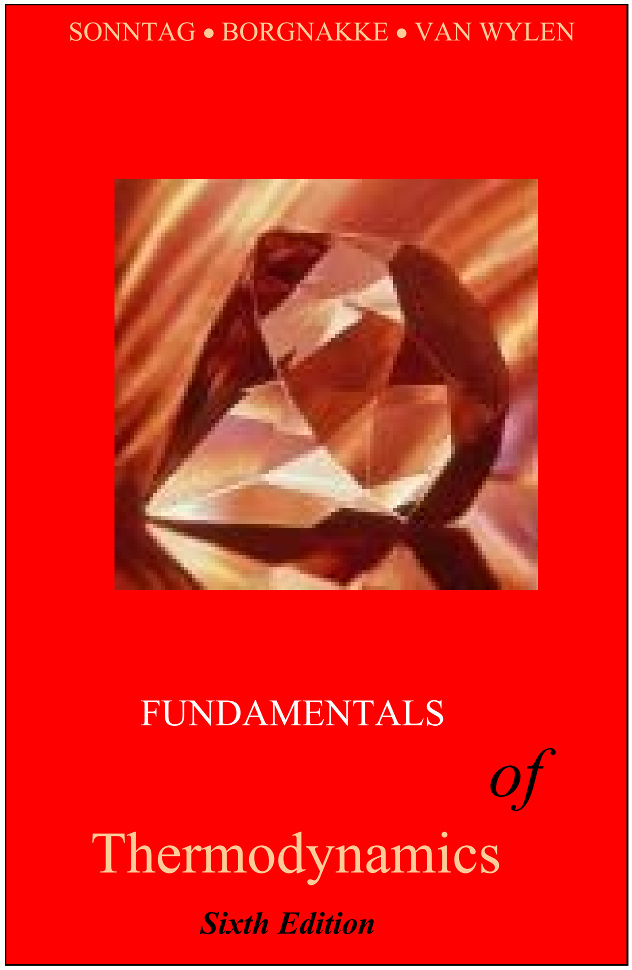
SOLUTION MANUAL
ENGLISH UNIT PROBLEMS
CHAPTER 4



CHAPTER 4

SUBSECTION	PROB NO.
Concept-Study Guide Problems	117-122
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Correspondence table

The correspondence between the problem set in this sixth edition versus the problem set in the 5'th edition text. Problems that are new are marked new and the SI number refers to the corresponding SI unit problem.

New	5th Ed.	SI	New	5th Ed.	SI
117	new	1	131	new	50
118	new	-	132	66	47
119	new	9	133	65	48
120	new	14	134	75	57
121	new	4	135	69	59
122	new	3	136	73	63
123	new	22	137	72	60
124	68	32	138	76	71
125	64	25	139	63	82
126	New	24	140	new	91
127	new	38	141	77	95
128	62	36	142	78	97
129	67	109	143	79	100
130	70	111			

Concept Problems

4.117E

The electric company charges the customers per kW-hour. What is that in english units?

The unit kW-hour is a rate multiplied with time. For the standard English Eng. units the rate of energy is in Btu/h and the time is in seconds. The integration in Eq.4.21 becomes

$$1 \text{ kW-hour} = 3412.14 \text{ Btu/h} \times 1 \text{ h} = \mathbf{3412.14\ Btu}$$

Conversions are found in Table A.1

4.118E

Work as F Δx has units of lbf-ft, what is that in Btu?

Conversions are found in Table A.1

$$1 \text{ lbf-ft} = \mathbf{1.28507 \times 10^{-3}\ Btu} = \frac{1}{778} \text{ Btu}$$

4.119E

A work of 2.5 Btu must be delivered on a rod from a pneumatic piston/cylinder where the air pressure is limited to 75 psia. What diameter cylinder should I have to restrict the rod motion to maximum 2 ft?

$$W = \int F\,dx = \int P\,dV = \int PA\,dx = PA\,\Delta x = P\,\frac{\pi}{4}D^2\,\Delta x$$

$$D = \sqrt{\frac{4W}{\pi P \Delta x}} = \sqrt{\frac{4 \times 2.5 \text{ Btu}}{\pi \times 75 \text{ psia} \times 2 \text{ ft}}} = \sqrt{\frac{4 \times 2.5 \times 778.17 \text{ lbf-ft}}{\pi \times 75 \times 144\ (\text{lbf/ft}^2) \times 2 \text{ ft}}}$$

$$= \mathbf{0.339\ ft}$$

4.120E

A force of 300 lbf moves a truck with 40 mi/h up a hill. What is the power?

Solution:

$$\dot{W} = F\,\mathbf{V} = 300 \text{ lbf} \times 40 \text{ (mi/h)}$$
$$= 12\,000 \times \frac{1609.3 \times 3.28084}{3600}\ \frac{\text{lbf-ft}}{\text{s}}$$
$$= 17\,600\ \frac{\text{lbf-ft}}{\text{s}} = \mathbf{22.62\ Btu/s}$$

4.121E

A 1200 hp dragster engine drives the car with a speed of 65 mi/h. How much force is between the tires and the road?

Power is force times rate of displacement as in Eq.4.2

Power, rate of work $\qquad \dot{W} = F\,\mathbf{V} = P\,\dot{V} = T\,\omega$

We need the velocity in ft/s: $\quad \mathbf{V} = \dfrac{65 \times 1609.3 \times 3.28084}{3600} = 95.33$ ft/s

We need power in lbf-ft/s: $\quad 1$ hp $= 550$ lbf-ft/s

$$F = \dot{W} / \mathbf{V} = \frac{1200 \times 550}{95.33}\,\frac{\text{lbf-ft/s}}{\text{ft/s}} = \mathbf{6923\ lbf}$$

4.122E

A 1200 hp dragster engine has a drive shaft rotating at 2000 RPM. How much torque is on the shaft?

Power is force times rate of displacement as in Eq.4.2

Power, rate of work $\dot{W} = F\,\mathbf{V} = P\,\dot{V} = T\,\omega$

We need to convert the RPM to a value for angular velocity ω

$$\omega = \text{RPM} \times \frac{2\pi}{60\text{ s}} = 2000 \times \frac{2\pi}{60\text{ s}} = 209.44\ \frac{\text{rad}}{\text{s}}$$

We need power in lbf-ft/s: 1 hp = 550 lbf-ft/s

$$T = \dot{W} / \omega = \frac{1200\text{ hp} \times 550\text{ lbf-ft/s-hp}}{209.44\text{ rad/s}} = \mathbf{3151\ lbf\text{-}ft}$$

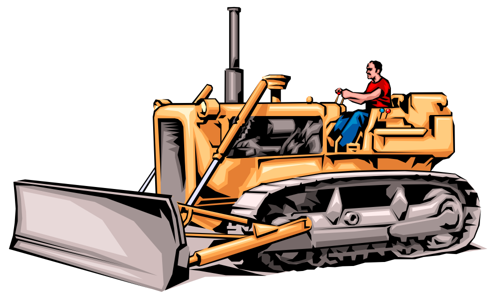
Simple Processes

4.123E

A bulldozer pushes 1000 lbm of dirt 300 ft with a force of 400 lbf. It then lifts the dirt 10 ft up to put it in a dump truck. How much work did it do in each situation?

Solution:

$W = \int F\, dx = F\, \Delta x$
$= 400\text{ lbf} \times 300\text{ ft}$
$= 120\,000\text{ lbf-ft} =$ **154 Btu**



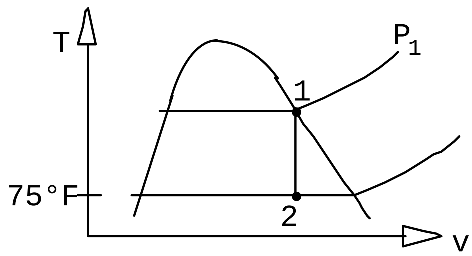
$W = \int F\, dz = \int mg\, dz = mg\, \Delta Z$
$= 1000\text{ lbm} \times 32.174\text{ ft/s}^2 \times 10\text{ ft} / (32.174\text{ lbm-ft / s}^2\text{-lbf})$
$= 10\,000\text{ lbf-ft} =$ **12.85 Btu**

4.124E

A steam radiator in a room at 75 F has saturated water vapor at 16 lbf/in.^{2} flowing through it, when the inlet and exit valves are closed. What is the pressure and the quality of the water, when it has cooled to 75F? How much work is done?

Solution:

After the valve is closed no flow, constant V and m.



1: $x_1 = 1$, $P_1 = 16$ lbf/in^2

$\Rightarrow v_1 = v_{g1} = 24.754$ ft^3/lbm

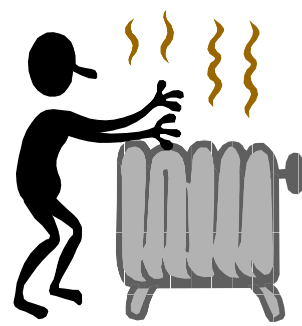
2: $T_2 = 75$ F, $v_2 = v_1 = 24.754$ ft^3/lbm

$P_2 = P_{g\,2} = \mathbf{0.43\ lbf/in^2}$

$v_2 = 24.754 = 0.01606 + x_2(739.584 - 0.01606)$

$x_2 = \mathbf{0.0334}$

${}_1W_2 = \int PdV = \mathbf{0}$



4.125E

A linear spring, $F = k_s(x - x_o)$, with spring constant k_s = 35 lbf/ft, is stretched until it is 2.5 in. longer. Find the required force and work input.

Solution:

$$F = k_s(x - x_0) = 35 \times 2.5/12 = 7.292 \text{ lbf}$$

$$W = \int F dx = \int k_s(x - x_0) d(x - x_0) = \frac{1}{2} k_s(x - x_0)^2$$

$$= \frac{1}{2} \times 35 \times (2.5/12)^2 = 0.76 \text{ lbf•ft} = \mathbf{9.76 \times 10^{-4}\ Btu}$$

4.126E

Two hydraulic cylinders maintain a pressure of 175 psia. One has a cross sectional area of 0.1 ft^2 the other 0.3 ft^2. To deliver a work of 1 Btu to the piston how large a displacement (V) and piston motion H is needed for each cylinder? Neglect P_{atm}

Solution:

$$W = \int F\, dx = \int P\, dV = \int PA\, dx = PA \times H = P\, \Delta V$$

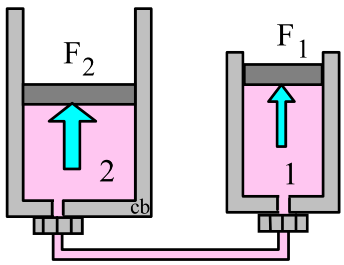
$$W = 1 \text{ Btu} = 778.17 \text{ lbf-ft}$$

$$\Delta V = \frac{W}{P} = \frac{778.17 \text{ lbf-ft}}{175 \times 144 \text{ lbf/ft}^2} = \mathbf{0.030\ 873\ ft^3}$$

Both cases the height is $H = \Delta V/A$

$$H_1 = \frac{0.030873}{0.1} = \mathbf{0.3087\ ft}$$

$$H_2 = \frac{0.030873}{0.3} = \mathbf{0.1029\ ft}$$



4.127E

A piston/cylinder has 15 ft of liquid 70 F water on top of the piston (m = 0) with cross-sectional area of 1 ft^2, see Fig. P2.57. Air is let in under the piston that rises and pushes the water out over the top edge. Find the necessary work to push all the water out and plot the process in a P-V diagram.

Solution:

$$P_1 = P_o + \rho g H$$

$$= 14.696 \text{ psia} + \frac{62.2 \times 32.174 \times 15}{32.174 \times 144} \; \frac{\text{lbm/ft}^3 \times \text{ft/s}^2 \times \text{ft}}{(\text{lbm-ft/s}^2\text{-lbf})\ (\text{in/ft})^2}$$

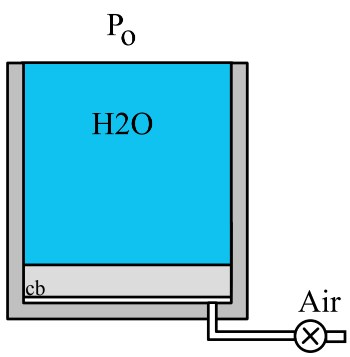
$$= 21.18 \text{ psia}$$

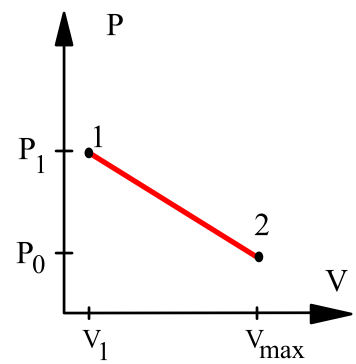
$$\Delta V = H \times A = 15 \times 1 = 15 \text{ ft}^3$$

$${}_1W_2 = \text{AREA} = \int P\, dV = ½ (P_1 + P_o)(V_{max} - V_1)$$

$$= ½ (21.18 + 14.696) \text{ psia} \times 15 \text{ ft}^3 \times 144 \text{ (in/ft)}^2$$

$$\mathbf{= 38\,746 \text{ lbf-ft} = 49.8 \text{ Btu}}$$





4.128E

A cylinder fitted with a frictionless piston contains 10 lbm of superheated refrigerant R-134a vapor at 100 lbf/in.^{2}, 300 F. The setup is cooled at constant pressure until the R-134a reaches a quality of 25%. Calculate the work done in the process.

Solution:

Constant pressure process boundary work. State properties from Table F.10

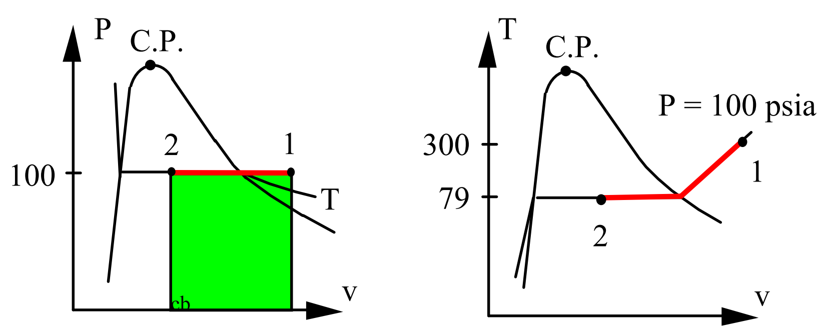
State 1: Table F.10.2 $\quad v_1 = 0.76629\ \text{ft}^3/\text{lbm}$;

State 2: Table F.10.1 $\quad v_2 = 0.013331 + 0.25 \times 0.46652 = 0.12996\ \ \text{ft}^3/\text{lbm}$

Interpolated to be at 100 psia, numbers at 101.5 psia could have been used.

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

$$= 10 \times 100 \times \frac{144}{778} \times (0.12996 - 0.76629) = \mathbf{-117.78\ Btu}$$



Review Problems

4.129E

The gas space above the water in a closed storage tank contains nitrogen at 80 F, 15 lbf/in.^{2}. Total tank volume is 150 ft^3 and there is 1000 lbm of water at 80 F. An additional 1000 lbm water is now forced into the tank. Assuming constant temperature throughout, find the final pressure of the nitrogen and the work done on the nitrogen in this process.

Solution:

Water is compressed liquid, so it is incompressible

$V_{H_2O\ 1} = mv_1 = 1000 \times 0.016073 = 16.073\ ft^3$

$V_{N_2\ 1} = V_{tank} - V_{H_2O\ 1} = 150 - 16.073 = 133.93\ ft^3$

$V_{N_2\ 2} = V_{tank} - V_{H_2O\ 2} = 150 - 32.146 = 117.85\ ft^3$

N_2 is an ideal gas so

$$P_{N_2\ 2} = P_{N_2\ 1} \times V_{N_2\ 1}/V_{N_2\ 2} = 15 \times \frac{133.93}{117.85} = \mathbf{17.046\ lbf/in^2}$$

$$W_{12} = \int PdV = P_1V_1 \ln\frac{V_2}{V_1} = \frac{15\times144\times133.93}{778} \ln\frac{117.85}{133.93} = \mathbf{-47.5\ Btu}$$

4.130E

A cylinder having an initial volume of 100 ft^3 contains 0.2 lbm of water at 100 F. The water is then compressed in an isothermal quasi-equilibrium process until it has a quality of 50%. Calculate the work done in the process assuming water vapor is an ideal gas.

Solution:

State 1: T_1, $v_1 = V/m = \frac{100}{0.2} = 500\ ft^3/lbm \quad (> v_g)$

since $P_g = 0.95$ psia, very low so water is an ideal gas from 1 to 2.

$$P_1 = P_g \times \frac{v_g}{v_1} = 0.950 \times \frac{350}{500} = 0.6652\ lbf/in^2$$

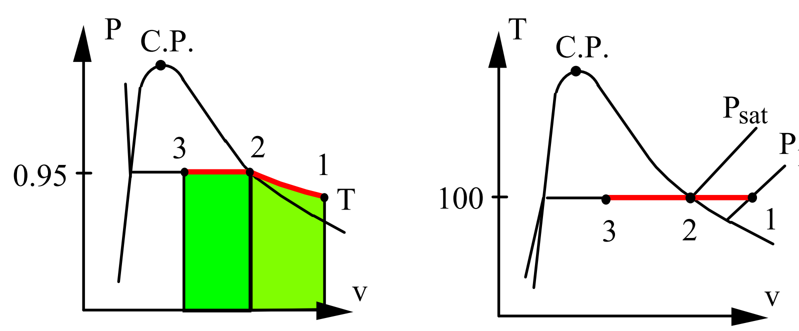
$$V_2 = mv_2 = 0.2*350 = 70\ ft^3$$

$$v_3 = 0.01613 + 0.5\times(350 - 0.01613) = 175.0\ ft^3/lbm$$

$${}_1W_2 = \int PdV = P_1V_1 \ln\frac{V_2}{V_1} = 0.6652 \times \frac{144}{778} \times 100 \ln\frac{70}{100} = -4.33\ Btu$$

$${}_2W_3 = P_{2=3} \times m(v_3 - v_2) = 0.95 \times 0.2 \times (175 - 350) \times 144 / 778 = -6.16\ Btu$$

$${}_1W_3 = -\ 6.16 - 4.33 = \mathbf{-10.49\ Btu}$$



Polytropic Processes

4.131E

Helium gas expands from 20 psia, 600 R and 9 ft^3 to 15 psia in a polytropic process with n = 1.667. How much work does it give out?

Solution:

Process equation: $PV^n = \text{constant} = P_1V_1^n = P_2V_2^n$

Solve for the volume at state 2

$$V_2 = V_1\ (P_1/P_2)^{1/n} = 9 \times \left(\frac{20}{15}\right)^{0.6} = 10.696\ ft^3$$

Work from Eq.4.4

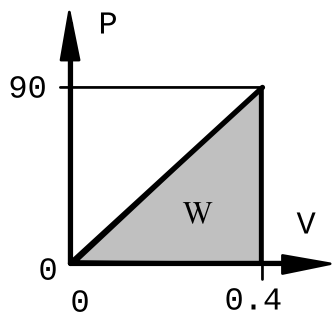
$$_1W_2 = \frac{P_2V_2\text{- } P_1\ V_1}{1\text{-n}} = \frac{15 \times 10.696 \text{ - } 20 \times 9}{1 \text{ - } 1.667} \times 144 \text{ lbf-ft}$$

$= 4223$ lbf-ft = **5.43 Btu**

4.132E

Consider a mass going through a polytropic process where pressure is directly proportional to volume (n = – 1). The process start with *P* = 0, *V* = 0 and ends with *P* = 90 lbf/in.^{2}, *V* = 0.4 ft^3.The physical setup could be as in Problem 2.22. Find the boundary work done by the mass.

Solution:



$$W = \int P dV = \text{AREA}$$

$$= \frac{1}{2}(P_1 + P_2)(V_2 - V_1)$$

$$= \frac{1}{2}(P_2 + 0)(V_2 - 0)$$

$$= \frac{1}{2}\ P_2\ V_2 = \frac{1}{2}\ \times 90 \times 0.4 \times 144$$

= **2592 ft lbf = 3.33 Btu**

4.133E

The piston/cylinder shown in Fig. P4.48 contains carbon dioxide at 50 lbf/in.^{2}, 200 F with a volume of 5 ft^3. Mass is added at such a rate that the gas compresses according to the relation $PV^{1.2}$ = constant to a final temperature of 350 F. Determine the work done during the process.

Solution:

From Eq. 4.4 for PV^n = const ($n \neq 1$)

$$_1W_2 = \int_1^2 PdV = \frac{P_2V_2 - P_1V_1}{1 - n} \qquad \text{Assuming ideal gas, } PV = mRT$$

$$_1W_2 = \frac{mR(T_2 - T_1)}{1 - n}, \quad \text{But } mR = \frac{P_1V_1}{T_1} = \frac{50 \times 144 \times 5}{659.7 \times 778} = 0.07014 \text{ Btu/R}$$

$$_1W_2 = \frac{0.07014(809.7 - 659.7)}{1 - 1.2} = \mathbf{-52.605\ Btu}$$

4.134E

Find the work for Problem 3.156E.

Solution:

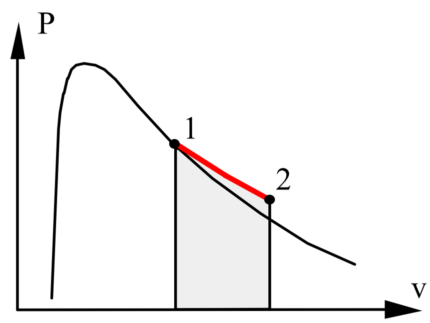
State 1: Table F.9 $P_1 = 274.6 \text{ lbf/in}^2$, $v_1 = 0.1924 \text{ ft}^3\text{/lbm}$

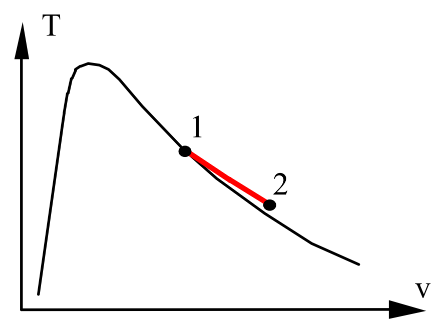
Process: $Pv = C = P_1v_1 = P_2v_2 \quad \Rightarrow \quad {}_1w_2 = \int Pdv = C \int v^{-1} \, dv = C \ln \frac{v_2}{v_1}$

State 2: $P_2 = 30 \text{ lbf/in}^2$; $v_2 = \frac{v_1 P_1}{P_2} = 0.1924 \times 274.6 / 30 = 1.761 \text{ ft}^3\text{/lbm}$

$${}_1w_2 = P_1v_1 \ln \frac{v_2}{v_1} = P_1v_1 \ln \frac{P_1}{P_2} = 274.6 \times 0.1924 \times 144 \ln \frac{274.6}{30}$$

$= 16845$ ft•lbf/lbm = **21.65 Btu/lbm**





Notice T is not constant. It is not an ideal gas in this range.

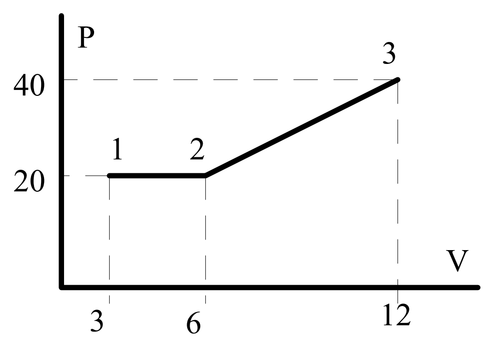
Multi-step Processes, Other Types of Work

4.135E

Consider a two-part process with an expansion from 3 to 6 ft^3 at a constant pressure of 20 lbf/in.^{2} followed by an expansion from 6 to 12 ft^3 with a linearly rising pressure from 20 lbf/in.^{2} ending at 40 lbf/in.^{2}. Show the process in a P-V diagram and find the boundary work.

Solution:

By knowing the pressure versus volume variation the work is found.



$$
{}_1W_3 = {}_1W_2 + {}_2W_3 = \int_1^2 PdV + \int_2^3 PdV = P_1 (V_2 - V_1) + \frac{1}{2} (P_2 + P_3)(V_3\text{-}V_2)
$$

$$
W = 20 \times 144 \times (6 - 3) + \frac{1}{2} (20 + 40)(12 - 6) \times 144
$$

$= 8640 + 25\,920 = 34\,560$ ft lbf.

$= (34\,560 / 778) =$ **44.42 Btu**

4.136E

A piston/cylinder has 2 lbm of R-134a at state 1 with 200 F, 90 lbf/in.^{2}, and is then brought to saturated vapor, state 2, by cooling while the piston is locked with a pin. Now the piston is balanced with an additional constant force and the pin is removed. The cooling continues to a state 3 where the R-134a is saturated liquid. Show the processes in a P-V diagram and find the work in each of the two steps, 1 to 2 and 2 to 3.

Solution :

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

Properties from table F.10.1 and 10.2

State 1: (T,P) => $v = 0.7239\ \mathrm{ft^3/lbm}$

State 2 given by fixed volume and $x_2 = 1.0$

State 2: $v_2 = v_1 = v_g$ => $\mathbf{{}_1W_2 = 0}$

$$T_2 = 50 + 10 \times \frac{0.7239 - 0.7921}{0.6632 - 0.7921} = 55.3\ \mathrm{F}$$

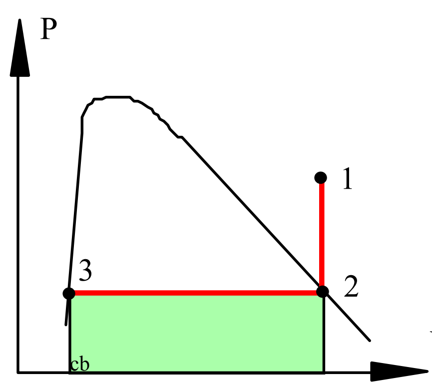
$$P_2 = 60.311 + (72.271 - 60.311) \times 0.5291 = 66.64\ \mathrm{psia}$$

State 3 reached at constant P (F = constant) state 3: $P_3 = P_2$ and

$v_3 = v_f = 0.01271 + (0.01291 - 0.01271) \times 0.5291 = 0.01282\ \mathrm{ft^3/lbm}$

${}_1W_3 = {}_1W_2 + {}_2W_3 = 0 + {}_2W_3 = \int P\,dV = P(V_3 - V_2) = mP(v_3 - v_2)$

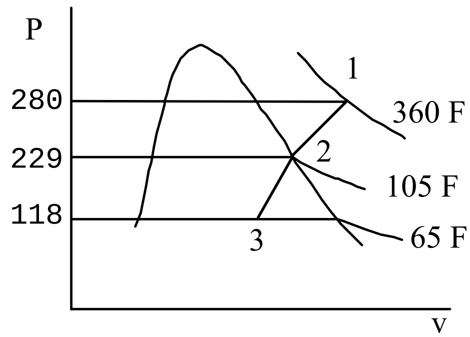
$$= 2\times 66.64\ (0.01282 - 0.7239)\ \frac{144}{778} = \mathbf{-17.54\ Btu}$$



4.137E

A cylinder containing 2 lbm of ammonia has an externally loaded piston. Initially the ammonia is at 280 lbf/in.^{2}, 360 F and is now cooled to saturated vapor at 105 F, and then further cooled to 65 F, at which point the quality is 50%. Find the total work for the process, assuming a piecewise linear variation of *P* versus *V*.

Solution:



State 1: (T, P) Table F.8.2

$v_1 = 1.7672$ ft^3/lbm

State 2: (T, x) Table F.8.1 sat. vap.

$P_2 = 229$ psia, $v_2 = 1.311$ ft^3/lbm

State 3: (T, x) $P_3 = 118$ psia,

$v_3 = (0.02614+2.52895)/2 = 1.2775$

$$W_{13} = \int_1^3 PdV \approx \left(\frac{P_1 + P_2}{2}\right)m(v_2 - v_1) + \left(\frac{P_2 + P_3}{2}\right)m(v_3 - v_2)$$

$$= 2\left[\left(\frac{280 + 229}{2}\right)(1.311 - 1.7672) + \left(\frac{229 + 118}{2}\right)(1.2775 - 1.311)\right] \frac{144}{778}$$

$= \mathbf{-45.1\ Btu}$

4.138E

A 1-ft-long steel rod with a 0.5-in. diameter is stretched in a tensile test. What is the required work to obtain a relative strain of 0.1%? The modulus of elasticity of steel is 30×10^6 lbf/in.^{2}.

Solution:

$$-{}_1W_2 = \frac{AEL_0}{2}(e)^2, \qquad A = \frac{\pi}{4}(0.5)^2 = \frac{\pi}{16}\ \text{in}^2$$

$$-{}_1W_2 = \frac{1}{2}\left(\frac{\pi}{16}\right) 30\times10^6 \times 1 \times (10^{-3})^2 = 2.94\ \text{ft•lbf}$$

Rates of Work

4.139E

An escalator raises a 200 lbm bucket of sand 30 ft in 1 minute. Determine the total amount of work done and the instantaneous rate of work during the process.

Solution:

$$W = \int F dx = F \int dx = F\ \Delta x$$

$$= 200 \times 30 = 6000 \text{ ft lbf} = (6000/778) \text{ Btu} = 7.71 \text{ Btu}$$

$$\dot{W} = W / \Delta t = 7.71 / 60 = \mathbf{0.129\ Btu/s}$$

4.140E

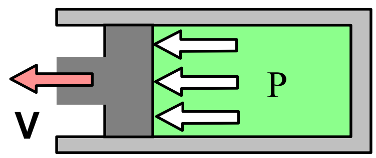
A piston/cylinder of diameter 10 inches moves a piston with a velocity of 18 ft/s. The instantaneous pressure is 100 psia. What is the volume displacement rate, the force and the transmitted power?

Solution:

Rate of work is force times rate of displacement. The force is pressure times area.

$F = PA = P\ \pi\ D^2/4 = 100\ \text{lbf/in}^2 \times (\pi/4)\ 10^2\ \text{in}^2 = 7854\ \text{lbf}$

$\dot{W} = F\mathbf{V} = 7854\ \text{lbf} \times 18\ \text{ft s}^{-1} = 141\ 372\ \text{lbf-ft/s} = \mathbf{181.7\ Btu/s}$



Heat Transfer Rates

4.141E

The sun shines on a 1500 ft^2 road surface so it is at 115 F. Below the 2 inch thick asphalt, average conductivity of 0.035 Btu/h ft F, is a layer of compacted rubbles at a temperature of 60 F. Find the rate of heat transfer to the rubbles.

Solution:

$$\dot{Q} = k\ A\ \frac{\Delta T}{\Delta x}$$

$$= 0.035 \times 1500 \times \frac{115 - 60}{2/12}$$

$$= \mathbf{17325\ Btu/h}$$

4.142E

A water-heater is covered up with insulation boards over a total surface area of 30 ft^2. The inside board surface is at 175 F and the outside surface is at 70 F and the board material has a conductivity of 0.05 Btu/h ft F. How thick a board should it be to limit the heat transfer loss to 720 Btu/h ?

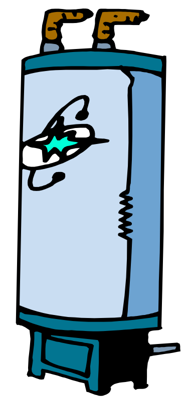
Solution:

Steady state conduction through a single layer board.

$$\dot{Q}_{cond} = k \; A \; \frac{\Delta T}{\Delta x} \quad \Rightarrow \quad \Delta x = k \; A \; \Delta T / \dot{Q}$$

$\Delta x = 0.05 \times 30 \; (175 - 70) \; / \; 720$

$= 0.219 \text{ ft} = \mathbf{2.6 \text{ in}}$



4.143E

The black grille on the back of a refrigerator has a surface temperature of 95 F with a total surface area of 10 ft^2. Heat transfer to the room air at 70 F takes place with an average convective heat transfer coefficient of 3 Btu/h ft^2 R. How much energy can be removed during 15 minutes of operation?

Solution:

$$\dot{Q} = hA\ \Delta T; \qquad Q = \dot{Q}\ \Delta t = hA\ \Delta T\ \Delta t$$

$$Q = 3\ (\text{Btu/h ft}^2\ \text{R}) \times 10\ \text{ft}^2 \times (95 - 70)\ \text{F} \times (15/60)\ \text{h} = \mathbf{187.5\ Btu}$$