylinder contains air at 300 K, 100 kPa. It is now compressed in a reversible adiabatic process to a volume 7 times as small. Use constant heat capacity and find the final pressure and temperature, the specific work and specific heat transfer for the process.

Solution:

Expansion ratio: $v_2/ v_1 = 1/7$

Process eq.: Rev. adiabatic and ideal gas gives $Pv^n = C$, with $n = k$

$$P_2 /P_1 = (v_2/v_1)^{-k} = 7^{1.4} = 15.245$$

$P_2 = P_1 (7^{1.4}) = 100 \times 15.245 =$ **1524.5 kPa**

$T_2 = T_1 (v_1/v_2)^{k-1} = 300 \times 7^{0.4} =$ **653.4 K**

${}_1q_2 =$ **0 kJ/kg**

Polytropic process work term from Eq.8.29

$${}_1w_2 = \frac{R}{1 - k} (T_2 - T_1) = \frac{0.287}{-0.4} (653.4 - 300) = \mathbf{-253.6\ kJ/kg}$$

Notice: $C_v = R/(k-1)$ so the work term is also the change in u consistent with the energy equation.

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8.108

A cylinder/piston contains 1 kg methane gas at 100 kPa, 20°C. The gas is compressed reversibly to a pressure of 800 kPa. Calculate the work required if the process is adiabatic.

Solution:

C.V. Methane gas of constant mass $m_2 = m_1 = m$ and reversible process.

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.3 (37): $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\ gen} = \int dQ/T$

Process: ${}_1Q_2 = 0 \quad \Rightarrow \quad s_2 = s_1$

thus isentropic process s = const and ideal gas gives relation in Eq.8.23

$$T_2 = T_1\,(P_2/P_1)^{\frac{k-1}{k}} = 293.15\left(\frac{800}{100}\right)^{0.230} = 472.9\ \text{K}$$

$${}_1W_2 = -mC_{V0}(T_2 - T_1) = -1 \times 1.736\ (472.9 - 293.15) = \mathbf{-312.0\ kJ}$$

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8.109

Do the previous problem but assume the process is isothermal.

Solution:

C.V. Methane gas of constant mass $m_2 = m_1 = m$ and reversible process.

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.14: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\,gen} = \int dQ/T$

Process: T = constant. For ideal gas then $u_2 = u_1$ and $s^o_{T2} = s^o_{T1}$

Energy eq. gives ${}_1W_2 = {}_1Q_2$ and $\int dQ/T = {}_1Q_2/T$

with the entropy change found from Eq.8.28

$$\Rightarrow \quad {}_1W_2 = {}_1Q_2 = mT(s_2 - s_1) = -mRT \ln(P_2/P_1)$$

$$= -0.5183 \times 293.2 \ln\left(\frac{800}{100}\right) = \mathbf{-316.0\ kJ}$$

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8.110

Do Problem 8.108 and assume the process is polytropic with n = 1.15

Process: Pv^n = constant with n = 1.15 ;

The T-P relation is given in Eq.8.37

$$T_2 = T_1\ (P_2/P_1)^{\frac{n-1}{n}} = 293.2 \left(\frac{800}{100}\right)^{0.130} = 384.2 \text{ K}$$

and the work term is given by Eq.8.38

$${}_1W_2 = \int mP\ dv = m(P_2v_2 - P_1v_1)/(1 - n) = mR\ (T_2 - T_1)/(1 - n)$$

$$= 1 \text{ kg} \times 0.5183 \frac{\text{kJ}}{\text{kg-K}} \times \frac{384.2 - 293.2}{1 - 1.15} \text{ K} = \mathbf{-314.5\ kJ}$$

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8.111

Hot combustion air at 1500 K expands in a polytropic process to a volume 6 times as large with n = 1.5. Find the specific boundary work and the specific heat transfer.

Energy Eq.: $u_2 - u_1 = {}_1q_2 - {}_1w_2$

Reversible work Eq. 8.38: $${}_1w_2 = \frac{1}{1\text{-}n}(P_2v_2 - P_1v_1) = \frac{R}{1\text{-}n}(T_2 - T_1)$$

Process Eq: $Pv^n = C$; $T_2 = T_1\,(v_1/v_2)^{n-1} = 1500\left(\frac{1}{6}\right)^{0.5} = 612.4\text{ K}$

Properties from Table A.7.1: $u_1 = 1205.25$ kJ/kg, $u_2 = 444.6$ kJ/kg

$${}_1w_2 = \frac{0.287}{1 - 1.5}(612.4 - 1500) = \mathbf{509.5\ kJ/kg}$$

$${}_1q_2 = u_2 - u_1 + {}_1w_2 = 444.6 - 1205.25 + 509.5 = \mathbf{-251\ kJ/kg}$$

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8.112

A mass of 1 kg of air contained in a cylinder at 1.5 MPa, 1000 K, expands in a reversible adiabatic process to 100 kPa. Calculate the final temperature and the work done during the process, using

a. Constant specific heat, value from Table A.5

b. The ideal gas tables, Table A.7

Solution:

C.V. Air.

Continuity Eq.: $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.37: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\ gen}$

Process: ${}_1Q_2 = 0$, ${}_1S_{2\ gen} = 0$ => $s_2 = s_1$

a) Using constant Cp from Table A.5 gives the power relation Eq.8.23.

$$T_2 = T_1(P_2/P_1)^{\frac{k-1}{k}} = 1000\left(\frac{0.1}{1.5}\right)^{0.286} = \mathbf{460.9\ K}$$

$${}_1W_2 = -(U_2 - U_1) = mC_{Vo}(T_1 - T_2)$$

$$= 1\text{ kg} \times 0.717\text{ kJ/kg-K} \times (1000 - 460.9)\text{ K} = \mathbf{386.5\ kJ}$$

b) Use the standard entropy function that includes variable heat capacity from A.7.1 and Eq.8.19

$$s_2 - s_1 = s^o_{T2} - s^o_{T1} - R\ln\frac{P_2}{P_1} = 0 \quad\Rightarrow\quad s^o_{T2} = s^o_{T1} + R\ln\frac{P_2}{P_1}$$

$$s^o_{T2} = 8.13493 + 0.287\ln(100/1500) = 7.35772\text{ kJ/kg-K}$$

Interpolation gives $T_2 =$ **486 K** and $u_2 = 349.5$ kJ/kg

$${}_1W_2 = m(u_1 - u_2) = 1(759.2 - 349.5) = \mathbf{409.7\ kJ}$$

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8.113

Helium in a piston/cylinder at 20°C, 100 kPa is brought to 400 K in a reversible polytropic process with exponent n = 1.25. You may assume helium is an ideal gas with constant specific heat. Find the final pressure and both the specific heat transfer and specific work.

Solution:

C.V. Helium

Continuity Eq.: $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: $Pv^n = C$ & $Pv = RT$ => $Tv^{n-1} = C$

Table A.5: $C_v =$ 3.116 kJ/kg K, $R = 2.0771$ kJ/kg K

From the process equation and $T_1 = 293.15$, $T_2 = 400$ K

$$T_1\, v^{n-1} = T_2\, v^{n-1} \quad => \quad v_2 / v_1 = (T_1 / T_2)^{1/n-1} = 0.2885$$

$P_2 / P_1 = (v_1 / v_2)^n = 4.73$ => $P_2 =$ **473 kPa**

The work is from Eq.8.29 per unit mass

$$_1w_2 = \int P\, dv = \int C\, v^{-n}\, dv = [\, C / (1\text{-}n)\,] \times (\, v_2^{1-n} - v_1^{1-n}\,)$$

$$= \frac{1}{1-n}(P_2\, v_2 - P_1\, v_1) = \frac{R}{1-n}(T_2 - T_1) = \mathbf{-887.7\ kJ/kg}$$

The heat transfer follows from the energy equation

$$_1q_2 = u_2 - u_1 + {}_1w_2 = C_v\,(T_2 - T_1) + (-\,887.7) = \mathbf{-554.8\ kJ/kg}$$

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8.114

The power stroke in an internal combustion engine can be approximated with a polytropic expansion. Consider air in a cylinder volume of 0.2 L at 7 MPa, 1800 K, shown in Fig. P8.114. It now expands in a reversible polytropic process with exponent, n = 1.5, through a volume ratio of 8:1. Show this process on *P–v* and *T–s* diagrams, and calculate the work and heat transfer for the process.

Solution:

C.V. Air of constant mass $m_2 = m_1 = m$.

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.3 (37): $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\,gen} = \int dQ/T$

Process: $PV^{1.50}$ = constant, $V_2/V_1 = 8$

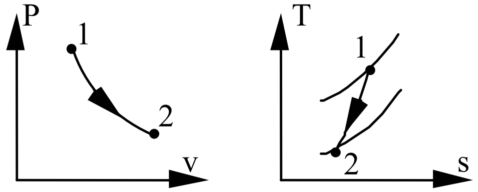
State 1: P_1 = 7 MPa, T_1 = 1800 K, V_1 = 0.2 L

$$m_1 = \frac{P_1V_1}{RT_1} = \frac{7000 \times 0.2 \times 10^{-3}}{0.287 \times 1800} = 2.71{\times}10^{-3}\text{ kg}$$

State 2: ($v = V_2/m$, ?) Must be on process curve so Eq.8.24 gives

$$T_2 = T_1\,(V_1/V_2)^{n-1} = 1800\,(1/8)^{0.5} = 636.4\text{ K}$$

Table A.7: u_1 = 1486.331 kJ/kg and interpolate u_2 = 463.05 kJ/kg



Notice:
$n = 1.5$, $k = 1.4$

$n > k$

Work from the process expressed in Eq.8.29

$${}_1W_2 = \int PdV = mR(T_2 - T_1)/(1 - n)$$

$$= \frac{2.71{\times}10^{-3} \times 0.287(636.4 - 1800)}{1 - 1.5} = \mathbf{1.81\ kJ}$$

Heat transfer from the energy equation

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2$$

$$= 2.71{\times}10^{-3} \times (463.05 - 1486.331) + 1.81 = \mathbf{-0.963\ kJ}$$

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8.115

A cylinder/piston contains saturated vapor R-410a at 10°C; the volume is 10 L. The R-410a is compressed to 2 MPa, 60°C in a reversible (internally) polytropic process. Find the polytropic exponent n and calculate the work and heat transfer.

Solution:

C.V. R-410a of constant mass $m_2 = m_1 = m$ out to ambient.

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.37: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\text{ gen}} = {}_1Q_2/T_{\text{amb}} + {}_1S_{2\text{ gen}}$

Process: $P_1v_1^n = P_2v_2^n$ Eq.8.36

State 1: (T_1, x_1) Table B.4.1 $P_1 = 1085.7$ kPa, $v_1 = 0.02383$ m^3/kg

$m = V_1/v_1 = 0.01/0.02383 = 0.4196$ kg

State 2: (T_2, P_2) Table B.4.2 $v_2 = 0.01536$ m^3/kg

From process eq. $P_2/P_1 = \dfrac{2000}{1085.7} = \left(\dfrac{0.02383}{0.01536}\right)^n$ => $\mathbf{n = 1.39106}$

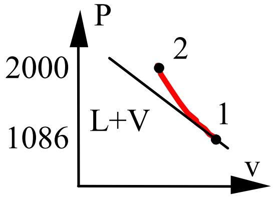
The work is from Eq.8.29

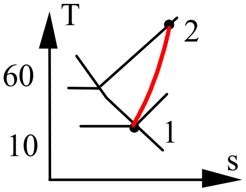
$$ {}_1W_2 = \int PdV = m\,\frac{P_2v_2 - P_1v_1}{1\text{-}n} = 0.4196\,\frac{2000 \times 0.01536 - 1085.7 \times 0.02383}{1 - 1.39106} $$

$= \mathbf{-5.20\ kJ}$

Heat transfer from energy equation

$$ {}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 0.4196\,(289.9 - 255.9) - 5.20 = \mathbf{9.07\ kJ} $$





Notice:
n = 1.39, k = 1.17

n > k

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8.116

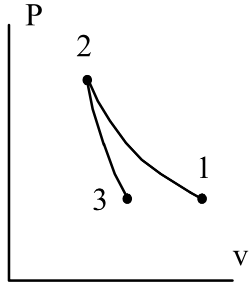
A cylinder/piston contains air at ambient conditions, 100 kPa and 20°C with a volume of 0.3 m^3. The air is compressed to 800 kPa in a reversible polytropic process with exponent, $n = 1.2$, after which it is expanded back to 100 kPa in a reversible adiabatic process.

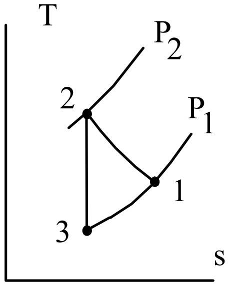
a. Show the two processes in *P–v* and *T–s* diagrams.

b. Determine the final temperature and the net work.

Solution:

a)





$$m = P_1V_1/RT_1 = \frac{100 \times 0.3}{0.287 \times 293.2} = 0.3565 \text{ kg}$$

b) The process equation is expressed in Eq.8.37

$$T_2 = T_1(P_2/P_1)^{\frac{n-1}{n}} = 293.2 \left(\frac{800}{100}\right)^{0.167} = 414.9 \text{ K}$$

The work is from Eq.8.38

$$_1w_2 = \int_1^2 P dv = \frac{P_2v_2 - P_1v_1}{1-n} = \frac{R(T_2-T_1)}{1-n} = \frac{0.287(414.9-293.2)}{1-1.20} = -174.6 \text{ kJ/kg}$$

Isentropic relation is from Eq.8.32

$$T_3 = T_2\,(P_3/P_2)^{\frac{k-1}{k}} = 414.9 \left(\frac{100}{800}\right)^{0.286} = \mathbf{228.9\ K}$$

With zero heat transfer the energy equation gives the work

$$_2w_3 = C_{V0}(T_2 - T_3) = 0.717(414.9 - 228.9) = +133.3 \text{ kJ/kg}$$

$$w_{NET} = 0.3565(-174.6 + 133.3) = \mathbf{-14.7\ kJ}$$

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Entropy generation

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8.117

One kg water at 500^{o}C and 1 kg saturated water vapor both at 200 kPa are mixed in a constant pressure and adiabatic process. Find the final temperature and the entropy generation for the process.

Solution:

Continuity Eq.: $m_2 - m_A - m_B = 0$

Energy Eq.5.11: $m_2u_2 - m_Au_A - m_Bu_B = -{}_1W_2$

Entropy Eq.8.37: $m_2s_2 - m_As_A - m_Bs_B = \int dQ/T + {}_1S_{2\ gen}$

Process: $P = \text{Constant} \;\Rightarrow\; {}_1W_2 = \int PdV = P(V_2 - V_1)$

$Q = 0$

Substitute the work term into the energy equation and rearrange to get

$$m_2u_2 + P_2V_2 = m_2h_2 = m_Au_A + m_Bu_B + PV_1 = m_Ah_A + m_Bh_B$$

where the last rewrite used $PV_1 = PV_A + PV_B$.

State A1: Table B.1.3 $h_A = 3487.03$ kJ/kg, $s_A = 8.5132$ kJ/kg K

State B1: Table B.1.2 $h_B = 2706.63$ kJ/kg, $s_B = 7.1271$ kJ/kg K

Energy equation gives:

$$h_2 = \frac{m_A}{m_2} h_A + \frac{m_B}{m_2} h_B = \frac{1}{2}\,3487.03 + \frac{1}{2}\,2706.63 = 3096.83 \text{ kJ/kg}$$

State 2: P_2, $h_2 = 3096.83$ kJ/kg => $s_2 = 7.9328$ kJ/kg K; $T_2 = $ **312.2°C**

With the zero heat transfer we have

$${}_1S_{2\ gen} = m_2s_2 - m_As_A - m_Bs_B$$

$$= 2 \times 7.9328 - 1 \times 8.5132 - 1 \times 7.1271 = \mathbf{0.225\ kJ/K}$$

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8.118

A computer chip dissipates 2 kJ of electric work over time and rejects that as heat transfer from its 50°C surface to 25°C air. How much entropy is generated in the chip? How much if any is generated outside the chip?

C.V.1 Chip with surface at 50°C, we assume chip state is constant.

Energy: $U_2 - U_1 = 0 = {}_1Q_2 - {}_1W_2 = W_{\text{electrical in}} - Q_{\text{out 1}}$

Entropy: $S_2 - S_1 = 0 = -\dfrac{Q_{\text{out 1}}}{T_{\text{surf}}} + {}_1S_{2\text{ gen1}}$

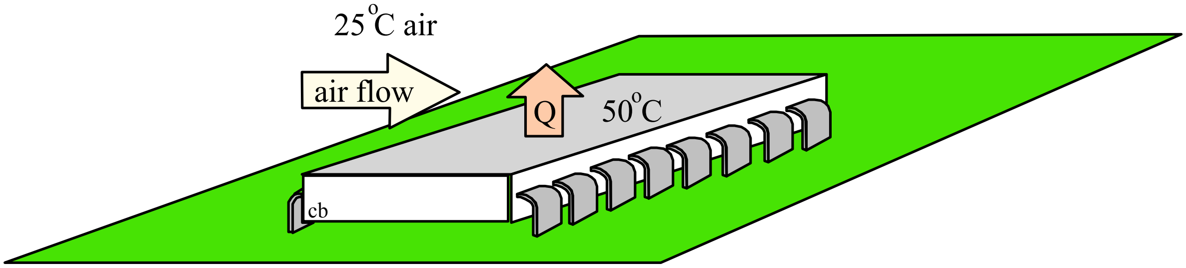
$${}_1S_{2\text{ gen1}} = \frac{Q_{\text{out 1}}}{T_{\text{surf}}} = \frac{W_{\text{electrical in}}}{T_{\text{surf}}} = \frac{2\text{ kJ}}{323.15\text{ K}} = \mathbf{6.19\ J/K}$$

C.V.2 From chip surface at 50°C to air at 25°C, assume constant state.

Energy: $U_2 - U_1 = 0 = {}_1Q_2 - {}_1W_2 = Q_{\text{out 1}} - Q_{\text{out 2}}$

Entropy: $S_2 - S_1 = 0 = \dfrac{Q_{\text{out1}}}{T_{\text{surf}}} - \dfrac{Q_{\text{out2}}}{T_{\text{air}}} + {}_1S_{2\text{ gen2}}$

$${}_1S_{2\text{ gen2}} = \frac{Q_{\text{out2}}}{T_{\text{air}}} - \frac{Q_{\text{out1}}}{T_{\text{surf}}} = \frac{2\text{ kJ}}{298.15\text{ K}} - \frac{2\text{ kJ}}{323.15\text{ K}} = \mathbf{0.519\ J/K}$$



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8.119

The unrestrained expansion of the reactor water in Problem 5.50 has a final state in the two-phase region. Find the entropy generated in the process.

A water-filled reactor with volume of 1 m^3 is at 20 MPa, 360°C and placed inside a containment room as shown in Fig. P5.50. The room is well insulated and initially evacuated. Due to a failure, the reactor ruptures and the water fills the containment room. Find the minimum room volume so the final pressure does not exceed 200 kPa.

Solution:

C.V.: Containment room and reactor.

Mass: $m_2 = m_1 = V_{reactor}/v_1 = 1/0.001823 = 548.5$ kg

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2 = 0 - 0 = 0$

Entropy Eq.8.14: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\ gen}$

State 1: (T, P) Table B.1.4 $u_1 = 1702.8$ kJ/kg, $s_1 = 3.877$

Energy equation implies $u_2 = u_1 = 1702.8$ kJ/kg

State 2: $P_2 = 200$ kPa, $u_2 < u_g$ => Two-phase Table B.1.2

$x_2 = (u_2 - u_f)/\ u_{fg} = (1702.8 - 504.47)/2025.02 = 0.59176$

$v_2 = 0.001061 + 0.59176 \times 0.88467 = 0.52457\ m^3/kg$

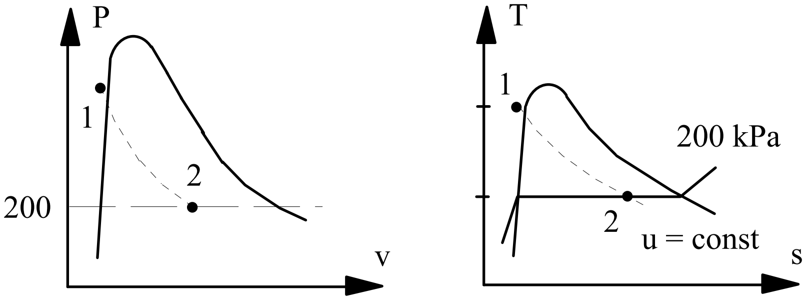
$s_2 = s_f + x_2 s_{fg} = 1.53 + 0.59176 \times 5.597 = 4.8421$ kJ/kg K

$V_2 = m_2\ v_2 = 548.5 \times 0.52457 = \mathbf{287.7\ m^3}$

From the entropy equation the generation is

${}_1S_{2\ gen} = m(s_2 - s_1) = 548.5\ (4.8421 - 3.877)$

$= \mathbf{529.4\ kJ/K}$



Entropy is generated due to the unrestrained expansion. No work was taken out as the volume goes up.

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8.120

A car uses an average power of 25 hp for a one hour round trip. With a thermal efficiency of 35% how much fuel energy was used? What happened to all the energy? What change in entropy took place if we assume ambient at 20°C?

Since it is a round trip, there are no changes in storage of energy for the car after it has cooled down again. All the energy is given out to the ambient in the form of exhaust flow (hot air) and heat transfer from the radiator and underhood air flow.

$$W = \int \dot{W}\, dt = 25 \text{ hp} \times 0.7457 \text{ (kW/hp)} \times 3600 \text{ s} = 67\ 113 \text{ kJ} = \eta\, Q$$

Fuel energy used to deliver the W

$$Q = E / \eta = 67\ 113 / 0.35 = \mathbf{191\ 751\ kJ}$$

$$\Delta S = Q / T = 191\ 751 / 293.15 = \mathbf{654.1\ kJ/K}$$

All the energy (Q) ends up in the ambient at the ambient temperature.

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8.121

Ammonia is contained in a rigid sealed tank unknown quality at 0°C. When heated in boiling water to 100°C its pressure reaches 1200 kPa. Find the initial quality, the heat transfer to the ammonia and the total entropy generation.

Solution:

C.V. Ammonia, which is a control mass of constant volume.

Energy Eq.5.11: $u_2 - u_1 = {}_1q_2 - {}_1w_2$

Entropy Eq.8.14: $s_2 - s_1 = \int dq/T + {}_1s_{2\,\text{gen}}$

State 2: 1200 kPa, 100°C => Table B.2.2

$s_2 = 5.5325$ kJ/kg K, $v_2 = 0.14347$ m^3/kg, $u_2 = 1485.8$ kJ/kg

State 1: $v_1 = v_2$ => Table B.2.1

$x_1 = (0.14347 - 0.001566)/0.28763 = 0.49336$

$u_1 = 741.28$ kJ/kg, $s_1 = 0.7114 + x_1 \times 4.6195 = 2.9905$ kJ/kg K

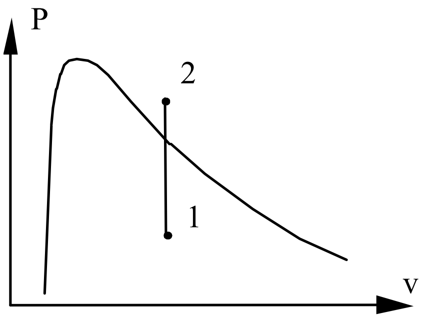
Process: V = constant => ${}_1w_2 = 0$

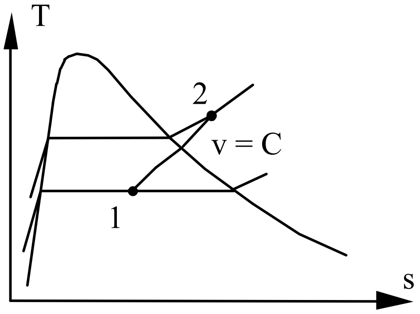
${}_1q_2 = (u_2 - u_1) = 1485.8 - 741.28 = 744.52$ kJ/kg

To get the total entropy generation take the C.V out to the water at 100°C.

${}_1s_{2\,\text{gen}} = s_2 - s_1 - {}_1q_2/T = 5.5325 - 2.9905 - 744.52/373.15$

$= \mathbf{0.547\ kJ/kg\ K}$





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8.122

An insulated cylinder/piston contains R-134a at 1 MPa, 50°C, with a volume of 100 L. The R-134a expands, moving the piston until the pressure in the cylinder has dropped to 100 kPa. It is claimed that the R-134a does 190 kJ of work against the piston during the process. Is that possible?

Solution:

C.V. R-134a in cylinder. Insulated so assume Q = 0.

State 1: Table B.5.2, $v_1 = 0.02185 \text{ m}^3/\text{kg}$, $u_1 = 409.39$ kJ/kg,

$s_1 = 1.7494$ kJ/kg K, $m = V_1/v_1 = 0.1/0.02185 = 4.577$ kg

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2 = 0 - 190 \Rightarrow$

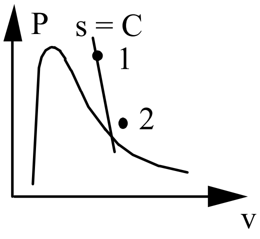
$u_2 = u_1 - {}_1W_2/m = 367.89$ kJ/kg

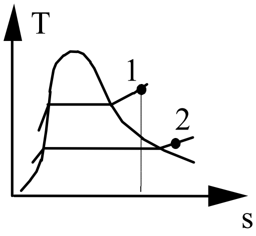
State 2: P_2 , u_2 $\Rightarrow$ Table B.5.2: $T_2 = -19.25°\text{C}$; $s_2 = 1.7689$ kJ/kg K

Entropy Eq.8.37: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2,gen} = {}_1S_{2,gen}$

${}_1S_{2,gen} = m(s_2 - s_1) = 0.0893$ kJ/K

This is possible since ${}_1S_{2,gen} > 0$





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8.123

A piece of hot metal should be cooled rapidly (quenched) to 25°C, which requires removal of 1000 kJ from the metal. The cold space that absorbs the energy could be one of three possibilities: (1) Submerge the metal into a bath of liquid water and ice, thus melting the ice. (2) Let saturated liquid R-410a at −20°C absorb the energy so that it becomes saturated vapor. (3) Absorb the energy by vaporizing liquid nitrogen at 101.3 kPa pressure.

a. Calculate the change of entropy of the cooling media for each of the three cases.

b. Discuss the significance of the results.

Solution:

a) Melting or boiling at const P & T

$$ {}_1Q_2 = m(u_2 - u_1) + Pm(v_2 - v_1) = m(h_2 - h_1) $$

1) Ice melting at 0°C , Table B.1.5: $m = {}_1Q_2 / h_{ig} = \frac{1000}{333.41} = 2.9993$ kg

$$ \Delta S_{H_2O} = ms_{ig} = 2.9993(1.221) = \mathbf{3.662\ kJ/K} $$

2) R-410a boiling at -20°C, Table B.4.1: $m = {}_1Q_2 / h_{fg} = \frac{1000}{243.65} = 4.104$ kg

$$ \Delta S_{R\text{-}410a} = ms_{fg} = 4.104\ (0.9625) = \mathbf{3.950\ kJ/K} $$

3) N_2 boiling at 101.3 kPa, Table B.6.1: $m = {}_1Q_2 / h_{fg} = \frac{1000}{198.842} = 5.029$ kg

$$ \Delta S_{N_2} = ms_{fg} = 5.029(2.5708) = \mathbf{12.929\ kJ/K} $$

b) The larger the $\Delta(1/T)$ through which the Q is transferred, the larger the ΔS.
For all cases we could also just have done it as ${}_1Q_2/T$.

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8.124

A cylinder fitted with a movable piston contains water at 3 MPa, 50% quality, at which point the volume is 20 L. The water now expands to 1.2 MPa as a result of receiving 600 kJ of heat from a large source at 300°C. It is claimed that the water does 124 kJ of work during this process. Is this possible?

Solution:

C.V.: H_2O in Cylinder

State 1: 3 MPa, $x_1 = 0.5$, Table B.1.2: $T_1 = 233.9^oC$

$v_1 = v_f + x_1 v_{fg} = 0.001216 + 0.5 \times 0.06546 = 0.033948 \text{ m}^3/\text{kg}$

$u_1 = u_f + x_1 u_{fg} = 1804.5 \text{ kJ/kg}$, $s_1 = s_f + x_1 s_{fg} = 4.4162 \text{ kJ/kg-K}$

$m_1 = V_1/v_1 = 0.02 / 0.033948 = 0.589 \text{ kg}$

1st Law: 1→2, $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$;

${}_1Q_2 = 600 \text{ kJ}$, ${}_1W_2 = 124 \text{ kJ}$?

Now solve for u_2

$u_2 = 1804.5 + (600 - 124)/0.589 = 2612.6 \text{ kJ/kg}$

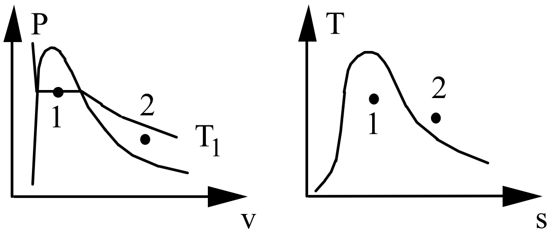
State 2: $P_2 = 1.2 \text{ MPa}$: $u_2 = 2612.6 \text{ kJ/kg}$ Table B.1.3

$T_2 \cong 200^oC$, $s_2 = 6.5898 \text{ kJ/kgK}$

2nd Law Eq.8.18: $\Delta S_{net} = m(s_2 - s_1) - \frac{Q_{cv}}{T_H}$; $T_H = 300^oC$, $Q_{CV} = {}_1Q_2$

$$\Delta S_{net} = 0.589\,(6.5898 - 4.4162) - \frac{600}{300 + 273} = 0.2335 \text{ kJ/K} \geq 0;$$

Process is possible



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8.125

A mass and atmosphere loaded piston/cylinder contains 2 kg of water at 5 MPa, 100°C. Heat is added from a reservoir at 700°C to the water until it reaches 700°C. Find the work, heat transfer, and total entropy production for the system and surroundings.

Solution:

C.V. Water out to surroundings at 700°C. This is a control mass.

Energy Eq.5.11: $U_2 - U_1 = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.37: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\,gen} = {}_1Q_2/T_{res} + {}_1S_{2\,gen}$

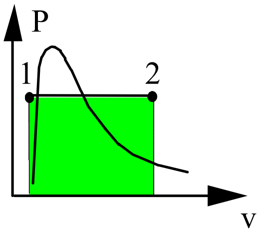
Process: P = constant so ${}_1W_2 = P(V_2 - V_1) = mP(v_2 - v_1)$

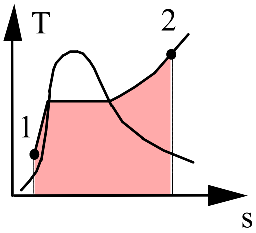
State 1: Table B.1.4: $h_1 = 422.72$ kJ/kg, $u_1 = 417.52$ kJ/kg,

$s_1 = 1.303$ kJ/kg K, $v_1 = 0.00104\ m^3/kg$

State 2: Table B.1.3: $h_2 = 3900.1$ kJ/kg, $u_2 = 3457.6$ kJ/kg,

$s_2 = 7.5122$ kJ/kg K, $v_2 = 0.08849\ m^3/kg$





Work is found from the process (area in P-V diagram)

$${}_1W_2 = mP(v_2 - v_1) = 2 \times 5000(0.08849 – 0.00104) = \mathbf{874.6\ kJ}$$

The heat transfer from the energy equation is

$${}_1Q_2 = U_2 - U_1 + {}_1W_2 = m(u_2 - u_1) + mP(v_2 - v_1) = m(h_2 - h_1)$$

$${}_1Q_2 = 2(3900.1 - 422.72) = \mathbf{6954.76\ kJ}$$

Entropy generation from entropy equation (or Eq.8.39)

$${}_1S_{2\,gen} = m(s_2 - s_1) - {}_1Q_2/T_{res} = 2(7.5122 - 1.303) - 6954/973 = \mathbf{5.27\ kJ/K}$$

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8.126

A piston/cylinder contains 1 kg water at 150 kPa, 20°C. The piston is loaded so pressure is linear in volume. Heat is added from a 600°C source until the water is at 1 MPa, 500°C. Find the heat transfer and the total change in entropy.

Solution:

CV H_2O out to the source, both ${}_1Q_2$ and ${}_1W_2$

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.14: $m(s_2 - s_1) = {}_1Q_2 / T_{SOURCE} + {}_1S_{2\ gen}$

Process: $P = A + BV \Rightarrow {}_1W_2 = \int P\, dV = ½ (P_1 + P_2)(V_2 - V_1)$

State 1: B.1.1 Compressed liquid use saturated liquid at same T:

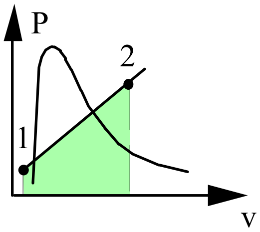
$v_1 = 0.001002\ m^3/kg$; $u_1 = 83.94\ kJ/kg$; $s_1 = 0.2966\ kJ/kg\ K$

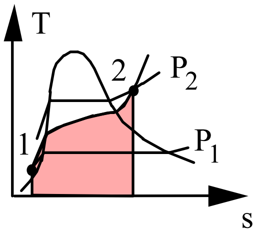
State 2: Table B.1.3 sup. vap.

$v_2 = 0.35411\ m^3/kg$

$u_2 = 3124.3\ kJ/kg$;

$s_2 = 7.7621\ kJ/kg\ K$





${}_1W_2 = ½ (1000 + 150)\ 1\ (0.35411 - 0.001002) = 203\ kJ$

${}_1Q_2 = 1(3124.3 - 83.94) + 203 = \mathbf{3243.4\ kJ}$

$m(s_2 - s_1) = 1(7.7621 - 0.2968) = 7.4655\ kJ/K$

${}_1Q_2 / T_{source} = 3.7146\ kJ/K$ (for source $Q = -{}_1Q_2$ recall Eq.8.18)

${}_1S_{2\ gen} = m(s_2 - s_1) - {}_1Q_2 / T_{SOURCE} = \Delta S_{total}$

$= \Delta S_{H2O} + \Delta S_{source} = 7.4655 - 3.7146 = \mathbf{3.751\ kJ/K}$

Remark: This is an external irreversible process (delta T to the source)

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8.127

A cylinder/piston contains water at 200 kPa, 200°C with a volume of 20 L. The piston is moved slowly, compressing the water to a pressure of 800 kPa. The loading on the piston is such that the product *PV* is a constant. Assuming that the room temperature is 20°C, show that this process does not violate the second law.

Solution:

C.V.: Water + cylinder out to room at 20°C

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.14: $m(s_2 - s_1) = {}_1Q_2 / T_{room} + {}_1S_{2\ gen}$

Process: $PV = \text{constant} = Pmv \Rightarrow v_2 = P_1v_1/P_2$

$${}_1w_2 = \int Pdv = P_1v_1 \ln(v_2/v_1)$$

State 1: Table B.1.3, $v_1 = 1.0803\ m^3/kg$, $u_1 = 2654.4\ kJ/kg$,
$s_1 = 7.5066\ kJ/kg\ K$

State 2: P_2 , $v_2 = P_1v_1/P_2 = 200 \times 1.0803/800 = 0.2701\ m^3/kg$
Table B.1.3: $u_2 = 2655.0\ kJ/kg$, $s_2 = 6.8822\ kJ/kg\ K$

$${}_1w_2 = 200 \times 1.0803 \ln\left(\frac{0.2701}{1.0803}\right) = -299.5\ kJ/kg$$

$${}_1q_2 = u_2 - u_1 + {}_1w_2 = 2655.0 - 2654.4 - 299.5 = -298.9\ kJ/kg$$

$${}_1s_{2,gen} = s_2 - s_1 - \frac{{}_1q_2}{T_{room}} = 6.8822 - 7.5066 + \frac{298.9}{293.15}$$

$$= 0.395\ kJ/kg\ K > 0$$ **satisfy 2nd law.**

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8.128

A piston/cylinder device keeping a constant pressure has 1 kg water at 20^{o}C and 1 kg of water at 100^{o}C both at 500 kPa separated by a thin membrane. The membrane is broken and the water comes to a uniform state with no external heat transfer. Find the final temperature and the entropy generation for the process.

Solution:

Continuity Eq.: $m_2 - m_A - m_B = 0$

Energy Eq.5.11: $m_2u_2 - m_Au_A - m_Bu_B = -{}_1W_2$

Entropy Eq.8.37: $m_2s_2 - m_As_A - m_Bs_B = \int dQ/T + {}_1S_{2\ gen}$

Process: $P = \text{Constant} \Rightarrow {}_1W_2 = \int PdV = P(V_2 - V_1)$

$Q = 0$

Substitute the work term into the energy equation and rearrange to get

$$m_2u_2 + P_2V_2 = m_2h_2 = m_Au_A + m_Bu_B + PV_1 = m_Ah_A + m_Bh_B$$

where the last rewrite used $PV_1 = PV_A + PV_B$.

State A1: Table B.1.4 $h_A = 84.41$ kJ/kg $s_A = 0.2965$ kJ/kg K

State B1: Table B.1.4 $h_B = 419.32$ kJ/kg $s_B = 1.3065$ kJ/kg K

Energy equation gives:

$$h_2 = \frac{m_A}{m_2}h_A + \frac{m_B}{m_2}h_B = \frac{1}{2}\,84.41 + \frac{1}{2}\,419.32 = 251.865 \text{ kJ/kg}$$

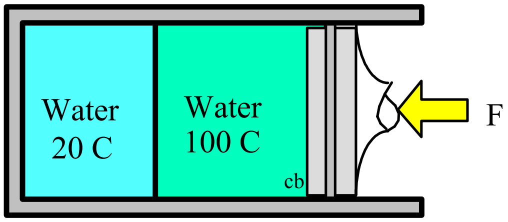
State 2: $h_2 = 251.865$ kJ/kg & $P_2 = 500$ kPa from Table B.1.4

$T_2 = 60.085°C$, $s_2 = 0.83184$ kJ/kg K

With the zero heat transfer we have

$${}_1S_{2\ gen} = m_2s_2 - m_As_A - m_Bs_B$$

$$= 2 \times 0.83184 - 1 \times 0.2965 - 1 \times 1.3065 = \mathbf{0.0607\ kJ/K}$$



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8.129

A piston cylinder has 2.5 kg ammonia at 50 kPa, -20°C. Now it is heated to 50°C at constant pressure through the bottom of the cylinder from external hot gas at 200°C. Find the heat transfer to the ammonia and the total entropy generation.

Solution:

C.V. Ammonia plus space out to the hot gas.

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.37: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2,gen} = {}_1Q_2/\ T_{gas} + {}_1S_{2\ gen}$

Process: $P = C \quad => \quad {}_1W_2 = Pm(v_2 - v_1)$

State 1: Table B.2.2 $v_1 = 2.4463\ m^3/kg$, $h_1 = 1434.6\ kJ/kg$,

$s_1 = 6.3187\ kJ/kg\ K$

State 2: Table B.2.2 $v_2 = 3.1435\ m^3/kg$, $h_2 = 1583.5\ kJ/kg$,

$s_2 = 6.8379\ kJ/kg\ K$

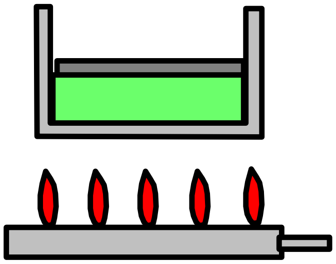
Substitute the work into the energy equation and solve for the heat transfer

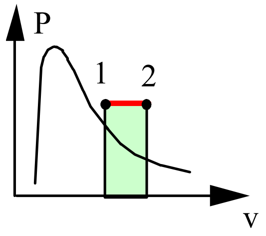
$${}_1Q_2 = m(h_2 - h_1) = 2.5\ (1583.5 – 1434.6) = \mathbf{372.25\ kJ}$$

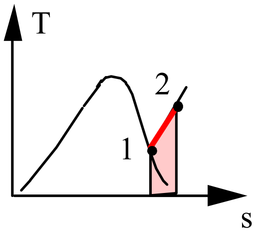
$${}_1S_{2\ gen} = m(s_2 – s_1) - {}_1Q_2/T_{gas}$$

$$= 2.5\ (6.8379 – 6.3187) – 372.25/473.15$$

$$= \mathbf{0.511\ kJ/K}$$







Remark: This is an internally reversible- externally irreversible process. The s is generated in the space between the 200°C gas and the ammonia. If there are any ΔT in the ammonia then it is also internally irreversible.

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8.130

Repeat the previous Problem but include the piston/cylinder steel mass of 1 kg that we assume has the same T as the ammonia at any time.

A piston cylinder has 2.5 kg ammonia at 50 kPa, -20°C. Now it is heated to 50°C at constant pressure through the bottom of the cylinder from external hot gas at 200°C. Find the heat transfer to the ammonia and the total entropy generation.

Solution:

C.V. Ammonia plus space out to the hot gas.

Energy Eq.5.11: $m_{NH3}(u_2 - u_1) + m_{steel}(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.37: $S_2 - S_1 = \int dQ/T + {}_1S_{2,gen} = {}_1Q_2/\, T_{gas} + {}_1S_{2\ gen}$

$S_2 - S_1 = m_{NH3}(s_2 - s_1) + m_{steel}(s_2 - s_1)$

Process: $P = C \quad => \quad {}_1W_2 = Pm_{NH3}(v_2 - v_1)_{NH3}$

State 1: (B.2.2) $v_1 = 2.4463\ m^3/kg$, $h_1 = 1434.6\ kJ/kg$, $s_1 = 6.3187\ kJ/kg\ K$

State 2: (B.2.2) $v_2 = 3.1435\ m^3/kg$, $h_2 = 1583.5\ kJ/kg$, $s_2 = 6.8379\ kJ/kg\ K$

Substitute the work into the energy equation and solve for the heat transfer

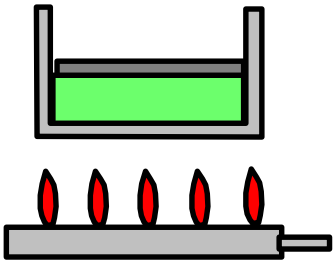
$${}_1Q_2 = m_{NH3}(h_2 - h_1) + m_{steel}(u_2 - u_1)$$

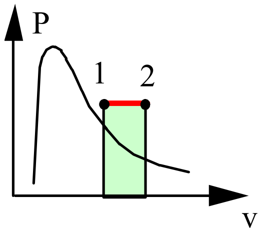
$$= 2.5\ (1583.5 - 1434.6) + 1 \times 0.46\ [50 - (-20)] = \mathbf{404.45\ kJ}$$

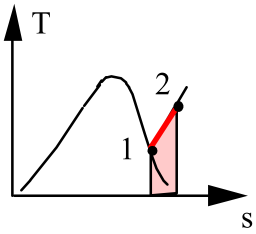
$${}_1S_{2\ gen} = m_{NH3}(s_2 - s_1) + m_{steel}(s_2 - s_1) - {}_1Q_2/T_{gas}$$

$$= 2.5\ (6.8379 - 6.3187) + 1 \times 0.46 \ln(\frac{323.15}{253.15}) - \frac{404.45}{473.15}$$

$$= \mathbf{0.555\ kJ/K}$$







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8.131

A piston/cylinder has ammonia at 2000 kPa, 80°C with a volume of 0.1 m^3. The piston is loaded with a linear spring and outside ambient is at 20°C, shown in Fig. P8.131. The ammonia now cools down to 20°C at which point it has a quality of 10%. Find the work, the heat transfer and the total entropy generation in the process.

CV Ammonia out to the ambient, both ${}_1Q_2$ and ${}_1W_2$

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.14: $m(s_2 - s_1) = {}_1Q_2 / T_{ambient} + {}_1S_{2\ gen}$

Process: $P = A + BV$ => ${}_1W_2 = \int P\, dV = ½\, m(P_1 + P_2)(v_2 - v_1)$

State 1: Table B.2.2

$v_1 = 0.07595\ m^3/kg$, $u_1 = 1421.6\ kJ/kg$, $s_1 = 5.0707\ kJ/kg\ K$

$m = V_1/v_1 = 0.1/0.07595 = 1.31665\ kg$

State 2: Table B.2.1

$v_2 = 0.001638 + 0.1 \times 0.14758 = 0.016396\ m^3/kg$

$u_2 = 272.89 + 0.1 \times 1059.3 = 378.82\ kJ/kg$

$s_2 = 1.0408 + 0.1 \times 4.0452 = 1.44532\ kJ/kg\ K$

${}_1W_2 = ½\, m(P_1 + P_2)(v_2 - v_1)$

$= ½ \times 1.31665\ kg\ (2000 + 857.5)\ kPa\ (0.016396 - 0.07595)\ m^3/kg$

$= \mathbf{-\ 112\ kJ}$

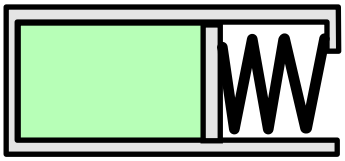
${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 1.31665\ (378.82 - 1421.6) - 112$

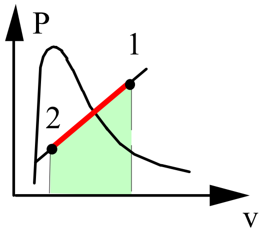
$\mathbf{= -\ 1484.98\ kJ}$

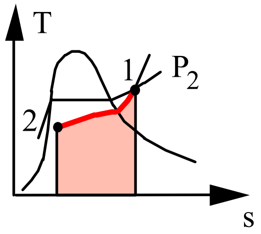
${}_1S_{2\ gen} = m(s_2 - s_1) - ({}_1Q_2 / T_{amb})$

$$= 1.31665\ (1.44532 - 5.0707) - \frac{-1484.98}{293.15}$$

$= -\ 4.77336 + 5.0656 = \mathbf{0.292\ kJ/k}$







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8.132

A 5 kg aluminum radiator holds 2 kg of liquid R-134a both at -10^oC. The setup is brought indoors and heated with 220 kJ from a heat source at 100^oC. Find the total entropy generation for the process assuming the R-134a remains a liquid.

Solution:

C.V. The aluminum radiator and the R-134a.

Energy Eq.5.11: $m_2u_2 - m_1u_1 = {}_1Q_2 - 0$

Process: No change in volume so no work as used above.

The energy equation now becomes (summing over the mass)

$$m_{al}\,(u_2 - u_1)_{al} + m_{R134a}\,(u_2 - u_1)_{R134a} = {}_1Q_2$$

Use specific heat from Table A.3 and A.4

$$m_{al}C_{al}\,(T_2 - T_1) + m_{R134a}C_{R134a}\ \ln\,(T_2 - T_1) = {}_1Q_2$$

$$T_2 - T_1 = {}_1Q_2 \,/\, [m_{al}C_{al} + m_{R134a}C_{R134a}\,]$$

$$= 220 \,/\, [5 \times 0.9 + 2 \times 1.43] = 29.89^oC$$

$$T_2 = -10 + 29.89 = 19.89^oC$$

Entropy generation from Eq.8.37

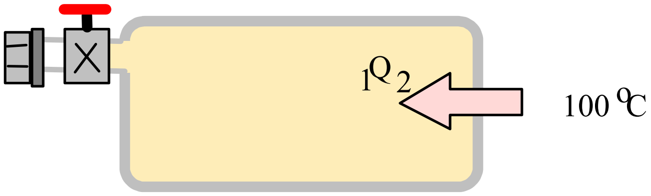
$${}_1S_{2\ gen} = m(s_2 - s_1) - {}_1Q_2/T$$

$$= m_{al}C_{al}\ \ln\,(T_2/T_1) + m_{R134a}C_{R134a}\ \ln\,(T_2/T_1)\ - \frac{{}_1Q_2}{T_{amb}}$$

$$= (5 \times 0.9 + 2 \times 1.43)\ \ln \frac{(19.89 + 273.15)}{-10 + 273.15} - \frac{220}{373.15}$$

$$= 0.7918 - 0.5896$$

$$= \mathbf{0.202\ kJ/K}$$



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8.133

Two 5 kg blocks of steel, one at 250°C the other at 25°C, come in thermal contact. Find the final temperature and the total entropy generation in the process?

C.V. Both blocks, no external heat transfer, C from Table A.3.

$$\text{Energy Eq.:}\quad U_2 - U_1 = m_A(u_2 - u_1)_A + m_B(u_2 - u_1)_B = 0 - 0$$

$$= m_A C(T_2 - T_{A1}) + m_B C(T_2 - T_{B1})$$

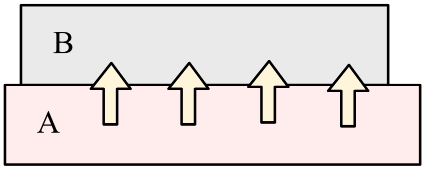
$$T_2 = \frac{m_A T_{A1} + m_B T_{B1}}{m_A + m_B} = \frac{1}{2} T_{A1} + \frac{1}{2} T_{B1} \;\mathbf{= 137.5^oC}$$

$$\text{Entropy Eq.:}\quad S_2 - S_1 = m_A(s_2 - s_1)_A + m_B(s_2 - s_1)_B = {}_1S_{2\,\text{gen}}$$

$${}_1S_{2\,\text{gen}} = m_A C \ln \frac{T_2}{T_{A1}} + m_B C \ln \frac{T_2}{T_{B1}}$$

$$= 5 \times 0.46 \ln \frac{137.5 + 273.15}{250 + 273.15} + 5 \times 0.46 \ln \frac{137.5 + 273.15}{298.15}$$

$$= -0.5569 + 0.7363 = \mathbf{0.1794\ kJ/K}$$



Heat transfer over a finite temperature difference is an irreversible process

8.134

Reconsider Problem 5.60 where CO_2 is compressed from -20^oC, x = 0.75 to a state of 3 MPa, 20^oC in a piston/cylinder where pressure is linear in volume. Assume heat transfer is from a reservoir at 100^oC and find the specific entropy generation in the process (external to the CO_2).

CV Carbon dioxide out to the source, both ${}_1Q_2$ and ${}_1W_2$

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.14: $S_2 - S_1 = \int dQ/T + {}_1S_{2,gen} = {}_1Q_2/T_{res} + {}_1S_{2,gen}$

Process: $P = A + BV$ => ${}_1W_2 = \int P\, dV = ½\, m(P_1 + P_2)(v_2 - v_1)$

State 1: Table B.3.1 P = 1969.6 kPa

$v_1 = 0.000969 + 0.75 \times 0.01837 = 0.01475\ m^3/kg,$

$u_1 = 39.64 + 0.75 \times 246.25 = 224.33$ kJ/kg,

$s_1 = 0.1672 + 0.75 \times 1.1157 = 1.004$ kJ/kg-K

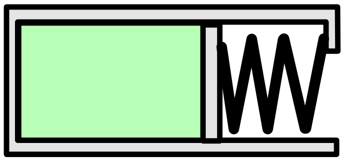
State 2: Table B.3 $v_2 = 0.01512\ m^3/kg$, $u_2 = 310.21$ kJ/kg, $s_2 = 1.3344$ kJ/kg-K

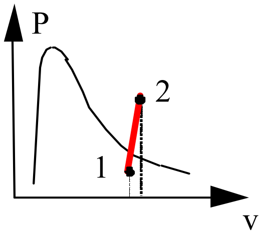
${}_1w_2 = ½\,(P_1 + P_2)(v_2 - v_1) = ½ \times (1969.6 + 3000)(0.01512 - 0.01475)$

$= 0.92$ kJ/kg

${}_1q_2 = u_2 - u_1 + {}_1w_2 = 310.21 - 224.33 + 0.92 = 86.8$ kJ/kg

${}_1s_{2,gen} = s_2 - s_1 - {}_1q_2/T_{res} = 1.3344 - 1.004 - \frac{86.8}{373.15} =$ **0.098 kJ/kg-K**





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8.135

One kilogram of ammonia (NH_3) is contained in a spring-loaded piston/cylinder, Fig. P8.135, as saturated liquid at −20°C. Heat is added from a reservoir at 100°C until a final condition of 800 kPa, 70°C is reached. Find the work, heat transfer, and entropy generation, assuming the process is internally reversible.

Solution:

C.V. = NH_3 out to the reservoir.

Continuity Eq.: $m_2 = m_1 = m$

Energy Eq.5.11: $E_2 - E_1 = m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.14: $S_2 - S_1 = \int dQ/T + {}_1S_{2,gen} = {}_1Q_2/T_{res} + {}_1S_{2,gen}$

Process: $P = A + BV$ linear in V =>

$${}_1W_2 = \int PdV = \frac{1}{2}(P_1 + P_2)(V_2 - V_1) = \frac{1}{2}(P_1 + P_2)m(v_2 - v_1)$$

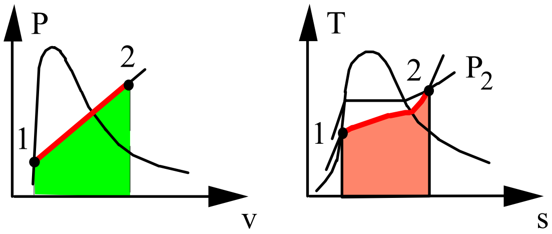
State 1: Table B.2.1

$P_1 = 190.08$ kPa,

$v_1 = 0.001504\ m^3/kg$

$u_1 = 88.76$ kJ/kg,

$s_1 = 0.3657$ kJ/kg K



State 2: Table B.2.2 sup. vapor

$v_2 = 0.199\ m^3/kg$, $u_2 = 1438.3$ kJ/kg, $s_2 = 5.5513$ kJ/kg K

$${}_1W_2 = \frac{1}{2}(190.08 + 800)1(0.1990 - 0.001504) = \mathbf{97.768\ kJ}$$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 1(1438.3 - 88.76) + 97.768 = \mathbf{1447.3\ kJ}$$

$${}_1S_{2,gen} = m(s_2 - s_1) - {}_1Q_2/T_{res} = 1(5.5513 - 0.3657) - \frac{1447.3}{373.15} = \mathbf{1.307\ kJ/K}$$

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8.136

The water in the two tanks of Problem 5.67 receives the heat transfer from a reservoir at 300°C. Find the total entropy generation due to this process.

Two rigid tanks are filled with water. Tank A is 0.2 m^3 at 100 kPa, 150°C and tank B is 0.3 m^3 at saturated vapor 300 kPa. The tanks are connected by a pipe with a closed valve. We open the valve and let all the water come to a single uniform state while we transfer enough heat to have a final pressure of 300 kPa. Give the two property values that determine the final state and heat transfer.

Take CV total A + B out to reservoir (neglect kinetic and potential energy)

Energy Eq.: $m_2 u_2 - m_A u_{A1} - m_B u_{B1} = {}_1Q_2 - {}_1W_2 = {}_1Q_2$

Entropy Eq.: $m_2 s_2 - m_A s_{A1} - m_B s_{B1} = {}_1Q_2/T_{res} + {}_1S_{2\ gen}$

State A1: u = 2582.75 kJ/kg, v = 1.93636 m^3/kg, s = 7.6133 kJ/kg-K

=> $m_{A1} = V/v = 0.2/1.93636 = 0.1033$ kg

State B1: u = 2543.55 kJ/kg, v = 0.60582 m^3/kg, s = 6.9918 kJ/kg-K

=> $m_{B1} = V/v = 0.3 / 0.60582 = 0.4952$ kg

The total volume (and mass) is the sum of volumes (mass) for tanks A and B.

$m_2 = m_{A1} + m_{B1} = 0.1033 + 0.4952 = 0.5985$ kg,

$V_2 = V_{A1} + V_{B1} = 0.2 + 0.3 = 0.5\ m^3$

=> $v_2 = V_2/m_2 = 0.5 / 0.5985 = 0.8354\ m^3/kg$

State 2: $[P_2, v_2]$ = [300 kPa, 0.8354 m^3/kg]

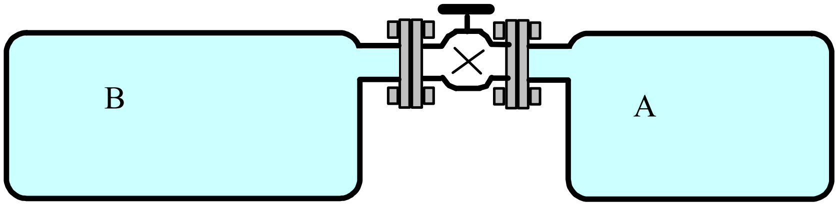
=> $T_2 = 274.76°C$ and $u_2 = 2767.32$ kJ/kg, s = 7.60835 kJ/kgK

From energy eq.

$${}_1Q_2 = 0.5985 \times 2767.32 - 0.1033 \times 2582.75 - 0.4952 \times 2543.55 = 129.9 \text{ kJ}$$

From entropy equation

$${}_1S_{2\ gen} = m_2 s_2 - m_A s_{A1} - m_B s_{B1} - {}_1Q_2/T_{res}$$
$$= 0.5985 \times 7.60835 - 0.1033 \times 7.6133 - 0.4952 \times 6.9918$$
$$- 129.9 / (273.15 + 300) = \mathbf{0.0782\ kJ/K}$$



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8.137

A piston cylinder loaded so it gives constant pressure has 0.75 kg saturated vapor water at 200 kPa. It is now cooled so the volume becomes half the initial volume by heat transfer to the ambient at 20^{o}C. Find the work, the heat transfer and the total entropy generation.

Solution:

Continuity Eq.: $m_2 - m_1 = 0$

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.37: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\text{ gen}}$

Process: $P = C \quad => \quad {}_1W_2 = \int PdV = mP(v_2 - v_1)$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = m(h_2 - h_1)$$

State 1: $v_1 = 0.88573\ m^3/kg$, $h_1 = 2706.63$ kJ/kg, $s_1 = 7.1271$ kJ/kg K

State 2: P_2, $v_2 = v_1/2 = 0.444286$ m3/kg => Table B.1.2

$$x_2 = (0.444286 - 0.001061)/0.88467 = 0.501$$

$$h_2 = 504.68 + x_2 \times 2201.96 = 1607.86 \text{ kJ/kg}$$

$$s_2 = 1.53 + x_2 \times 5.5970 = 4.3341 \text{ kJ/kg K}$$

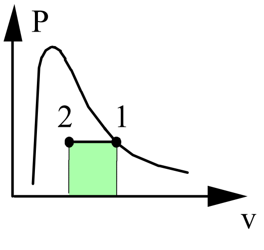
${}_1W_2 = 0.75 \times 200(0.444286 - 0.88573) =$ **-66.22 kJ**

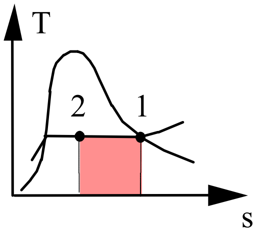
${}_1Q_2 = 0.75(1607.86 - 2706.63) =$ **-824.1 kJ**

${}_1S_{2\text{ gen}} = m(s_2 - s_1) - {}_1Q_2/T = 0.75(4.3341 - 7.1271) - (-824.1/293.15)$

$= -2.09475 + 2.81119 =$ **0.716 kJ/K**

Notice: The process is externally irreversible (T receiving Q is not T_1)





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8.138

A piston/cylinder of total 1 kg steel contains 0.5 kg ammonia at 1600 kPa both masses at 120°C. Some stops are placed so a minimum volume is 0.02 m^3, shown in Fig. P8.138. Now the whole system is cooled down to 30°C by heat transfer to the ambient at 20°C, and during the process the steel keeps same temperature as the ammonia. Find the work, the heat transfer and the total entropy generation in the process.

$1: \; v_1 = 0.11265 \text{ m}^3\text{/kg}, \quad u_1 = 1516.6 \text{ kJ/kg}, \quad s_1 = 5.5018 \text{ kJ/kg K}$

$V_1 = mv_1 = 0.05634 \text{ m}^3$

Stop 1a: $v_{stop} = V/m = 0.02/0.5 = 0.04 \text{ m}^3\text{/kg}$

$P_{stop} = P_1 \;\Rightarrow\; T \sim 42^{o}C$ (saturated)

$2: \quad 30^{o}C < T_{stop}$ so $\quad v_2 = v_{stop} = 0.04 \text{ m}^3\text{/kg}$

$$x_2 = \left(\frac{v_2\text{-}v_f}{v_{fg}}\right) = \frac{0.04 - 0.00168}{0.10881} = 0.35217$$

$u_2 = 320.46 + x_2 \times 1016.9 = 678.58 \text{ kJ/kg}$

$s_2 = 1.2005 + x_2 \times 3.7734 = 2.5294 \text{ kJ/kg K}$

${}_1W_2 = \int P\, dV = P_1 m\, (v_2\text{-}v_1) = 1600 \times 0.5\, (0.004 - 0.11268) = -\,58.14 \text{ kJ}$

${}_1Q_2 = m\,(u_2 - u_1) + m_{st}(u_2 - u_1) + {}_1W_2$

$= 0.5(\,678.58 - 1516.6\,) + 1{\times}0.46(30 - 120) - 58.14$

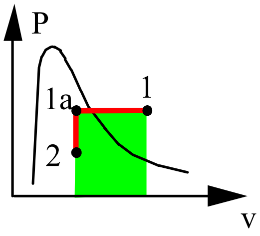
$= -419.01 - 41.4 - 58.14 = \mathbf{-518.55\ kJ}$

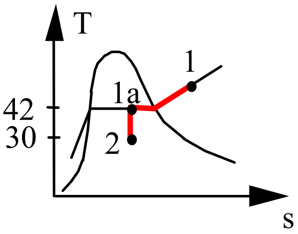
${}_1S_{2\,gen} = m(s_2 - s_1) + m_{st}\,(s_2 - s_1) - {}_1Q_2/T_{amb}$

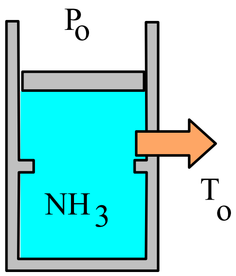
$$= 0.5\,(2.5294 - 5.5018) + 1{\times}0.46 \ln \frac{273{+}30}{273{+}120} - \frac{-518.5}{293.15}$$

$= -\,1.4862 - 0.1196 + 1.6277$

$= \mathbf{0.02186\ kJ/K}$







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8.139

A hollow steel sphere with a 0.5-m inside diameter and a 2-mm thick wall contains water at 2 MPa, 250°C. The system (steel plus water) cools to the ambient temperature, 30°C. Calculate the net entropy change of the system and surroundings for this process.

C.V.: Steel + water. This is a control mass.

Energy Eq.: $U_2 - U_1 = {}_1Q_2 - {}_1W_2 = m_{H_2O}(u_2 - u_1) + m_{steel}(u_2 - u_1)$

Process: V = constant => ${}_1W_2 = 0$

$m_{steel} = (\rho V)_{steel} = 8050 \times (\pi/6)\left[(0.504)^3 - (0.5)^3\right] = 12.746$ kg

$V_{H2O} = (\pi/6)(0.5)^3, \quad m_{H_2O} = V/v = 6.545\times10^{-2}/0.11144 = 0.587$ kg

$v_2 = v_1 = 0.11144 = 0.001004 + x_2 \times 32.889 \Rightarrow x_2 = 3.358\times10^{-3}$

$u_2 = 125.78 + 3.358\times10^{-3} \times 2290.8 = 133.5$ kJ/kg

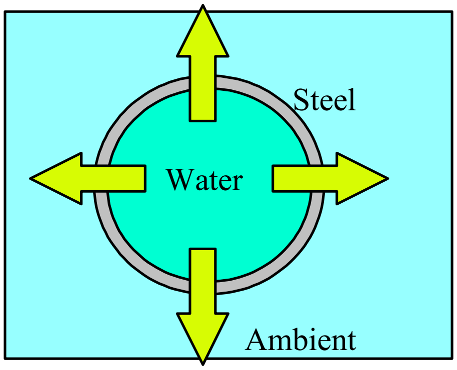
$s_2 = 0.4639 + 3.358\times10^{-3} \times 8.0164 = 0.4638$ kJ/kg K

$${}_1Q_2 = m_{H_2O}(u_2 - u_1) + m_{steel}(u_2 - u_1)$$
$$= 0.587(133.5 - 2679.6) + 12.746 \times 0.48(30 - 250)$$
$$= -1494.6 + (-1346) = -2840.6 \text{ kJ}$$

$$\Delta S_{TOT} = \Delta S_{STEEL} + \Delta S_{H_2O} = 12.746 \times 0.48 \ln(303.15 / 523.15)$$
$$+ 0.587(0.4638 - 6.545) = \mathbf{-6.908\ kJ/K}$$

$\Delta S_{SURR} = -{}_1Q_2/T_0 = +2840.6/303.2 = \mathbf{+9.370\ kJ/K}$

$\Delta S_{NET} = -6.908 + 9.370 = \mathbf{+2.462\ kJ/K}$



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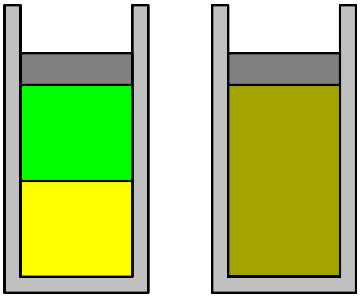
8.140

One kg of air at 300 K is mixed with one kg air at 400 K in a process at a constant 100 kPa and Q = 0. Find the final T and the entropy generation in the process.



C.V. All the air.

Energy Eq.: $U_2 - U_1 = 0 - W$

Entropy Eq.: $S_2 - S_1 = 0 + {}_1S_{2\ gen}$

Process Eq.: $P = C; \quad W = P(V_2 - V_1)$

Substitute W into energy Eq.

$$U_2 - U_1 + W = U_2 - U_1 + P(V_2 - V_1) = H_2 - H_1 = 0$$

Due to the low T let us use constant specific heat

$$H_2 - H_1 = m_A(h_2 - h_1)_A + m_B(h_2 - h_1)_B$$
$$= m_AC_p(T_2 - T_{A1}) + m_BC_p(T_2 - T_{B1}) = 0$$

$$T_2 = \frac{m_AT_{A1} + m_BT_{B1}}{m_A + m_B} = \frac{1}{2}T_{A1} + \frac{1}{2}T_{B1} \ \mathbf{= 350\ K}$$

Entropy change is from Eq. 8.16 with no change in P

$${}_1S_{2\ gen} = S_2 - S_1 = m_AC_p \ln\frac{T_2}{T_{A1}} + m_BC_p \ln\frac{T_2}{T_{B1}}$$
$$= 1 \times 1.004 \ln\frac{350}{300} + 1 \times 1.004 \ln\frac{350}{400}$$
$$= 0.15477 - 0.13407 = \mathbf{0.0207\ kJ/K}$$

Remark: If you check, the volume does not change and there is no work.

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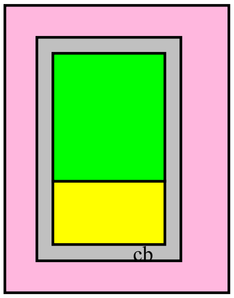
8.141

One kg of air at 100 kPa is mixed with one kg air at 200 kPa, both at 300 K, in a rigid insulated tank. Find the final state (P, T) and the entropy generation in the process.



C.V. All the air.

Energy Eq.: $U_2 - U_1 = 0 - 0$

Entropy Eq.: $S_2 - S_1 = 0 + {}_1S_{2\ gen}$

Process Eqs.: $V = C$; $W = 0$, $Q = 0$

States A1, B1: $u_{A1} = u_{B1}$

$V_A = m_ART_1/P_{A1}$; $V_B = m_BRT_1/P_{B1}$

$$U_2 - U_1 = m_2u_2 - m_Au_{A1} - m_Bu_{B1} = 0 \quad \Rightarrow \quad u_2 = (u_{A1} + u_{B1})/2 = u_{A1}$$

State 2: $\mathbf{T_2 = T_1 = 300\ K}$ (from u_2); $m_2 = m_A + m_B = 2$ kg;

$$V_2 = m_2RT_1/P_2 = V_A + V_B = m_ART_1/P_{A1} + m_BRT_1/P_{B1}$$

Divide with m_ART_1 and get

$$2/P_2 = 1/P_{A1} + 1/P_{B1} = \frac{1}{100} + \frac{1}{200} = 0.015\ \text{kPa}^{-1} \quad \Rightarrow \quad P_2 = \mathbf{133.3\ kPa}$$

Entropy change from Eq. 8.25 with the same T, so only P changes

$${}_1S_{2\ gen} = S_2 - S_1 = -m_AR \ln \frac{P_2}{P_{A1}} - m_BR \ln \frac{P_2}{P_{B1}}$$

$$= -1 \times 0.287\ [\ \ln \frac{133.3}{100} + \ln \frac{133.3}{200}\ ]$$

$$= -0.287\ (0.2874 - 0.4057) = \mathbf{0.034\ kJ/K}$$

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8.142

A spring loaded piston cylinder contains 1.5 kg air at 27°C and 160 kPa. It is now heated in a process where pressure is linear in volume, P = A + BV, to twice the initial volume where it reaches 900 K. Find the work, the heat transfer and the total entropy generation assuming a source at 900 K.

Solution:

C.V. Air out to the 900 K source. Since air T is lower than the source temperature we know that this is an irreversible process.

Continuity Eq.: $m_2 = m_1 = m,$

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.37: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\,\text{gen}} = {}_1Q_2/T_{\text{SOURCE}} + {}_1S_{2\,\text{gen}}$

Process: $P = A + BV$

State 1: (T_1, P_1) Table A.7 $u_1 = 214.36$ kJ/kg

$$V_1 = mRT_1/ P_1 = (1.5 \times 0.287 \times 300) / 160 = 0.8072 \text{ m}^3$$

State 2: $(T_2, v_2 = 2\, v_1)$ Table A.7 $u_2 = 674.824$ kJ/kg

$$P_2 = RT_2/ v_2 = RT_2/2v_1 = T_2\, P_1/ 2T_1 = P_1\, T_2/2\, T_1$$

$$= 160 \times 900 / (2 \times 300) = 240 \text{ kPa}$$

From the process equation we can express the work as

$${}_1W_2 = \int PdV = 0.5 \times (P_1 + P_2)\,(V_2 - V_1) = 0.5 \times (P_1 + P_2)\, V_1$$

$$= 0.5 \times (160 + 240)\, 0.8072 = \mathbf{161.4\ kJ}$$

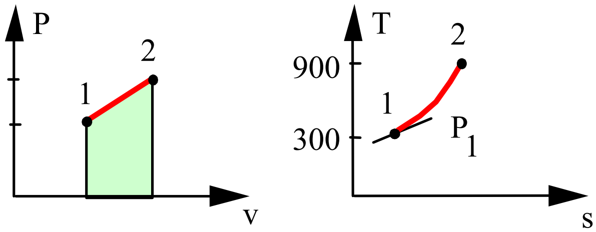
$${}_1Q_2 = 1.5 \times (\,674.824 - 214.36) + 161.4 = \mathbf{852.1\ kJ}$$

Change in s from Eq.8.19 and Table A.7 values

$${}_1S_{2\,\text{gen}} = m(s^o_{T2} - s^o_{T1} - R \ln \frac{P_2}{P_1}) - {}_1Q_2/T_{\text{SOURCE}}$$

$$= 1.5 \times [8.0158 - 6.8693 - 0.287 \ln (\frac{240}{160})] - (\frac{852.1}{900})$$

$$= 1.545 - 0.947 = \mathbf{0.598\ kJ/K}$$



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8.143

Air in a rigid tank is at 900 K, 500 kPa and it now cools to the ambient temperature of 300 K by heat loss to the ambient. Find the entropy generation.

C.V. Air out to ambient. No size given so do it per unit mass.

Energy Eq.5.11: $u_2 - u_1 = C_v (T_2 - T_1) = {}_1q_2 - {}_1w_2$

Entropy Eq.8.14: $s_2 - s_1 = {}_1q_2/T_{amb} + {}_1s_{2\ gen\ tot}$

Process: V = constant => $v_2 = v_1$ also ${}_1W_2 = 0$

Ideal gas: $P_2 = P_1 T_2 / T_1 = 500 \times 300/900 = 166.67$ kPa

From Table A.7: $u_1 = 674.82$ kJ/kg; $s_{T1} = 8.01581$ kJ/kg-K;

$u_2 = 214.36$ kJ/kg; $s_{T2} = 6.86926$ kJ/kg-K

$${}_1q_2 = u_2 - u_1 = 214.36 - 674.82 = -460.46 \text{ kJ/kg}$$

$${}_1s_{2\ gen\ tot} = s_2 - s_1 - \frac{{}_1q_2}{T_{amb}} = s_{T2} - s_{T1} - R\ \ln(\frac{P_2}{P_1}) - \frac{{}_1q_2}{T_{amb}}$$

$$= 6.86926 - 8.01581 - 0.287\ \ln(\frac{166.67}{500}) - \frac{-460.46}{300}$$

$$= \mathbf{0.661\ kJ/kg\text{-}K}$$

We could also have used constant specific heat being slightly less accurate.

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8.144

A rigid storage tank of 1.5 m^3 contains 1 kg argon at 30°C. Heat is then transferred to the argon from a furnace operating at 1300°C until the specific entropy of the argon has increased by 0.343 kJ/kg K. Find the total heat transfer and the entropy generated in the process.

Solution:

C.V. Argon out to 1300°C. Control mass. , m = 1 kg

Argon is an ideal gas with constant heat capacity.

Energy Eq.5.11: $m (u_2 - u_1) = m C_v (T_2 - T_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.14: $m(s_2 - s_1) = {}_1Q_2/T_{res} + {}_1S_{2\text{ gen tot}}$

Process: V = constant => $v_2 = v_1$ also ${}_1W_2 = 0$

Properties: Table A.5 R = 0.20813, $C_v = 0.312$ kJ/kg K

State 1: $(T_1, v_1= V/m)$ $P_1 = mRT_1/V = 42.063$ kPa

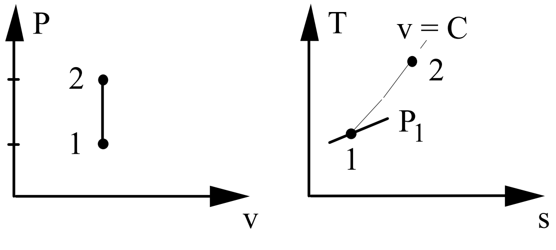
State 2: $s_2 = s_1 + 0.343$, and change in s from Eq.8.28 or Eq.8.26

$$s_2 - s_1 = C_p \ln (T_2 / T_1) - R \ln (T_2 / T_1) = C_v \ln (T_2 / T_1)$$

$$T_2 / T_1 = \exp[\frac{s_2 - s_1}{C_v}] = \exp[\frac{0.343}{0.312}] = \exp(1.09936) = 3.0$$

Pv = RT => $(P_2 / P_1) (v_2 / v_1) = T_2 / T_1 = P_2 / P_1$

$$T_2 = 3.0 \times T_1 = 909.45 \text{ K}, \quad P_2 = 3.0 \times P_1 = 126.189 \text{ kPa}$$



Heat transfer from energy equation

${}_1Q_2 = 1 \times 0.312 (909.45 – 303.15) =$ **189.2 kJ**

Entropy generation from entropy equation (2nd law)

${}_1S_{2\text{ gen tot}} = m(s_2 – s_1) – {}_1Q_2/T_{res}$

$= 1 \times 0.343 – 189.2 / (1300 + 273) =$ **0.223 kJ/K**

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8.145

Argon in a light bulb is at 110 kPa, 70°C. The light is turned off so the argon cools to the ambient 20°C. Disregard the glass and any other mass and find the specific entropy generation.

Solution:

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

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2$

Entropy Eq.8.37: $s_2 - s_1 = \int dq/T + {}_1s_{2\ gen} = {}_1q_2/T_{room} + {}_1s_{2\ gen}$

Process: $v = \text{constant and ideal gas} \Rightarrow P_2/P_1 = T_2/T_1$

$${}_1q_2 = u_2 - u_1 = C_v (T_2 - T_1) = 0.312\ (20 - 70) = -15.6 \text{ kJ/kg}$$

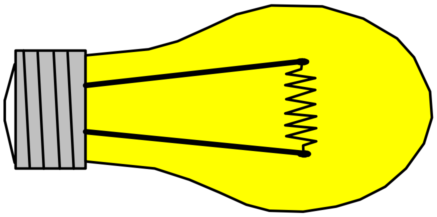
Evaluate changes in s from Eq.8.16 or 8.17

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

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

$$= 0.312 \ln [\ (20 + 273)/(70 + 273)\ ] = -0.0491 \text{ kJ/kg K}$$

$${}_1s_{2\ gen} = s_2 - s_1 - {}_1q_2/T_{room} = -0.0491 + 15.6 / 293.15 = \mathbf{0.0041\ kJ/kgK}$$



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8.146

A rigid container with volume 200 L is divided into two equal volumes by a partition, shown in Fig. P8.146. Both sides contain nitrogen, one side is at 2 MPa, 200°C, and the other at 200 kPa, 100°C. The partition ruptures, and the nitrogen comes to a uniform state at 70°C. Assume the temperature of the surroundings is 20°C, determine the work done and the net entropy change for the process.

Solution:

C.V. : A + B no change in volume. $\mathbf{{}_1W_2 = 0}$

$m_{A1} = P_{A1}V_{A1}/RT_{A1} = (2000 \times 0.1)/(0.2968 \times 473.2) = 1.424$ kg

$m_{B1} = P_{B1}V_{B1}/RT_{B1} = (200 \times 0.1)/(0.2968 \times 373.2) = 0.1806$ kg

$P_2 = m_{TOT}RT_2/V_{TOT} = (1.6046 \times 0.2968 \times 343.2)/0.2 = 817$ kPa

From Eq.8.25

$$\Delta S_{SYST} = 1.424\left[1.042 \ln\frac{343.2}{473.2} - 0.2968 \ln\frac{817}{2000}\right]$$

$$+ 0.1806\left[1.042 \ln\frac{343.2}{373.2} - 0.2968 \ln\frac{817}{200}\right] = -0.1894 \text{ kJ/K}$$

$${}_1Q_2 = U_2 - U_1 = 1.424 \times 0.745(70 - 200) + 0.1806 \times 0.745(70 - 100)$$

$$= -141.95 \text{ kJ}$$

From Eq.8.18

$\Delta S_{SURR} = -\,{}_1Q_2/T_0 = 141.95/293.2 = +0.4841$ kJ/K

$\Delta S_{NET} = -0.1894 + 0.4841 =$ **+0.2947 kJ/K**

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8.147

Nitrogen at 200°C, 300 kPa is in a piston cylinder, volume 5 L, with the piston locked with a pin. The forces on the piston require a pressure inside of 200 kPa to balance it without the pin. The pin is removed and the piston quickly comes to its equilibrium position without any heat transfer. Find the final P, T and V and the entropy generation due to this partly unrestrained expansion.

Solution:

C.V. Nitrogen gas.

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2 = - \int P_{eq}\, dV = -P_2\,(V_2 - V_1)$

Entropy Eq.8.14: $m(s_2 - s_1) = 0 + {}_1S_{2\ gen}$

Process: ${}_1Q_2 = 0$ (already used), $P = P_{eq}$ after pin is out.

State 1: 200 °C, 300 kPa State 2: $P_2 = P_{eq} =$ **200 kPa**

$$m = P_1V_1/RT_1 = 300 \times 0.005 / 0.2968 \times 473.15 = 0.01068 \text{ kg}$$

The energy equation becomes

$$mu_2 + P_2V_2 = mu_1 + P_2V_1 = mh_2 \quad =>$$

$$h_2 = u_1 + P_2V_1/m = u_1 + P_2V_1\ RT_1\ /P_1V_1 = u_1 + (P_2/P_1)\ RT_1$$

Solve using constant C_p, C_v

$$C_p\ T_2 = C_v\ T_1 + (P_2/P_1)\ RT_1$$

$$T_2 = T_1\ [C_v + (P_2/P_1)\ R] / C_p$$

$$= 473.15\ [0.745 + (200 / 300) \times 0.2368] / 1.042$$

$$= \mathbf{428.13\ K}$$

$$V_2 = V_1(\ T_2 / T_1) \times (\ P_1/P_2\ ) = 0.005 \times \frac{428.13}{473.15} \times \frac{300}{200}$$

$$= 0.00679 \text{ m}^3$$

$${}_1S_{2\ gen} = m(s_2 - s_1) \cong m[C_p \ln (T_2/T_1) - R \ln (P_2/ P_1)]$$

$$= P_1V_1\ /RT_1\ [C_p \ln (T_2/T_1) - R \ln (P_2/ P_1)]$$

$$= 0.01068\ [1.042 \times \ln (428.13/473.15) - 0.2968 \times \ln (200 / 300)]$$

$$= \mathbf{0.000173\ kJ/K}$$

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8.148

A rigid tank contains 2 kg of air at 200 kPa and ambient temperature, 20°C. An electric current now passes through a resistor inside the tank. After a total of 100 kJ of electrical work has crossed the boundary, the air temperature inside is 80°C. Is this possible?

Solution:

C.V.: Air in tank out to ambient;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$, $\quad {}_1W_2 = -100$ kJ

Entropy Eq.8.37: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\,\text{gen}} = {}_1Q_2/T_{\text{amb}} + {}_1S_{2\,\text{gen}}$

Process: Constant volume and mass so $v_2 = v_1$

State 1: $T_1 = 20^{\text{o}}\text{C}$, $P_1 = 200$ kPa, $\quad m_1 = 2$ kg

State 2: $T_2 = 80^{\text{o}}\text{C}$, $v_2 = v_1$

Ideal gas, Table A.5: $R = 0.287$ kJ/kg-K, $\quad C_v = 0.717$ kJ/kg-K

Assume constant specific heat then energy equation gives

$${}_1Q_2 = mC_v(T_2 - T_1) + {}_1W_2 = 2 \times 0.717(80 - 20) - 100 = -14.0 \text{ kJ}$$

Change in s from Eq.8.17 (since second term drops out)

$$s_2 - s_1 = C_v \ln (T_2/T_1) + R\ln \frac{v_2}{v_1} \;;\quad v_2 = v_1,\quad \ln \frac{v_2}{v_1} = 0$$

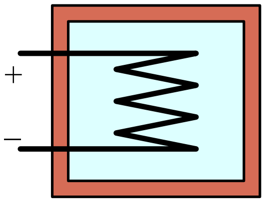
$$s_2 - s_1 = C_v\ln (T_2/T_1) = 0.1336 \text{ kJ/kg-K}$$

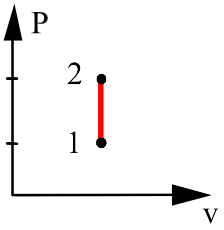
Now Eq.8.37

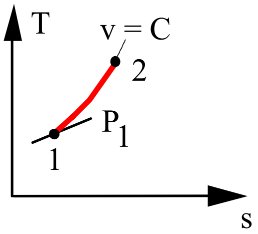
$${}_1S_{2\,\text{gen}} = m(s_2 - s_1) - {}_1Q_2/T_{\text{amb}} = 2 \times 0.1336 + \frac{14}{293} = 0.315 \text{ kJ/K} \;\geq 0,$$

Process is Possible

Note: $P_2 = P_1 \frac{T_2}{T_1}$ in Eq.8.16 $\quad s_2 - s_1 = C_p \ln\frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$, results in the same answer as Eq.8.17.







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8.149

The air in the tank of Problem 5.117 receives the heat transfer from a reservoir at 450 K. Find the entropy generation due to the process from 1 to 3.

C.V. Air out to reservoir.

Energy eq.: $m(u_3 - u_1) = {}_1Q_3 - {}_1W_3$

Entropy eq.: $m(s_3 - s_1) = {}_1Q_3 / T_{res} + {}_1S_{3\,gen}$

State 1: $m = P_1V_1 / RT_1 = \frac{100 \times 0.75}{0.287 \times 300} \frac{kPa\ m^3}{kJ/kg} = 0.871\ kg$

Process 1 to 2: Constant volume heating, $dV = 0 \Rightarrow {}_1W_2 = 0$

$P_2 = P_1\ T_2 / T_1 = 100 \times 400 / 300 = 133.3\ kPa$

Process 2 to 3: Isothermal expansion, $dT = 0 \Rightarrow u_3 = u_2$ and

$P_3 = P_2\ V_2 / V_3 = 133.3 \times 0.75 / 1.5 = 66.67\ kPa$

$${}_2W_3 = \int_2^3 P\ dV = P_2V_2 \ln\left(\frac{V_3}{V_2}\right) = 133.3 \times 0.75 \ln(2) = 69.3\ kJ$$

The overall process:

$${}_1W_3 = {}_1W_2 + {}_2W_3 = {}_2W_3 = 69.3\ kJ$$

From the energy equation

$${}_1Q_3 = m(u_3 - u_1) + {}_1W_3 = m\ C_v\ (T_3 - T_1) + {}_1W_3$$
$$= 0.871 \times 0.717\ (400 - 300) + 69.3 = 131.8\ kJ$$

$${}_1S_{3\,gen} = m(s_3 - s_1) - {}_1Q_3 / T_{res}$$
$$= m\left(C_P \ln\frac{T_3}{T_1} - R \ln\frac{P_3}{P_1}\right) - {}_1Q_3 / T_{res}$$
$$= 0.871\left[\ 1.004 \ln\frac{400}{300} - 0.287 \ln\frac{66.67}{100}\ \right] - \frac{131.8}{450}$$

$= \mathbf{0.060\ kJ/K}$

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8.150

Nitrogen at 600 kPa, 127°C is in a 0.5 m^3 insulated tank connected to a pipe with a valve to a second insulated initially empty tank of volume 0.5 m^3, shown in Fig. P8.150. The valve is opened and the nitrogen fills both tanks at a uniform state. Find the final pressure and temperature and the entropy generation this process causes. Why is the process irreversible?

Solution:

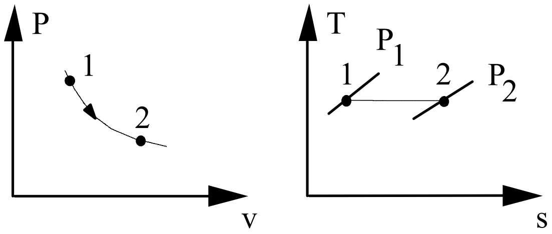
CV Both tanks + pipe + valve Insulated : Q = 0 Rigid: W = 0

Energy Eq.5.11: $m(u_2 - u_1) = 0 - 0 \quad => \quad u_2 = u_1 = u_{a1}$

Entropy Eq.8.37: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\ gen} = {}_1S_{2\ gen} \quad (dQ = 0)$

1: $P_1 , T_1 , V_a \quad => \quad m = PV/RT = (600 \times 0.5)/ (0.2968 \times 400) = 2.527$ kg

2: $V_2 = V_a + V_b$; uniform state $v_2 = V_2 / m$; $u_2 = u_{a1}$



Ideal gas u (T) => $u_2 = u_{a1}$ => $T_2 = T_{a1}$ = **400 K**

$P_2 = mR T_2 / V_2 = (V_1 / V_2) P_1 = ½ \times 600 =$ **300 kPa**

From entropy equation and Eq.8.19 for entropy change

$S_{gen} = m(s_2 - s_1) = m[s_{T2} - s_{T1} - R \ln(P_2 / P_1)]$

$= m [0 - R \ln (P_2 / P_1)] = -2.527 \times 0.2968 \ln ½ =$ **0.52 kJ/K**

Irreversible due to unrestrained expansion in valve P ↓ but no work out.

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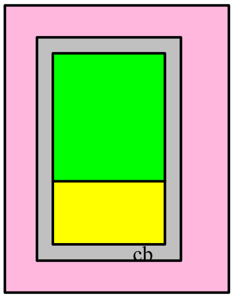
8.151

One kg of carbon dioxide at 100 kPa, 500 K is mixed with two kg carbon dioxide at 200 kPa, 2000 K, in a rigid insulated tank. Find the final state (P, T) and the entropy generation in the process using constant heat capacity from Table A.5.



C.V. All the carbon dioxide.

Continuity: $m_2 = m_A + m_B = 3$ kg

Energy Eq.: $U_2 - U_1 = 0 - 0$

Entropy Eq.: $S_2 - S_1 = 0 + {}_1S_{2\ gen}$

Process Eqs.: $V = C$; $W = 0$, $Q = 0$

$V_A = m_A R T_1/P_{A1}$; $V_B = m_B R T_1/P_{B1}$

$$U_2 - U_1 = m_2 u_2 - m_A u_{A1} - m_B u_{B1} = 0$$

$$= m_2 C_v T_2 - m_A C_v T_{A1} - m_B C_v T_{B1}$$

$$\Rightarrow T_2 = (m_A T_{A1} + m_B T_{B1})/ m_2 = \frac{1}{3} \times 500 + \frac{2}{3} \times 2000 = \mathbf{1500\ K}$$

State 2: $V_2 = m_2 R T_2/P_2 = V_A + V_B = m_A R T_{A1}/P_{A1} + m_B R T_{B1}/P_{B1}$

$$= 1 \times R \times 500/100 + 2 \times R \times 2000/200 = 25\ R$$

Substitute m_2, T_2 and solve for P_2

$$P_2 = 3\ R\ T_2/25\ R = 3 \times 1500 / 25 = \mathbf{180\ kPa}$$

Entropy change from Eq. 8.16

$$(s_2 - s_1)_A = C_p \ln\frac{T_2}{T_{A1}} - R \ln\frac{P_2}{P_{A1}} = 0.842 \ln\frac{1500}{500} - 0.1889 \ln\frac{180}{100}$$

$$= 0.814 \text{ kJ/kgK}$$

$$(s_2 - s_1)_B = C_p \ln\frac{T_2}{T_{B1}} - R \ln\frac{P_2}{P_{B1}} = 0.842 \ln\frac{1500}{2000} - 0.1889 \ln\frac{180}{200}$$

$$= -0.2223 \text{ kJ/kgK}$$

$${}_1S_{2\ gen} = S_2 - S_1 = m_A(s_2 - s_1)_A + m_B(s_2 - s_1)_B$$

$$= 1 \times 0.814 + 2\ (-0.2223) = \mathbf{0.369\ kJ/K}$$

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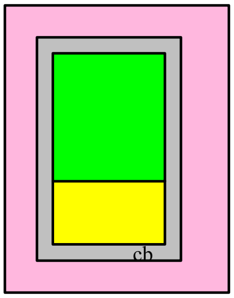
8.152

One kg of carbon dioxide at 100 kPa, 500 K is mixed with two kg carbon dioxide at 200 kPa, 2000 K, in a rigid insulated tank. Find the final state (P, T) and the entropy generation in the process using table A.8.



C.V. All the carbon dioxide.

Continuity: $m_2 = m_A + m_B = 3$ kg

Energy Eq.: $U_2 - U_1 = 0 - 0$

Entropy Eq.: $S_2 - S_1 = 0 + {}_1S_{2\ gen}$

Process Eqs.: $V = C$; $W = 0$, $Q = 0$

$V_A = m_A R T_1/P_{A1}$; $V_B = m_B R T_1/P_{B1}$

$$U_2 - U_1 = m_2u_2 - m_Au_{A1} - m_Bu_{B1} = 0$$

$$u_2 = (m_Au_{A1} + m_Bu_{B1})/\ m_2 = \frac{1}{3} \times 307.06 + \frac{2}{3} \times 1912.67 = 1377.47 \text{ kJ/kg}$$

Interpolate in Table A.8: $T_2 = 1540.2$ K, $s^o_{T2} = 6.6740$ kJ/kgK

State 2: $V_2 = m_2RT_2/P_2 = V_A + V_B = m_ART_{A1}/P_{A1} + m_BRT_{B1}/P_{B1}$

$$= 1 \times R \times 500/100 + 2 \times R \times 2000/200 = 25\ R$$

Substitute m_2, T_2 and solve for P_2

$$P_2 = 3\ R\ T_2/25\ R = 3 \times 1540.2 / 25 = \mathbf{184.82\ kPa}$$

Entropy change from Eq. 8.19

$$(s_2 - s_1)_A = s^o_{T2} - s^o_{T1} - R \ln \frac{P_2}{P_{A1}} = 6.674 - 5.3375 - 0.1889 \ln \frac{184.82}{100}$$

$$= 1.2205 \text{ kJ/kgK}$$

$$(s_2 - s_1)_B = s^o_{T2} - s^o_{T1} - R \ln \frac{P_2}{P_{B1}} = 6.674 - 7.0278 - 0.1889 \ln \frac{184.82}{200}$$

$$= -0.33889 \text{ kJ/kgK}$$

$${}_1S_{2\ gen} = S_2 - S_1 = m_A(s_2 - s_1)_A + m_B(s_2 - s_1)_B$$

$$= 1 \times 1.2205 + 2\ (-0.33889) = \mathbf{0.543\ kJ/K}$$

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8.153

A cylinder/piston contains carbon dioxide at 1 MPa, 300°C with a volume of 200 L. The total external force acting on the piston is proportional to V^3. This system is allowed to cool to room temperature, 20°C. What is the total entropy generation for the process?

Solution:

C.V. Carbon dioxide gas of constant mass $m_2 = m_1 = m$ out to ambient.

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.37,18: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\text{ gen}} = {}_1Q_2/T_{amb} + {}_1S_{2\text{ gen}}$

Process: $P = CV^3$ or PV^{-3} = constant, which is polytropic with $n = -3$

State 1: (T, P) => $m = P_1V_1/RT_1 = \dfrac{1000 \times 0.2}{0.18892 \times 573.2} = 1.847\text{ kg}$

State 2: (T, ?) state must be on process curve and ideal gas leads to Eq.8.23

$$\Rightarrow \quad P_2 = P_1(T_2/T_1)^{\frac{n}{n-1}} = 1000(293.2/573.2)^{3/4} = 604.8\text{ kPa}$$

$$V_2 = V_1(T_1/T_2)^{\frac{1}{n-1}} = 0.16914\text{ m}^3$$

$${}_1W_2 = \int PdV = (P_2V_2 - P_1V_1)/(1-n)$$

$$= [604.8 \times 0.16914 - 1000 \times 0.2] / [1 - (-3)] = -24.4\text{ kJ}$$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2$$

$$= 1.847 \times 0.653\ (20 - 300) - 24.4 = -362.1\text{ kJ}$$

From Eq.8.16

$$m(s_2 - s_1) = 1.847\left[0.842 \ln \frac{293.2}{573.2} - 0.18892 \ln \frac{604.8}{1000}\right]$$

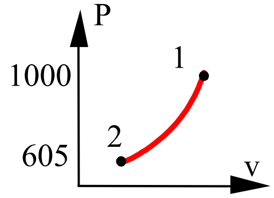
$$= 1.847[-0.4694] = -0.87\text{ kJ/K}$$

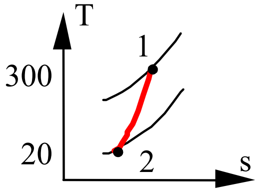
$$\Delta S_{SURR} = -\,{}_1Q_2/T_{amb} = +362.1 / 293.2 = +1.235\text{ kJ/K}$$

From Eq.8.37 or 8.39

$${}_1S_{2\text{ gen}} = m(s_2 - s_1) - {}_1Q_2/T_{amb} = \Delta S_{NET} = \Delta S_{CO2} + \Delta S_{SURR}$$

$$= -0.87 + 1.235 = \mathbf{+0.365\text{ kJ/K}}$$





Notice:
$n = -3$, $k = 1.3$

$n < k$

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8.154

A mass of 2 kg ethane gas at 500 kPa, 100°C, undergoes a reversible polytropic expansion with exponent, *n* = 1.3, to a final temperature of the ambient, 20°C. Calculate the total entropy generation for the process if the heat is exchanged with the ambient.

Solution:

C.V. Ethane gas of constant mass $m_2 = m_1 = m$ out to ambient.

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.37: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\,gen} = {}_1Q_2/T_{amb} + {}_1S_{2\,gen}$

Process: $Pv_1{}^n = P_2v_2{}^n$

State 1: (T_1, P_1) State 2: $(T_2, ?)$ on process curve

$$P_2 = P_1\,(T_2/T_1)^{\frac{n}{n-1}} = 500\left(\frac{293.2}{373.2}\right)^{4.333} = 175.8 \text{ kPa}$$

Work is integrated in Eq.8.29

$${}_1w_2 = \int_1^2 Pdv = \frac{P_2v_2 - P_1v_1}{1-n} = \frac{R(T_2-T_1)}{1-n} = \frac{0.2765(293.2-373.2)}{1-1.30} = \mathbf{+73.7\ kJ/kg}$$

Heat transfer is from the energy equation

$${}_1q_2 = C_{V0}(T_2 - T_1) + {}_1w_2 = 1.49(293.2 - 373.2) + 73.7 = -45.5 \text{ kJ/kg}$$

Entropy change from Eq.8.16

$$s_2 - s_1 = C_{P0} \ln (T_2/T_1) - R \ln(P_2/P_1)$$

$$= 1.766 \ln\frac{293.2}{373.2} - 0.2765 \ln\frac{175.8}{500} = -0.1371 \text{ kJ/kg K}$$

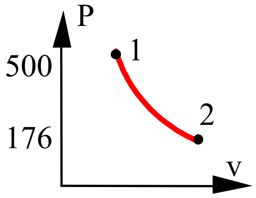
$$m(s_2 - s_1) = \Delta S_{SYST} = 2(-0.1371) = -0.2742 \text{ kJ/K}$$

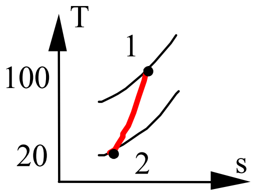
$$\Delta S_{SURR} = -{}_1Q_2/T_0 = +\,2 \times 45.5/293.2 = +0.3104 \text{ kJ/K}$$

Generation from entropy equation or Eq.8.37 or 39

$${}_1S_{2\,gen} = m(s_2 - s_1) - {}_1Q_2/T_{amb} = \Delta S_{NET} = \Delta S_{SYST} + \Delta S_{SURR}$$

$$= -0.2742 + 0.3104 = \mathbf{+0.0362\ kJ/K}$$





Notice:
$n = 1.3,\ k = 1.186$

$n > k$

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8.155

The air in the engine cylinder of Problem 5.128 looses the heat to the engine coolant at 100°C. Find the entropy generation (external to the air) using constant specific heat.

Take CV as the air. $m_2 = m_1 = m$;

Energy Eq.5.11 $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.37: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\ gen} = {}_1Q_2/T_{amb} + {}_1S_{2\ gen}$

Process Eq.: $Pv^n = \text{Constant}$ (polytropic)

From the ideal gas law and the process equation we can get:

State 2: $P_2 = P_1 \left(v_2 / v_1\right)^{-n} = 4000 \times 10^{-1.5} = 126.5 \text{ kPa}$

$$T_2 = T_1 \ (P_2v_2 / P_1v_1) = (1527 + 273) \frac{126.5 \times 10}{4000} = 569.3 \text{ K}$$

From process eq.: $${}_1W_2 = \int P\, dV = \frac{m}{1-n} (P_2v_2 - P_1v_1) = \frac{mR}{1-n} (T_2 - T_1)$$

$$= \frac{0.1 \times 0.287}{1 - 1.5} (569.3 - 1800) = 70.64 \text{ kJ}$$

From energy eq.: ${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = mC_v(T_2 - T_1) + {}_1W_2$

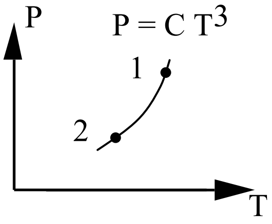
$$= 0.1 \times 0.717(569.3 - 1800) + 70.64 = -17.6 \text{ kJ}$$

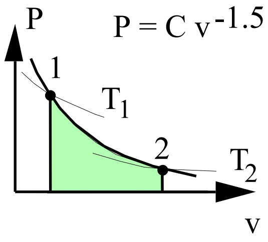
$$m(s_2 - s_1) = m\ [C_P \ln(T_2/T_1) - R \ln(P_2/P_1)]$$

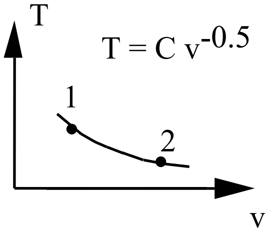
$$= 0.1\ [\ 1.004 \ln \frac{569.3}{1800} - 0.287 \ln \frac{126.5}{4000}\ ] = -0.01645 \text{ kJ/K}$$

$${}_1S_{2\ gen} = m(s_2 - s_1) - {}_1Q_2/T_{amb}$$

$= -0.011645 + 17.6/373.15 =$ **0.0307 kJ/K**







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8.156

A cylinder/piston contains 100 L of air at 110 kPa, 25°C. The air is compressed in a reversible polytropic process to a final state of 800 kPa, 200°C. Assume the heat transfer is with the ambient at 25°C and determine the polytropic exponent *n* and the final volume of the air. Find the work done by the air, the heat transfer and the total entropy generation for the process.

Solution:

C.V. Air of constant mass $m_2 = m_1 = m$ out to ambient.

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.14,18: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\ gen} = {}_1Q_2/T_0 + {}_1S_{2\ gen}$

Process: $Pv_1{}^n = P_2v_2{}^n$ Eq.8.36

State 1: (T_1, P_1) State 2: (T_2, P_2)

Thus the unknown is the exponent n.

$$m = P_1V_1/(RT_1) = 110 \times 0.1/(0.287 \times 298.15) = 0.1286 \text{ kg}$$

The relation from the process and ideal gas is in Eq.8.37

$$T_2/T_1 = (P_2/P_1)^{\frac{n-1}{n}} \Rightarrow \frac{473.15}{298.15} = \left(\frac{800}{110}\right)^{\frac{n-1}{n}} \Rightarrow \frac{n-1}{n} = 0.2328$$

$$\mathbf{n = 1.3034}, \quad V_2 = V_1(P_1/P_2)^{\frac{1}{n}} = 0.1\left(\frac{110}{800}\right)^{0.7672} = \mathbf{0.02182\ m^3}$$

The work is from Eq.8.38

$${}_1W_2 = \int PdV = \frac{P_2V_2 - P_1V_1}{1 - n} = \frac{800 \times 0.02182 - 110 \times 0.1}{1 - 1.3034} = \mathbf{-21.28\ kJ}$$

Heat transfer from the energy equation

$${}_1Q_2 = mC_v(T_2 - T_1) + {}_1W_2$$

$$= 0.1286 \times 0.717 \times (200 - 25) - 21.28 = \mathbf{-5.144\ kJ}$$

Entropy change from Eq.8.25

$$s_2 - s_1 = C_{P0}\ln(T_2/T_1) - R\ln(P_2/P_1)$$

$$= 1.004\ln\left(\frac{473.15}{298.15}\right) - 0.287\ln\left(\frac{800}{110}\right) = -0.106\ \frac{\text{kJ}}{\text{kg K}}$$

From the entropy equation (also Eq.8.18)

$${}_1S_{2,gen} = m(s_2 - s_1) - {}_1Q_2/T_0$$

$$= 0.1286 \times (-0.106) + (5.144/298.15) = \mathbf{0.00362\ kJ/K}$$

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8.157

A piston/cylinder contains air at 300 K, 100 kPa. A reversible polytropic process with n = 1.3 brings the air to 500 K. Any heat transfer if it comes in is from a 325°C reservoir and if it goes out it is to the ambient at 300 K. Sketch the process in a P-v and a T-s diagram. Find the specific work and specific heat transfer in the process. Find the specific entropy generation (external to the air) in the process.

Solution:

Process : $Pv^n = C$

$$ {}_1w_2 = \int P\,dv = \left(\frac{P_2v_2 - P_1v_1}{1-n}\right) = \frac{R}{1-n}\,(T_2 - T_1) $$

$$ = \frac{0.287}{1-1.3}\,(500-300) = \mathbf{-191.3\ kJ/kg} $$

Energy equation

$$ {}_1q_2 = u_2 - u_1 + {}_1w_2 = C_v\,(T_2 - T_1) + {}_1w_2 $$

$$ = 0.717\,(500-300) - 191.3 = \mathbf{-47.93\ kJ/kg} $$

The ${}_1q_2$ is negative and thus goes out. Entropy is generated between the air and ambient.

$$ s_2 - s_1 = {}_1q_2/T_{amb} + {}_1s_{2\ gen} $$

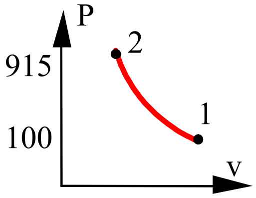
$$ {}_1s_{2\ gen} = s_2 - s_1 - {}_1q_2/T_{amb} = C_p \ln(T_2/T_1) - R\ln(P_2/P_1) - {}_1q_2/T_{amb} $$

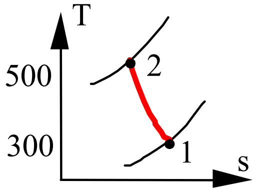
$$ P_2/P_1 = (T_2/T_1)^{n/(n-1)} = (500/300)^{1.3/0.3} = 9.148 $$

$$ {}_1s_{2\ gen} = 1.004 \ln\left(\frac{500}{300}\right) - 0.287 \ln 9.148 - \left(\frac{-47.93}{300}\right) $$

$$ = 0.51287 - 0.635285 + 0.15977 $$

$$ \mathbf{= 0.03736\ kJ/kg\ K} $$





Notice:
n = 1.3, k = 1.4

n < k

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Rates or fluxes of entropy

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8.158

A mass of 3 kg nitrogen gas at 2000 K, V = C, cools with 500 W. What is dS/dt?

Assume that we do not generate any s in the nitrogen then

Entropy Eq. 8.42: $\dot{S}_{CV} = \frac{\dot{Q}}{T} = -\frac{500}{2000} = \mathbf{-0.25\ W/K}$

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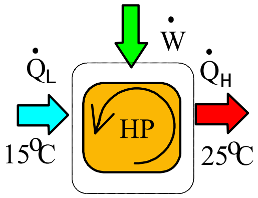
8.159

A reversible heat pump uses 1 kW of power input to heat a 25^{o}C room, drawing energy from the outside at 15^{o}C. Assuming every process is reversible, what are the total rates of entropy into the heat pump from the outside and from the heat pump to the room?

Solution:

C.V.TOT.



Energy Eq.: $\dot{Q}_L + \dot{W} = \dot{Q}_H$

Entropy Eq.: $\frac{\dot{Q}_L}{T_L} - \frac{\dot{Q}_H}{T_H} = 0 \quad \Rightarrow \quad \dot{Q}_L = \dot{Q}_H \frac{T_L}{T_H}$

$$\dot{Q}_H \frac{T_L}{T_H} + \dot{W} = \dot{Q}_H \quad \Rightarrow \quad \dot{Q}_H = \frac{T_H}{T_H - T_L} \dot{W}$$

$$\frac{\dot{Q}_H}{T_H} = \frac{1}{T_H - T_L} \dot{W} = \frac{1}{25 - 15} (1) = \mathbf{0.1\ kW/K}$$

$$\frac{\dot{Q}_L}{T_L} = \frac{\dot{Q}_H}{T_H} = \mathbf{0.1\ kW/K}$$

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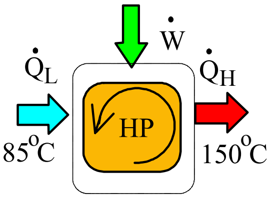
8.160

A heat pump, see problem 7.52, should upgrade 5 MW of heat at 85^{o}C to heat delivered at 150^{o}C. For a reversible heat pump what are the fluxes of entropy in and out of the heat pump?



C.V.TOT. Assume reversible Carnot cycle.

Energy Eq.: $\dot{Q}_L + \dot{W} = \dot{Q}_H$

Entropy Eq.: $0 = \frac{\dot{Q}_L}{T_L} - \frac{\dot{Q}_H}{T_H} \quad \Rightarrow \quad \frac{\dot{Q}_L}{T_L} = \frac{\dot{Q}_H}{T_H}$

The fluxes of entropy become the same as

$$\frac{\dot{Q}_H}{T_H} = \frac{\dot{Q}_L}{T_L} = \frac{5}{273.15 + 85} \frac{\text{MW}}{\text{K}} = \mathbf{0.01396\ MW/K}$$

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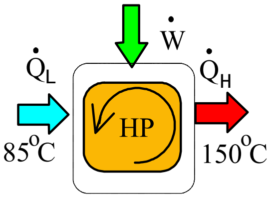
8.161

Reconsider the heat pump in the previous problem and assume it has a COP of 2.5. What are the fluxes of entropy in and out of the heat pump and the rate of entropy generation inside it?



C.V. TOT.

Energy Eq.: $\dot{Q}_L + \dot{W} = \dot{Q}_H$

Entropy Eq.: $0 = \frac{\dot{Q}_L}{T_L} - \frac{\dot{Q}_H}{T_H} + \dot{S}_{\text{gen tot}}$

Definition of COP: $\beta_{HP} = \frac{\dot{Q}_H}{\dot{W}_{in}} = 2.5; \quad \beta_{REF} = \beta_{HP} - 1 = \frac{\dot{Q}_L}{\dot{W}_{in}} = 1.50$

$$\dot{W}_{in} = \dot{Q}_L/\beta_{REF} = 5/1.50 = 3.333 \text{ MW}$$

$$\dot{Q}_H = \dot{Q}_L + \dot{W} = 5 \text{ MW} + 3.333 \text{ MW} = 8.333 \text{ MW}$$

$$\frac{\dot{Q}_L}{T_L} = \frac{5}{273.15 + 85} \frac{\text{MW}}{\text{K}} = \mathbf{0.01396\ MW/K}$$

$$\frac{\dot{Q}_H}{T_H} = \frac{8.333}{273.15 + 85} \frac{\text{MW}}{\text{K}} = \mathbf{0.01969\ MW/K}$$

From the entropy equation

$$\dot{S}_{\text{gen tot}} = \frac{\dot{Q}_H}{T_H} - \frac{\dot{Q}_L}{T_L} = (0.01969 - 0.01396) \frac{\text{MW}}{\text{K}} = \mathbf{5.73\ kW/K}$$

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8.162

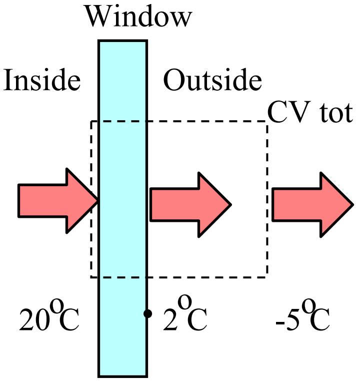
A window receives 200 W of heat transfer at the inside surface of 20$^{\mathrm{o}}$C and transmits the 200 W from its outside surface at 2$^{\mathrm{o}}$C continuing to ambient air at –5$^{\mathrm{o}}$C. Find the flux of entropy at all three surfaces and the window's rate of entropy generation.

Flux of entropy: $\dot{S} = \frac{\dot{Q}}{T}$

$$\dot{S}_{\text{inside}} = \frac{200}{293.15}\ \frac{W}{K} = 0.682 \text{ W/K}$$

$$\dot{S}_{\text{win}} = \frac{200}{275.15}\ \frac{W}{K} = 0.727 \text{ W/K}$$

$$\dot{S}_{\text{amb}} = \frac{200}{268.15}\ \frac{W}{K} = 0.746 \text{ W/K}$$



Window only: $\dot{S}_{\text{gen win}} = \dot{S}_{\text{win}} - \dot{S}_{\text{inside}} = 0.727 - 0.682 =$ **0.045 W/K**

If you want to include the generation in the outside air boundary layer where T changes from 2$^{\mathrm{o}}$C to the ambient –5$^{\mathrm{o}}$C then chose the control volume as CV tot and it becomes

$$\dot{S}_{\text{gen tot}} = \dot{S}_{\text{amb}} - \dot{S}_{\text{inside}} = 0.746 - 0.682 = 0.064 \text{ W/K}$$

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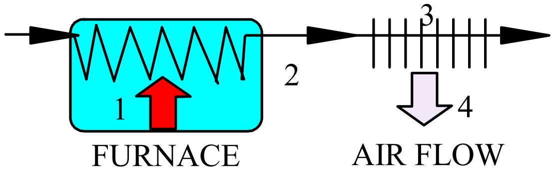
8.163

An amount of power, say 1000 kW, comes from a furnace at 800°C going into water vapor at 400°C. From the water the power goes to a solid metal at 200°C and then into some air at 70°C. For each location calculate the flux of *s* through a surface as ($\dot{Q}/T$). What makes the flux larger and larger?

Solution:

$T_1 \;\Rightarrow\; T_2 \;\Rightarrow\; T_3 \;\Rightarrow\; T_4$

furnace vapor metal air



Flux of s: $F_s = \dot{Q}/T$ with T as absolute temperature.

$F_{s1} = 1000/1073.15 = 0.932$ kW/K, $F_{s2} = 1000/673.15 = 1.486$ kW/K

$F_{s3} = 1000/473.15 = 2.11$ kW/K, $F_{s4} = 1000/343.15 = 2.91$ kW/K

T	800	400	200	70	(°C)
T_{amb}	1073	673	476	646	K
Q/T	0.932	1.486	2.114	2.915	kW/K

${}_1S_{2\,gen}$ for every change in T

Q over ΔT is an irreversible process

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8.164

Room air at 23^{o}C is heated by a 2000 W space heater with a surface filament temperature of 700 K, shown in Fig. P8.164. The room at steady state looses the power to the outside which is at 7^{o}C. Find the rate(s) of entropy generation and specify where it is made.

Solution:

For any C.V at steady state the entropy equation as a rate form is Eq.8.43

$$\frac{dS_{c.v.}}{dt} = 0 = \int d\dot{Q}/T + \dot{S}_{gen}$$

C.V. Heater Element

$$\dot{S}_{gen} = -\int d\dot{Q}/T = -(-2000/700) = \mathbf{2.857\ W/K}$$

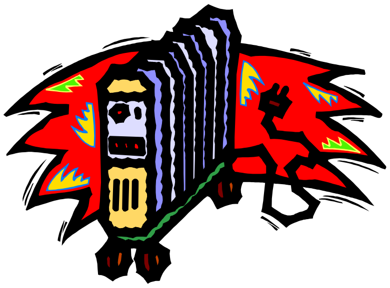
C.V. Space between heater 700 K and room 23°C

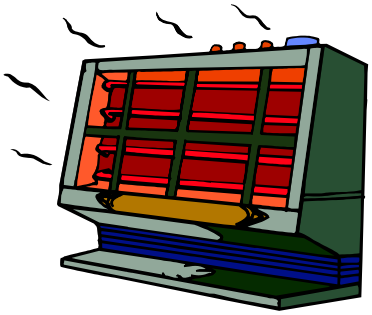
$$\dot{S}_{gen} = -\int d\dot{Q}/T = (-2000 / 700) - [-2000 / (23+273)] = \mathbf{3.9\ W/K}$$

C.V. Wall between 23°C inside and 7°C outside

$$\dot{S}_{gen} = -\int d\dot{Q}/T = [-2000 / (23+273)] - [2000 / (7 + 273)] = \mathbf{0.389\ W/K}$$

Notice biggest $\dot{S}_{gen}$ is for the largest change in 1/T.





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8.165

A car engine block receives 2 kW at its surface of 450 K from hot combustion gases at 1500 K. Near the cooling channel the engine block transmits 2 kW out at its 400 K surface to the coolant flowing at 370 K. Finally, in the radiator the coolant at 350 K delivers the 2 kW to air which is at 25 C. Find the rate of entropy generation inside the engine block, inside the coolant and in the radiator/air combination.

For a C.V at steady state we have the entropy equation as a rate form as Eq.8.43

$$\frac{dS_{c.v.}}{dt} = 0 = \int d\dot{Q}/T + \dot{S}_{gen}$$

CV1. Engine block receives 2 kW at 450 K and it leaves at 400 K

$$\dot{S}_{gen1} = -\int d\dot{Q}/T = \frac{-2000}{450} - [\frac{-2000}{400}] = \mathbf{0.555\ W/K}$$

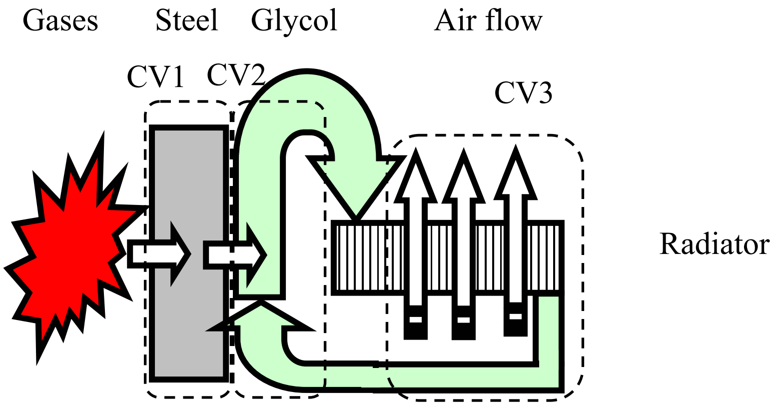
CV2. The coolant receives 2 kW at 370 K andf gives it out at 350 K

$$\dot{S}_{gen2} = -\int d\dot{Q}/T = [\frac{-2000}{370}] - [\frac{-2000}{350}] = \mathbf{0.309\ W/K}$$

CV3 Radiator to air heat transfer.

$$\dot{S}_{gen3} = -\int d\dot{Q}/T = [\frac{-2000}{350}] - [\frac{-2000}{298.15}] = \mathbf{0.994\ W/K}$$

Notice the biggest $\dot{S}_{gen}$ is for the largest change $\Delta[1/T]$



Remark: The flux of S is $\dot{Q}/T$ flowing across a surface. Notice how this flux increases as the heat transfer flows towards lower and lower T.

T [K]	1500	450	370	298.15
$\dot{Q}/T$ [W/K]	1.33	4.44	5.40	6.71

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8.166

Consider an electric heater operating in steady state with 1 kW electric power input and a surface temperature of 600 K that gives heat transfer to the room air at 22^{o}C. What is the rate of entropy generation in the heating element? What is it outside?

For any C.V at steady state the entropy equation as a rate form is Eq.8.43

$$\frac{dS_{c.v.}}{dt} = 0 = \int d\dot{Q}/T + \dot{S}_{gen}$$

C.V. Heater Element. The energy equation has 1 kW in as work and 1 kW out as heat transfer

$$\dot{S}_{gen\ element} = -\int d\dot{Q}/T = -\frac{-1000}{600} = \mathbf{1.667\ W/K}$$

C.V. Space between heater 600 K and room at 22°C. This control volume has 1 kW in at 600 K and 1 kW out at 22^{o}C both are heat transfers.

$$\dot{S}_{gen\ outside\ element} = -\int d\dot{Q}/T = -\frac{1000}{600} - [\frac{-1000}{22 + 273}] = \mathbf{1.723\ W/K}$$

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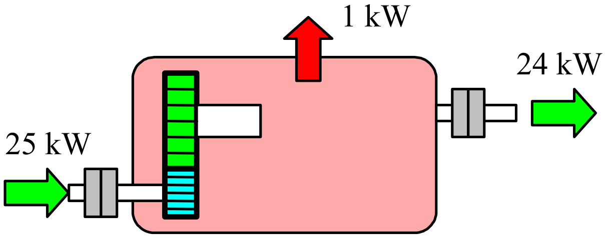
8.167

The automatic transmission in a car receives 25 kW shaft work and gives out 24 kW to the drive shaft. The balance is dissipated in the hydraulic fluid and metal casing, all at 45^{o}C, which in turn transmits it to the outer atmosphere at 20^{o}C. What is the rate of entropy generation inside the transmission unit? What is it outside the unit?

Solution:

C.V. Total unit. Steady state and surface at 45^{o}C



Energy Eq:

$$0 = \dot{W}_{in} - \dot{W}_{out} - \dot{Q}_{out}$$

Entropy Eq.: $$0 = -\frac{\dot{Q}_{out}}{T_{oil}} + \dot{S}_{gen}$$

From energy Eq.: $$\dot{Q}_{out} = \dot{W}_{in} - \dot{W}_{out} = 25 - 24 = 1 \text{ kW}$$

From entropy Eq.: $$\dot{S}_{gen} = \frac{\dot{Q}_{out}}{T_{oil}} = \frac{1}{273.15 + 45} \frac{\text{kW}}{\text{K}} = \mathbf{3.1\ W/K}$$

C.V. From surface at 45^{o}C to atm. at 20^{o}C.

Entropy Eq.: $$0 = \frac{\dot{Q}_{out}}{T_{oil}} - \frac{\dot{Q}_{out}}{T_{amb}} + \dot{S}_{gen\ outside}$$

$$\dot{S}_{gen\ outside} = \dot{Q}_{out} \left[\frac{1}{T_{amb}} - \frac{1}{T_{oil}}\right] = 1 \text{ kW} \left[\frac{1}{293} - \frac{1}{318}\right] = \mathbf{0.268\ W/K}$$

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8.168

A farmer runs a heat pump using 2 kW of power input. It keeps a chicken hatchery at a constant 30^{o}C while the room loses 10 kW to the colder outside ambient at 10^{o}C. What is the rate of entropy generated in the heat pump? What is the rate of entropy generated in the heat loss process?

Solution:

C.V. Hatchery, steady state.

To have steady state at 30^{o}C for the hatchery

Energy Eq.: $0 = \dot{Q}_H - \dot{Q}_{Loss} \quad \Rightarrow \quad \dot{Q}_H = \dot{Q}_{Loss} = 10 \text{ kW}$

C.V. Heat pump, steady state

Energy eq.: $0 = \dot{Q}_L + \dot{W} - \dot{Q}_H \quad \Rightarrow \quad \dot{Q}_L = \dot{Q}_H - \dot{W} = 8 \text{ kW}$

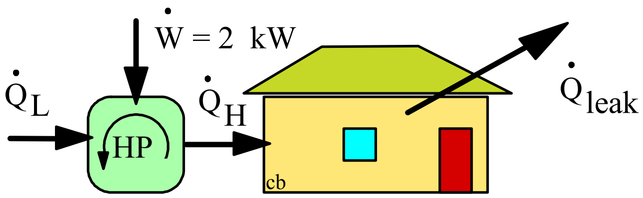
Entropy Eq.: $0 = \frac{\dot{Q}_L}{T_L} - \frac{\dot{Q}_H}{T_H} + \dot{S}_{gen\ HP}$

$$\dot{S}_{gen\ HP} = \frac{\dot{Q}_H}{T_H} - \frac{\dot{Q}_L}{T_L} = \frac{10}{273+30} - \frac{8}{273+10} = \mathbf{0.00473\ kW/K}$$

C.V. From hatchery at 30^{o}C to the ambient 10^{o}C. This is typically the walls and the outer thin boundary layer of air. Through this goes $\dot{Q}_{Loss}$.

Entropy Eq.: $0 = \frac{\dot{Q}_{Loss}}{T_H} - \frac{\dot{Q}_{Loss}}{T_{amb}} + \dot{S}_{gen\ walls}$

$$\dot{S}_{gen\ walls} = \frac{\dot{Q}_{Loss}}{T_{amb}} - \frac{\dot{Q}_{Loss}}{T_H} = \frac{10}{283} - \frac{10}{303} = \mathbf{0.00233\ kW/K}$$



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Review problems

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8.169

A device brings 2 kg of ammonia from 150 kPa, -20°C to 400 kPa, 80°C in a polytropic process. Find the polytropic exponent, n, the work and the heat transfer. Find the total entropy generated assuming a source at 100°C.

Solution:

C.V. Ammonia of constant mass $m_2 = m_1 = m$ out to source.

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.14, 8.18: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\ gen} = {}_1Q_2/T + {}_1S_{2\ gen}$

Process: $P_1v_1^n = P_2v_2^n$ Eq. (8.36)

State 1: Table B.2.2

$v_1 = 0.79774\ m^3/kg$, $s_1 = 5.7465\ kJ/kg\ K$, $u_1 = 1303.3\ kJ/kg$

State 2: Table B.2.2

$v_2 = 0.4216\ m^3/kg$, $s_2 = 5.9907\ kJ/kg\ K$, $u_2 = 1468.0\ kJ/kg$

$$\ln (P_2/P_1) = \ln (v_1/v_2)^n = n \times \ln (v_1/v_2)$$

$$\ln \left(\frac{400}{150}\right) = n \times \ln \left(\frac{0.79774}{0.4216}\right) = 0.98083 = n \times 0.63773$$

$\Rightarrow$ $n = \mathbf{1.538}$

The work term is integration of PdV as done in text leading to Eq.8.38

$${}_1W_2 = \frac{m}{1 - n}(P_2v_2 - P_1v_1)$$

$$= \frac{2}{1 - 1.538} \times (400 \times 0.4216 - 150 \times 0.79774) = \mathbf{-182.08\ kJ}$$

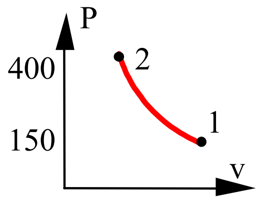
Notice we did not use Pv = RT as we used the ammonia tables.

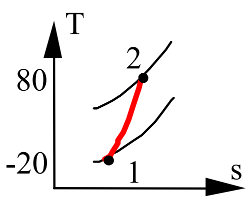
$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 2\ (1468 - 1303.3) - 182.08 = \mathbf{147.3\ kJ}$$

From Eq.8.18

$${}_1S_{2\ gen} = m(s_2 - s_1) - {}_1Q_2/T = 2\ (5.9907 - 5.7465) - \frac{147.3}{373.15}$$

$$= \mathbf{0.0936\ kJ/K}$$





Notice:
n = 1.54, k = 1.3

n > k

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8.170

An insulated cylinder/piston has an initial volume of 0.15 m^3 and contains steam at 400 kPa, 200°C. The steam is expanded adiabaticly, and the work output is measured very carefully to be 30 kJ. It is claimed that the final state of the water is in the two-phase (liquid and vapor) region. What is your evaluation of the claim?

Solution:

C.V. Water.

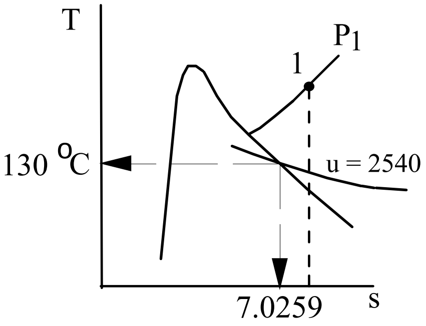
Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.3: $m(s_2 - s_1) = \int dQ/T$

Process: ${}_1Q_2 = 0$ and reversible

State 1: (T, P) Table B.1.3

$v_1 = 0.5342, \; u_1 = 2646.8, \; s_1 = 7.1706$ kJ/kg K



$$m = \frac{V_1}{v_1} = \frac{0.15}{0.5342} = 0.2808 \text{ kg}$$

With the assumed reversible process we have from entropy equation

$$s_2 = s_1 = 7.1706 \text{ kJ/kg K}$$

and from the energy equation

$$u_2 = u_1 - {}_1W_2/m = 2646.8 - \frac{30}{0.2808} = 2540.0 \text{ kJ/kg}$$

State 2 given by (u, s) check Table B.1.1: s_G (at $u_G = 2540$) $= 7.0259 < s_1$

⇒ **State 2 must be in superheated vapor region.**

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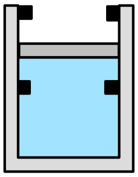
8.171

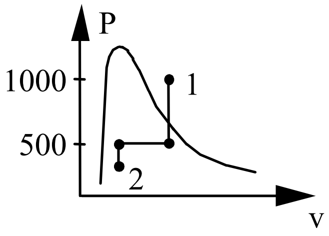
Water in a piston/cylinder is at 1 MPa, 500°C. There are two stops, a lower one at which $V_{\text{min}} = 1\ \text{m}^3$ and an upper one at $V_{\text{max}} = 3\ \text{m}^3$. The piston is loaded with a mass and outside atmosphere such that it floats when the pressure is 500 kPa. This setup is now cooled to 100°C by rejecting heat to the surroundings at 20°C. Find the total entropy generated in the process.

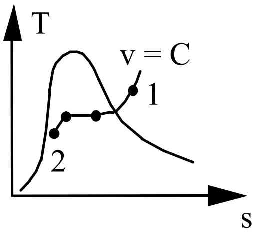
C.V. Water.

Initial state: Table B.1.3: $v_1 = 0.35411\ \text{m}^3/\text{kg}$, $u_1 = 3124.3$, $s_1 = 7.7621$

$m = V/v_1 = 3/0.35411 = 8.472\ \text{kg}$







Final state: 100°C and on line in P-V diagram.

Notice the following: $v_g(500\ \text{kPa}) = 0.3749 > v_1$, $v_1 = v_g(154°\text{C})$

$T_{\text{sat}}(500\ \text{kPa}) = 152°\text{C} > T_2$, so now piston hits bottom stops.

State 2: $v_2 = v_{\text{bot}} = V_{\text{bot}}/m = 0.118\ \text{m}^3/\text{kg}$,

$x_2 = (0.118 - 0.001044)/1.67185 = 0.0699$,

$u_2 = 418.91 + 0.0699 \times 2087.58 = 564.98\ \text{kJ/kg}$,

$s_2 = 1.3068 + 0.0699 \times 6.048 = 1.73\ \text{kJ/kg K}$

Now we can do the work and then the heat transfer from the energy equation

$_1W_2 = \int P dV = 500(V_2 - V_1) = -1000\ \text{kJ}$ $\quad (_1w_2 = -118\ \text{kJ/kg})$

$_1Q_2 = m(u_2 - u_1) + {}_1W_2 = -22683.4\ \text{kJ}$ $\quad (_1q_2 = -2677.5\ \text{kJ/kg})$

Take C.V. total out to where we have 20°C:

$m(s_2 - s_1) = {}_1Q_2/T_0 + S_{\text{gen}} \Rightarrow$

$S_{\text{gen}} = m(s_2 - s_1) - {}_1Q_2/T_0 = 8.472\ (1.73 - 7.7621) + 22683 / 293.15$

$\mathbf{= 26.27\ kJ/K}$ $\quad (= \Delta S_{\text{water}} + \Delta S_{\text{sur}})$

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8.172

Assume the heat transfer in problem 5.63 came from a 200°C reservoir. What is the total entropy generation in the process?

C.V. Water in A and B. Control mass goes through process: 1 -> 2

Continuity Eq.: $m_2 - m_{A1} - m_{B1} = 0 \quad => m_2 = m_{A1} + m_{B1} = 0.5 + 0.5 = 1$ kg

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

Entropy Eq.: $m_2\, s_2 - m_A s_{A1} - m_B s_{B1} = {}_1Q_2/T_{res} + {}_1S_{2\ gen}$

State A1: $v_{A1} = 0.001067 + x_{A1} \times 0.71765 = 0.072832$; $V_{A1} = mv = 0.036416$ m^3

$u_{A1} = 535.08 + 0.1 \times 2002.14 = 735.22$ kJ/kg;

$s_{A1} = 1.6072 + 0.1 \times 5.4455 = 2.15175$ kJ/kgK

State B1: $v_{B1} = 1.5493$ m^3/kg; $u_{B1} = 2966.69$ kJ/kg; $s_{B1} = 8.2217$ kJ/kg-K

$V_{B1} = (mv)_{B1} = 0.77465$ m^3

State 2: If $V_2 > V_{A1}$ then $P_2 = 200$ kPa that is the piston floats.

For $(T_2, P_2) = (150°C, 200\text{ kPa})$ => superheated vapor

$u_2 = 2576.87$ kJ/kg; $v_2 = 0.95964$ m^3/kg, $s_2 = 7.2795$ kJ/kgK

$V_2 = m_2 v_2 = 0.95964$ m^3 $> V_{A1}$ checks OK.

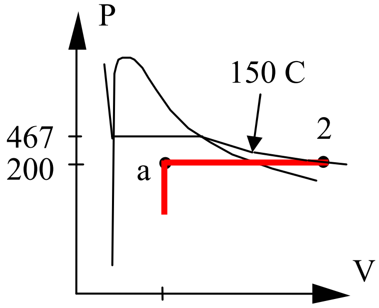
Process: ${}_1W_2 = P_2\,(V_2 - V_1) = 200\,(0.95964 - 0.77465 - 0.036416) = 29.715$ kJ

From the energy and entropy equations:

$${}_1Q_2 = m_2 u_2 - m_{A1}u_{A1} - m_{B1}u_{B1} + {}_1W_2$$
$$= 1 \times 2576.87 - 0.5 \times 735.222 - 0.5 \times 2966.69 + 29.715 = 755.63 \text{ kJ}$$

$${}_1S_{2\ gen} = m_2\, s_2 - m_A s_{A1} - m_B s_{B1} - {}_1Q_2/T_{res}$$
$$= 1 \times 7.2795 - 0.5 \times 2.15175 - 0.5 \times 8.2217 - 755.63/473.15$$
$$= \mathbf{0.496\ kJ/K}$$

The possible state 2 (P,V) combinations are shown. State a is 200 kPa, $v_a = V_{A1}/m_2 = 0.036$ and thus two-phase $T_a = 120°C$ less than T_2



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8.173

A closed tank, *V* = 10 L, containing 5 kg of water initially at 25°C, is heated to 175°C by a heat pump that is receiving heat from the surroundings at 25°C. Assume that this process is reversible. Find the heat transfer to the water and the work input to the heat pump.

C.V.: Water from state 1 to state 2.

Process: constant volume (reversible isometric)

$1\text{: } v_1 = V/m = 0.002 \Rightarrow\ x_1 = (0.002 - 0.001003)/43.358 = 0.000023$

$u_1 = 104.86 + 0.000023 \times 2304.9 = 104.93\text{ kJ/kg}$

$s_1 = 0.3673 + 0.000023 \times 8.1905 = 0.36759\text{ kJ/kg K}$

Continuity eq. (same mass) and V = C fixes v_2

$2\text{: } T_2,\ v_2 = v_1 \Rightarrow$

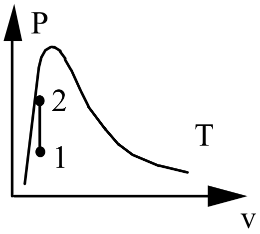
$x_2 = (0.002 - 0.001121)/0.21568 = 0.004075$

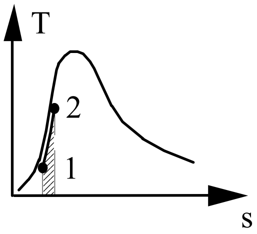
$u_2 = 740.16 + 0.004075 \times 1840.03 = 747.67\text{ kJ/kg}$

$s_2 = 2.0909 + 0.004075 \times 4.5347 = 2.1094\text{ kJ/kg K}$

Energy eq. has W = 0, thus provides heat transfer as

$_1Q_2 = m(u_2 - u_1) = \mathbf{3213.7\ kJ}$



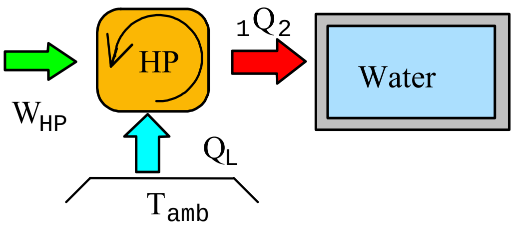


Entropy equation for the total (tank plus heat pump) control volume gives for a reversible process:

$m(s_2 - s_1) = Q_L/T_0 \qquad \Rightarrow\ Q_L = mT_0(s_2 - s_1) = 2596.6\text{ kJ}$

and then the energy equation for the heat pump gives

$$W_{HP} = {}_1Q_2 - Q_L = \mathbf{617.1\ kJ}$$



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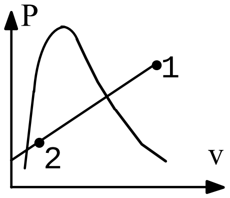
8.174

A cylinder/piston contains 3 kg of water at 500 kPa, 600°C. The piston has a cross-sectional area of 0.1 m^2 and is restrained by a linear spring with spring constant 10 kN/m. The setup is allowed to cool down to room temperature due to heat transfer to the room at 20°C. Calculate the total (water and surroundings) change in entropy for the process.

State 1: Table B.1.3,

$v_1 = 0.8041\ m^3/kg, \quad u_1 = 3299.6\ kJ/kg, \quad s_1 = 7.3522\ kJ/kg\text{-}K$



State 2: T_2 & on line in P-V diagram.

$$P = P_1 + (k_s/A_{cyl}^2)(V - V_1)$$

Assume state 2 is two-phase, $P_2 = P_{sat}(T_2) = 2.339$ kPa

$$v_2 = v_1 + (P_2 - P_1)A_{cyl}^2/mk_s$$

$$v_2 = 0.8041 + (2.339 - 500)0.01/(3 \times 10) = 0.6382 = v_f + x_2 v_{fg}$$

$$x_2 = (0.6382 - 0.001002)/57.7887 = 0.011,$$

$$u_2 = 109.46\ kJ/kg, \quad s_2 = 0.3887\ kJ/kg\text{-}K$$

$${}_1W_2 = \frac{1}{2}(P_1 + P_2)m \times (v_2 - v_1)$$

$$= \frac{1}{2}(500 + 2.339) \times 3 \times (0.6382 - 0.8041) = -125\ kJ$$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 3(109.46 - 3299.6) - 125 = -9695.4\ kJ$$

$$\Delta S_{tot} = S_{gen,tot} = m(s_2 - s_1) - {}_1Q_2/T_{room}$$

$$= 3(0.3887 - 7.3522) + 9695.4/293.15 = \mathbf{12.18\ kJ/K}$$

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8.175

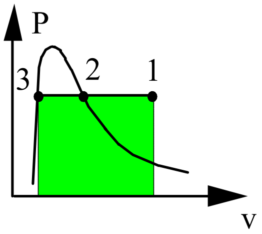
A cylinder fitted with a frictionless piston contains water. A constant hydraulic pressure on the back face of the piston maintains a cylinder pressure of 10 MPa. Initially, the water is at 700°C, and the volume is 100 L. The water is now cooled and condensed to saturated liquid. The heat released during this process is the Q supply to a cyclic heat engine that in turn rejects heat to the ambient at 30°C. If the overall process is reversible, what is the net work output of the heat engine?

C.V.: H_2O, $1 \rightarrow 3$, this is a control mass:

Continuity Eq.: $m_1 = m_3 = m$

Energy Eq.: $m(u_3 - u_1) = {}_1Q_3 - {}_1W_3$;

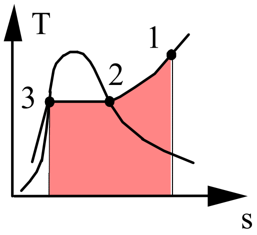
Process: $P = C \Rightarrow {}_1W_3 = \int P\, dV = Pm(v_3 - v_1)$



State 1: 700°C, 10 MPa, $V_1 = 100$ L Table B.1.4

$v_1 = 0.04358\ m^3/kg \Rightarrow m = m_1 = V_1/v_1 = 2.295$ kg

$h_1 = 3870.5$ kJ/kg, $s_1 = 7.1687$ kJ/kg K



State 3: $P_3 = P_1 = 10$ MPa, $x_3 = 0$ Table B.1.2

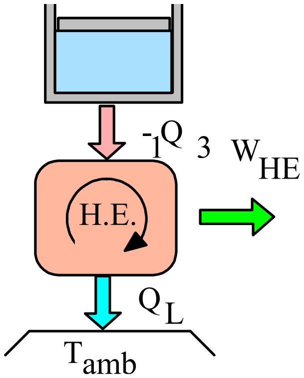
$h_3 = h_f = 1407.5$ kJ/Kg, $s_3 = s_f = 3.3595$ kJ/Kg K

$${}_1Q_3 = m(u_3 - u_1) + Pm(v_3 - v_1) = m(h_3 - h_1)$$

$$= -5652.6 \text{ kJ}$$

Heat transfer to the heat engine:

$$Q_H = -{}_1Q_3 = 5652.6 \text{ kJ}$$



Take control volume as total water and heat engine.

Process: Rev., $\Delta S_{net} = 0$; $T_L = 30^oC$

2nd Law: $\Delta S_{net} = m(s_3 - s_1) - Q_{cv}/T_L$;

$$Q_{cv} = T_o\, m(s_3 - s_1) = -2650.6 \text{ kJ}$$

$$\Rightarrow \quad Q_L = -Q_{cv} = 2650.6 \text{ kJ}$$

$W_{net} = W_{HE} = Q_H - Q_L =$ **3002 kJ**

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8.176

A resistor in a heating element is a total of 0.5 kg with specific heat of 0.8 kJ/kgK. It is now receiving 500 W of electric power so it heats from 20°C to 150° C. Neglect external heat loss and find the time the process took and the entropy generation.

C.V. Heating element.

Energy Eq.: $m(u_2 - u_1) = {}_1W_{2\ \text{in}} = \dot{W}_{\text{electrical in}}\ \Delta t$

Entropy Eq.: $m(s_2 - s_1) = 0 + {}_1S_{2\ \text{gen}}$ (no heat transfer)

$$\Delta t = m(u_2 - u_1) / \dot{W}_{\text{electrical in}} = m\ C\ (T_2 - T_1) / \dot{W}_{\text{electrical in}}$$

$$= 0.5\ \text{kg} \times 800\ \text{J/kg-K} \times (150 - 20)\ \text{K} / 500\ \text{(J/s)} = \mathbf{104\ s}$$

$$ {}_1S_{2\ \text{gen}} = m(s_2 - s_1) = m\ C \ln \frac{T_2}{T_1} = 0.5\ \text{kg} \times 0.8\ \text{kJ/kg-K} \ln \left(\frac{150 + 273}{20 + 273}\right)$$

$$= \mathbf{0.15\ kJ/K}$$

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8.177

Two tanks contain steam, and they are both connected to a piston/cylinder as shown in Fig. P8.177. Initially the piston is at the bottom and the mass of the piston is such that a pressure of 1.4 MPa below it will be able to lift it. Steam in A is 4 kg at 7 MPa, 700°C and B has 2 kg at 3 MPa, 350°C. The two valves are opened, and the water comes to a uniform state. Find the final temperature and the total entropy generation, assuming no heat transfer.

Solution:

Control mass: All water $m_A + m_B$.

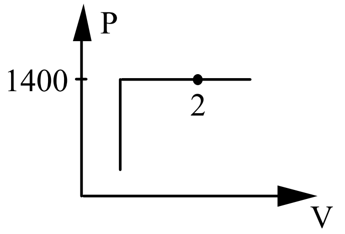
Continuity Eq.: $m_2 = m_A + m_B = 6$ kg

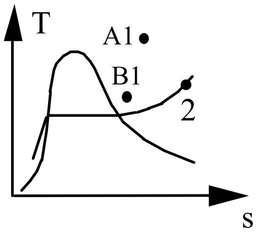
Energy Eq.5.11: $m_2u_2 - m_Au_{A1} - m_Bu_{B1} = {}_1Q_2 - {}_1W_2 = - {}_1W_2$

Entropy Eq.8.14: $m_2s_2 - m_As_{A1} - m_Bs_{B1} = {}_1S_{2\ gen}$

B.1.3: $v_{A1} = 0.06283$, $u_{A1} = 3448.5$, $s_{A1} = 7.3476$, $V_A = 0.2513\ m^3$

B.1.3: $v_{B1} = 0.09053$, $u_{B1} = 2843.7$, $s_{B1} = 6.7428$, $V_B = 0.1811\ m^3$





The only possible P, V combinations for state 2 are on the two lines.

Assume $V_2 > V_A + V_B \Rightarrow P_2 = P_{lift}$, ${}_1W_2 = P_2(V_2 - V_A - V_B)$

Substitute into energy equation:

$m_2h_2 = m_Au_{A1} + m_Bu_{B1} + P_2(V_A + V_B)$

$= 4 \times 3448.5 + 2 \times 2843.7 + 1400 \times 0.4324$

State 2: $h_2 = 3347.8$ kJ/kg, $P_2 = 1400$ kPa, $v_2 = 0.2323$, $s_2 = 7.433$

$\mathbf{T_2 = 441.9\ °C}$,

Check assumption: $V_2 = m_2v_2 = 1.394\ m^3 > V_A + V_B$ **OK.**

${}_1S_{2\ gen} = 6 \times 7.433 - 4 \times 7.3476 - 2 \times 6.7428 =$ **1.722 kJ/K**

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8.178

A cylinder fitted with a piston contains 0.5 kg of R-134a at 60°C, with a quality of 50 percent. The R-134a now expands in an internally reversible polytropic process to ambient temperature, 20°C at which point the quality is 100 percent. Any heat transfer is with a constant-temperature source, which is at 60°C. Find the polytropic exponent n and show that this process satisfies the second law of thermodynamics.

Solution:

C.V.: R-134a, Internally Reversible, Polytropic Expansion: $PV^n = \text{Const.}$

Cont.Eq.: $m_2 = m_1 = m$; Energy Eq.: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\ gen}$

State 1: $T_1 = 60^oC$, $x_1 = 0.5$, Table B.5.1: $P_1 = P_g = 1681.8$ kPa,

$v_1 = v_f + x_1 v_{fg} = 0.000951 + 0.5{\times}0.010511 = 0.006207\ m^3/kg$

$s_1 = s_f + x_1 s_{fg} = 1.2857 + 0.5{\times}0.4182 = 1.4948$ kJ/kg K,

$u_1 = u_f + x_1 u_{fg} = 286.19 + 0.5{\times}121.66 = 347.1$ kJ/kg

State 2: $T_2 = 20^oC$, $x_2 = 1.0$, $P_2 = P_g = 572.8$ kPa, Table B.5.1

$v_2 = v_g = 0.03606\ m^3/kg$, $s_2 = s_g = 1.7183$ kJ/kg-K

$u_2 = u_g = 389.19$ kJ/kg

Process: $PV^n = \text{Const.}\ \Rightarrow\ \frac{P_1}{P_2} = \left(\frac{v_2}{v_1}\right)^n\ \Rightarrow\ n = \ln\frac{P_1}{P_2} / \ln\frac{v_2}{v_1} = \mathbf{0.6122}$

$${}_1W_2 = \int PdV = \frac{P_2V_2 - P_1V_1}{1-n}$$

$$= 0.5(572.8 \times 0.03606 - 1681.8 \times 0.006207)/(1 - 0.6122) = 13.2 \text{ kJ}$$

2nd Law for C.V.: R-134a plus wall out to source:

$\Delta S_{net} = m(s_2 - s_1) - \frac{Q_H}{T_H}$; Check $\Delta S_{net} \geq 0$

$Q_H = {}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 34.2$ kJ

$\Delta S_{net} = 0.5(1.7183 - 1.4948) - 34.2/333.15 = 0.0092$ kJ/K,

$\boldsymbol{\Delta S_{net} > 0}$ **Process Satisfies 2nd Law**

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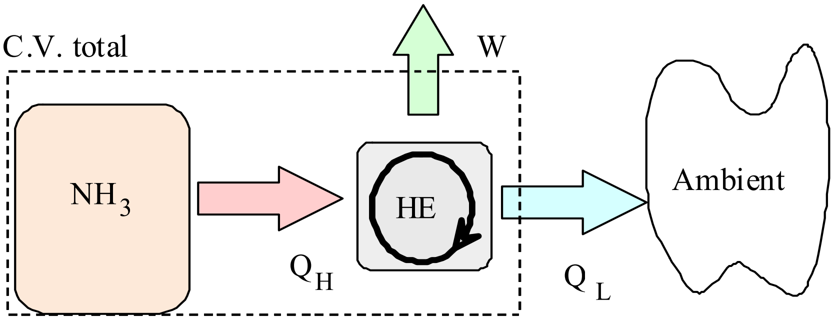
8.179

A rigid tank with 0.5 kg ammonia at 1600 kPa, 160°C is cooled in a reversible process by giving heat to a reversible heat engine that has its cold side at ambient 20°C, shown in Fig. P8.179. The ammonia eventually reaches 20°C and the process stops. Find the heat transfer from the ammonia to the heat engine and the work output of the heat engine.



C.V. Ammonia

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.3: $m(s_2 - s_1) = \int dQ/T$ (T not constant)

Process: v = constant ⇒ ${}_1W_2 = 0$

State 1: (T, P) Table B.2.2: $u_1 = 1596.1$ kJ/kg, $v_1 = 0.12662\ m^3/kg$,

$s_1 = 5.7485$ kJ/kgK

State 2: T_2 and $v_2 = v_1$ Table B.2.1 as $v_2 < v_g$

⇒ 2-phase, $P_2 = P_{sat} = 857.5$ kPa

$$x_2 = (v_2 - v_f)/v_{fg} = (0.12662 - 0.001638)/0.14758 = 0.846876$$

$$u_2 = u_f + x_2\ u_{fg} = 272.89 + 0.846876 \times 1059.3 = 1170\ \text{kJ/kg}$$

$$s_2 = s_f + x_2\ s_{fg} = 1.0408 + 0.846876 \times 4.0452 = 4.4666\ \text{kJ/kgK}$$

From the energy equation

$$Q_H = -{}_1Q_2 = -m(u_2 - u_1) = -0.5(1170 - 1596.1) = \mathbf{213.05\ kJ}$$

Take now CV total ammonia plus heat engine out to ambient

Entropy Eq.8.3: $m(s_2 - s_1) = -\dfrac{Q_L}{T_{amb}}$ ⇒

$$Q_L = -mT_{amb}\,(s_2 - s_1) = -\ 0.5 \times 293.15\ (4.4666 - 5.7485)$$
$$= 187.89\ \text{kJ}$$

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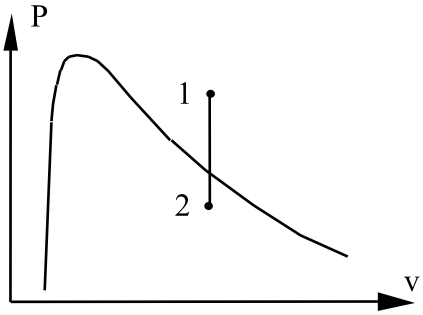
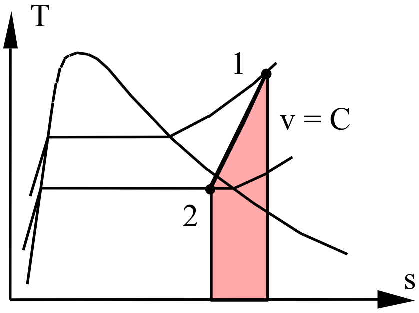
Now the CV heat engine can give the engine work from the energy equation

Energy H.E.: $W_{HE} = Q_H - Q_L = 213.05 - 187.89 =$ **25.2 kJ**





Notice to get ${}_1q_2 = \int T\, ds$ we must know the function T(s) which we do not readily have for this process.

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8.180

A piston/cylinder with constant loading of piston contains 1 L water at 400 kPa, quality 15%. It has some stops mounted so the maximum possible volume is 11 L. A reversible heat pump extracting heat from the ambient at 300 K, 100 kPa heats the water to 300°C. Find the total work and heat transfer for the water and the work input to the heat pump.

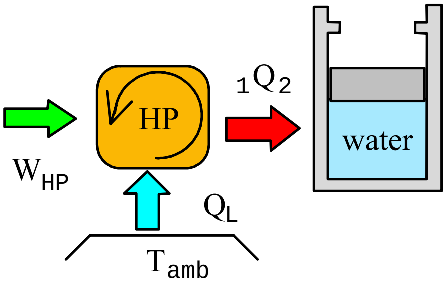
Solution: Take CV around the water and check possible P-V combinations.

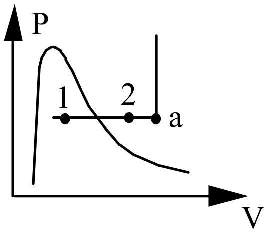
State 1: $v_1 = 0.001084 + 0.15 \times 0.46138 = 0.07029 \text{ m}^3/\text{kg}$

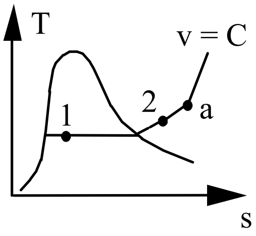
$u_1 = 604.29 + 0.15 \times 1949.26 = 896.68 \text{ kJ/kg}$

$s_1 = 1.7766 + 0.15 \times 5.1193 = 2.5445 \text{ kJ/kg K}$

$m_1 = V_1/v_1 = 0.001/0.07029 = 0.0142 \text{ kg}$







State a: $v = 11\ v_1 = 0.77319 \text{ m}^3/\text{kg}$,

400 kPa

=> Sup. vapor $T_a = 400^{\circ}\text{C} \ > T_2$

State 2: Since $T_2 < T_a$ then piston is not at stops but floating so $P_2 = 400$ kPa.

$(T, P) \;\Rightarrow\; v_2 = 0.65484 \text{ m}^3/\text{kg} \;\Rightarrow\; V_2 = (v_2/v_1) \times V_1 = 9.316 \text{ L}$

$_1W_2 = \int P\, dV = P(V_2 - V_1) = 400\ (9.316 - 1) \times 0.001 = \mathbf{3.33\ kJ}$

$_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 0.0142\ (2804.8 - 896.68) + 3.33 = \mathbf{30.43\ kJ}$

Take CV as water plus the heat pump out to the ambient.

$m(s_2 - s_1) = Q_L/T_o \;\Rightarrow$

$Q_L = mT_o\ (s_2 - s_1) = 300 \times 0.0142\ (7.5661 - 2.5445) = 21.39 \text{ kJ}$

$W_{HP} = {}_1Q_2 - Q_L = \mathbf{9.04\ kJ}$

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8.181

A cylinder with a linear spring-loaded piston contains carbon dioxide gas at 2 MPa with a volume of 50 L. The device is of aluminum and has a mass of 4 kg. Everything (Al and gas) is initially at 200°C. By heat transfer the whole system cools to the ambient temperature of 25°C, at which point the gas pressure is 1.5 MPa. Find the total entropy generation for the process.

CO_2: $m = P_1V_1/RT_1 = 2000 \times 0.05/(0.18892 \times 473.2) = 1.1186 \text{ kg}$

$$V_2 = V_1(P_1/P_2)(T_2/T_1) = 0.05(2/1.5)(298.2/473.2) = 0.042 \text{ m}^3$$

$${}_1W_{2\,CO_2} = \int PdV = \frac{P_1+P_2}{2}(V_2 - V_1) = \frac{2000+1500}{2}(0.042 - 0.050) = -14.0 \text{ kJ}$$

$${}_1Q_{2\,CO_2} = mC_{V0}(T_2-T_1) + {}_1W_2 = 1.1186\times0.6529(25-200)-14.0 = -141.81 \text{ kJ}$$

$${}_1Q_{2\,Al} = mC(T_2 - T_1) = 4 \times 0.90(25 - 200) = -630 \text{ kJ}$$

System: $CO_2 + Al$

Entropy Eq.: $m_{CO_2}(s_2 - s_1)_{CO_2} + m_{AL}(s_2 - s_1)_{AL} = {}_1Q_2/T_0 + {}_1S_{2\,gen}$

$${}_1Q_2 = -141.81 - 630 = -771.81 \text{ kJ}$$

$$\Delta S_{SYST} = m_{CO_2}(s_2 - s_1)_{CO_2} + m_{AL}(s_2 - s_1)_{AL}$$

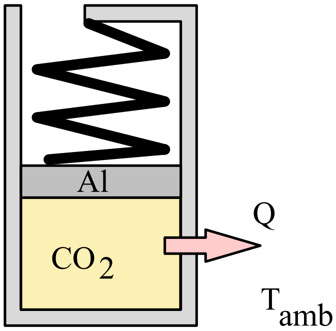
$$= 1.1186\left[0.8418 \ln\frac{298.2}{473.2} - 0.18892 \ln\frac{1.5}{2.0}\right] + 4 \times 0.9 \ln(298.2/473.2)$$

$$= -0.37407 - 1.6623 = -2.0364 \text{ kJ/K}$$

$$\Delta S_{SURR} = -({}_1Q_2/T_0) = +(771.81/298.15) = +2.5887 \text{ kJ/K}$$

$${}_1S_{2\,gen} = m_{CO_2}(s_2 - s_1)_{CO_2} + m_{AL}(s_2 - s_1)_{AL} - ({}_1Q_2/T_0)$$

$$= -2.0364 + 2.5887 = \mathbf{+0.552 \text{ kJ/K}}$$



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8.182

An un-insulated cylinder fitted with a piston contains air at 500 kPa, 200°C, at which point the volume is 10 L. The external force on the piston is now varied in such a manner that the air expands to 150 kPa, 25 L volume. It is claimed that in this process the air produces 70% of the work that would have resulted from a reversible, adiabatic expansion from the same initial pressure and temperature to the same final pressure. Room temperature is 20°C.

a) What is the amount of work claimed?
b) Is this claim possible?

Solution:

C.V.: Air; $R = 0.287$ kJ/kg-K, $C_p = 1.004$ kJ/kg K, $C_v = 0.717$ kJ/kg K

State 1: $T_1 = 200^oC$, $P_1 = 500$ kPa, $V_1 = 10$ L $= 0.01$ m^3;

$$m_1 = V_1/v_1 = P_1V_1/RT_1 = 0.0368 \text{ kg}$$

State 2: $P_2 = 150$ kPa, $V_2 = 25$ L $= 0.025$ m^3

$\eta_s = 70\%$; Actual Work is 70% of Isentropic Work

a) Assume Reversible and Adiabatic Process; $s_1 = s_{2s}$

$$T_{2s} = T_1\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = 473.15\ (150\ /\ 500)\ = 335.4 \text{ K}$$

1st Law: ${}_1Q_{2s} = m(u_{2s} - u_1) + {}_1W_{2s}$; ${}_1Q_{2s} = 0$

Assume constant specific heat

${}_1W_{2\,s} = mC_v(T_1 - T_{2s}) = 3.63$ kJ

${}_1W_{2\,ac} = 0.7\times{}_1W_{2\,s} =$ **2.54 kJ**

b) Use Ideal Gas Law; $T_{2\,ac} = T_1P_2V_2\ /\ P_1V_1 = 354.9$ K

1st Law: ${}_1Q_{2\,ac} = mC_v(T_{2\,ac} - T_1) + {}_1W_{2\,ac} = -0.58$ kJ

2nd Law: $\Delta S_{net} = m(s_2 - s_1) - \dfrac{Q_{cv}}{T_o}$; $Q_{CV} = {}_1Q_{2\,ac}$, $T_o = 20^oC$

$$s_2 - s_1 = Cp\ \ln\frac{T_2}{T_1} - R\ \ln\frac{P_2}{P_1} = 0.0569 \text{ kJ/kg-K}$$

$\Delta S_{net} = 0.00406$ kJ/K ≥ 0 ;   **Process is Possible**

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8.183

A piston/cylinder assembly contains 2 kg of liquid water at 20°C, 100 kPa and it is now heated to 300°C by a source at 500°C. A pressure of 1000 kPa will lift the piston off the lower stops. Find the final volume, work, heat transfer and total entropy generation.

Solution:

C.V. Water out to source at 500°C. This is a control mass.

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.14: $m(s_2 - s_1) = {}_1Q_2 / T_{SOURCE} + {}_1S_{2\ gen}$

Process: $V = V_1$ if $P < P_{LIFT}$ or $P = P_{LIFT}$ if $V > V_1$

Any state of this system must be on the two lines shown in the P-v diagram.

Initial state: Table B.1.1: $v_1 = 0.001002$, $u_1 = 83.94$, $= 0.2966$

$$V_1 = mv_1 = 2 \times 0.001002 = 0.002\ m^3$$

Final state: 300°C and on line in P-V diagram. Now check at state 1a.

State 1a: $v_{1a} = v_1$, $P = 1000$ kPa => compressed liquid $T_{1a} < 180°C$

As final state is at 300°C higher than T_{1a} we must be further out so

State 2: 1000 kPa, 300°C => Superheated vapor in Table B.1.3

$$v_2 = 0.25794,\quad u_2 = 2793.2,\quad s_2 = 7.1228$$

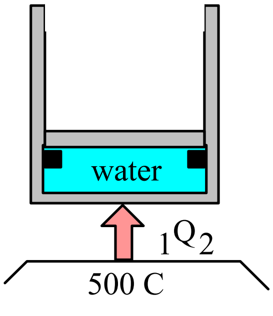
$$V_2 = mv_2 = 2 \times 0.25794 = 0.51588\ m^3$$

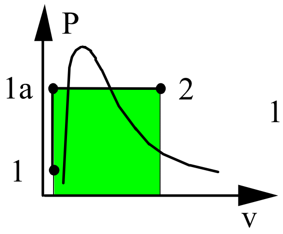
$${}_1W_2 = \int PdV = P_2(V_2 - V_1) = 1000\ (0.51588 - 0.002) = \mathbf{513.9\ kJ}$$

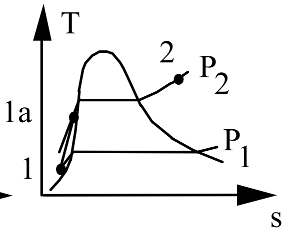
$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 2(2793.2 - 83.94) + 513.9 = \mathbf{5932\ kJ}$$

$${}_1S_{2\ gen} = m(s_2 - s_1) - {}_1Q_2/T_{SOURCE} = 2\ (7.1228 - 0.2966) - \frac{5932}{773.15}$$

$$= 13.652 - 7.673 = \mathbf{5.98\ kJ/K} \quad (= \Delta S_{water} + \Delta S_{sur})$$







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8.184

A gas in a rigid vessel is at ambient temperature and at a pressure, P_1, slightly higher than ambient pressure, P_0. A valve on the vessel is opened, so gas escapes and the pressure drops quickly to ambient pressure. The valve is closed and after a long time the remaining gas returns to ambient temperature at which point the pressure is P_2. Develop an expression that allows a determination of the ratio of specific heats, *k*, in terms of the pressures.

C.V.: air remaining in tank,

First part of the process is an isentropic expansion s = constant.

$$P_1,\ T_0 \rightarrow P_0,\ T_x \qquad T_x/T_0 = (P_0/P_1)^{\frac{k-1}{k}}$$

Second part of the process is a constant vol. heat transfer. $P_0,\ T_x \rightarrow P_2,\ T_0$

$$\frac{P_0}{P_2} = \frac{T_x}{T_0} \;\Rightarrow\; \frac{P_0}{P_2} = \left(\frac{P_0}{P_1}\right)^{\frac{k-1}{k}} \;\rightarrow\; \mathbf{k = \frac{\ln (P_1/P_0)}{\ln (P_1/P_2)}}$$

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8.185

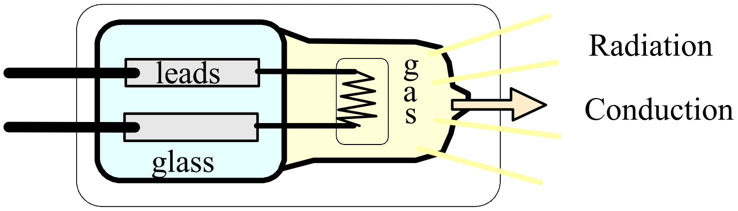
A small halogen light bulb receives an electrical power of 50 W. The small filament is at 1000 K and gives out 20% of the power as light and the rest as heat transfer to the gas, which is at 500 K; the glass is at 400 K. All the power is absorbed by the room walls at 25°C. Find the rate of generation of entropy in the filament, in the total bulb including glass and the total room including bulb.

Solution:

$\dot{W}_{el} = 50$ W

$\dot{Q}_{RAD} = 10$ W

$\dot{Q}_{COND} = 40$ W



We will assume steady state and no storage in the bulb, air or room walls.

C.V. Filament steady-state

Energy Eq.5.31: $\quad dE_{c.v.}/dt = 0 = \dot{W}_{el} - \dot{Q}_{RAD} - \dot{Q}_{COND}$

Entropy Eq.8.43: $\quad dS_{c.v.}/dt = 0 = -\dfrac{\dot{Q}_{RAD}}{T_{FILA}} - \dfrac{\dot{Q}_{COND}}{T_{FILA}} + \dot{S}_{gen}$

$$\dot{S}_{gen} = (\dot{Q}_{RAD} + \dot{Q}_{COND})/T_{FILA} = \dot{W}_{el}/T_{FILA} = \frac{50}{1000} = \mathbf{0.05\ W/K}$$

C.V. Bulb including glass

$\dot{Q}_{RAD}$ leaves at 1000 K $\qquad\qquad$ $\dot{Q}_{COND}$ leaves at 400 K

$$\dot{S}_{gen} = \int d\dot{Q}/T = -(-10/1000) - (-40/400) = \mathbf{0.11\ W/K}$$

C.V. Total room. All energy leaves at 25°C

Eq.5.31: $\quad dE_{c.v.}/dt = 0 = \dot{W}_{el} - \dot{Q}_{RAD} - \dot{Q}_{COND}$

Eq.8.43: $\quad dS_{c.v.}/dt = 0 = -\dfrac{\dot{Q}_{TOT}}{T_{WALL}} + \dot{S}_{gen}$

$$\dot{S}_{gen} = \frac{\dot{Q}_{TOT}}{T_{WALL}} = 50/(25+273) = \mathbf{0.168\ W/K}$$

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Solutions using the Pr and vr functions in Table A.7.2

If you would like to see more of these please let me know (claus@umich.edu) and I can prepare more of the problem solutions using these functions.

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8.97

A piston/cylinder, shown in Fig. P8.97, contains air at 1380 K, 15 MPa, with $V_1 = 10\text{ cm}^3$, $A_{cyl} = 5\text{ cm}^2$. The piston is released, and just before the piston exits the end of the cylinder the pressure inside is 200 kPa. If the cylinder is insulated, what is its length? How much work is done by the air inside?

Solution:

C.V. Air, Cylinder is insulated so adiabatic, Q = 0.

Continuity Eq.: $m_2 = m_1 = m$,

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2 = - {}_1W_2$

Entropy Eq.8.37: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\text{ gen}} = 0 + {}_1S_{2\text{ gen}}$

State 1: (T_1, P_1) State 2: $(P_2, ?)$

So one piece of information is needed for the ?, assume reversible process.

$${}_1S_{2\text{ gen}} = 0 \quad \Rightarrow \quad s_2 - s_1 = 0$$

State 1: Table A.7.1: $u_1 = 1095.2\text{ kJ/kg}$,

Table A.7.2: $P_{r1} = 340.53$, $v_{r1} = 2.7024$

$$m = P_1V_1/RT_1 = \frac{15000 \times 10\times10^{-6}}{0.287 \times 1380} = 0.000379\text{ kg}$$

State 2: P_2 and from Entropy eq.: $s_2 = s_1$

$$\Rightarrow \quad P_{r2} = P_{r1}P_2/P_1 = 340.53\times200/15000 = 4.5404$$

Interpolate in A.7.2 to match the P_{r2} value

$T_2 = 447\text{ K}$, $u_2 = 320.85\text{ kJ/kg}$, $v_{r2} = 65.67$

$$\Rightarrow \quad V_2 = V_1v_{r2}/v_{r1} = 10 \times 65.67 / 2.7024 = \mathbf{243\text{ cm}^3}$$

$$\Rightarrow \quad L_2 = V_2 /A_{cyl} = 243/5 = \mathbf{48.6\text{ cm}}$$

$$\Rightarrow \quad {}_1w_2 = u_1 - u_2 = 774.4\text{ kJ/kg}, \qquad {}_1W_2 = m_1w_2 = \mathbf{0.2935\text{ kJ}}$$

We could also have done $V_2 = V_1 (T_2P_1/T_1P_2)$ from ideal gas law and thus did not need the vr function for this problem

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8.107

A piston/cylinder contains air at 300 K, 100 kPa. It is now compressed in a reversible adiabatic process to a volume 7 times as small. Use constant heat capacity and find the final pressure and temperature, the specific work and specific heat transfer for the process.

Solution: Here we use the v_r function from Table A.7.2

Expansion ratio: $v_2/ v_1 = 1/7$

Process eq.: Rev. adiabatic and ideal gas gives $Pv^n = C$, with $n = k$

Since we know the v ratio and s is constant we use the v_r function

$v_{r1} = 179.49 \Rightarrow v_{r2} = v_{r1}\, v_2/ v_1 = 179.49/7 = 25.641$

Table A.7.2: Interpolate $T_2 =$ **640.7 K**

$$P_2 = P_1 \times (T_2 / T_1) \times (v_1/v_2) = 100 \times (640.7/300) \times 7 = \mathbf{1495\ kPa}$$

Adiabatic: ${}_1q_2 =$ **0 kJ/kg**

Polytropic process work term from Eq.8.38

$$ {}_1w_2 = -(u_2 - u_1) = -(466.37 - 214.36) = \mathbf{-252.0\ kJ/kg}$$

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8.112

A mass of 1 kg of air contained in a cylinder at 1.5 MPa, 1000 K, expands in a reversible adiabatic process to 100 kPa. Calculate the final temperature and the work done during the process, using

a. Constant specific heat, value from Table A.5

b. The ideal gas tables, Table A.7

Solution:

C.V. Air.

Continuity Eq.: $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.8.37: $m(s_2 - s_1) = \int dQ/T + {}_1S_{2\ gen}$

Process: ${}_1Q_2 = 0$, ${}_1S_{2\ gen} = 0$ => $s_2 = s_1$

a) Using constant Cp from Table A.5 gives the power relation Eq.8.32.

$$T_2 = T_1(P_2/P_1)^{\frac{k-1}{k}} = 1000\left(\frac{0.1}{1.5}\right)^{0.286} = \mathbf{460.9\ K}$$

$${}_1W_2 = -(U_2 - U_1) = mC_{Vo}(T_1 - T_2)$$

$$= 1 \times 0.717(1000 - 460.9) = \mathbf{386.5\ kJ}$$

b) Use the tabulated **reduced pressure function** that includes variable heat capacity from A.7.2

$$P_{r2} = P_{r1} \times P_2/P_1 = 91.65 \times \frac{0.1}{1.5} = 6.11$$

Interpolation gives $T_2 = \mathbf{486\ K}$ and $u_2 = 349.4$ kJ/kg

$${}_1W_2 = m(u_1 - u_2) = 1(759.2 - 349.4) = \mathbf{409.8\ kJ}$$

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