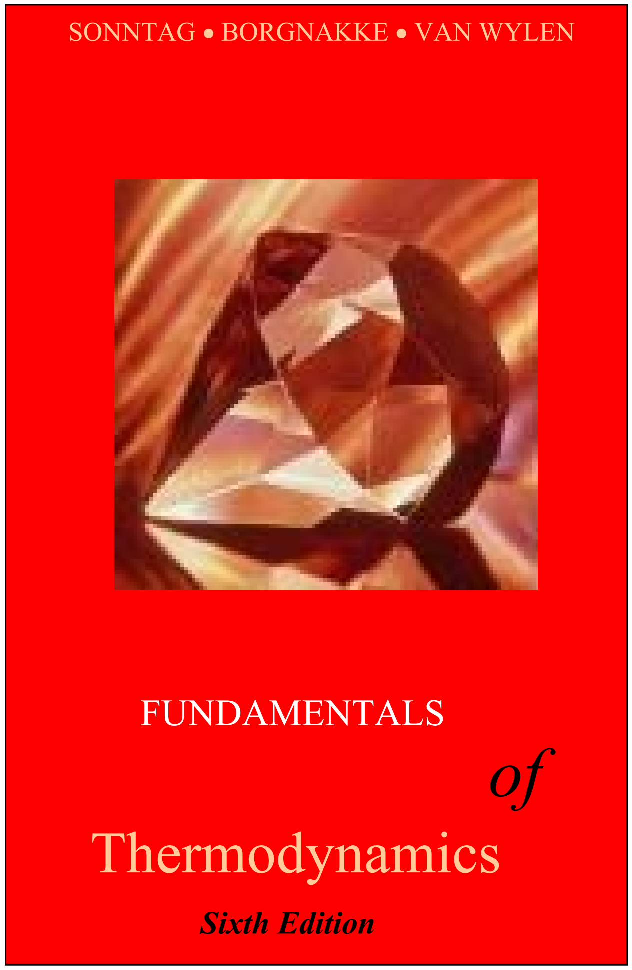
SOLUTION MANUAL
ENGLISH UNIT PROBLEMS
CHAPTER 6



CHAPTER 6

SUBSECTION	PROB NO.
Concept-Study Guide Problems	139-143
Continuity and Flow Rates	144-146
Single Flow Devices	147-160
Multiple Flow Devices	161-165
Multiple Devices, Cycle Processes	166-169
Transient processes	170-174
Review Problem	175

New	5th	SI	New	5th	SI	New	5th	SI
139	new	6	152	84	43	165	85	96
140	new	9	153	87	49	166	90	59
141	new	14	154	88	51	167	91	99
142	new	19	155	new	54	168	92	100
143	new	20	156	new	61	169	93	105
144	73	22	157	77	67	170	94	111
145	new	27	158	76	63	171	new	112
146	74	26	159	new	69	172	95	114
147	75	-	160	89	72	173	100	110mod
148	new	33	161	86	78	174	102	119
149	81	30	162	79	84	175	101	133
150	82	36	163	78	86			
151	83	40	164	new	88			

Concept-Study Guide Problems

6.139E

Liquid water at 60 F flows out of a nozzle straight up 40 ft. What is nozzle $\mathbf{V}_{exit}$?

Energy Eq.6.13: $h_{exit} + \frac{1}{2}\mathbf{V}_{exit}^2 + gH_{exit} = h_2 + \frac{1}{2}\mathbf{V}_2^2 + gH_2$

If the water can flow 40 ft up it has specific potential energy of gH_2 which must equal the specific kinetic energy out of the nozzle $\mathbf{V}_{exit}^2/2$. The water does not change P or T so h is the same.

$$\mathbf{V}_{exit}^2/2 = g(H_2 - H_{exit}) = gH \quad =>$$

$$\mathbf{V}_{exit} = \sqrt{2gH} = \sqrt{2 \times 32.174 \times 40 \text{ ft}^2/\text{s}^2} = \mathbf{50.7\ ft/s}$$

6.140E

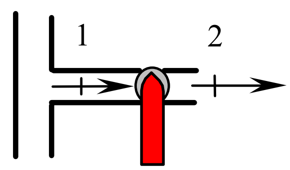
R-134a at 90 F, 125 psia is throttled so it becomes cold at 10 F. What is exit P?

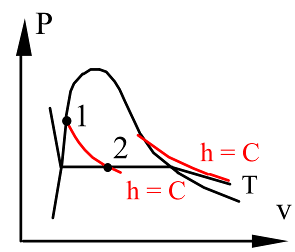
State 1 is slightly compressed liquid so

Table F.5.1: $h = h_f = 105.34$ Btu/lbm

At the lower temperature it becomes two-phase since the throttle flow has constant h and at 10 F: $h_g = 168.06$ Btu/lbm

$P = P_{sat} =$ **26.8 psia**





6.141E

In a boiler you vaporize some liquid water at 103 psia flowing at 3 ft/s. What is the velocity of the saturated vapor at 103 psia if the pipe size is the same? Can the flow then be constant P?

The continuity equation with average values is written

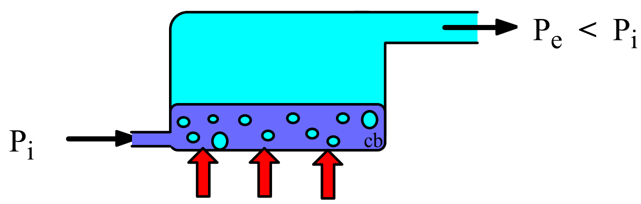
$$\dot{m}_i = \dot{m}_e = \dot{m} = \rho A\mathbf{V} = A\mathbf{V}/v = A\mathbf{V}_i/v_i = A\mathbf{V}_e/v_e$$

From Table F.7.2 at 103 psia we get

$$v_f = 0.01776 \;\; \text{ft}^3/\text{kg}; \quad v_g = 4.3115 \;\; \text{ft}^3/\text{kg}$$

$$\mathbf{V}_e = \mathbf{V}_i \; v_e/v_i = 3 \; \frac{4.3115}{0.01776} = \mathbf{728\ ft/s}$$

To accelerate the flow up to that speed you need a large force (ΔPA) so a large pressure drop is needed.



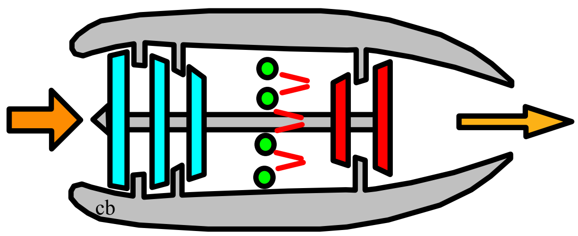
6.142E

Air at 60 ft/s, 480 R, 11 psia with 10 lbm/s flows into a jet engine and it flows out at 1500 ft/s, 1440 R, 11 psia. What is the change (power) in flow of kinetic energy?

$$\dot{m}\,\Delta KE = \dot{m}\,\frac{1}{2}\,(\mathbf{V}_e^2 - \mathbf{V}_i^2)$$

$$= 10\text{ lbm/s} \times \frac{1}{2}\,(1500^2 - 60^2)\ (\text{ft/s})^2\ \frac{1}{32.174}\ (\text{lbf/lbm-ft/s}^2)$$

$$= \mathbf{349\ 102\ lbf\text{-}ft/s = 448.6\ Btu/s}$$



6.143E

An initially empty cylinder is filled with air from 70 F, 15 psia until it is full. Assuming no heat transfer is the final temperature larger, equal to or smaller than 70 F? Does the final T depends on the size of the cylinder?

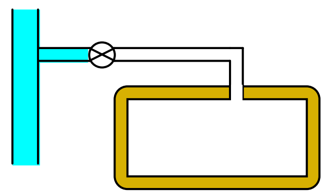
This is a transient problem with no heat transfer and no work. The balance equations for the tank as C.V. become

Continuity Eq.: $m_2 - 0 = m_i$

Energy Eq.: $m_2u_2 - 0 = m_ih_i + Q - W = m_ih_i + 0 - 0$

Final state: $u_2 = h_i$ & $P_2 = P_i$

$T_2 > T_i$ and it does not depend on V



Continuity and Flow Rates

6.144E

Air at 95 F, 16 lbf/in.^{2}, flows in a 4 in. × 6 in. rectangular duct in a heating system. The volumetric flow rate is 30 cfm (ft^3/min). What is the velocity of the air flowing in the duct?

Solution:

Assume a constant velocity across the duct area with

$$A = 4 \times 6 \times \frac{1}{144} = 0.167 \text{ ft}^2$$

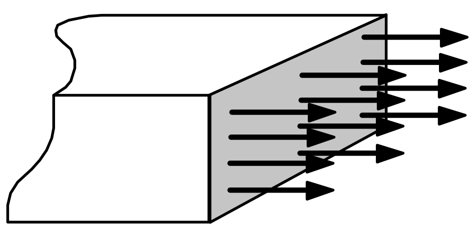
and the volumetric flow rate from Eq.6.3,

$$\dot{V} = \dot{m}v = A\mathbf{V}$$

$$\mathbf{V} = \frac{\dot{V}}{A} = \frac{30}{60 \times 0.167} = \mathbf{3.0\ ft/s}$$

Ideal gas so note:

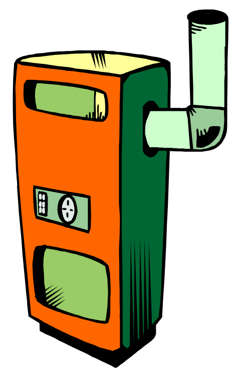
$$\left(\begin{array}{c} \text{note ideal gas:} \quad v = \frac{RT}{P} = \frac{53.34 \times 554.7}{16 \times 144} = 12.842 \text{ ft}^3\text{/lbm} \\ \dot{m} = \frac{\dot{V}}{v} = \frac{30}{60 \times 12.842} = 0.0389 \text{ lbm/s} \end{array} \right)$$



6.145E

A hot air home heating system takes 500 ft^3/min (cfm) air at 14.7 psia, 65 F into a furnace and heats it to 130 F and delivers the flow to a square duct 0.5 ft by 0.5 ft at 15 psia. What is the velocity in the duct?

Solution:



The inflate flow is given by a $\dot{m}_i$

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

Ideal gas: $v_i = \frac{RT_i}{P_i} = \frac{53.34 \times 525}{14.7 \times 144} = 13.23 \; \frac{ft^3}{lbm}$

$$v_e = \frac{RT_e}{P_e} = \frac{53.34 \times (130 + 460)}{15 \times 144}$$

$$= 14.57 \; ft^3/ \; lbm$$

$$\dot{m}_i = \dot{V}_i / v_i = 500/(60 \times 13.23) = 0.63 \; lbm/s$$

$$\mathbf{V}_e = \dot{m} \; v_e / \; A_e = \frac{0.63 \times 14.57}{0.5 \times 0.5} \; \frac{ft^3/s}{ft^2} = \mathbf{36.7 \; ft/s}$$

6.146E

Saturated vapor R-134a leaves the evaporator in a heat pump at 50 F, with a steady mass flow rate of 0.2 lbm/s. What is the smallest diameter tubing that can be used at this location if the velocity of the refrigerant is not to exceed 20 ft/s?

Solution:

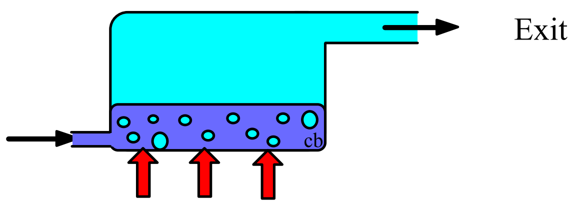
Mass flow rate Eq.6.3: $\dot{m} = \dot{V}/v = A\mathbf{V}/v$

Exit state Table F.10.1: (T = 50 F, x =1) => $v = v_g = 0.792\ \text{ft}^3/\text{lbm}$

The minimum area is associated with the maximum velocity for given $\dot{m}$

$$A_{MIN} = \frac{\dot{m} v_g}{\mathbf{V}_{MAX}} = \frac{0.2\ \text{lbm/s} \times 0.792\ \text{ft}^3/\text{lbm}}{20\ \text{ft/s}} = 0.00792\ \text{ft}^2 = \frac{\pi}{4} D_{MIN}^2$$

D_{MIN} == **0.1004 ft = 1.205 in**



Single Flow Devices

6.147E

A pump takes 40 F liquid water from a river at 14 lbf/in.^{2} and pumps it up to an irrigation canal 60 ft higher than the river surface. All pipes have diameter of 4 in. and the flow rate is 35 lbm/s. Assume the pump exit pressure is just enough to carry a water column of the 60 ft height with 15 lbf/in.^{2} at the top. Find the flow work into and out of the pump and the kinetic energy in the flow.

Solution:

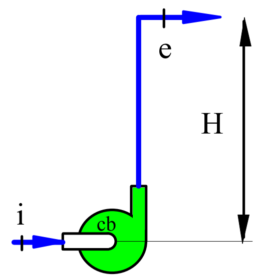
Flow work $\dot{m}Pv$;

Table F.7.1 $v_i = v_f = 0.01602 \text{ ft}^3/\text{lbm}$

$P_e = P_o + Hg/v$

$$= [15 + \frac{60 \times 32.174}{32.174 \times 0.01602 \times 144}] \text{ lbf/in}^2$$

$$= (15 + 26) \text{ lbf/in}^2 = 41 \text{ lbf/in}^2$$



$$\dot{W}_{flow,\, i} = \dot{m}Pv = 35 \times 14 \times 0.01602 \times 144/778 = 1.453 \text{ Btu/s}$$

$$\mathbf{V}_i = \mathbf{V}_e = \dot{m}v/\left(\frac{\pi}{4}D^2\right) = 35 \times 0.01602 \times 144/\left(\frac{\pi}{4}4^2\right) = 6.425 \text{ ft/s}$$

$$KE_i = \frac{1}{2}\mathbf{V}_i^2 = KE_e = \frac{1}{2}\mathbf{V}_e^2 = \frac{1}{2}(6.425)^2 \text{ ft}^2/\text{s}^2 = 20.64 \text{ ft}^2/\text{s}^2$$

$$= 20.64/(32.174 \times 778) = 0.000825 \text{ Btu/lbm}$$

$$\dot{W}_{flow,\, e} = \dot{m}P_e v_e = 35 \times 41 \times 0.01602 \times 144/778 = 4.255 \text{ Btu/s}$$

6.148E

In a jet engine a flow of air at 1800 R, 30 psia and 90 ft/s enters a nozzle where the air exits at 1500 R, 13 psia, as shown in Fig. P.6.33. What is the exit velocity assuming no heat loss?

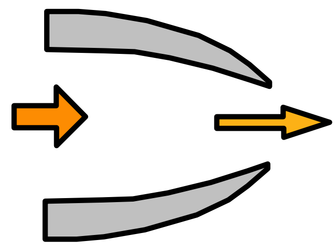
Solution:

C.V. nozzle. No work, no heat transfer

Continuity $\dot{m}_i = \dot{m}_e = \dot{m}$

Energy : $\dot{m}\,(h_i + ½\mathbf{V}_i^2) = \dot{m}(h_e + ½\mathbf{V}_e^2)$

Due to high T take h from table F.5



$$½\mathbf{V}_e^2 = ½\,\mathbf{V}_i^2 + h_i - h_e$$

$$= \frac{90^2}{2 \times 32.174 \times 778} + 449.79 - 369.28$$

$$= 0.16 + 80.51 = 80.67 \text{ Btu/lbm}$$

$$\mathbf{V}_e = (2 \times 32.174 \times 778 \times 80.67)^{1/2}$$

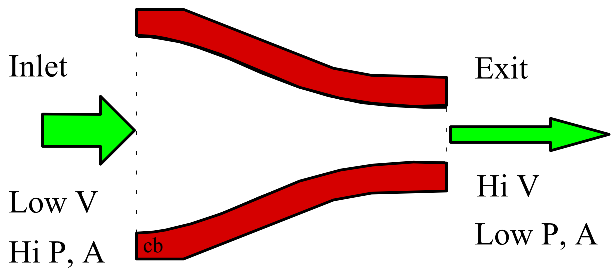
$= \mathbf{2010\ ft/s}$

6.149E

Nitrogen gas flows into a convergent nozzle at 30 lbf/in.^{2}, 600 R and very low velocity. It flows out of the nozzle at 15 lbf/in.^{2}, 500 R. If the nozzle is insulated find the exit velocity.

Solution:

C.V. Nozzle steady state one inlet and exit flow, insulated so it is adiabatic.



Energy Eq.6.13: $h_1 + \varnothing = h_2 + \frac{1}{2}\mathbf{V}_2^2$

$$\mathbf{V}_2^2 = 2 (h_1 - h_2) \cong 2\, C_{PN_2} \; (T_1 - T_2) = 2 \times 0.249 \times (600 - 500)$$

$$= 24.9 \text{ Btu/lbm}$$

$$\mathbf{V}_2^2 = 2 \times 24.9 \times 778 \times 32.174 \text{ ft}^2/\text{s}^2 = 1\,246\,562 \text{ ft}^2 / \text{s}^2$$

$$\mathbf{V_2 = 1116 \text{ ft/s}}$$

6.150E

A diffuser shown in Fig. P6.36 has air entering at 14.7 lbf/in.^{2}, 540 R, with a velocity of 600 ft/s. The inlet cross-sectional area of the diffuser is 0.2 in.^{2}. At the exit, the area is 1.75 in.^{2}, and the exit velocity is 60 ft/s. Determine the exit pressure and temperature of the air.

Solution:

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

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

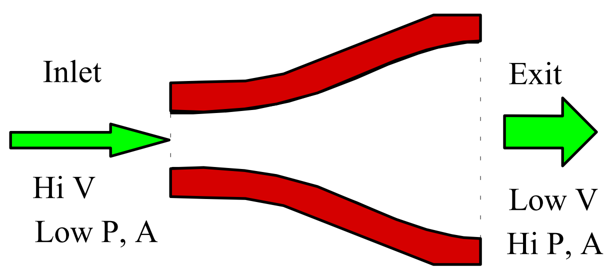
$h_e - h_i = (1/2)\times(600^2 - 60^2)/(32.174\times778) = 7.119$ Btu/lbm

$$T_e = T_i + (h_e - h_i)/C_p = 540 + 7.119/0.24 = \mathbf{569.7\ R}$$

Now use the continuity equation and the ideal gas law

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

$$P_e = P_i\left(\frac{T_e}{T_i}\right)\left(\frac{A_i\mathbf{V}_i}{A_e\mathbf{V}_e}\right) = 14.7\left(\frac{569.7}{540}\right)\left(\frac{0.2\times600}{1.75\times60}\right) = \mathbf{17.72\ lbf/in.^2}$$



6.151E

Helium is throttled from 175 lbf/in.^{2}, 70 F, to a pressure of 15 lbf/in.^{2}. The. diameter of the exit pipe is so much larger than the inlet pipe that the inlet and exit velocities are equal. Find the exit temperature of the helium and the ratio of the pipe diameters.

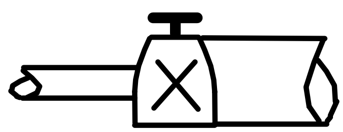
C.V. Throttle. Steady state,

Process with: $q = w = 0$; and $\mathbf{V}_i = \mathbf{V}_e$, $Z_i = Z_e$

Energy Eq.6.13: $h_i = h_e$, Ideal gas => $T_i = T_e =$ **75 F**

$\dot{m} = \frac{A\mathbf{V}}{RT/P}$ But $\dot{m}$, $\mathbf{V}$, T are constant => $P_iA_i = P_eA_e$

$$\Rightarrow \frac{D_e}{D_i} = \left(\frac{P_i}{P_e}\right)^{1/2} = \left(\frac{175}{15}\right)^{1/2} = \mathbf{3.416}$$



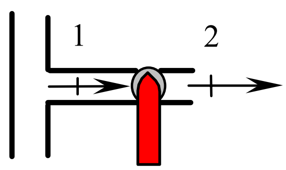
6.152E

Water flowing in a line at 60 lbf/in.^{2}, saturated vapor, is taken out through a valve to 14.7 lbf/in.^{2}. What is the temperature as it leaves the valve assuming no changes in kinetic energy and no heat transfer?

C.V. Valve. Steady state, single inlet and exit flow

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

Energy Eq.6.12: $\dot{m}_1 h_1 + \dot{Q} = \dot{m}_2 h_2 + \dot{W}$



Process: Throttling

Small surface area: $\dot{Q} = 0$;

No shaft: $\dot{W} = 0$

Table F.7.1 $h_2 = h_1 = 1178$ btu/lbm $\Rightarrow$ $\mathbf{T_2 = 254.6\ F}$

6.153E

A small, high-speed turbine operating on compressed air produces a power output of 0.1 hp. The inlet state is 60 lbf/in.^{2}, 120 F, and the exit state is 14.7 lbf/in.^{2}, −20 F. Assuming the velocities to be low and the process to be adiabatic, find the required mass flow rate of air through the turbine.

Solution:

C.V. Turbine, no heat transfer, no ΔKE, no ΔPE

Energy Eq.6.13: $h_{in} = h_{ex} + w_T$

Ideal gas so use constant specific heat from Table A.5

$$w_T = h_{in} - h_{ex} \cong C_p(T_{in} - T_{ex})$$

$$= 0.24(120 - (-20)) = 33.6 \text{ Btu/lbm}$$

$$\dot{W} = \dot{m} w_T \quad \Rightarrow$$

$$\dot{m} = \dot{W}/w_T = \frac{0.1 \times 550}{778 \times 33.6} = \mathbf{0.0021\ lbm/s = 7.57\ lbm/h}$$

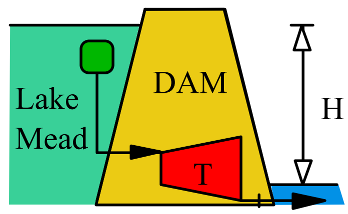
The dentist's drill has a small air flow and is not really adiabatic.

6.154E

Hoover Dam across the Colorado River dams up Lake Mead 600 ft higher than the river downstream, as shown in Fig. P6.51. The electric generators driven by water-powered turbines deliver 1.2×10^6 Btu/s. If the water is 65 F, find the minimum amount of water running through the turbines.

Solution:

C.V.: H_2O pipe + turbines,



Continuity: $\dot{m}_{in} = \dot{m}_{ex}$;

Energy Eq.6.13: $(h + \mathbf{V}^2/2 + gz)_{in} = (h + \mathbf{V}^2/2 + gz)_{ex} + w_T$

Water states: $h_{in} \cong h_{ex}$; $v_{in} \cong v_{ex}$

Now the specific turbine work becomes

$$w_T = gz_{in} - gz_{ex} = (32.174/32.174) \times 600/778 = 0.771 \text{ Btu/lbm}$$

$$\dot{m} = \dot{W}_T/w_T = 1.2{\times}10^6/0.771 = 1.556{\times}10^6 \text{ lbm/s}$$

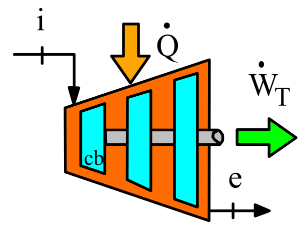
$$\dot{V} = \dot{m}v = 1.556{\times}10^6 \times 0.016043 = \mathbf{24\ 963\ ft^3/s}$$

6.155E

A small expander (a turbine with heat transfer) has 0.1 lbm/s helium entering at 160 psia, 1000 R and it leaves at 40 psia, 540 R. The power output on the shaft is measured to 55 Btu/s. Find the rate of heat transfer neglecting kinetic energies.

Solution:

C.V. Expander. Steady operation



Continuity Eq.: $\dot{m}_i = \dot{m}_e = \dot{m}$

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

$\dot{Q} = \dot{m}\,(h_e - h_i) + \dot{W}$

Use heat capacity from Table F.4: $C_{p\ He} = 1.24$ Btu/lbm R

$\dot{Q} = \dot{m}C_p\,(T_e - T_i) + \dot{W}$

$= 0.1$ lbm/s × 1.24 Btu/lbm R (540 - 1000) R + 55 btu/s

$= -\ 57.04 + 55 =$ **-2.0 Btu/s**

6.156E

An exhaust fan in a building should be able to move 5 lbm/s air at 14.4 psia, 68 F through a 1.25 ft diameter vent hole. How high a velocity must it generate and how much power is required to do that?

Solution:

C.V. Fan and vent hole. Steady state with uniform velocity out.

Continuity Eq.: $\dot{m}$ = constant = $\rho A\mathbf{V} = A\mathbf{V} / v = A\mathbf{V}P/RT$

Ideal gas : $Pv = RT$, and area is $A = \frac{\pi}{4} D^2$

Now the velocity is found

$$\mathbf{V} = \dot{m}\, RT/(\frac{\pi}{4} D^2\, P) = \frac{5 \times 53.34 \times (459.7 + 68)}{\frac{\pi}{4} \times 1.25^2 \times 14.4 \times 144} = \mathbf{55.3\ ft/s}$$

The kinetic energy out is

$$\frac{1}{2}\mathbf{V}_2^2 = \frac{1}{2} \times 55.3^2 / 32.174 = 47.52 \text{ lbf-ft/lbm}$$

which is provided by the work (only two terms in energy equation that does not cancel, we assume $\mathbf{V}_1 = 0$)

$$\dot{W}_{in} = \dot{m}\,\frac{1}{2}\mathbf{V}_2^2 = 5 \times 47.52 = \mathbf{237.6\ lbf\text{-}ft/s} = \mathbf{0.305\ Btu/s}$$

6.157E

In a steam generator, compressed liquid water at 1500 lbf/in.^{2}, 100 F, enters a 1-in. diameter tube at the rate of 5 ft^3/min. Steam at 1250 lbf/in.^{2}, 750 F exits the tube. Find the rate of heat transfer to the water.

Solution:

C.V. Steam generator. Steady state single inlet and exit flow.

Constant diameter tube: $A_i = A_e = \frac{\pi}{4}\left(\frac{1}{12}\right)^2 = 0.00545 \text{ ft}^2$

Table B.1.4 $\dot{m} = \dot{V}_i/v_i = 5 \times 60/0.016058 = 18\,682$ lbm/h

$\mathbf{V}_i = \dot{V}_i/A_i = 5/(0.00545\times 60) = 15.3$ ft/s

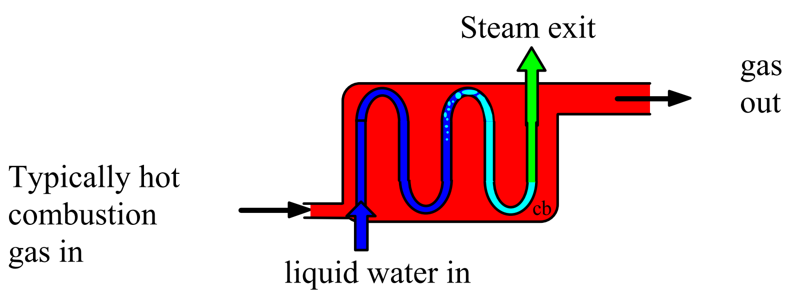
Exit state properties from Table B.1.3

$\mathbf{V}_e = \mathbf{V}_i \times v_e/v_i = 15.3\times 0.503/0.016058 = 479.3$ ft/s

The energy equation Eq.6.12 is solved for the heat transfer as

$$\dot{Q} = \dot{m}\left[(h_e - h_i) + \left(\mathbf{V}_e^2 - \mathbf{V}_i^2\right)/2\right]$$

$$= 18\,682\left[1342.4 - 71.99 + \frac{479.3^2 - 15.3^2}{2\times 32.174\times 778}\right] = \mathbf{2.382\times 10^7\ Btu/h}$$



6.158E

Carbon dioxide gas enters a steady-state, steady-flow heater at 45 lbf/in.^{2} 60 F, and exits at 40 lbf/in.^{2}, 1800 F. It is shown in Fig. P6.63 here changes in kinetic and potential energies are negligible. Calculate the required heat transfer per lbm of carbon dioxide flowing through the heater.

Solution:

C.V. Heater Steady state single inlet and exit flow.

Energy Eq.6.13: $q + h_i = h_e$

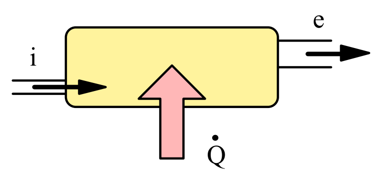


Table F.6 $q = h_e - h_i = \frac{20470.8 - (-143.4)}{44.01} =$ **468.4 Btu/lbm**

(Use C_{P0} then $q \cong 0.203(1800 - 60) = 353.2$ Btu/lbm)

Too large ΔT, T_{ave} to use C_{p0} at room temperature.

6.159E

A flow of liquid glycerine flows around an engine, cooling it as it absorbs energy. The glycerine enters the engine at 140 F and receives 13 hp of heat transfer. What is the required mass flow rate if the glycerine should come out at a maximum 200 F?

Solution:

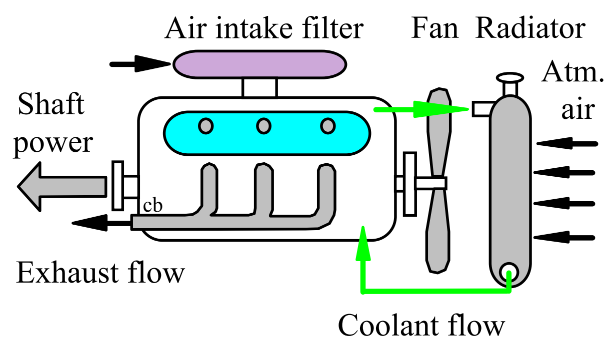
C.V. Liquid flow (glycerine is the coolant), steady flow. no work.

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

$$\dot{m} = \dot{Q}/(h_e - h_i) = \frac{\dot{Q}}{C_{gly}(T_e - T_i)}$$

From table F.3: $C_{gly} = 0.58$ Btu/lbm R

$$\dot{m} = \frac{13 \text{ hp} \times (2544.4/3600) \text{ btu/s-hp}}{0.58 \text{ btu/lbm-R } (200 - 140) \text{ R}} = \mathbf{0.264 \text{ lbm/s}}$$



6.160E

A small water pump is used in an irrigation system. The pump takes water in from a river at 50 F, 1 atm at a rate of 10 lbm/s. The exit line enters a pipe that goes up to an elevation 60 ft above the pump and river, where the water runs into an open channel. Assume the process is adiabatic and that the water stays at 50 F. Find the required pump work.

Solution:

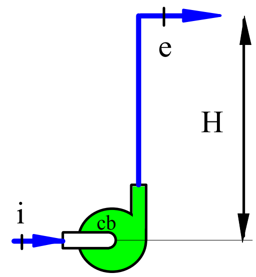
C.V. pump + pipe. Steady state , 1 inlet, 1 exit flow. Assume same velocity in and out, no heat transfer.

Continuity Eq.: $\dot{m}_{in} = \dot{m}_{ex} = \dot{m}$

Energy Eq.6.12:

$$\dot{m}(h_{in} + (1/2)\mathbf{V}_{in}^2 + gz_{in}) = \dot{m}(h_{ex} + (1/2)\,\mathbf{V}_{ex}^2 + gz_{ex}) + \dot{W}$$

States: $h_{in} = h_{ex}$ same (T, P)



$$\dot{W} = \dot{m}g(z_{in} - z_{ex}) = 10\text{lbm/s} \times \frac{32.174\ \text{ft/s}^2}{32.174\ \text{lbm ft/s}^2\ /\text{lbf}} \times (-\ 60)\ \text{ft}$$

= **-600 lbf-ft/s = -0.771 Btu/s**

I.E. 0.771 Btu/s required input

Multiple Flow Devices

6.161E

A steam turbine receives water at 2000 lbf/in.^{2}, 1200 F at a rate of 200 lbm/s as shown in Fig. P6.78. In the middle section 40 lbm/s is withdrawn at 300 lbf/in.^{2}, 650 F and the rest exits the turbine at 10 lbf/in.^{2}, 95% quality. Assuming no heat transfer and no changes in kinetic energy, find the total turbine work.

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

Continuity Eq.6.9: $\dot{m}_1 = \dot{m}_2 + \dot{m}_3$; => $\dot{m}_3 = \dot{m}_1 - \dot{m}_2 = 160$ lbm/s

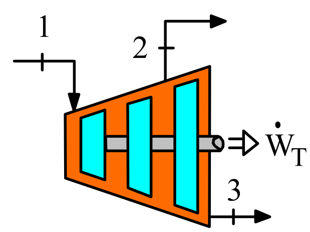
Energy Eq.6.10: $\dot{m}_1 h_1 = \dot{W}_T + \dot{m}_2 h_2 + \dot{m}_3 h_3$

Table F.7.2 $h_1 = 1598.6$ Btu/lbm,

$h_2 = 1341.6$ Btu/lbm

Table F.7.1 : $h_3 = h_f + x_3 h_{fg} = 161.2 + 0.95 \times 982.1$

$= 1094.2$ Btu/lbm



From the energy equation, Eq.6.10

$$\dot{W}_T = \dot{m}_1 h_1 - \dot{m}_2 h_2 - \dot{m}_3 h_3 = 200 \times 1598.6 - 40 \times 1341.6 - 160 \times 1094.2$$

$$= \mathbf{9.1 \times 10^4 \ Btu/s}$$

6.162E

A condenser, as the heat exchanger shown in Fig. P6.84, brings 1 lbm/s water flow at 1 lbf/in.^{2} from 500 F to saturated liquid at 1 lbf/in.^{2}. The cooling is done by lake water at 70 F that returns to the lake at 90 F. For an insulated condenser, find the flow rate of cooling water.

Solution:

C.V. Heat exchanger

Energy Eq.6.10: $\dot{m}_{cool}h_{70} + \dot{m}_{H_2O}h_{500} = \dot{m}_{cool}h_{90} + \dot{m}_{H_2O}h_{f\,1}$

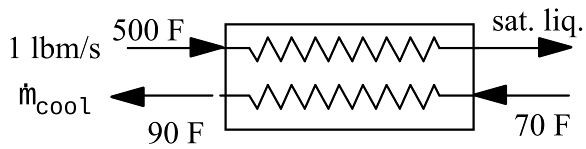


Table F.7.1: h_{70} = 38.09 Btu/lbm, h_{90} = 58.07 Btu/lbm, $h_{f,1}$ = 69.74 Btu/lbm

Table F.7.2: $h_{500,1}$ = 1288.5 btu/lbm

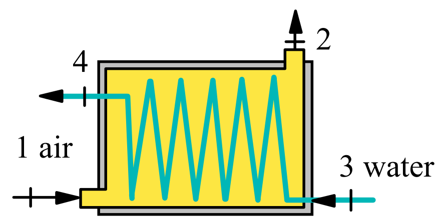
$$\dot{m}_{cool} = \dot{m}_{H_2O}\frac{h_{500} - h_{f,\,1}}{h_{90} - h_{70}} = 1 \times \frac{1288.5 - 69.74}{58.07 - 38.09} = \mathbf{61\ lbm/s}$$

6.163E

A heat exchanger is used to cool an air flow from 1400 to 680 R, both states at 150 lbf/in.^{2}. The coolant is a water flow at 60 F, 15 lbf/in.^{2} and it is shown in Fig. P6.86. If the water leaves as saturated vapor, find the ratio of the flow rates $\dot{m}_{H_2O}/\dot{m}_{air}$.

Solution:

C.V. Heat exchanger, steady flow 1 inlet and 1 exit for air and water each. The two flows exchange energy with no heat transfer to/from the outside.



Continuity Eqs.: Each line has a constant flow rate through it.

Energy Eq.6.10: $\dot{m}_{air}h_1 + \dot{m}_{H_2O}h_3 = \dot{m}_{air}h_2 + \dot{m}_{H_2O}h_4$

Process: Each line has a constant pressure.

Table F.5: $h_1 = 343.016$ Btu/lbm, $h_2 = 162.86$ Btu/lbm

Table F.7: $h_3 = 28.08$ Btu/lbm, $h_4 = 1150.9$ Btu/lbm (at 15 psia)

$$\dot{m}_{H_2O}/\dot{m}_{air} = \frac{h_1 - h_2}{h_4 - h_3} = \frac{343.016 - 162.86}{1150.9 - 28.08} = \mathbf{0.1604}$$

6.164E

An automotive radiator has glycerine at 200 F enter and return at 130 F as shown in Fig. P6.88. Air flows in at 68 F and leaves at 77 F. If the radiator should transfer 33 hp what is the mass flow rate of the glycerine and what is the volume flow rate of air in at 15 psia?

Solution:

If we take a control volume around the whole radiator then there is no external heat transfer - it is all between the glycerin and the air. So we take a control volume around each flow separately.

Heat transfer: $\dot{Q} = 33 \text{ hp} = 33 \times 2544.4 / 3600 = 23.324 \text{ Btu/s}$

Glycerine: $\dot{m}h_i + (-\dot{Q}) = \dot{m}h_e$

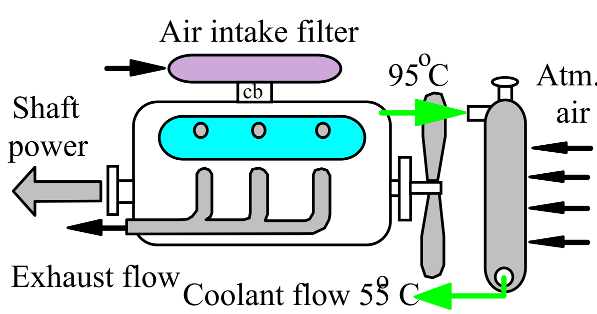
Table F.3: $\dot{m}_{gly} = \frac{-\dot{Q}}{h_e - h_i} = \frac{-23.324}{0.58(130 - 200)} = \mathbf{0.574\ lbm/s}$

Air $\dot{m}h_i + \dot{Q} = \dot{m}h_e$

Table F.4: $\dot{m}_{air} = \frac{\dot{Q}}{h_e - h_i} = \frac{\dot{Q}}{C_{air}(T_e - T_i)} = \frac{23.324}{0.24(77 - 68)} = 8.835 \text{ lbm/s}$

$$\dot{V} = \dot{m}v_i\ ; \quad v_i = \frac{RT_i}{P_i} = \frac{53.34 \times 527.7}{15 \times 144} = 13.03 \text{ ft}^3\text{/lbm}$$

$$\dot{V}_{air} = \dot{m}v_i = 8.835 \times 13.03 = \mathbf{115\ ft^3/s}$$



6.165E

An insulated mixing chamber receives 4 lbm/s R-134a at 150 lbf/in.^{2}, 220 F in a line with low velocity. Another line with R-134a as saturated liquid 130 F flows through a valve to the mixing chamber at 150 lbf/in.^{2} after the valve. The exit flow is saturated vapor at 150 lbf/in.^{2} flowing at 60 ft/s. Find the mass flow rate for the second line.

Solution:

C.V. Mixing chamber. Steady state, 2 inlets and 1 exit flow.

Insulated $q = 0$, No shaft or boundary motion $w = 0$.

Continuity Eq.6.9: $\dot{m}_1 + \dot{m}_2 = \dot{m}_3$;

Energy Eq.6.10: $\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 (h_3 + \frac{1}{2}\mathbf{V}_3^2)$

$$\dot{m}_2 (h_2 - h_3 - \tfrac{1}{2}\mathbf{V}_3^2) = \dot{m}_1 (h_3 + \tfrac{1}{2}\mathbf{V}_3^2 - h_1)$$

State 1: Table F.10.1: 150 psia, 220 F, $h_1 = 209.63$ Btu/lbm

State 2: Table F.10.1: $x = 0$, 130 F, $h_2 = 119.88$ Btu/lbm

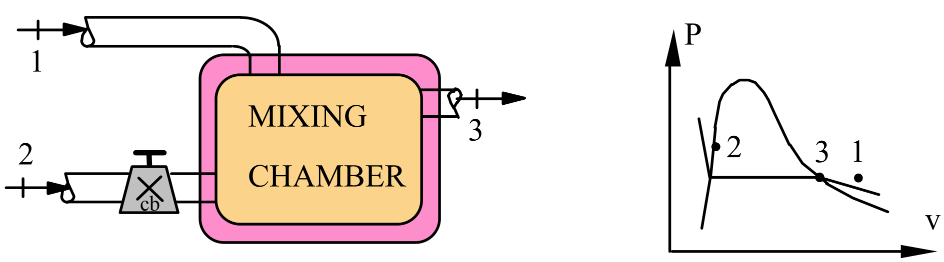
State 3: Table F.10.2: $x = 1$, 150 psia, $h_3 = 180.61$ Btu/lbm

$$\tfrac{1}{2}\mathbf{V}_3^2 = \tfrac{1}{2} \times 60^2 /(32.174 \times 778) = 0.072 \text{ Btu/lbm}$$

$$\dot{m}_2 = \dot{m}_1 (h_3 + \tfrac{1}{2}\mathbf{V}_3^2 - h_1)/ (h_2 - h_3 - \tfrac{1}{2}\mathbf{V}_3^2)$$

$$= 4 (180.61 + 0.072 - 209.63)/ (119.88 - 180.61 - 0.072) = \mathbf{1.904\ lbm/s}$$

Notice how kinetic energy was insignificant.



Multiple Devices, Cycle Processes

6.166E

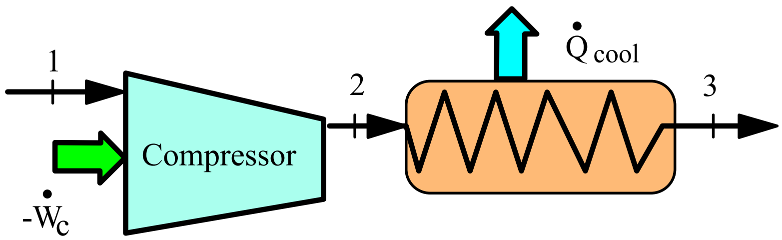
An air compressor takes in air at 14 lbf/in.^{2}, 60 F and delivers it at 140 lbf/in.^{2}, 1080 R to a constant-pressure cooler, which it exits at 560 R. Find the specific compressor work and the specific heat transfer.

Solution

C.V. air compressor $q = 0$

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

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



Compressor section Cooler section

Table F.5:

$$w_{c\ in} = h_2 - h_1 = 261.1 - 124.3 = \mathbf{136.8\ Btu/lbm}$$

C.V. cooler $w = \emptyset$

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

Energy Eq.6.13: $h_2 = q_{out} + h_3$

$$q_{out} = h_2 - h_3 = 261.1 - 133.98 = \mathbf{127.12\ Btu/lbm}$$

6.167E

The following data are for a simple steam power plant as shown in Fig. P6.99.

State	1	2	3	4	5	6	7
P psia	900	890	860	830	800	1.5	1.4
T F		115	350	920	900		110
h Btu/lbm	-	85.3	323	1468	1456	1029	78

State 6 has $x_6 = 0.92$, and velocity of 600 ft/s. The rate of steam flow is 200 000 lbm/h, with 400 hp input to the pump. Piping diameters are 8 in. from steam generator to the turbine and 3 in. from the condenser to the steam generator. Determine the power output of the turbine and the heat transfer rate in the condenser.

Turbine: $A_5 = \pi D_5^2/4 = 0.349 \text{ ft}^2$, $v_5 = 0.964 \text{ ft}^3/\text{lbm}$

$$\mathbf{V}_5 = \dot{m}v_5/A_5 == \frac{200\,000 \times 0.964}{3600 \times 0.349} = 153 \text{ ft/s}$$

$$w = (h_5 + 0.5\mathbf{V}_5^2) - (h_6 + 0.5\mathbf{V}_6^2) = 1456 - 1029 - \frac{600^2 - 153^2}{2 \times 25\,037}$$

$$= 420.2 \text{ Btu/lbm}$$

Recall the conversion 1 Btu/lbm = 25 037 ft^2/s^2, 1 hp = 2544 Btu/h

$$\dot{W}_{TURB} = \frac{420.2 \times 200\,000}{2544} = \mathbf{33\,000 \text{ hp}}$$

6.168E

For the same steam power plant as shown in Fig. P6.99 and Problem 6.167E determine the rate of heat transfer in the economizer which is a low temperature heat exchanger and the steam generator. Determine also the flow rate of cooling water through the condenser, if the cooling water increases from 55 to 75 F in the condenser.

Condenser: $A_7 = \pi D_7^2/4 = 0.0491\ ft^2$, $v_7 = 0.01617\ ft^3/lbm$

$$\mathbf{V}_7 = \dot{m}v_7/A_7 = \frac{200000 \times 0.01617}{3600 \times 0.0491} = 18\ ft/s$$

$$q = 78.02 - 1028.7 + \frac{18^2 - 600^2}{2 \times 25\,037} = -957.9\ Btu/lbm$$

$\dot{Q}_{COND} = 200\ 000\ (-957.9) =$ **-1.916×10^8 Btu/h**

Economizer $\mathbf{V}_3 \approx \mathbf{V}_2$ since liquid v is constant: $v_3 \approx v_2$ and $A_3 = A_2$,

$q = h_3 - h_2 = 323.0 - 85.3 = 237.7\ Btu/lbm$

$\dot{Q}_{ECON} = 200\ 000\ (237.7) =$ **4.75×10^7 Btu/h**

Generator: $A_4 = \pi D_4^2/4 = 0.349\ ft^2$, $v_4 = 0.9595\ ft^3/lbm$

$$\mathbf{V}_4 = \dot{m}v_4/A_4 = \frac{200\,000 \times 0.9505}{3600 \times 0.349} = 151\ ft/s$$

$A_3 = \pi D_3^2/4 = 0.349\ ft^2$, $v_3 = 0.0491\ ft^3/lbm$

$$\mathbf{V}_3 = \dot{m}v_3/A_3 = \frac{200\,000 \times 0.0179}{3600 \times 0.0491} = 20\ ft/s\ ,$$

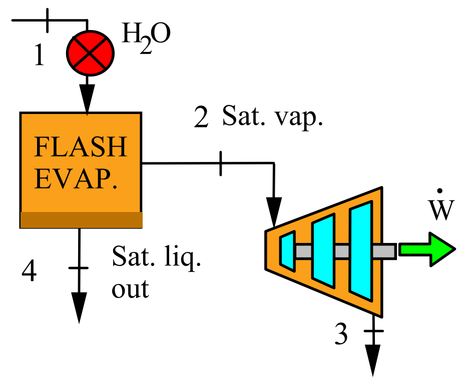
$$q = 1467.8 - 323.0 + \frac{151^2 - 20^2}{2 \times 25\,037} = \mathbf{1145.2\ Btu/lbm}$$

$\dot{Q}_{GEN} = 200\ 000 \times (1145.2) =$ **2.291×10^8 Btu/h**

6.169E

A proposal is made to use a geothermal supply of hot water to operate a steam turbine, as shown in Fig. P6.105. The high pressure water at 200 lbf/in.^{2}, 350 F, is throttled into a flash evaporator chamber, which forms liquid and vapor at a lower pressure of 60 lbf/in.^{2}. The liquid is discarded while the saturated vapor feeds the turbine and exits at 1 lbf/in.^{2}, 90% quality. If the turbine should produce 1000 hp, find the required mass flow rate of hot geothermal water in pound-mass per hour.

Solution:



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

Table F.7.3: $h_1 = 321.8$ Btu/lbm

$h_1 = 321.8 = 262.25 + x \times 915.8$

$\Rightarrow \quad x = 0.06503 = \dot{m}_2/\dot{m}_1$

Table F.7.2: $h_2 = 1178.0$ Btu/lbm;

Table F.7.1: $h_3 = 69.74 + 0.9 \times 1036 = 1002.1$ Btu/lbm

$$\dot{W} = \dot{m}_2(h_2 - h_3) \quad => \quad \dot{m}_2 = \frac{1000 \times 2545}{1178.0 - 1002.1} = 14\,472 \text{ lbm/h}$$

$\Rightarrow \dot{m}_1 =$ **222 539 lbm/h**

Notice conversion 1 hp = 2445 Btu/h from Table A.1

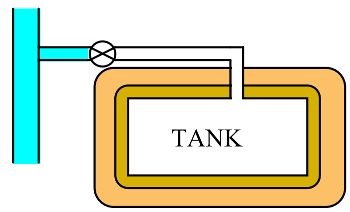
Transient Processes

6.170E

A 1-ft^3 tank, shown in Fig. P6.111, that is initially evacuated is connected by a valve to an air supply line flowing air at 70 F, 120 lbf/in.^{2}. The valve is opened, and air flows into the tank until the pressure reaches 90 lbf/in.^{2}. Determine the final temperature and mass inside the tank, assuming the process is adiabatic. Develop an expression for the relation between the line temperature and the final temperature using constant specific heats.

Solution:

C.V. Tank:



Continuity Eq.6.15: $m_2 = m_i$

Energy Eq.6.16: $m_2u_2 = m_ih_i$

Table F.5: $u_2 = h_i = 126.78$ Btu/lbm

$\Rightarrow T_2 = \mathbf{740\ R}$

$$m_2 = \frac{P_2V}{RT_2} = \frac{90 \times 144 \times 1}{53.34 \times 740} = \mathbf{0.3283\ lbm}$$

Assuming constant specific heat,

$h_i = u_i + RT_i = u_2$, $RT_i = u_2 - u_i = C_{Vo}(T_2 - T_i)$

$C_{Vo}T_2 = (C_{Vo} + R)T_i = C_{Po}T_i$, $T_2 = (C_{Po}/C_{Vo})\ T_i = kT_i$

For $T_i = 529.7$ R & constant C_{Po}, $T_2 = 1.40 \times 529.7 = \mathbf{741.6\ R}$

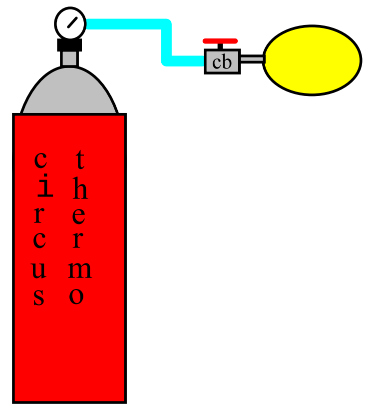
6.171E

Helium in a steel tank is at 40 psia, 540 R with a volume of 4 ft^3. It is used to fill a balloon. When the tank pressure drops to 24 psia the flow of helium stops by itself. If all the helium still is at 540 R how big a balloon did I get? Assume the pressure in the balloon varies linearly with volume from 14.7 psia (V = 0) to the final 24 psia. How much heat transfer did take place?

Solution:

Take a C.V. of all the helium.

This is a control mass, the tank mass changes density and pressure.



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

Process Eq.: $P = 14.7 + CV$

State 1: P_1, T_1, V_1

State 2: $P_2, T_2, V_2 = ?$

Ideal gas:

$$P_2 V_2 = mRT_2 = mRT_1 = P_1V_1$$

$$V_2 = V_1(P_1/P_2) = 4 \times (40/24) = 6.6667 \text{ ft}^3$$

$$V_{bal} = V_2 - V_1 = 6.6667 - 4 = 2.6667 \text{ ft}^3$$

$${}_1W_2 = \int P\, dV = \text{AREA} = ½ (P_1 + P_2)(V_2 - V_1)$$

$$= ½(40 + 24) \times 2.6667 \times 144 = 12\,288 \text{ lbf-ft} = 15.791 \text{ Btu}$$

$$U_2 - U_1 = {}_1Q_2 - {}_1W_2 = m (u_2 - u_1) = mC_v (T_2 - T_1) = 0$$

so ${}_1Q_2 = {}_1W_2$ = **15.79 Btu**

Remark: The process is transient, but you only see the flow mass if you select the tank or the balloon as a control volume. That analysis leads to more terms that must be elliminated between the tank control volume and the balloon control volume.

6.172E

A 20-ft^3 tank contains ammonia at 20 lbf/in.^{2}, 80 F. The tank is attached to a line flowing ammonia at 180 lbf/in.^{2}, 140 F. The valve is opened, and mass flows in until the tank is half full of liquid, by volume at 80 F. Calculate the heat transferred from the tank during this process.

Solution:

C.V. Tank. Transient process as flow comes in.

$m_1 = V/v_1 = 20/16.765 = 1.193$ lbm

$m_{f2} = V_{f2}/v_{f2} = 10/0.026677 = 374.855$ lbm,

$m_{g2} = V_{g2}/v_{g2} = 10/1.9531 = 5.120$ lbm

$m_2 = m_{f2} + m_{g2} = 379.975$ lbm $\Rightarrow$ $x_2 = m_{g2}/ m_2 = 0.013475$

Table F.8.1, $u_2 = 130.9 + 0.013475 \times 443.4 = 136.9$ Btu/lbm

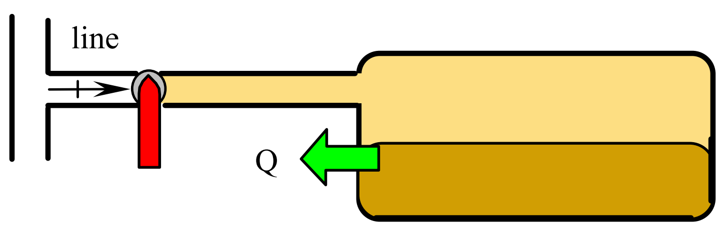
$u_1 = 595.0$ Btu/lbm, $h_i = 667.0$ Btu/lbm

Continuity Eq,: $m_i = m_2 - m_1 = 378.782$ lbm ,

Energy eq.: $Q_{CV} + m_i h_i = m_2 u_2 - m_1 u_1$

$Q_{CV} = 379.975 \times 136.9 - 1.193 \times 595.0 - 378.782 \times 667.0$

$=$ **-201 339 Btu**



6.173E

An initially empty bottle, V = 10 ft^3, is filled with water from a line at 120 lbf/in.^{2}, 500 F. Assume no heat transfer and that the bottle is closed when the pressure reaches line pressure. Find the final temperature and mass in the bottle.

Solution;

C.V. Bottle, transient process with no heat transfer or work.

Continuity Eq.6.15: $m_2 - m_1 = m_{in}$;

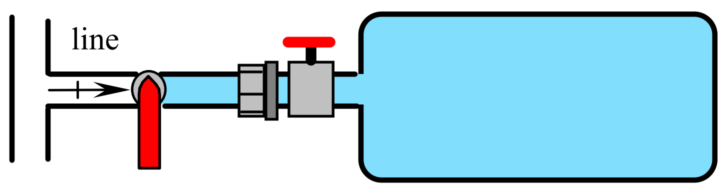
Energy Eq.6.16: $m_2u_2 - m_1u_1 = - m_{in} h_{in}$

State 1: $m_1 = 0$ => $m_2 = m_{in}$ and $u_2 = h_{in}$

State 2: $P_2 = P_{line}$, Table F.7 $u_2 = h_{in} = 1277.1$ Btu/lbm

$\Rightarrow$ $\mathbf{T_2 \cong 764\ F}$, $v_2 = 6.0105$ ft^3/lbm

$m_2 = V/v_2 = 10/6.0105 =$ **1.664 lbm**



6.174E

A nitrogen line, 540 R, and 75 lbf/in.^{2}, is connected to a turbine that exhausts to a closed initially empty tank of 2000 ft^3, as shown in Fig. P6.119. The turbine operates to a tank pressure of 75 lbf/in.^{2}, at which point the temperature is 450 R. Assuming the entire process is adiabatic, determine the turbine work.

C.V. turbine & tank $\Rightarrow$ Transient problem

Conservation of mass: $m_i = m_2 = m$

$1^{\underline{st}}$ Law: $m_i h_i = m_2 u_2 + W_{CV}$; $W_{CV} = m(h_i - u_2)$

Inlet state: $P_i = 75$ lbf/in^2, $T_i = 540$ R

Final state 2: $P_2 = 75$ lbf/in^2, $T_2 = 450$ R

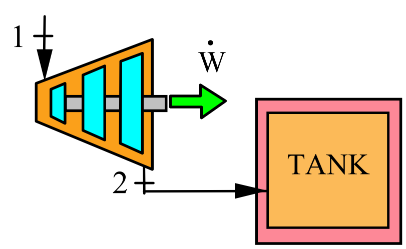
$$v_2 = RT_2/P_2 = 55.15 \times 450/(75 \times 144) = 2.298 \text{ ft}^3/\text{lbm}$$

$$m_2 = V/v_2 = 2000/2.298 = 870.32 \text{ lbm}$$

$$h_i - u_2 = u_i + RT_i - u_2 = RT_i + C_v\,(T_i - T_2)$$

$$= \frac{55.15}{778.17}\,540 + 0.178\,(540 - 450) = 38.27 + 16.02 = 54.29\ \frac{\text{Btu}}{\text{lbm}}$$

$W_{CV} = 870.32 \times 54.29 =$ **47 250 Btu**



Review Problem

6.175E

A mass-loaded piston/cylinder containing air is at 45 lbf/in.^{2}, 60 F with a volume of 9 ft^3, while at the stops V = 36 ft^3. An air line, 75 lbf/in.^{2}, 1100 R, is connected by a valve, as shown in Fig. P6.133. The valve is then opened until a final inside pressure of 60 lbf/in.^{2} is reached, at which point T=630 R. Find the air mass that enters, the work, and heat transfer.

Solution:

C.V. Cylinder volume.

Continuity Eq.6.15: $m_2 - m_1 = m_{in}$

Energy Eq.6.16: $m_2u_2 - m_1u_1 = m_{in}h_{line} + {}_1Q_2 - {}_1W_2$

Process: P_1 is constant to stops, then constant V to state 2 at P_2

State 1: P_1, T_1 $\quad m_1 = \dfrac{P_1V}{RT_1} = \dfrac{45 \times 9 \times 144}{53.34 \times 519.7} = 2.104$ lbm

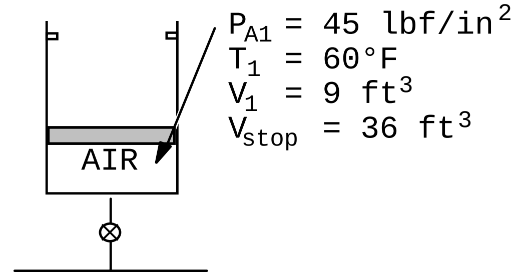
Open to: $P_2 = 60$ lbf/in^2

Table F.5:

$h_i = 266.13$ btu/lbm

$u_1 = 88.68$ Btu/lbm

$u_2 = 107.62$ Btu/lbm



$P = P_1$ until $V = V_{stop}$ then constant V

$${}_1W_2 = \int PdV = P_1(V_{stop} - V_1) = 45 \times (36 - 9)\frac{144}{778} = \mathbf{224.9\ Btu}$$

$$m_2 = P_2V_2/RT_2 = 60{\times}36{\times}144\ /(53.34{\times}630) = 9.256 \text{ lbm}$$

$${}_1Q_2 = m_2u_2 - m_1u_1 - m_i\,h_i + {}_1W_2$$

$$= 9.256 \times 107.62 - 2.104 \times 88.68 - 7.152 \times 266.13 + 224.9$$

$$= \mathbf{-868.9\ Btu}$$