$$\bar{R} = 8.314\ \frac{KPa\text{-}m^3}{Kmole\text{-}K} = 8.314\ \frac{KJ}{Kmole\text{-}K}$$] Same for all gases.

English 1.986 $\frac{Btu}{lbmole\text{-}°R}$

Convient to go to mass terms... diffeent for each gas Table A-1

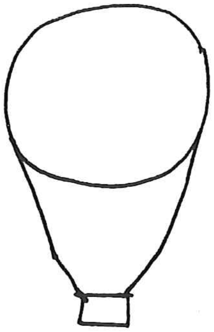
Air $0.287\ \frac{KJ}{Kg\text{-}K}$

He: $2.0769\ \frac{KJ}{Kg\text{-}K}$

Have we talked about Kmoles before?

1 mole = 6.023×10^{23} particles.
1 Kmole = 10^3 moles.

Have balloom – D = 10 m
⇒ $523.6\ m^3$



Find difference in mass ~~between~~ if balloon contains air vs. helium.

Air: $\boxed{Pv = RT}$ → $\boxed{PV = mRT}$

$$P\left[\frac{V}{m}\right] = RT \Rightarrow m = \frac{PV}{RT}$$

$$= \frac{100\ KPa \mid 523.6\ m^3 \mid \overset{Kg.}{\cancel{Kmole}}\text{-}K \mid\ \mid \cancel{28.9\ Kg}}{\mid\ \mid \underset{0.287}{\cancel{8.314}}\ KPa\text{-}m^3 \mid 300K \mid \cancel{Kmole}} = 607.\ Kg$$

Must be absolute T, °K.

He: Calculation is the same, except: MW = 4 Kg/Kmole.

$$\frac{100\ KPa \mid 523.6\ m^3 \mid \overset{Kg.}{\cancel{Kmole}}\text{-}K \mid\ \mid \cancel{4\ Kg}}{\mid\ \mid \underset{2.0769}{\cancel{8.314}}\ KPa\text{-}m^3 \mid 300K \mid \cancel{Kmole}} = 84.0\ Kg$$

⇒ Differene can be used as lift.

~~April 11~~

Next: Take Helium Balloon to 40,000 ft ⇒ P = 25 KPa
T = -60°C

Balloon originally
10 m diameter
P = 100 KPa
T = 27°C = 300K

How large will balloon be if its not vented?

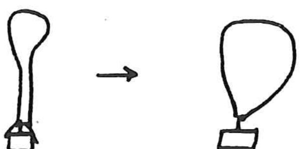
Since mass = constant:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

273 - 60 = 213K

$$V_2 = V_1\left[\frac{P_1}{P_2}\right]\left[\frac{T_2}{T_1}\right] = [523.6\ m^3]\left[\frac{100\ KPa}{25\ KPa}\right]\left[\frac{213\ K}{300K}\right] = 1487.\cancel{0}0\ m^3$$

⇒ D = 14.16 m^3



Up by almost x3.

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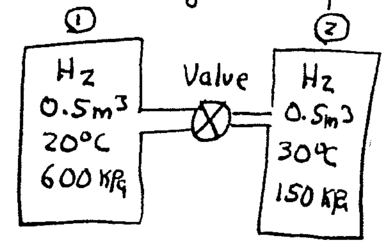
A little tougher example:



Two partly-filled H_2 cylinders – connect, open.
- in morning - 15°C
⇒ What is P_f ?

Open Value
→ Allow heat to leave ⇒ $T_f = 15°C$
→ Find P_f

Can anybody outline approach ?

① Find mass in each tank via ideal gas law.
② After mixing & cooling, treat assembly as one tank.
③ Only unknown ~~[illegible]~~ in ideal gas law will be P.

Tank ①

$$m = \frac{PV}{RT} = \frac{600\ \text{KPa} \;\big|\; 0.5\ \text{m}^3 \;\big|\; \overset{\text{Kg}}{\cancel{\text{Kmole}}}\text{-K} \;\big|\; \;\big|\; \cancel{2\ \text{Kg}}}{\;\big|\; \underset{4.124}{\cancel{8.314}}\ \text{KPa-m}^3 \;\big|\; 20°C? \;\big|\; \cancel{\text{Kmole}}} = 0.246\ \text{Kg}.$$

273 + 20° = 293K

Tank ②

$$m = \frac{150\ \text{KPa} \;\big|\; 0.5\ \text{m}^3 \;\big|\; \overset{\text{Kg}}{\cancel{\text{Kmole}}}\text{-K} \;\big|\; \;\big|\; \cancel{2\ \text{Kg}}}{\;\big|\; \underset{4.124}{\cancel{8.314}}\ \text{KPa-m}^3 \;\big|\; 303\ \text{K} \;\big|\; \cancel{\text{Kmole}}} = 0.059\ \text{Kg}$$

273 + 30

$$m_T = m_1 + m_2 = 0.305\ \text{Kg}.$$
$$V_T = V_1 + V_2 = 1\ \text{m}^3$$

273+15

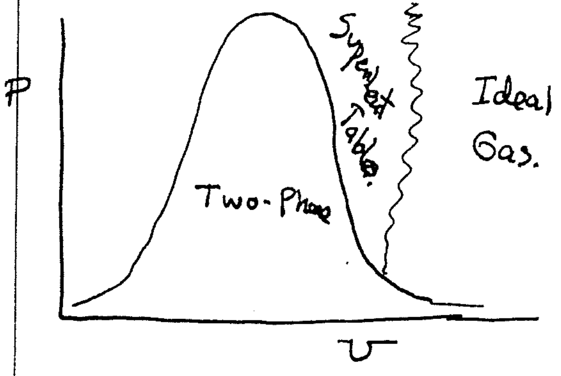
$$P = \frac{mRT}{V} = \frac{0.305\ \text{Kg} \;\big|\; \overset{4.124}{\cancel{8.314}}\ \text{KPa-m}^3 \;\big|\; 288\ \text{K} \;\big|\; \;\big|\; \cancel{\text{Kmole}}}{\;\big|\; \underset{\text{Kg.}}{\cancel{\text{Kmole}}}\text{-K} \;\big|\; \;\big|\; 1.0\ \text{m}^3 \;\big|\; \cancel{2\ \text{Kg}}}$$

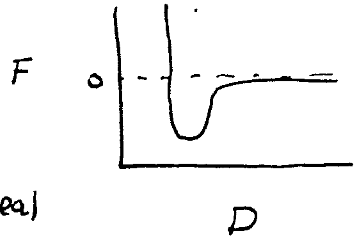
$$\boxed{P = 265.2\ \text{KPa}}$$

Where can we use ideal gas ?

Qualitatively : - When separation between molecules is large.
- When KE is high enough ~~so~~ (high T) so that collisions are elastic ⇒ Avoid "sticky" regime in attraction well.

On P-v diagram:





Rules:

① Use superheat tables for props if they are provided ⇒ Wouldn't put them together unless props were non-ideal.
② Use ideal gas at high ~~P~~ T, Low P. → Will tell you in a second how to tell.
③ Thi

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For ideal gas $Pv = RT$ or $1 = \frac{Pv}{RT}$

If behavior is non-ideal (e.g., steam) then $\frac{Pv}{RT} \neq 1$

Call this ratio the compressibility - Z

$Z \equiv \frac{Pv}{RT}$ If $Z = 1 \Rightarrow$ May have an Ideal gas.

- What does this Represent?
- Where do we find it?

How to find Z for any material and any condition.

Reduced Pressure: $P_R = \frac{P}{P_c}$ ← Actual Pressure; ← Critical Pressure (Table A-1)

Reduced Temperature $T_R = \frac{T}{T_c}$ ← Actual T (K); ← Critical T (K) (Table A-1)

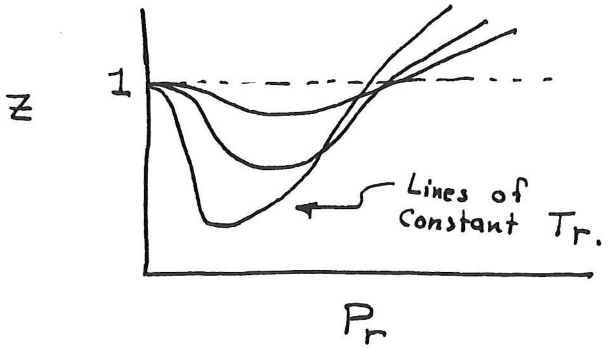


Fig A1 → A3 (3 parts)

April 8

Example!

Need to buy an expensive cryogenic throttling valve for N_2 at 140 K, ~~70 bar~~ ~~700~~ KPa 7000

⇒ ~~E~~ Engineer in next cubicle gets job.

To correctly size the valve, you have to know v.

Easy way; ideal gas:

$$v = \frac{RT}{P} = \frac{\cancel{8.314}\ .2968\ \text{kPa-m}^3}{\cancel{\text{Kmole}}\ \text{Kg}\text{-K}} \left| \frac{140\ \text{K}}{} \right| \frac{}{7000\ \text{kPa}} \left| \frac{\cancel{\text{Kmole}}}{\cancel{28\ \text{Kg}}} \right. = 5.94 \times 10^{-3}\ \frac{m^3}{Kg}.$$

⇒ Order valve, it doesn't work, ~~guy~~ neighbor across way goes to Fargo office.

You get the job:

$Z = \frac{Pv}{RT}$ $v = \frac{ZRT}{P}$

	Actual Value	Critical Value (A-1)	Reduced Value
T	140 K	126 K	$T_r = \frac{T}{T_c} = 1.11$
P	~~70 bar~~ 7000 KPa	33.9 bar 3390 KPa	$P_r = \frac{P}{P_c} = 2.06$

$Z = 0.41$

$$v = \frac{0.41 \;\Big|\; \overset{.2968}{\cancel{8.314}}\ \text{kPa-m}^3 \;\Big|\; 140\,\text{K} \;\Big|\; \;\Big|\; \cancel{\text{kmole}}}{\;\Big|\; \underset{\text{kg}}{\cancel{\text{kmole}}}\text{-K} \;\Big|\; \;\Big|\; 7000\,\text{kPa} \;\Big|\; \cancel{28\ \text{kg}}} = 2.43\times10^{-3}\ \frac{\text{m}^3}{\text{kg}}$$

(5.94×10^{-3})

⇒ Old value was sized way too big. ⇒ May seem like a joke., but I've seen this happen & cost somebody a ton of \$.

Summary!

How do I decide what approach to use?

⇒ In two phase region, or ~~near supe~~ superheat ⇒ Use tables

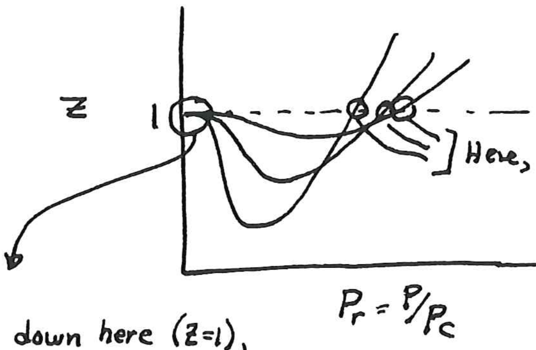
- → H_2O
- → R-12
- → R-134a

} As long as you are on the tables, you should use them.

⇒ Ideal gas:

- → Air
- → N_2, O_2, CO_2, CO ... most gases that are well above their boiling points. (non cryogenic applications).

If you want to know for sure – calculate Z from T_R, P_R



Here, you are not ideal, just crossing 1 going from one non-ideal effect to another.

If you are down here (Z=1), then ideal gas holds.

⇒ If $Z \neq 1$ and you don't have tables, use $\boxed{Pv = ZRT}$.

~~In enero~~ For H_2O, could get u and h from Tables. Need to use another kind of ~~table~~ approach for ideal gases.

In superheat vapor tables $u = u(T,P)$ depends on both.

For ideal gases $u = u(T)$ only ... no p dependence.

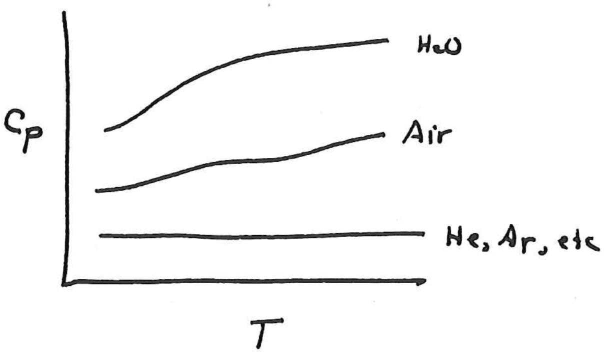
Definition: heat capacity $C_v(T) \equiv \left(\frac{\partial u}{\partial T}\right)_v = \frac{du}{dT}$ for ideal gas.

$$C_p(T) \equiv \left(\frac{\partial h}{\partial T}\right)_p = \frac{dh}{dT} \text{ for ideal gas.}$$

For ideal gases, the advantage is:

$$du = C_v dT \Rightarrow u_2 - u_1 = \int_{T_1}^{T_2} C_v dT$$

$$dh = C_p dT \Rightarrow h_2 - h_1 = \int_{T_1}^{T_2} C_p dT$$



- C_p, C_v vary with T
- Except for inert gases
- Within reasonably small temperature intervals, C_p, C_v can be treated as constants
- $\Delta u = C_v \Delta T$
  $\Delta h = C_p \Delta T$

⇒ Most tables give C_p: Can get C_v for ideal gas from

$$C_v = C_p - \underset{\text{Gas constant.}}{\underset{\uparrow}{R}}$$

⇒ Lastly ⇒ Ideal gas tables:

$$dh = C_p dT$$

$$h(T) = h_{ref} + \int_{T_{ref}}^{T} C_p dT \Rightarrow \text{Let } T_{ref} = 0 \text{ K}, \quad h_{ref} = 0 \text{ kJ/kg.}$$

$$h(T) = \int_0^T C_p dT \Rightarrow \text{Table with form } (A\text{-}\overset{17}{16} \rightarrow A\text{-}\overset{25}{22})$$

T	h	u
—	—	—
—	—	—
—	—	—

- Ideal Gases
- Accounts for variation of C_p, C_v with T.

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April 1

First Law - Formal Definition:

Sum of all energy flows crossing boundary of system = change in energy of System.

Divide into Q and W.

Do RHS first.

What is logical sign on Q?

$= \Delta E_{sys}$

Q in = pos → will tend to increase sys energy

$$\boxed{Q - W = \Delta U + \Delta KE + \Delta PE}$$

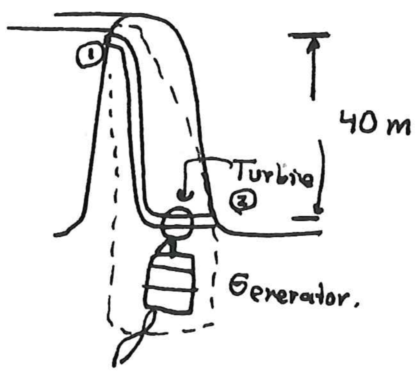
← First Law

W out = pos → will tend to decrease sys energy

⇒ Note that the signs on Q & W are a direct consequence of our arbitrary choice of sign convention

⇒ Must be consistent always.

A couple of examples:



$V_1 = 5\ m/s$
$V_2 = 5\ m/s.$

Assume well insulated, no change in T, find W_{elect} for 1 kg H_2O.

→ Draw CV.

$$\cancel{Q}^{0} - W = \cancel{\Delta U}^{0} + \cancel{\Delta KE}^{0} + \Delta PE$$

Which are zero?

$$-W = mg(z_2 - z_1) \quad \leftarrow \quad z_2 - z_1 \text{ or } z_1 - z_2$$

$$= \frac{1\ kg}{} \bigg| \frac{9.81\ m}{s^2} \bigg| \frac{-40\ m}{} = -392.4\ J$$

$$\boxed{W = 0.392\ KJ/kg\ H_2O}$$

$$100\ W = \frac{100\ J}{s} \bigg| \frac{kg\ H_2O}{392.4\ J} = 0.25\ kg/s.$$

Now replace turbine with a big grid to restrict the flow:

$$\cancel{Q}^{0} - \cancel{W}^{0} = \Delta U + \cancel{\Delta KE}^{0} + \Delta PE \Rightarrow \Delta U = 0.392\ KJ/kg\ H_2O.$$

April 10

Pressure in a balloon is $P \sim V^2$

Initially you have balloon

$V_1 = 1$ liter
$= 10^{-3} m^3$
$P_1 = 150$ KPa.

~~Run electric resistor heater until volume doubles. Find~~

Know that inside balloon, $P \sim V^2$

If you add 0.6 KJ of heat to balloon, you find the volume has doubles - Find increase in U.

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How to do it?

$$\underset{\uparrow \atop 0.6\,KJ}{Q} - W = \Delta U + \cancel{\Delta KE}^{0} + \cancel{\Delta PE}^{0}$$

~~[illegible]~~

Have Q, but what is correct sign? It's In, so its positive.

How about W. (Is W=0)? Gas expands, so it does work on balloon material.

$$W = \int_{V_1}^{V_2} P\,dV$$ but P varies with, so cannot directly integrate

$$P \sim V^2 \Rightarrow \frac{P}{V^2} = \text{const} = \frac{P_1}{V_1^2}$$

$$\Rightarrow P = \frac{P_1}{V_1^2} V^2$$

Now substitute: $$W = \int_{V_1}^{V_2} \frac{P_1}{V_1^2} V^2 dV = \frac{P_1}{3V_1^2}\left[V_2^3 - V_1^3\right]$$

$$= \frac{150\text{ KPa}}{3\,(10^{-3}m)^2}\left[(2\times10^{-3}m)^3 - (1\times10^{-3}m)^3\right] = 0.35\text{ KPa-m}^3$$

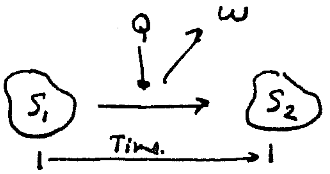
$$= 0.35\text{ KJ}$$

Back to first law... what is sign on W? Positive since work is done on environment by system.

$$0.6 - 0.35 = \Delta U = \underline{\underline{0.25\text{ KJ}}}$$

Other forms of the first law:

Present form:



$$\Delta E = Q - W = \Delta U + \Delta KE + \Delta PE$$

Make change small:
Differential Form: $$\boxed{\delta Q - \delta W = dE}$$

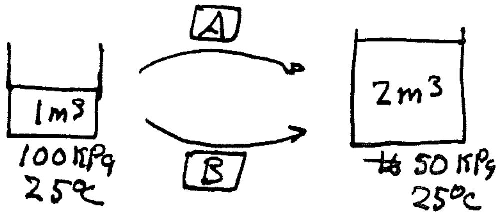
What do we mean by δQ, δW. ?

$\Rightarrow$ Going from 1 → 2, $$\Delta E = \int_1^2 dE = E_2 - E_1$$

~~But~~ $$W = \int_1^2 \delta W$$

→ need to know pathway to integrate.

In our example yesterday:



ΔE was the same for both paths, but $W_A \neq W_B$.
δW is called inexact differential.

Since ~~Q - W = Δt~~ $Q - W = \Delta E$

	ΔE	W	Q
Path A	Same	60.54 KJ	Makes up diff.
Path B		69.31 KJ	

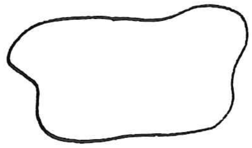
~~ΔE is~~

⇒ Key point.

⇒ For all paths $\boxed{Q - W = \text{const}}$

You just don't initially know ~~whether~~ what goes to Q vs W.

One last form of the first law:



Rate of Energy Crossing Boundary = Rate of Change of Energy in System.

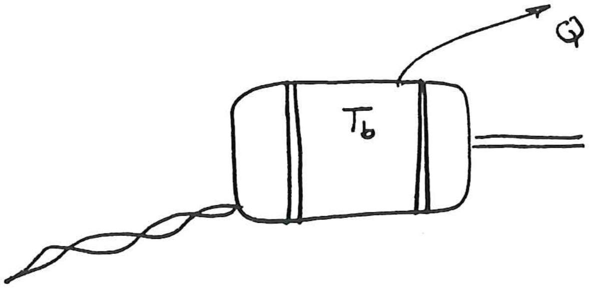
$$\boxed{\underbrace{\dot{Q} - \dot{W}}_{KJ/s} = \frac{dE}{dt}}$$

E – is energy

So rate of energy change is $\frac{dE}{dt}$

Example of first law in this form:

$T_o = 80°F$



Electric Power – 1 Btu/s

$Q = \underbrace{hA}_{10\ \frac{Btu}{hr\text{-}°R}}(T_b - T_o)$ ⇐ Rate at which heat leaves motor.

⇒ saying Q is proportional to ΔT

⇒ Driven by ΔT

Torque = 12.8 $ft\text{-}lb_f$

Speed = 500 RPM

Find T_b.

First: extend English units: Btu = British Thermal Unit
= Heat needed to raise 1 lb_m of H_2O by 1°F, ⇒ Use as energy unit for work & heat.

- Note that it isn't derived from lb_m, ft, sec, so will need conversion factor. later.
- First - Draw CV.

First Law:

April 4

$$\dot{Q} - \dot{W} = \cancel{\frac{dU}{dt}}^{0} + \cancel{\frac{d(KE)}{dt}}^{0} + \cancel{\frac{d(PE)}{dt}}^{0}$$

– Tougher.

What's zero?

$$\dot{Q} - \dot{W}_{elect} - \dot{W}_{Shaft} = 0 \Rightarrow \dot{Q} = \dot{W}_{elect} + \dot{W}_{shaft}$$

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$\dot{Q}$ $\qquad$ $\dot{W}_{elect} = \left.\begin{matrix} 1\ \text{Btu/s} \\ -1\ \text{Btu/s} \end{matrix}\right\}?$ $\qquad -1\ \text{Btu/s.}$

$\dot{W}_{shaft} = \cancel{12.8\ \text{ft-lb}_f}$ $\qquad$ Torque x $\underline{\text{angular velocity}}$ ↳ radians/s.

$$= \frac{12.8\ \text{ft-lb}_f}{}\Big|\frac{500\ \text{Rev}}{\text{min}}\Big|\frac{2\pi\ \text{Rad}}{\text{Rev}}\Big|\frac{\text{min}}{60\ \text{s}}\Big|\frac{}{\cancel{778\ \text{ft-lb}_f}} = 670.2\ \frac{\text{ft-lb}_f}{\text{s}}$$

Lets stop and look at this for a second: $\qquad W = F \cdot d \Rightarrow \text{ft-lb}_f$

$\dot{W} = \text{Power} = \frac{\text{ft-lb}_f}{\text{s}}$

So now we need to convert work to Btu.

$$\frac{670.2\ \text{ft-lb}_f}{\text{s}}\Big|\frac{\text{Btu}}{778\ \text{ft-lb}_f} = 0.861\ \frac{\text{Btu}}{\text{s}}$$

Sign on this? ⇒ "+"

Is s

$$Q = -1\ \frac{\text{Btu}}{\text{s}} + 0.861\ \frac{\text{Btu}}{\text{s}} = -0.139\ \text{Btu/s}$$

Sign is "-" so Q is leaving -

$$Q = hA(T_b - T_o) \Rightarrow T_b = T_o + \frac{Q}{hA}$$

$$T_b = 80°\text{F} + \frac{0.139\ \text{Btu}}{\text{s}}\Big|\frac{\text{hr} - °\text{R}}{10\ \text{Btu}}\Big|\frac{3600\ \text{s}}{\text{hr}} = 130°\text{F}$$

I have done two tricky things here.

① I changed sign on Q

⇒ "Rate at which heat leaves moter" = $hA(T_b - T_o)$

⇒ Our 1st Law Q was the rate at which heat <u>entered</u> the moter (it just ended up with a "-" sign).

② Calculated a $\Delta °R$ on right side. How can I get away with this?

$°F \neq °R$ $\qquad (0°F = 460°R)$

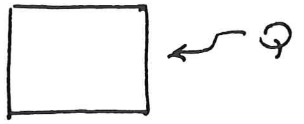
<u>But</u> $\qquad \Delta °F = \Delta °R$

$0°F \rightarrow 32°F \Rightarrow \Delta °F = 32$
$460°R \rightarrow 492°R \Rightarrow \Delta °R = 32$

} i.e., the degrees are the same size, but 0 is at different locations.

April 12

Example: Place 1 kg air inside a closed container



How much heat is needed to take it from 300 K → 600 K?

First Law: $Q - \cancel{W}^{0} = \Delta U$

① From Table A-~~16~~ 17 ⇒

u at 300K = 214.07 KJ/Kg.

u at 600 K = 434.78 KJ/Kg

$\Delta U = Q = \underline{220.71 \text{ KJ}}$.

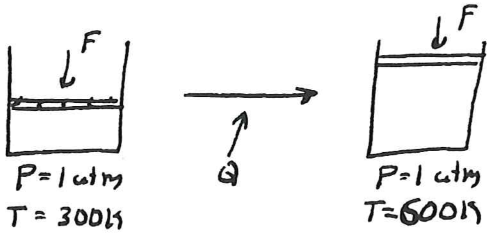
---

② Assume constant C_p, C_v between 300 → 600K. [Pick value at 450K from Table A-~~1a~~ 2].

$$\Delta U = m C_v \Delta T = (1 \text{ Kg})\left(0.733 \tfrac{\text{KJ}}{\text{Kg-K}}\right)(300 \text{ K}) = 219.9 \text{ kJ}/\cancel{\text{kg}}$$

$m \int C_v dT = ?$

Next, let gas be in a piston/cylinder system initially at 1 atm.



Find Q

Two approaches:

$$Q - W = \Delta U \Rightarrow Q = \cancel{\Delta U} \; U_2 - U_1 + W$$

$$Q = m(u_2 - u_1) + P(V_2 - V_1)$$

$$V_2 = \frac{mRT}{P} = \frac{1 \text{ Kg} \mid 8.314 \text{ KPa-m}^3 \mid 600 \text{ K} \mid \quad \mid \text{Kmole}}{\quad \mid \text{Kmole-K} \mid \quad \mid 100 \text{ KPa} \mid 28.9 \text{ Kg}} = 1.73 \text{ m}^3$$

$$V_1 = \frac{1 \mid 8.314 \mid 300\text{K} \mid \quad \mid}{\quad \mid \quad \mid \quad \mid 100 \text{ KPa} \mid 28.9} = 0.86 \text{ m}^3$$

From Table A-~~16~~ 17

600 K → u_2 = 434.78 KJ/Kg

300 K → u_1 = 214.07 KJ/Kg.

$$Q = \frac{1 \text{ Kg} \mid 434.78 - 214.07 \text{ KJ}}{\quad \mid \text{Kg}} + \frac{100 \text{ KPa} \mid 1.73 \text{m}^3 - 0.86 \text{m}^3}{\quad \mid \quad}$$

$$\boxed{Q = 307.71 \text{ KJ}}$$

This is a bit of a pain: constant P first law: $Q - W = \Delta U$
where all terms are active.

$$Q - P(V_2 - V_1) = U_2 - U_1 \;; \quad Q = U_2 - U_1 + P(V_2 - V_1)$$

$$= U_2 + P_2V_2 - (U_1 + P_1V_1)$$ (with understanding that $P_1 = P_2$.)

But P, V, are propertis just like U ⇒ Define a new combined property, enthalpy

$$\boxed{H \equiv U + PV \;, \quad \text{or} \quad h = u + Pv}$$

⇒ For constant P $\quad Q = H_2 - H_1 = m(h_2 - h_1)$

Alternate approach: First Law for constant P systems:

$$Q = m(h_2 - h_1)$$

$300\text{K} \rightarrow h_1 = 300.19$ KJ/Kg
$600\text{K} \rightarrow h_2 = 607.02$ KJ/Kg.

$$Q = (1\,\text{Kg})(607.02 - 300.19\ \text{KJ/Kg}) = \boxed{306.83\ \text{KJ}}$$

Same No. except for Rounding.

⇒ Why is this case higher than const. volume case?
→ Get work out in addition to T increase.

~~Entrop~~ • Enthalpy has other uses
- Think about ~~#~~ Δh as change in u + work involved in changing volume.

- Cannot say $Q = m(h_2 - h_1)$ if $P \neq$ constant. Because $W \neq P\Delta V$
$W = \int P\,dV$

- Do spring example }
- Do polytropic example }
- C_p

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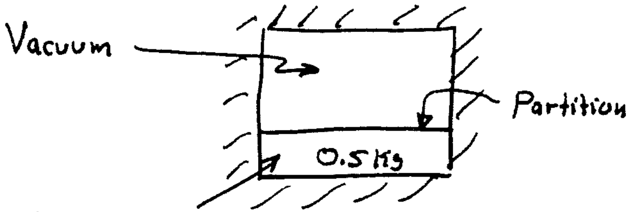
Walk through a few more examples.



Break Partition
⇒ $P_2 = 10$ KPa.

Find V_{tank}, T_2.

Liquid Water
600 KPa
60°C

Look at First Law
→ First draw C.S.

$$\cancel{Q}^{0} - \cancel{W}^{0} = \Delta U$$

⇒ $U_2 = U_1$ or, since m stays constant: $u_2 = u_1$

u_1: Compressed Liquid: Use saturated liquid approximation: $u_1 = u_f \begin{cases} @\ 60°C\ ? \\ @\ 600\,\text{KPa}\ ? \end{cases}$

⇒ 60°C because <u>pressure</u> has almost no influence on u for liquids.

~~$U_1 = U_{f,60°C}$~~ $= [0.5\ \text{Kg}][251.11\ \text{KJ/Kg}] = 125.56\ \text{KJ}$

$U_1 = m u_{f,60°C}$

⇒ What do we know about state 2?

$u_2 = 251.11$ KJ/Kg
$P_2 = 10$ KPa.

⇒ Go to saturated tables @ 10 KPa

$u_f = 191.82$ KJ/Kg
$u_g = 2437.9$ KJ/Kg.

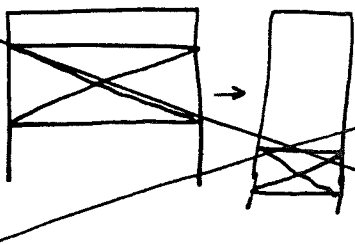
⇒ We are between these → So we have a two-phase mixture.
⇒ Immediately, table tells us $T_2 = T_{sat} = 45.81°C$

$$X_2 = \frac{u_2 - u_f}{u_g - u_f} = \frac{251.11 - 191.82}{2437.9 - 191.82} = 0.0264$$

$$V_2 = m v_2 = m\left[v_f + x(v_g - v_f)\right] = (0.5\,\text{Kg})\left[0.00101 + \overset{0.0264}{\cancel{\quad}}(14.674 - 0.00101)\right]$$

$$\boxed{V_2 = 0.194\ \text{m}^3}$$

~~One more example:~~



~~• Auto Engine~~
~~• $P_1 = 7000$ KPa~~
~~• $T_1 = 2000$ K~~
~~• Compression Ratio = $9.5 = \frac{V_2}{V_1}$~~
~~• Given: $PV^{1.4}$ = constant.~~
~~⇒ Find work:~~

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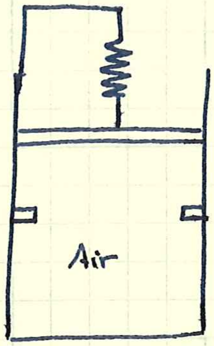


$V_1 = 3\ m^3$
$V_{stops} = 2\ m^3$

$P_1 = 200$ KPa $P_{atm} = 100$ KPa.
$T_1 = \overset{900}{\cancel{600}}$ K.

- When piston reacles stops, spring just disengages from piston.
- Stops seal flow.

Find how much heat must be extracted to drop P to $\overset{75}{\cancel{50}}$ KPa

$Q - W = \Delta U \Rightarrow Q = W + \Delta U$

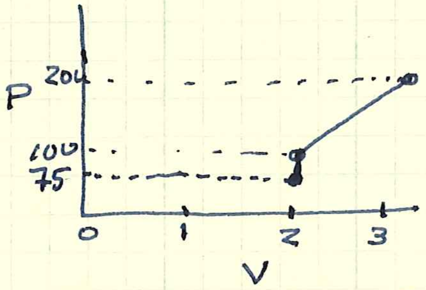
Spring is linear

$P = 200$ at $V = 3$
100 at $V = 2$ $\Big\}$ $P = 100(V-2)+100$
$= 100V - 100$

$$W = \int_{V_1}^{V_2} P\,dV$$

$$= \int_{V_1}^{V_2} [100V - 100]\,dV$$

$$= \frac{100}{2}V^2 - 100V\Big|_{V_1}^{V_2}$$



$$= \cancel{\frac{100}{2}}\ 50\left[2^2 - 3^2\right] - 100(2-3) = -350\ \underbrace{\text{KPa-m}^3}_{\text{KJ}}$$

April 15

How to find ΔU? Just need T_1, T_2 for ideal gas

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \Rightarrow T_2 = T_1\left[\frac{P_2}{P_1}\right]\left[\frac{V_2}{V_1}\right] = \overset{900}{\cancel{600}}\text{K}\left[\frac{\overset{75}{\cancel{50}}}{200}\right]\left[\frac{2}{3}\right] = 225\text{ K.}$$

$$\Delta u = \overset{u_{225} - u_{900}}{\cancel{u_{900} - u_{225}}} = \overset{160.41 - 674.51}{\cancel{674.58 - 160.41\text{ KJ}}} = -514.17\ \text{KJ/kg}.$$

$$m = \frac{PV}{RT} = \frac{200\text{ KPa} \mid 3m^3 \mid \text{kg-K}}{\mid 0.287\text{ KPa-m}^3 \mid 900\text{K}} = 2.32\text{ kg}$$

$$\Delta U = m\Delta u = (2.32\text{ kg})(-514.17\ \text{KJ/kg}) = -1194.36\text{ KJ}$$

$$Q = \Delta U + W = -1194.36\text{ KJ} - 350 = \underbrace{-1544.36\text{ KJ}}_{<0\ \rightarrow\ Q\text{ comes out.}}$$

How would our handling of this problem differ if we replared air with He?

$$Q = \Delta U + W$$

$$W = \int_{V_1}^{V_2} P\,dV \Rightarrow \text{Same}$$

$$T_2 = T_1 \left[\frac{P_2}{P_1}\right]\left[\frac{V_2}{V_1}\right] \rightarrow \text{Same}$$

$\Delta U = ?$ No Table!

$$\Delta u = C_v \Delta T = \frac{3.1156\ \text{kJ}}{\text{kg-K}} \Big| 225 - 900\ \text{K} = -2103.\ \text{kJ/kg}$$

m will be different:

$$m = \frac{PV}{RT} = \frac{200\ \text{kPa} \,|\, 3\ \text{m}^3 \,|\, \text{kg-K}}{2.0769\ \text{kPa-m}^3 \,|\, 900\ \text{K}}$$

$$= 0.321\ \text{kg}.$$

$$\Delta U = m\Delta u = (0.321\ \text{kg})(\cancel{0.321} - 2103\ \text{kJ/kg}) = -675.0\ \text{kJ}$$

$$Q = W + \Delta U = -350 - 675 = -1025\ \text{kJ}$$

(air was -1544).

If I reverse cycle: [Add Q, get W out] I get the begining of a power cycle.

He better than air Given Q, → more T rise → more P rise → more work.

Not Practical, but Sometimes used in nuclear gas turbines for this reason.

!

Air: Constant Specific heats? Same as for He.

Variable Specific Heats: $C_v = a + bT + CT^2 + dT^3$ ← Table A-2(c).

$$\Delta u = \int C_v\,dT = \int [a + bT + CT^2 + dT^3]\,dT$$

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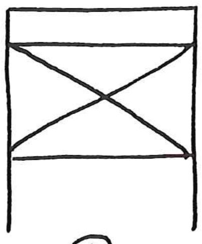
First step in estimating horsepower from auto engine is to find work delivered during expansion stroke: ⇒ Also get final T

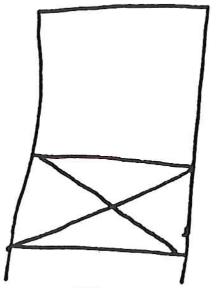
Given: Compression Ratio = 10
V-8: 5.0 liter displacement.



①

Before Expansion.
$T_1 = 2000\ K$
$P_1 = 7000\ kPa$ } Burned Fuel

Expansion is so fast -
No time for heat transfer: $Q = 0$
⇒ $PV^{1.4} = \text{const.}$



②

Compression Ratio: $= \dfrac{V_2}{V_1} = 10 \quad = \quad V_2 = 10V_1$

Displacement Volume = Volume swept by all 8 cylinders:

$5 \text{ liters} = 8\left[V_2 - V_1\right] \qquad 5 = (8)(9V_1) \Rightarrow V_1 = 6.94\times10^{-5} m^3$
$V_2 = 6.94\times10^{-4} m^3$

$\cancel{Q}^{0} - W = \Delta U$

Replace; Next. P.

~~$W = \int_{V_1}^{V_2} P\,dV \qquad PV^{1.4} = P_1V_1^{1.4} \Rightarrow P = \dfrac{P_1V_1^{1.4}}{V^{1.4}}$~~

~~$W = P_1V_1^{1.4}\int_{V_1}^{V_2}\dfrac{dV}{V^{1.4}} = -\dfrac{P_1V_1^{1.4}}{0.4}\left[V_2^{-0.4} - V_1^{-0.4}\right]$~~

~~$W = -\dfrac{(7000\ kPa)(6.94\times10^{-5} m^3)^{1.4}}{0.4}\left[(6.94\times10^{-4} m^3)^{-0.4} - (6.94\times10^{-5} m^3)^{-0.4}\right]$~~

~~$\boxed{W = 0.731\ kJ}$~~

Find T_2: How to do it?

First Law: $-W = \Delta U \Rightarrow \Delta U = -0.731\ kJ.$

$m = \dfrac{P_1V_1}{RT_1} = \dfrac{7000\ kPa \mid 6.94\times10^{-5} m^3 \mid kmole\text{-}K \mid \quad \mid 28.9\ kg}{\quad \mid \quad \mid 8.314\ kPa\text{-}m^3 \mid 2000 K \mid kmole} =$

$8.44\times10^{-4}\ kg$

35.1

$$w = \int_{V_1}^{V_2} P\,dV$$

$$PV^{n} = P_1 V_1^{n} \Rightarrow P = \frac{P_1 V_1^{n}}{V^{n}}$$

$$\Rightarrow w = \int_{V_1}^{V_2} \frac{P_1 V_1^{n}}{V^{n}}\,dV = \frac{P_1 V_1^{n}}{1-n}\left[V_2^{1-n} - V_1^{1-n}\right]$$

$$w = \frac{P_1 V_1^{n} V_2^{1-n} - P_1 V_1}{1-n}$$

$$\cancel{P_1 V_1^{n}\left[\frac{V_2^{n}}{V_1^{n}}\right]}$$

$$P_1 V_1^{n} = P_2 V_2^{n} \qquad V_1^{n} = \frac{P_2}{P_1} V_2^{n}$$

$$w = \frac{P_1 \cancel{V_1^{n}} \left[\frac{P_2}{P_1} V_2^{n}\right] V_2^{1-n} - P_1 V_1}{1-n} = \boxed{\frac{P_2 V_2 - P_1 V_1}{1-n}}$$

$$\text{But} \quad PV = mRT \Rightarrow \quad \boxed{w = \frac{mR(T_2 - T_1)}{1-n}}$$

$$P_2 = \frac{P_1 V_1^{1.4}}{V_2^{1.4}} = [7000\ \text{KPa}]\left[\frac{1}{1[illegible]}\right]^{1.4} = 278.7\ \text{KPa}$$

$$w = \frac{(278.7\ \text{KPa})(6.94\times10^{-4}\,\text{m}^3) - (7000\ \text{KPa})(6.94\times10^{-5}\,\text{m}^3)}{1-1.4}$$

$$= 0.731\ \text{KPa-m}^3 = \boxed{0.731\ \text{KJ}}$$

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$$u_2 - u_1 = \frac{\Delta U}{m} = \frac{-0.731\ \text{KJ}}{8.44\times 10^{-4}\ \text{Kg}} = -865.8\ \text{KJ/Kg}.$$

$$u_2 = u_1 - 865.8 = 812.93\ \text{KJ/Kg}.$$

@ 2000 K, $u_1 = 1678.7$ KJ/Kg. (Table A-16)

for $u_2 = 812.93 \xrightarrow[\text{Table A-16}]{\text{Interpolate}} \underline{T_2 = 1062.7\ \text{K}}$

~~Alternate approach: Ideal Gas.~~

~~$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \Rightarrow T_2 = T_1\left[\frac{P_2}{P_1}\right]\left[\frac{V_2}{V_1}\right]$$~~

~~$$P_2 = P_1\left[\frac{V_1}{V_2}\right]^{1.4} = [7000\ \text{KPa}]\left[\frac{6.94\times 10^{-5}}{6.94\times 10^{-4}}\right]^{1.4} = 278.7\ \text{KPa}$$~~

~~$$T_2 = \left[\frac{278.7}{7000}\right][10][2000] =$$~~

~~April 13~~
April 17

Summarize Chapter: Hint: 3-75: Don't necessarily assume its an ideal gas.

- First Law (without KE & PE) $Q - W = \Delta U$ ⇒ Always holds for closed systems.
- Or dividing work term up $Q - W_{\text{Boundary}} - W_{\text{other}} = \Delta U$
- Boundary work ⇒ Work associated with expansion & contraction of system boundary

$$W = \int_{V_1}^{V_2} P\,dV$$

If P varies between V_1 and V_2, then you need to substitute in $P = f(V)$ before doing integral.

- For the special case of $P = \text{constant}$

$W = P(V_2 - V_1)$ First Law: $Q - W_{\text{other}} = \Delta H$

⇒ i.e., boundary work term is included in combined property enthalpy.

More use in ch. 4.

For special case - polytropic, $PV^n = \text{const}$

$$W = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{mR(T_2 - T_1)}{1-n}$$

Two major approaches to handling properties.

1. Ideal Gas Approximation
2. Property Tables.

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$h_{avg} = h_f + x(h_g - h_f)$
Average prop of mix calc. from quality

Quality can be calculated from any average prop of mix
$X = \dfrac{h_{avg} - h_f}{h_g - h_f}$

If available - property tables should be used:

- Saturated Tables — f, g, two-phase mixtures; quality X.
- Superheat Tables — Relates u, v, h as function of P, T
- Compressed Liquids

⟹ Approximate as Saturated Liquid <u>at</u> <u>same</u> <u>T</u>.

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Ideal Gas $\quad Pv = RT \quad PV = mRT \qquad \dfrac{P_1 V_1}{T_1} = \dfrac{P_2 V_2}{T_2}$

Use if $Z \cong 1$ $\quad$ Air, O_2, N_2, etc.

For ideal gases.

$$\left.\begin{aligned} \Delta u &= \int_{T_1}^{T_2} C_v \, dT \\ \Delta h &= \int_{T_1}^{T_2} C_p \, dT \end{aligned}\right\}$$

For small range of T's, and <u>always</u> for inert gases (He, Ar, Ne, Kr) take C_p, C_v as constants.

Other approach when C_p, C_v vary, use ideal gas tables

<u>T</u>	<u>u</u>	<u>h</u>
–	–	–
–	–	–
–	–	–

What is difference between these tables & the superheat tables?

① Only one table instead of multiple tables for different P's
② No listing for v - can get from ideal gas law.

<u>Common Mistakes</u>

→ Using anything but absolute T in ideal gas law.
→ Using " " " P " " " "
→ Applying ideal gas law to non-ideal materials.
  → Liquids.
  → Vapors in the saturated/near superheat region.

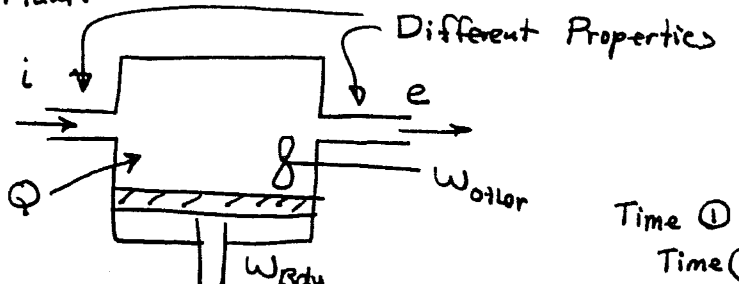
⟹ Next step will be flow systems:

Chapter 4: Control Volumes ⟹ Open Systems:

- Most Engineering Problems involve flow: Open system analysis very important!

e.g., Pumps, turbines, water heaters, hair dryers

Major Features:



Time ① → Time ②

Before with control surfaces: worked with an equation that expressed concervation of energy ⇒ First Law.

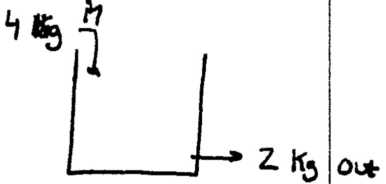
In those problems, mass was fixed:

Now mass can vary, so we start out with conservation of mass.

Mass entering CV - Mass leaving CV = Accumulation or change in mass:

For two fixed endstates:

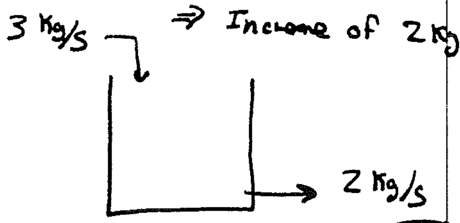
$$\sum m_i - \sum m_e = \Delta m_{cv}$$



⇒ Increase of 2 kg.

At a single point in time

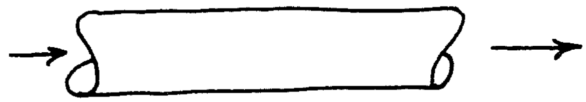
$$\sum \dot{m}_i - \sum \dot{m}_e = \frac{dm_{cv}}{dt}$$



mass in bucket increases @ rate of 1 kg/s.

$$= \frac{dm_{cv}}{dt}.$$

Not much more than this to say, except:



For a flow

$$\dot{m} = \rho V A = \frac{VA}{v}$$

Density

Average Velocity

Cross-Sectional area.

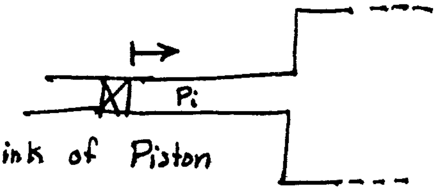
Need to rederive an expanded version of the first law:

Energy Entering CV - Energy Leaving CV = Change in CV energy.

$$Q + \sum m_i E_i - W_{Bdy} - W_{other} - \sum m_e E_e = \cancel{E}(\Delta E)_{cv.}$$

$$= (m_2 u_2 - m_1 u_1)_{cv}$$

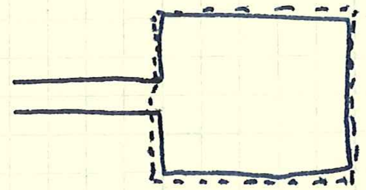
Need to worry about the energy associated with flows.

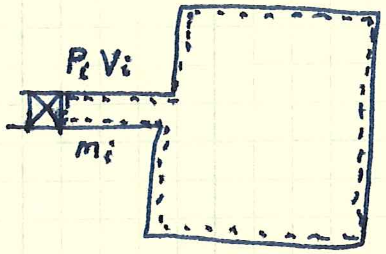


Think of Piston

Energy in = internal ~~e~~energy + PV work needed to force fluid into CV.

not just internal energy, but work needed





$$m_i E_i = (m_2 u_2 - m_1 u_1)_{cv}$$

$$m_i = m_2 - m_1 \quad \Rightarrow \quad E_i = \frac{(m_2 u_2 - m_1 u_1)_{cv}}{m_2 - m_1}$$

First law - closed system: $Q - W = \Delta U$

$$-(-m_i P_i v_i) = \underbrace{(m_i + m_1)}_{m_2} u_2 - m_i u_i - m_1 u_1$$

$$m_i \left[u_i + P_i v_i \right] = (m_2 u_2 - m_1 u_1)_{cv}$$

$\Rightarrow$ By comparison, $\boxed{E_i = h_i}$

$\Rightarrow$ When crossing the boundary, the appropriate form of energy is h

$$mE_i = m_i u_i + \cancel{m P_i v_i}\ \underbrace{\int P\,dV}_{\text{Inlet}} = m_i u_i + m_i P_i v_i$$

$$mE_i = m_i(u_i + P_i v_i) = m h_i$$

April 24

So the first law becomes (for fixed endstates):

$$\boxed{Q - W_{Bdy} - W_{other} = \sum m_e h_e - \sum m_i h_i + (m_2 u_2 - m_1 u_1)_{cv}}$$

What happen for closed system? Get of First law back.

At a single point in time:

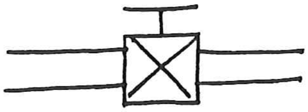
$$\boxed{\dot{Q} - \dot{W}_{Bdy} - \dot{W}_{other} = \sum \dot{m}_e h_e - \sum \dot{m}_i h_i + \frac{d}{dt}\left[mu\right]_{cv}}$$

Special Form: Steady-State: No accumulation of mass or energy in CV

$$\boxed{\dot{Q} - \cancelto{0}{\dot{W}_{Bdy}} - \dot{W}_{other} = \sum \dot{m}_e h_e - \sum \dot{m}_i h_i} \Longleftarrow$$ Form that's used the most.

Think about some simple examples & work up!

Steam Throttling Value:



~~30~~ MPa
32
520°C

100 KPa
$T_2 = ?$

Idealization: Process occurs fast enough so no heat is lost.

First Law: $$\cancelto{0}{\dot{Q}} - \cancelto{0}{\dot{W}_{other}} - \cancelto{0}{\dot{W}_{Bdy}} = \sum \dot{m}_e h_e - \sum \dot{m}_i h_i + \cancelto{0}{\frac{d}{dt}\left[mu\right]_{cv}}$$

~~April 15~~

⇒ What terms go to zero?

⇒ One inlet & one outlet ⇒ $h_e = h_i$

$$h_i \underset{(\text{Superheat})}{\overset{A-4}{=}} 3133.7 \text{ KJ/Kg}$$

{What do we know about state ②?

$$\Rightarrow \left.\begin{aligned} h_2 &= 3133.7 \text{ KJ/Kg} \\ P_2 &= 100 \text{ KPa} \end{aligned}\right\}$$ Saturated or Superheated ?

Sat. Tables for 100 KPa ⇒

P	T(°C)	hf	hg
100	99.63	417.46	2675.5

$\overset{?}{\Longrightarrow}$ Superheated!

13-782 500 SHEETS FILLER 5 SQUARE
42-381 50 SHEETS EYE-EASE® 5 SQUARE
42-382 100 SHEETS EYE-EASE® 5 SQUARE
42-389 200 SHEETS EYE-EASE® 5 SQUARE
42-392 100 RECYCLED WHITE 5 SQUARE
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