THERMOS - HEAT

DYNAMIS - Power

Thermodynamics - Study of Energy (Heat + Work)
AND Properties

Applications:
Engines (car, airplanes)
refrigeration
computers, wind turbines, fuel cells
Medical

History
Developed to support Efficiency steam Engines

1697 - Thomas Savery - first useful Engine

1824 - Carnot published on Thermodynamics

1818 - Robert Stirling developed the Stirling Engine
→ external combustion

Sec 1.2 Defining Systems

system - what we will study ("thing of intrest")
→ be specific

surroundings - everything else

Boundary - the line that divides system & Environment
→ real or imaginary, preference to the imaginary

There is strategy to using this methodology.
This is Key.

<u>closed system</u> - fixed quantity of matter

<u>open system</u> - A region of space through which
control volume mass may flow

<u>Choose Wisely:</u>

1. What variables are known (or/and unknown)
2. What is your goal
3. If you struggle revisit (system/boundary) This,

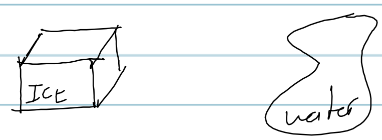
<u>1.3</u> Describing Systems & Their Behavior

<u>Properties</u> - characteristics of a system that can be assigned a value.

(Don't need to know History) → always has a before & after

<u>State</u> - condition of the system given its properties

<u>Process</u> - Transformation from one state to another



state: solid   state: liquid

process: melting

	before	after
Known:	T, m, V (volume)	T, mass

steady state - no property change with time.

Thermodynamic cycle - a number of processes that begin and end at the same state

Extensive and Intensive Properties

Extensive - depends on size of system (mass)
may vary with time

intensive - independent of size (temperature)
may vary w/ position & time

Intensive	Extensive
Pressure	mass
Temperature	volume [m^3]
boiling point	electric resistance
	Energy [W]
specific volume [m^3/kg]	

Equilibrium - IF A system is isolated from its surroundings AND no changes occur

quasi-equilibrium - very very small changes may be occuring

Thursday 8/30/2012

Primary Units

		SI (metric)	English (imperial)	
mass	Kilograms	Kg	pounds mass	lbm
Length	meters	m	foot	ft
Time		s		s

Secondary Units

	SI	English	
Force	N	pounds force	lbf

$F = ma$ $\qquad$ $F = 1\,lb_m \cdot 32.2\,ft/s^2$

$F = kg\ m/s^2 = N$ $\qquad$ $= 32.2\ lb_m\ ft/s^2$

History

1866 - congress leagalizes metric system
1902 - Law requiring metric
1975 - Ford creates US metric Board (USMB)
Dissolved 1982

U.S.A., Liberia, Burma

Train Tracks:

$$\frac{18\,\cancel{ft}}{} \left| \frac{12\,\cancel{in}}{1\,\cancel{ft}} \right| \frac{2.54\,cm}{1\,\cancel{in}} = 548.6\ cm$$

Example

What Force is required to accelerate 3 lb_m to 15 ft/s^2?

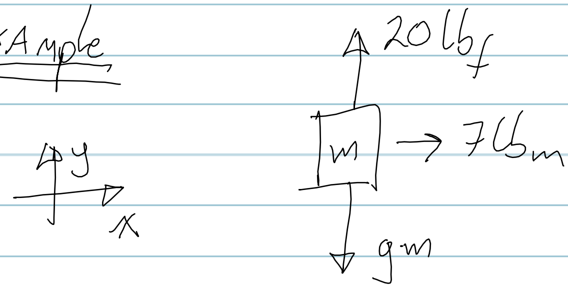
$$F = m \cdot a \quad \Rightarrow \quad F = 3\,lb_m \times 15\,ft/s^2$$

$$F = 45\,lb_m\,ft/s^2 \qquad 1\,lb_f = 32.2\,lb_m\,ft/s^2$$

$$\therefore\ F = 45\,lb_m\,ft/s^2 \left(\frac{1\,lb_f \cdot s^2}{32.2\,lb_m\,ft}\right)$$

$$F = 1.40\,lb_f$$

Example



what is net acceleration

$$F = m \cdot a \qquad F_g = m \cdot g = \frac{7\,\cancel{lb_m}}{} \Big| \frac{32.2\,\cancel{ft}}{\cancel{s^2}} \Big| \frac{lb_f\,\cancel{s^2}}{\cancel{32.2}\,\cancel{lb_m}\,\cancel{ft}} = 7\,lb_f$$

$$20\,lb_f - 7\,lb_f = 13\,lb_f \uparrow$$

$$F = m \cdot a$$

$$13\,lb_f = 7\,lb_m \cdot a$$

$$a = \frac{13\,\cancel{lb_f}}{7\,\cancel{lb_m}} \Big| \frac{32.2\,\cancel{lb_m}\,ft}{s^2\,\cancel{lb_f}} \qquad \therefore\ a = 59.8\,ft/s^2$$

1.5 Specific Volume

→ intensive properties

$$\text{Density} = \frac{m}{V} \;[=]\; \frac{kg}{m^3}$$

Specific volume $\quad v = \frac{1}{\rho} \;[=]\; \frac{m^3}{kg}$ ← stratigically useful

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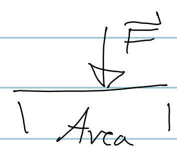
1.6 Pressure

Force in the Normal direction divided by area



Absolute Pressure (w/r/t zero) → zero pressure of a complete vaccum

Gage - Relative to the atmospheric pressure or difference between absolute pressure and atmosphere

$$\begin{cases} P_{gage} = P_{ABS} - P_{ATM} \\ P_{vac} = P_{atm} - P_{ABS} \\ P_{vac} = -P_{gage} \end{cases}$$

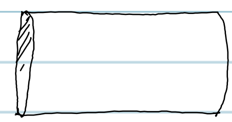
$P_{atm} = 101\,325\ N/m^2$

$14.69\ psi$

1 PASCAL	$= 1\ N/m^2$	$= 1\ pa$
1 KPa	$= 10^3\ N/m^2$	$\stackrel{!}{=} 1\ KPa$
1 bar	$= 10^5$ " "	
1 MPa	$= 10^6$ " "	
1 PSI	$= 1\ lbf/in^2$	

EXAMPLE

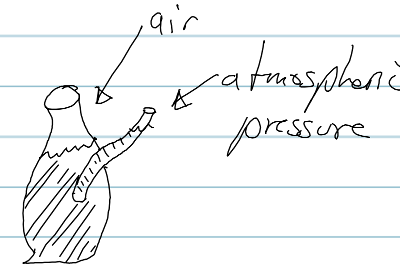
Tank is filled to 100 psi (goge)



$$P_{GAGE} = P_{ABS} - P_{ATM}$$

$$P_{ABS} = 100\,PSI + 14.69\,Psi = 114.69\,psi$$

used by sailors near the sea $\rightarrow$

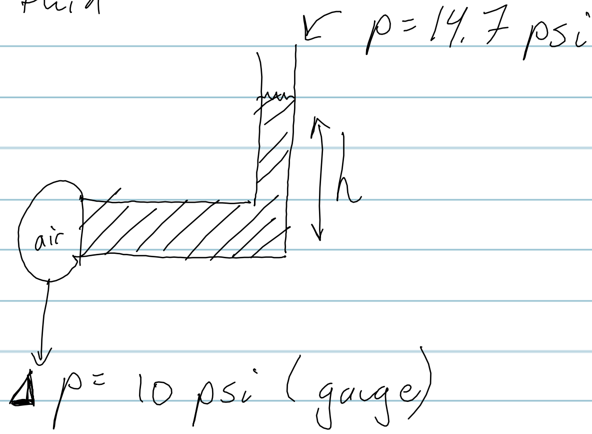


Pressure Difference in Fluid Column

$\Delta P = \rho \cdot g \cdot h \rightarrow$ height of fluid column

ρ – density of fluid

$g \rightarrow$ acceleration of gravity



$\rho_{water} = 62.4\ lbm/ft^3$

$g = 32.2\ ft/s^2$

$\Delta p = 10\ lbf/in^2$

So; $h = \dfrac{\Delta P}{\rho g}$ $\therefore$ $h = \dfrac{10\,\cancel{lbf}}{\cancel{in^2}} \cdot \dfrac{\cancel{ft^3}}{62.4\,\cancel{lbm}} \cdot \dfrac{1\,\cancel{s^2}}{32.2\,\cancel{ft}} \cdot \dfrac{144\,\cancel{in^2}}{1\,\cancel{ft^2}} \cdot \left(\dfrac{32.2\,\cancel{lbm}\,\cancel{ft}}{\cancel{lbf}\,\cancel{s^2}}\right)$

$h = 23\ ft$

1.7 Temperature

Isothermal Process → Temperature remains constant during process

Adiabatic Process → No heat transfer with surroundings

Kelvin & Celcius

$T(°C) = T(K) - 273.15$

0K absolute zero

0°C Water freezes

100°C Water boils (at certain pressure)

Rankine & Fahrenheit

$T(°F) = T(R) - 459.6$

0°R absolute zero

32°F water freezes

212°F water boils

Tuesday Sept. 4, 2012

The First Law of Thermodynamics (conservation of Energy)

2.1 Mechanical Energy

$$W = \int_{x_1}^{x_2} F_x \, dx$$

$F_x = m a_x = m \, dV_x/dt$ CHAIN RULE $V_x = dx/dt$

$F_x = m \, \frac{dV_x}{dx} \frac{dx}{dt}$

$= m \frac{dV_x}{dx} V_x$ Now $W = \int_{x_1}^{x_2} F_x \, dx$

$$= \int_{V_1}^{V_2} m V_x \, dV_x$$

$$\boxed{W = \tfrac{1}{2} m (V_2^2 - V_1^2)}$$

in the context of velocity

Kinetic Energy -

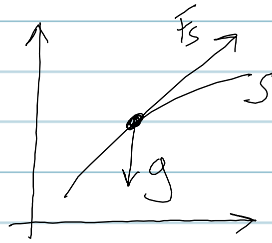
$$\Delta KE = KE_2 - KE_1 = \tfrac{1}{2} m (V_2^2 - V_1^2)$$

Units for Work

SI: N·m or J

English: ft·lbf or BTU $1\,BTU = 778.17\,ft\,lb_f$

Now, Consider a system with a Force due to gravity



$S = f(x, y, z)$ a path

$$W = \int_{S_1}^{S_2} \vec{F_S} \cdot d\vec{s}$$

$$\int_{S_1}^{S_2} F_{SA} \cdot ds = \frac{1}{2} m \left(V_2^2 - V_1^2 \right) + \underbrace{mg \left(z_2 - z_1 \right)}_{\text{potential Energy}}$$

all forces except gravity

if only gravity acts:

$$0 = \frac{1}{2} m \left(V_2^2 - V_1^2 \right) + mg \left(z_2 - z_1 \right)$$

$$\Delta PE = PE_2 - PE_1 = mg \left(z_2 - z_1 \right)$$

1st Law:

total energy

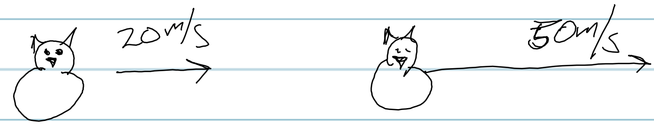
internal energy

$$\Delta E = \Delta U + \Delta KE + \Delta PE$$ → This later becomes strategy (foreshadowing)

EXAMPLE

Object with a mass of 5kg is accelerated from 20 m/s to 50 m/s

FIND: Net Work [KJ]



Assumptions:

1. $\Delta PE = 0$
2. No other interactions

$$W = \int_{s_1}^{s_2} \vec{F}_{SA} \cdot d\vec{s} = \frac{1}{2} m (V_2^2 - V_1^2) + mg\cancel{(Z_2 - Z_1)}$$

$\rightarrow 0$ via assumption 1

$$W = \frac{1}{2}(50\,kg)\left((50\,m/s)^2 - (20\,m/s)^2\right)$$

$$W = 52{,}500\ \frac{\cancel{kg}\,\cancel{m^2}}{\cancel{s^2}}\left(\frac{1\,\cancel{N}\,\cancel{s^2}}{1\,\cancel{kg}\cdot\cancel{m}}\ \frac{1\,\cancel{J}}{1\,\cancel{N}\,\cancel{m}}\right)\left(\frac{1\,KJ}{1{,}000\,\cancel{J}}\right)$$

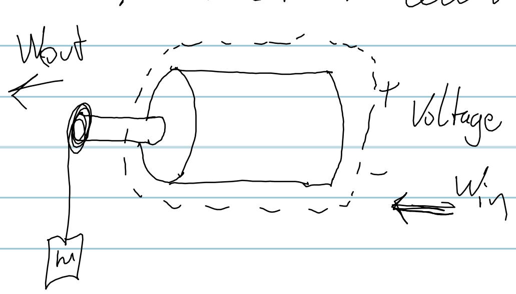
$$\boxed{W = 52.5\ KJ}$$

2.1.4 Conservation of Energy in mechanics

$W = \Delta KE + \Delta PE$ (This is a simplified view, only valid in Ch 2)

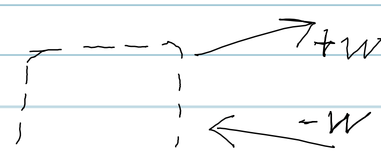
2.2

Work is done by a system if the sole external effect could have been the raising of a weight.



$W > 0$ work done by system

$W < 0$ work done on the system



Not A Property

Power

James Watt (1736–1819) } marketing

"horse-power"

$$\text{Power} = \text{Force} \cdot \frac{\text{distance}}{\text{time}}$$

$$= 180\,lb_f \; \frac{181\,ft}{min} = 33{,}000 \; \frac{ft\,lb_f}{min} = 1\,Hp$$

$$\dot{W} = \text{work}/\text{time}$$

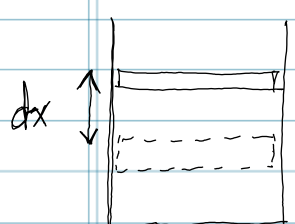
$\uparrow$ rate of Work being done

$$1\ \text{watt} = 1\ \frac{J}{s}$$

$$1\ hP = 2545\ \frac{BTU}{hr}$$

2.2.3 Expansion & Compression Work

$$W = \text{Force} \cdot \text{distance}$$

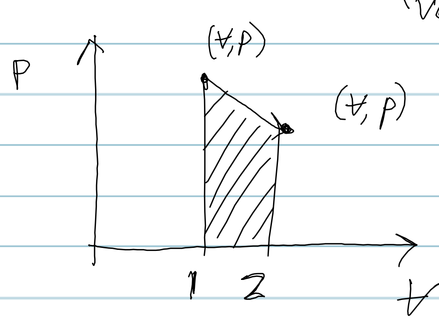


$$\delta W = (F)\,dx$$

$$\delta W = P \cdot \underbrace{A\ dx}_{dV}$$

$$W = \int_1^2 P\, dV \quad \leftarrow \text{volume}$$

$$W = m \int_1^2 P\, dv \quad \leftarrow \text{specific Volume}$$



Polytropic Process

$$PV^n = \text{constant}$$

$$P_1 V_1^n = P_2 V_2^n = \text{constant}$$

$$P = \frac{\text{konstant}}{V^n}$$

$$W = \int_1^2 P\,dV = \int_1^2 \frac{\text{const}}{V^n}\,dV$$

$$= \frac{\text{constant} \cdot V^{-n+1}}{-n+1}\Bigg|_1^2$$

$$= \frac{\text{constant}}{1-n}\left(V_2^{1-n} - V_1^{1-n}\right)$$

$$= \frac{P_2 V_2^n V_2^{1-n} - P_1 V_1^n V^{1-n}}{1-n}$$

$$W = \frac{P_2 V_2 - P_1 V_1}{1-n} \qquad (n \neq 1)$$

$$W = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right) \qquad (n = 1)$$

Thursday Sept 6th

EXAMPLE: System w/ $\forall_1 = 0.04\,m^3$ @ $P = 200\,KPa$

PART A – system is heated (constant pressure) to $\forall = 0.1\,m^3$

FIND: W in KJ

$$W = P\int_1^2 d\forall$$

$$= P\,(V_2 - V_1)$$

finally $W = 12\ KPa\ m^3$ Great, now get KJ

$$\frac{12\,KPa}{} \left| \frac{1{,}000\,N\,m^3}{1\,KPa\ m^2} \right| \frac{1\,J}{1\,N\cdot m} \left| \frac{KJ}{1\,J\ 1{,}000} \right.$$

So, ∴ $\boxed{W = 12\,KJ}$

PART B – Same system BUT $P\forall = \text{constant}$ here $n=1$ polytropic

$$W = P_1\forall_1 \ln\left(\frac{\forall_2}{\forall_1}\right)$$

$$W = 200\,KPa\,(0.04\,m^3)\ln\left(\frac{0.1}{0.04}\right) = \boxed{7.33\,KJ}$$

$P_2 =$

Part G - same system, $p\forall^{1.3} = $ constant $(n \neq 1)$

Polytropic

$$W = \frac{P_2 \forall_2 - P_1 \forall_1}{1-n}$$

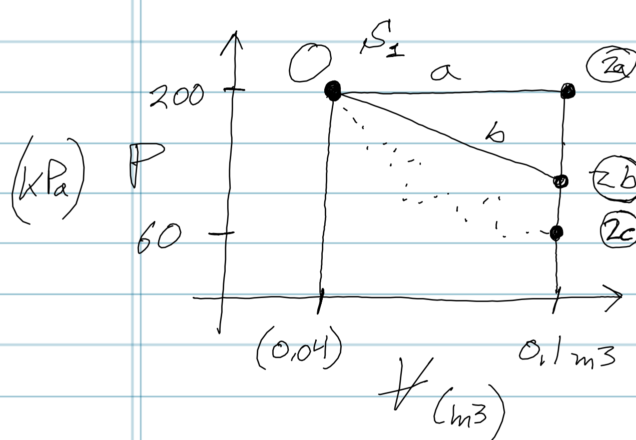
$$p_1 \forall_1^{1.3} = p_2 \forall_2^{1.3}$$

$$(200 kPa)(0.04 m^3)^{1.3} = P_2 (0.1 m^3)^{1.3}$$

$$P_2 = 60.773 \ KPa$$

$$W = \frac{60.773 kPa \cdot (0.1 m^3) - 200 kPa (0.04 m^3)}{1 - 1.3}$$

$$\therefore \boxed{W = 6.41 \ KJ}$$



Draw P V diagram every time.

2.2.6 Other Types of Work

Extension of a Solid Bar

$$F = \sigma \cdot A$$

Normal Stress (σ), Cross sectional Area (A)

$$W = \int_{x_1}^{x_2} -\sigma A \, dx$$

Shaft Power

velocity, radius, angular velocity

$$V = R \cdot \omega$$

$$\tau = F_t \cdot R \qquad [\cancel{ft\ lbf} \text{ or } N \cdot m]$$

torque, radius

$$\dot{W} = F_t \cdot V = \left(\frac{\tau}{\cancel{R}} \cancel{R} \cdot \omega\right) = \tau \cdot \omega$$

Power

Electric Work (Power)

$$\dot{W} = \mathcal{E} \cdot i \qquad 1 \text{ WATT} = 1 \text{ VOLT} \cdot 1 \text{ AMP}$$

voltage current

EXAMPLE: 12 Volt Battery

10 Amps operating for 3 hours

FIND: Work & Power

W & $\dot{W}$

$$\dot{W} = \mathcal{E} i$$

$\mathcal{E} = 12$ Volt

$i = 10$ Amps

$t = 3$ hrs

$1\,W = 1\,V \cdot 1\,A$

Power = 120 watts

Integrate for work or

$$\frac{120\,\cancel{W}}{} \cdot \frac{3\,\text{hours}}{} \cdot \frac{1\,J}{1\,\cancel{W} \cdot s} \cdot \frac{3{,}600\,s}{1\,\text{hour}}$$

Work = 1,296,000 J

2.3 Energy of a System

property which can be looked up

Internal Energy U or u

per unit mass

$$E_2 - E_1 = (U_2 - U_1) + (KE_2 - KE_1) + (PE_2 - PE_1)$$

internal energy

$$E_2 - E_1 = m(u_2 - u_1) + \frac{1}{2}m(V_2^2 - V_1^2) + mg(z_2 - z_1)$$

2.4 Heat Transfer

Energy transfer via heat, NOT categorized as work (always driven by a temperature difference (gradient))

$$E_2 - E_1 = Q - W$$

Heat transfer

(not a property)

$Q > 0$ heat-into system

$Q < 0$ Heat Lost

Adiabatic - without heat transfer

Types of Heat transfer:

- Conduction- $(\rightarrow)$ typically communicated though solids
- Convection- $(\rightarrow)$ " liquids
- Radiation- $(\rightsquigarrow)$ wave-form, no medium required

Big in space

Convection - Heat transfer via molecular motion

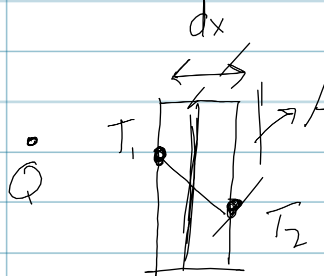
Fourier's Law

$$\dot{Q}_x = -KA \frac{dT}{dx}$$

A — cross-sectional area

K — thermal conductivity

dT/dx — temperature gradient



$$\dot{Q} = -KA \frac{\Delta T}{\Delta x} = -KA \frac{T_2 - T_1}{l}$$

if K is high the material is a GOOD conductor

K is low poor conductor

Example

$T_1 = 20°C$ $\quad T_2 = -10°C$ $\quad A = 1 m^2$

$x_1 = 0 m$ $\quad x_2 = 0.01 m$

$K = 0.5 \frac{W}{m°K}$ $\quad T_1 = 293.2 K$

$T_2 = 263.2 K$

$$\dot{Q}_x = -\frac{0.5 W}{} (1 m^2) \left(\frac{293.2 - 263.2 K}{-0.01 m} \right)$$

$$\dot{Q}_x = 1500 W$$ (rate) (magnitude)

Radiation

No medium required, this is a result of changes in electronic configuration of atoms or molecules by photons or waves

STEFAN - BOLTZMANN LAW:

$$\dot{Q}_e = \varepsilon \sigma A T^4$$

ε → emissivity → surface property

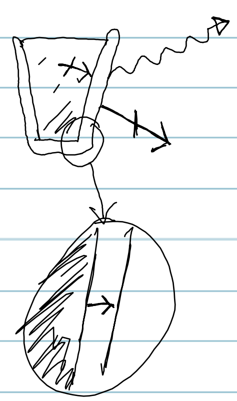
σ → S.B. constant

A → area

T → Temp

$\sigma = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$

*Use Kelvin



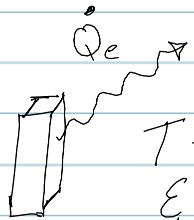
Here we can see the movement of heat.

Tuesday Sept 11th

QUIZ This Thursday*
New homework due next Tuesday
Exam in two weeks

Radiation -

$$\dot{Q}_e = \varepsilon \sigma A T_b^4$$



$T = 200°C \quad (473.2\,K)$
$\varepsilon = 0.5$
$A = 1\,m^2$

$$\dot{Q}_e = (0.5)\left(5.67 \times 10^{-8} \frac{W}{m^2K^4}\right)(1\,m^2)(473.2\,K)^4 = 1420\,W$$

Radiation Exchange
Between objects & surroundings

$$\dot{Q}_e = \varepsilon \sigma A \left(T_b^4 - T_{SUR}^4\right)$$

Convection - (moving fluid)

Energy Transfer between solid surface and moving fluid.

Newton's Law of Cooling:

$$\dot{Q}_c = h \cdot A \cdot (T_b - T_f)$$ → Temperature of the fluid

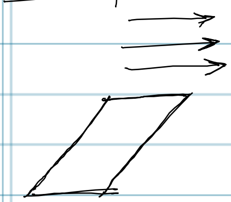
h → heat transfer co-efficient*

A → surface Area

T_b → Temperature of the Base

(Table 2.1 pg 57)

EXAMPLE



hot plate

$h = 10\,W/m^2 \cdot K \qquad A = 1\,m^2$

$T_b = 100°C \;(373.2\,K)$

$T_f = 20°C \;(293.2\,K)$

$$\dot{Q}_c = hA(T_b - T_f)$$

$$= \frac{10\,W}{m^2 \cdot K} \cdot 1\,m \left(80°K\right)$$

$$\dot{Q}_c = 800\,W$$

Be Careful with Areas (who experiencing what)

& Temperatures (gut-check)

2.5 Energy Balance For Closed System

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

$$E_2 - E_1 = Q - W$$

Rate Form

1st law;
$$\frac{dKE}{dt} + \frac{dPE}{dt} + \frac{dU}{dt} = \dot{Q} - \dot{W}$$

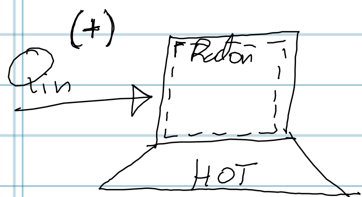
$$dE/dt = \dot{Q} - \dot{W}$$

EXAMPLE - Radon gas @ 65 KPa

200°C to 400°C

$m = 0.393$ Kg   @200°C $u = 26.6$ KJ/Kg

@400°C $u = 37.8$ KJ/Kg



1^{st} Law $\cancel{\Delta KE} + \cancel{\Delta PE} + \Delta U = Q - \cancel{W}$

$$Q = \Delta u = m(u_2 - u_1) = 4.4 \text{ KJ}$$

EXAMPLE - A closed system w/ $m = 5$ lbm

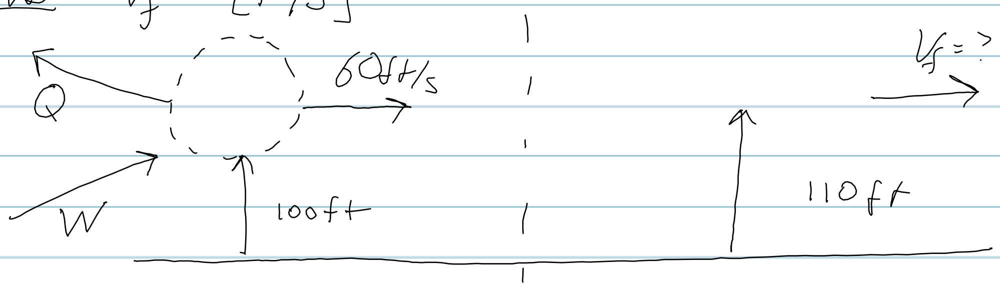
$V_i = 60$ ft/s @ 100 ft

60 BTU of Work is done on the System

Gives off 20 BTU of heat

$\Delta u = 7$ BTU/lbm   final elevation is 110 ft.

FIND: V_f [ft/s]



Boundry moves with object

$Q = -20$ BTU $z_2 - z_1 = 10$ ft

$W = -60$ BTU

$m = 5$ lbm $\Delta u = 7$ BTU/lbm

1^{st} Law:

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

$$\cancel{\tfrac{1}{2} m (V_f^2 - V_i)^2 + mg\Delta y + m\Delta u = Q - W}$$

$$\cancel{= (-20_{BTU} + 60\,BTU)\frac{2}{5\,lb_m}}$$

$$\cancel{V_f^2 - (60\,ft/s)^2 + 32.2\,ft/s^2\,(10\,ft) + 7\,BTU/lb_m}$$

$$\Delta U = 5\,lb_m \cdot \frac{7\,BTU}{1\,lb_m} = 35\,BTU$$

$$\Delta PE = 5\,lb_m\ \frac{32.2\,ft}{s^2}\cdot 10\,ft\ \frac{lb_f\,s^2}{32.2\,lb_m\,ft}\ \Big|\ \frac{1\,BTU}{778.17\,ft\,lb_f}$$

$$= 0.064\ BTU$$

Substituting

$$\Delta KE = 4.936\ BTU = \frac{1}{2}(5\,lb_m)\left(V_f^2 - (60\,ft/s)^2\right)$$

$$V_f^2 - (60\,ft/s)^2 = \frac{4.936\,BTU \cdot 2}{5\,lb_m} \times \frac{778.17\,ft\,lb_f}{1\,BTU} \times \frac{32.2\,lb_m \cdot ft}{lb_f\,s^2}$$

$$= 49{,}432.7\ \frac{ft^2}{s^2}$$

$$\boxed{V_f = 230.4\ ft/s}$$

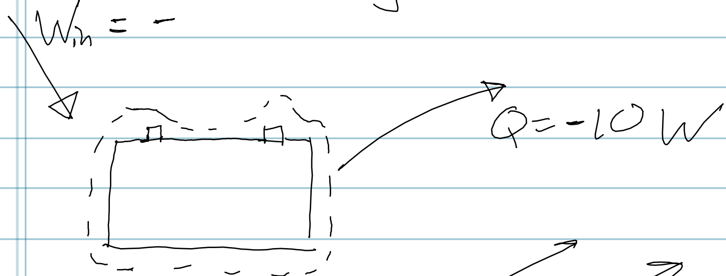
The Devil is in the details of the Units

EXAMPLE: We're charging a battery

@ 20A & 12.8V

Rate of Heat transfer = 10 W

FIND: The rate at which internal energy is increasing.



1ST Law (RATE FORM)

$$\underbrace{\cancel{\frac{dKE}{dt}}}_{\text{ZERO}} + \underbrace{\cancel{\frac{dPE}{dt}}}_{\text{ZERO}} + \frac{dU}{dt} = \dot{Q} - \dot{W}$$

$$\dot{W} = -\mathcal{E}\, i$$

$$= -(12.8V)(20A)$$

$$= -256\,W$$

$$\frac{dU}{dt} = -10W - (-256W)$$

$$\boxed{\frac{dU}{dt} = 246\,W}$$

Thursday Sep 13th, 2012

2.6 Energy analysis of cycles

cycle → begins & ends @ the same state

Power Cycles:

Delivers a Net Work Transfer of Energy to the sourandings

$$W_{cycle}^{*} = Q_{in} - Q_{OUT}$$ (heat transfer)

*only for power cycle

Thermal efficiency - extent of energy converted from heat to work

$$\eta = \frac{W_{cycle}}{Q_{in}}$$ (power cycle)

$\frac{\text{what we get}}{\text{what we put in}}$

$$\eta = 1 - \frac{Q_{OUT}}{Q_{in}}$$ (alternate form)

2.6.3 Refrigeration & heat pump cycles

Our purpose here is to transfer heat

$$\boxed{W_{cycle} = Q_{OUT} - Q_{IN}}$$

Refrigeration - cooling

Heat Pump - heating

Refrigeration: $\beta = \dfrac{Q_{IN}}{W_{cycle}}$

Heat Pump: $\gamma = \dfrac{Q_{OUT}}{W_{cycle}}$

EXAMPLE:

A heat Pump has $\gamma = 3.5$ the Net Work is 5,000 KJ.

Goal: Q_{in} & Q_{out}

$$\gamma = \frac{Q_{OUT}}{W_{cycle}}$$

$$\downarrow$$

$$Q_{out} = \gamma \cdot W_{cycle}$$

$$= 3.5 \cdot 5{,}000\,KJ$$

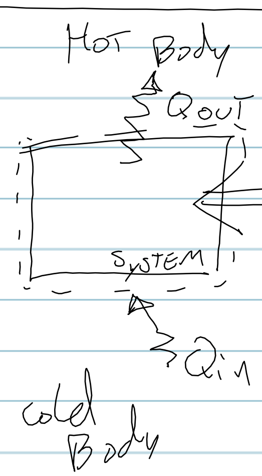
$$Q_{out} = 17{,}500\,KJ$$

$$W_{cycle} = Q_{OUT} - Q_{in}$$

$$5000\,KJ = 17{,}500\,KJ - Q_{IN}$$

$$Q_{IN} = 12{,}500\,KJ$$

Thermal Resivors



$W_{cycle} = Q_{OUT} - Q_{in}$

" "

$\Longrightarrow W_{cycle} = Q_{in} - Q_{OUT}$

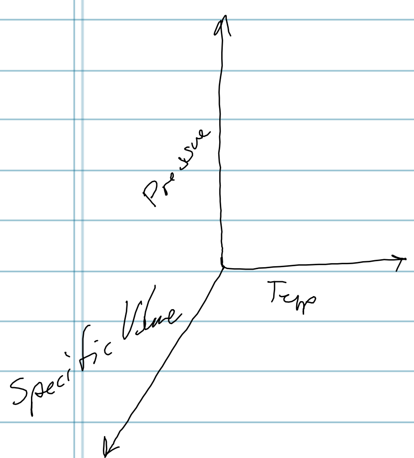
2.7 Energy Storage

- Batteries
- Flywheel
- Ultra-Capacitors → Rapid discharge
- Super-Conductors (Magnets)
- Compressed gas → for wind farms
- Pumped Hydro → pump water up-hill for later

Chapter 3 PROPERTIES

u, ρ, T, P, ν (specific volume)

The state is defined by Thermodynamic Properties



Tuesday 9/18/2012 First EXAM Next MONDAY

Chapter 3: Evaluating Properties

Pure Substances & Phase

- A SYSTEM of Liquid & Vapor (steam) (2 phases)
- SLUSH, both Liquid and ICE.

STATE PRINCIPLE

$P = P(T, V)$ & $u = u(T, V)$

OR

we Know T & P

$v(T, P)$ (specific Volume)

for example:

STATE$_1$ STATE$_2$ . . . .

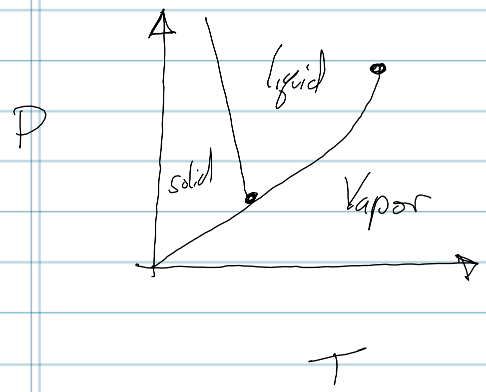
$P = 1$ Bar

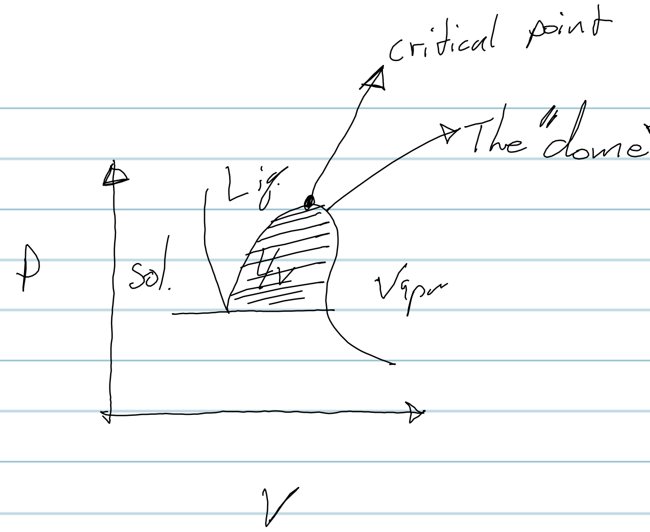
$T = 300°C$

$u_1 = ? = u(\overset{\checkmark}{P}, \overset{\checkmark}{T})$

$v_1 = ?$

PVT Surface





Two Phase Regions - 2 phases exist in equilibrium

Liquid-Vapor, solid-liquid, solid-vapor

Critical Point - Where saturated liquid and saturated vapor lines meet

T_c, P_c

Critical Temp & Pressure - maximum Temperature where liquid & Vapor may co-exist

Vapor Dome - Dome shaped region composed of 2 Phases Liquid-Vapor STATES

Phase Changes:

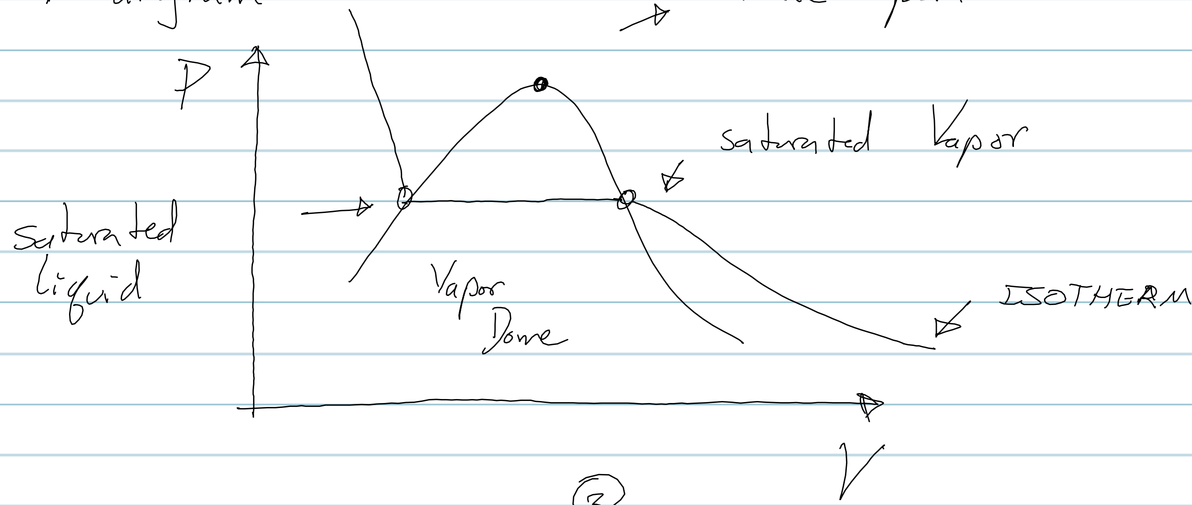
Vaporization - Liquid to Vapor

Condensation - Vapor to Liquid

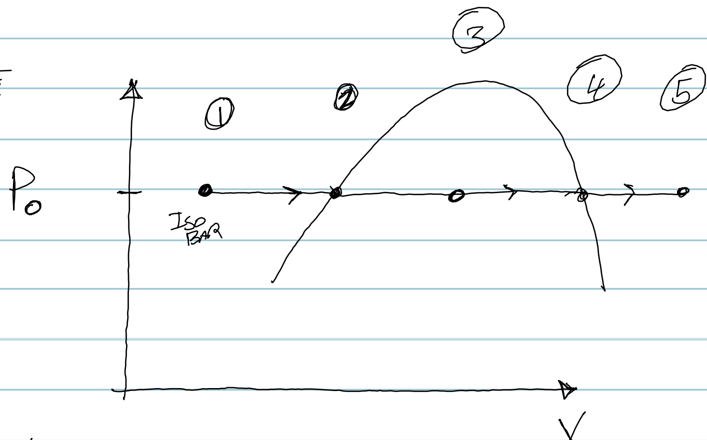
Melting - solid to Liquid

Sublimation - solid to vapor

PV diagram



EXAMPLE



1 sub cooled liquid

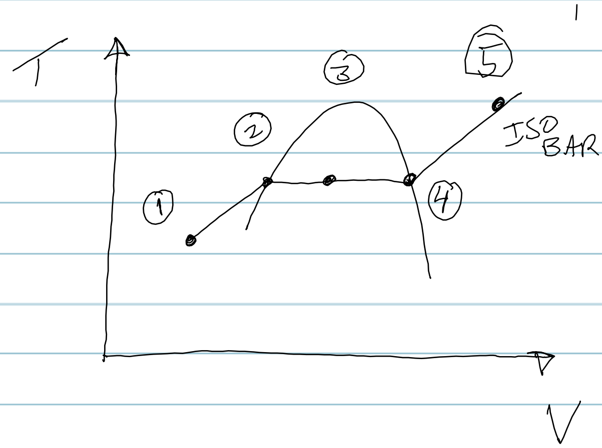
2 saturated liquid

3 2 Phase

4 Saturated Vapor

5 Super heated Vapor

NOTE: This is constant Pressure Journey



Quality:

$x \equiv$ fraction of Vapor (based on mass)

So;

$$x = \frac{m_{vapor}}{m_{vapor} + m_{liquid}} = \frac{m_{vapor}}{m_{(vapor+liquid)}} \qquad 0 \le x \le 1$$

OR

$$x = \frac{\nu - \nu_f}{\nu_g - \nu_f}$$

$f \rightarrow$ fluid (specific volume of liquid/fluid)

Specific volume of vapor/gas

Appendix A2 - A6 $\rightarrow$ WATER "steam tables"

A7 - A9 $\rightarrow$ R22 (refridgerant)

A10 - A12 $\rightarrow$ R134-A "newer R22"

A13 - A15 $\rightarrow$ Ammonia

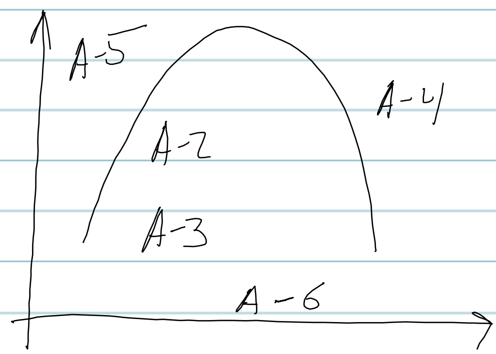
A16 - A18 $\rightarrow$ Propane

Exam 1 on Monday

Thursday Sept 20th, 2012

6:10pm. Buckly 314

Chapters 1, 2, 3.1-3.5



Open book (No phones)
focus

H.W. #4 Due 9/25
2.59, 2.76, 2.81,
3.5, 3.14, 3.17

EXAMPLE

STEAM @ 100°C $\quad x = 1/2$

inside the dome

TABLE A-2

$$v_f = 1.0435 \times 10^{-3}\ m^3/Kg$$

$$x = \frac{v - v_f}{v_g - v_f}$$

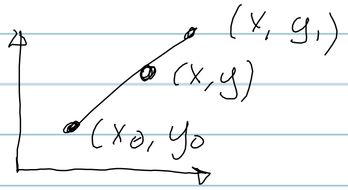
$$v_g = 1.67\ m^3/Kg$$

$$v = x\, v_g + (1-x) v_f$$

$$v = (1/2)(1.67 m^3/Kg) + (1/2)(1.0435 \times 10^{-3}\ m^3/Kg)$$

$$v = 0.855\ m^3/Kg$$

What if $T = 105°C$ Use linear interpolation



$$\frac{X - X_0}{X_1 - X_0} = \frac{Y - Y_0}{y_1 - y_0}$$

X_1 & y_1 are poits @ 110°C
X_0 & y_0 are points @ 100°C

$T = 110°C \quad \nu_f = 1.0516 \times 10^{-3}\ m^3/kg$

$\nu_g = 1.210\ m^3/kg$

$@T = 100°C \quad \nu_f = 1.0435 \times 10^{-3}\ m^3/kg$

$\nu_g = 1.673\ m^3/kg$

$@\ T = 105°C$

$$\frac{105-100}{110-100} = \frac{\nu_f - 1.0435\times10^{-3}}{1.0516\times10^{-3}\ m^3/kg - 1.0435\cdot10^{-3}}$$

$\therefore\ \nu_f = 1.048 \times 10^{-3}\ m^3/kg$ //

$$\frac{105-100}{110-100} = \frac{\nu_g - 1.673}{1.21 - 1.673}$$

$\therefore\ \nu_g = 1.44115\ m^3/kg$ //

Figure it out on TI-89

Interpolation → Function..?

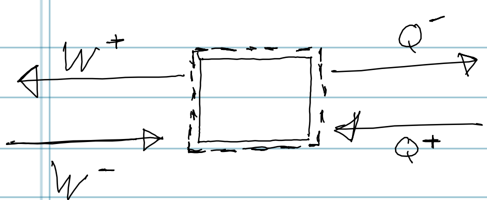
EXAM REVIEW

Chapter 1
- Units lb_f + lb_m
- intro to Properties
  V, P, T
- System Boundry / Diagram

$P = P_{ATM} + \rho g L$

Chapter 2
- Kinetic Energy $\Delta KE = \frac{1}{2} m (V_f^2 - V_i^2)$
- POTENTIAL Energy $\Delta PE = mg(z_2 - z_1)$

- Work & Heat Transfer



Work ⇒ $W = \int P\,dV$

Polytropic: $pv^n = \text{constant}$

$n = 1$ $W = p_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$ $p \cdot v = \text{constant}$

$n \neq 1$ $W = \frac{P_2 V_2 - P_1 V_1}{1-n}$ $P \cdot V^n = \text{constant}$

Electric Power
$\dot{W} = -\mathcal{E} \cdot i$

Shaft Power $\dot{W} = \tau \cdot \omega$

Heat Transfer

Conduction $\dot{Q}_x = -KA \, dT/d_x$

Convection $\dot{Q}_c = hA(T_b - T_f)$

surface to cool   fluid temp

Radiation $\dot{Q}_e = \varepsilon \sigma A (T_b^4 - T_s^4)$ (Kelvin)

1st Law:

could come from here

$\Delta KE + \Delta PE + \Delta U = Q - W$ [time is a factor]

(This is where signs are important)

RATE FORM:

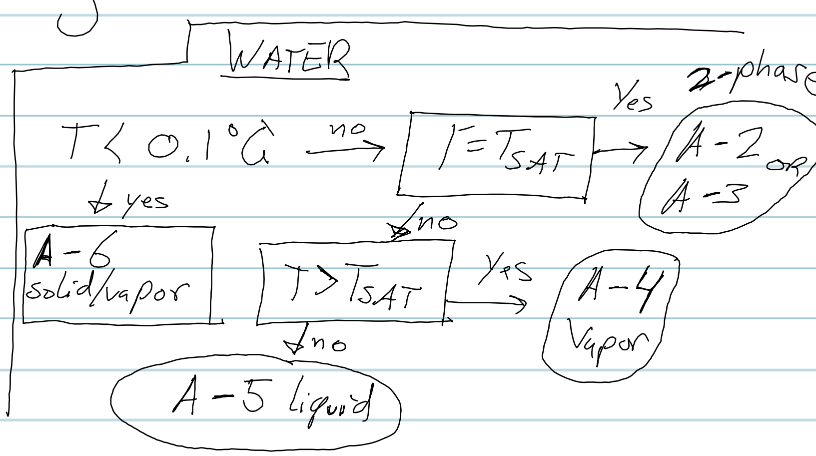
$$\frac{dKE}{dt} + \frac{dPE}{dt} + \frac{dU}{dt} = \dot{Q} - \dot{W}$$

Chapter 3

- Tables in the back of the book & surface

P-V diagrams
T-V diagrams } pVT surface

- Quality



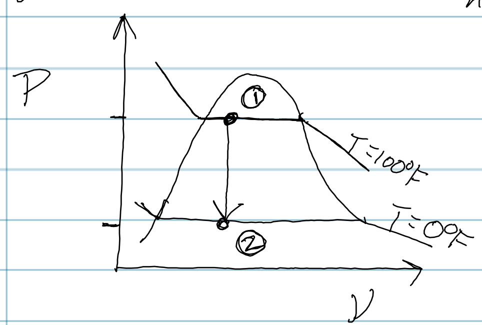
Tuesday 9/25/2012

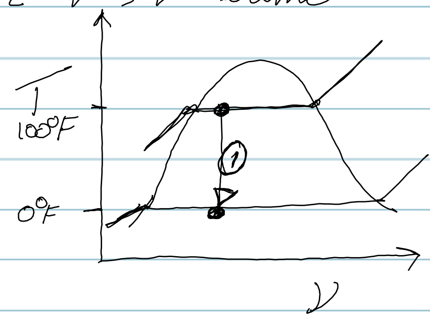
EXAMPLE: 2-phase liquid vapor mixture of ammonia

$T = 100°F$ w/ $v = 1.0 \frac{ft^3}{lb_m}$

Find: quality (x) if $T \rightarrow T = 0°F$

NOTE $v \rightarrow v$ same





$v_1 = v_2 = 1.0 \, ft^3/lb_m$

@ 0°F

$v_{f_2} = 0.02419$ ft^3/lb_m pg 962

$v_{g_2} = 9.11$ A-13E

$$x_2 = \frac{v_2 - v_{f2}}{v_{g2} - v_{f2}}$$

$x_2 = 0.107$ → % vapor // (closer to left)

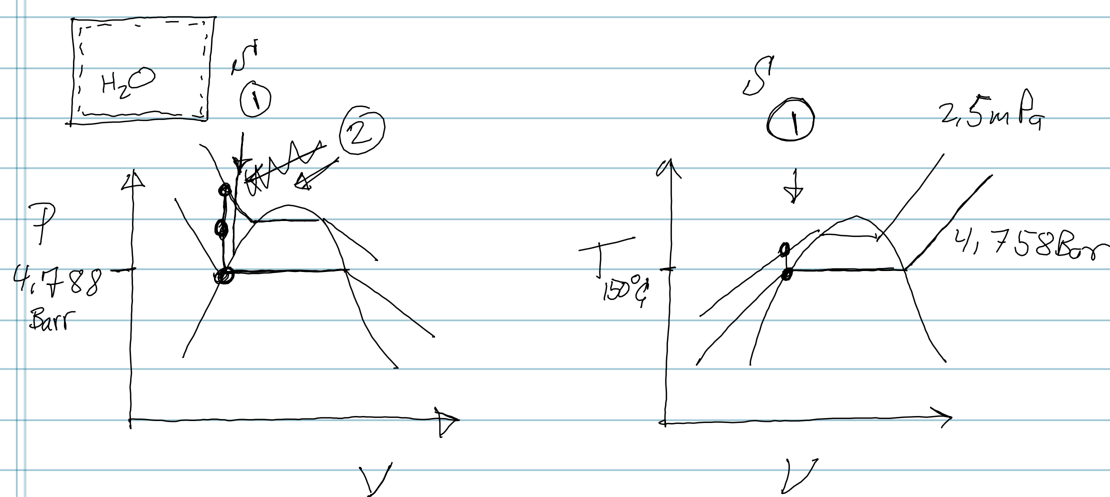
EXAMPLE

2000 Kg of water (initially saturated liquid)

AT 150°C heated in a closed, rigid, container

to $P_2 = 2.5$ mPa

FIND: T_2 [°C] & Volume of Tank [m^3]



Assume: $m_1 = m_2 = 2{,}000$ Kg

$V_1 = V_2$, $v_1 = v_2$

@ STATE 1:

$v_1 = v_f = 1.0905 \times 10^{-3}\ m^3/Kg$ @ $T = 150°C$

$T_2(v_2, P_2)$ A-5

$$\frac{T_2 - 140}{180 - 140} = \frac{1.0905 - 1.0784}{1.1261 - 1.0784}$$

$T_2 = 150.17\ °C$ //

Specific volume & mass will give volume

3.6 Evaluating Internal Energy and Enthalpy

$$H = U + pV$$

Enthalpy Internal energy Pressure · Volume

So;

$$h = u + pv \quad \left[\frac{KJ}{Kg}\right]$$

In Vapor dome:

$$u = u_f + x(u_g - u_f)$$

$$h = h_f + x(h_g - h_f)$$

$h_{fg} = h_g - h_f$

→ enthalpy of vaporization

$u_g - u_f$ → internal energy of vaporization

EXAMPLE

IF $P = 35$ bars & $h = 1,500$ KJ/kg

What is the state

$h_f = 1049.8$ KJ/kg

$h_g = 2803.4$ KJ/kg

$$x = \frac{h - h_f}{h_g - h_f} \quad \therefore \quad X = 0.25$$

→ 2 phase region

3.8 Applying Energy balance & Property tables

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

$$\Delta U = m(\Delta u)$$

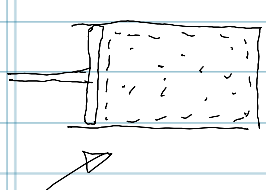
EXAMPLE → R134a is compressed in piston-cylinder assembly

No Heat Transfer from 30 psi, 20°F to 160 psi

$m = 0.04$ lbm

FIND: T_2

$W = -0.56$ BTU



W

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

assume zero

zero

$$m(u_2 - u_1) = -W$$

$u_1(T_1, P_1)$

$u_2(P_2, T_2)$

First, find u_1 check A-11E

$T_{SAT} = 15.38$°F

∴ we have vapor

A12E $\quad u_1 = 96.26 \ \frac{BTU}{lbm}$ @ 30 psi, 20°F

$$m u_2 - m u_1 = -W$$

$$u_2 = -\frac{W}{m} + u_1$$

. . .

$$u_2 = 110.26 \ \frac{BTU}{lbm}$$

Now Table A-12E for T_2 via interpolation

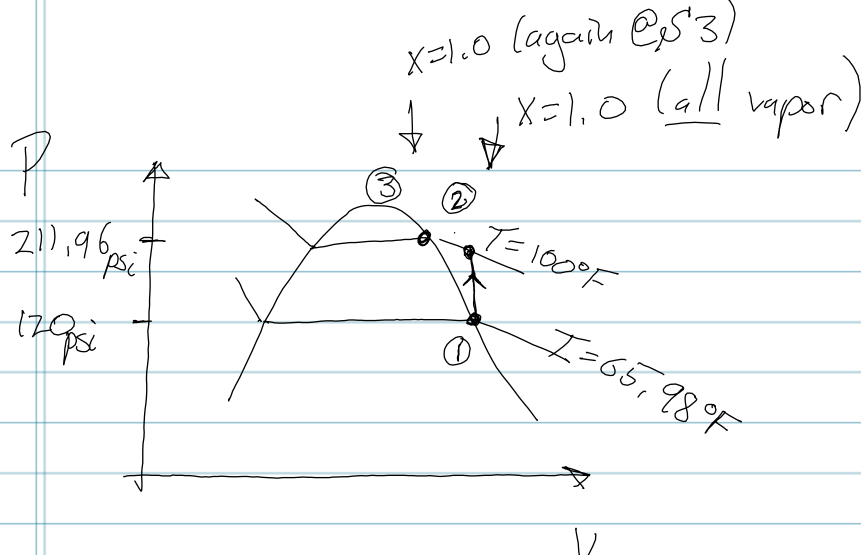
$T_2 =$

EXAMPLE Ammonia in a piston-cylinder assembly

Undergoes 2 processes $\quad Q_{23} = -98.9$ BTU

STATE 1	STATE 2	STATE 3
$P_1 = 120 \text{ Psi}$	$T_2 = 100°F$	$T_3 = T_2$
$x_1 = 1$	$V_2 = V_1$	$x_3 = 1$

FIND: Q_{12} AND W_{23}



$1 \to 2$ $\qquad \cancel{\Delta KE} + \cancel{\Delta PE} + \Delta U_{12} = Q_{12} - \cancel{W_{12}}$

assumed zero $\qquad\qquad$ zero by inspection

" "

$2 \to 3$ $\qquad \Delta U_{23} = Q_{23} - W_{23}$

@120psi x=1 sat. A14^E pg966

We need $u_1(P_1, x_1)$ $\qquad u_1 = 572.73$ BTU/lbm

@100°F $\quad = u_2(T_2, v_2)$ $\qquad v_1 = 2.4745$ ft³/lbm $\quad v_1(P_1, x)$

$u_3(T_3, x_3)$ $\qquad v_2 =$ " "

$T_3 = T_2$

@130 PSI 100°F

$v = 2.4824$ ft³/lb

$u = 589.33$ BTU/lbm

@140 psi T=100°F

$v = 2.2868$ ft³/lb

$u = 587.79$ BTU/lbm

via interpolation

@ $u_2 = 589.17$ BTU/lbm

@ STATE 3 T=100°F x=1

$u_3 = 576.51$ BTU/lb

A-13E

Thursday Sept 27, 2012

(continued): $\Delta U_{12} = Q_{12} - 0$

$$Q_{12} = m(u_2 - u_1)$$

$$= 2.2\,lb_m (589.17 - 572.73) \frac{BTU}{lb_m}$$

$$Q_{12} = 36.17\,BTU$$

Now

$$\Delta U_{23} = Q_{23} - W_{23}$$

$$W_{23} = Q_{23} - m(u_3 - u_2)$$

$$= -98.9\,BTU - 2.2\,lb_m (576.51 - 589.17\,BTU)$$

$$W_{23} = -71.05\,BTU$$

3.9 Specific Heat –

NOTE: $u(T, v)$ & $h(T, p)$

(specific heat)

$$c_v = \left(\frac{\partial u}{\partial T}\right)_v$$ → specific volume (held constant)

$$c_p = \left(\frac{\partial h}{\partial T}\right)_p$$

specific internal energy

specific internal enthalpy

$$\left[\frac{KJ}{Kg \cdot K}\right] \text{ OR } \left[\frac{BTU}{lb_m \, {}^\circ R}\right]$$

Specific Heat:

A-19 liquids & Solids

A-20 GASES

Fig 3.9 C_p for H_2O pg (118)

Specific heat ratio $K = \frac{C_p}{C_v}$ //

3.10 Incompressible substance model:

if v is approximately constant (liquids)

we call it "incompressable"

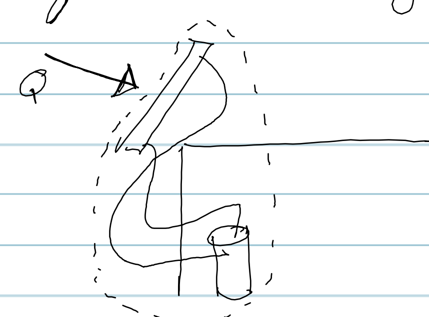
$$C_v(T) = du/dT \qquad c_p \approx c_v$$

EXAMPLE - a solar water heater is used to heat water

From 73.6°F to 101.7°F over a 90 minute period

FIND: Heat Transfer to H_2O [W] if volume = 20 gallons

Closed system



Example (continued)

Radiation*
↳ conduction
↳ convection → might affect a little

Closed system

Assume:
→ water is incompressible
→ Work is zero
→ ΔKE & $\Delta PE = 0$

1st law:

$$\underbrace{\Delta KE + \Delta PE}_{\text{ZERO}} + U = Q - \cancel{W} \rightarrow \text{assumed zero}$$

$Q = m\,\Delta u \longrightarrow \Delta u = C_p \Delta T$

use this assumption

$= m C \Delta T$

$=$

NOTE: $\frac{V}{v} = m = \frac{20 \text{ gallons}}{0.01609 \frac{ft^3}{lbm}}$

from $1 \text{ gallon} = 1.3368 \, ft^3$

$\therefore m = 166.2 \text{ lbm}$

Also $C = 0.9999 \frac{BTU}{lbm \, °R}$ TABLE A19E

$Q = m \cdot C \cdot \Delta T$

$= 166.2 \text{ lbm} \left(0.9999 \frac{BTU}{lbm \, °R} \right) \cdot (101.7 - 73.6) °R$

$= 4{,}665.5 \text{ BTU}$

$\dot{Q} = \frac{Q}{\Delta t} = \frac{4{,}665.5 \text{ BTU}}{1.5 \text{ hours}}$

$1 \text{ Wh} = 3.413 \text{ BTU}$

$\boxed{\dot{Q} = 911 \text{ W}}$

3.11 PVT Relationships For GASSES

R - Universal gas Constant

$$\bar{R} = \begin{cases} 8.314 \ KJ/Kmol\ °K \\ 1.986 \ BTU/lb_m mol\ °R \\ 1545 \ lb_f/lbmol\ °R \end{cases}$$

$\overline{\text{per}}$ molar units

Compressibility factor

$$Z = \frac{p\bar{v}}{\bar{R} \cdot T}$$

Unitless; Dimensionless

$\bar{v} = M v$ → M is molecular weight

$$Z = \frac{pv}{RT}$$

M → molecular weight

$$R = \frac{\bar{R}}{M}$$

TABLE A-1

3.11.3 Compressibility Chart

Reduced Pressure:

$$P_R = \frac{P}{P_c}$$ ← TABLE A-1

Reduced Temperature:

$$T_R = \frac{T}{T_c}$$ ←

Pseudoreduced specific volume –

$$v_R' = \frac{\bar{v}}{\bar{R}\left(\frac{T_c}{P_c}\right)}$$

OR

$$v_R' = \frac{v}{R\left(\frac{T_c}{P_c}\right)}$$

Tuesday Oct 2^{nd}, 2012

3.11.4 Equations of STATE

$$Z = 1 + \hat{B}(T)\cdot\rho + \hat{C}(T)\cdot\rho^2 + \hat{D}(T)\rho^3 + \ldots$$

Explicit in Helmholtz Energy

OUTDATED
- Van der Walls
- Benedict Webb Rubin (BWR)

3.12 Ideal Gas Model

when: $Z \approx 1.0$ $\qquad Z = \dfrac{PV}{RT}$

$P_R < 0.05$

$T_R > 1.5$ $\qquad$ *These things give us accuracy

(Use steam tables, mostly, for water vapor)

$PV = RT$ (specific volume)

$P\forall = mRT$ (molecular weight)

For Ideal Gasses:

$u = u(T)$ → Chapter 11

$h = u + pv = u(T) + RT \quad \therefore h(T)$

To evaluate u and h:

$$c_v = du/dT \qquad c_p = \frac{dh}{dT}$$

u

$du = c_v\, dT$

$$\int_1^2 du = \int_1^2 c_v(T)\, dT$$

$$\boxed{u_2 - u_1 = \int_1^2 c_v(T)\, dT}$$

h

$dh = c_p\, dT$

$$\int_1^2 dh = \int_1^2 c_p(T)\, dT$$

$$\boxed{h_2 - h_1 = \int_1^2 c_p(T)\, dT}$$

CASE 1

IF $c_v(T)$ and $c_p(T)$ are constant

$$\boxed{u_2 - u_1 = c_v(T_2 - T_1)}$$

$$\boxed{h_2 - h_1 = c_p(T_2 - T_1)}$$

CASE 2

FOR CASE 1: TABLE A-21 (pg 926) gives coefficients

T from 300K to 1000K

$$\frac{\bar{c}_p}{\bar{R}} = \alpha + \beta T + \gamma T^2 + \delta T^3 + \varepsilon T^4$$

$$h_2 - h_1 = \int_1^2 \qquad dT$$

For Case 2 C_p & C_v are constant

$\Delta u = C_v \Delta T$

C_v & C_p Table A-20

$\Delta h = C_p \Delta T$

$T_{AVG} = \frac{T_1 + T_2}{2}$ → dictates C_v or C_p (from table)

→ you can start here to see if it's a good assumption

$$\boxed{C_p = C_v + R}$$

$$K = \frac{C_p(T)}{C_v(T)} \qquad C_p = \frac{KR}{K-1} \qquad C_v = \frac{R}{K-1}$$

*Use in homework

Special Case → monatomic gasses (one-molecule)

Noble Gasses

↳ atoms are not bound to each other

Ar, Ne, He

$$C_p = \frac{5}{2} R$$

$$C_v = C_p - R = \frac{3}{2} R$$

EXAMPLE → p/c - A

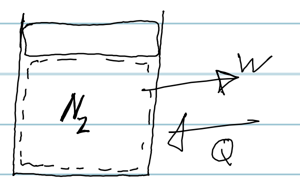
$\forall = 0.1 m^3$ Nitrogen @ 150 KPa

& 27°C

Compressed to

$P_2 = 1 MPa$ $T = 150°C$ $W = 20 KJ$

FIND: Q



STATE 1	STATE 2
$\forall = 0.1 m^3$	
$P_1 = 150 KPa$	$P_2 = 1 MPa$
$T = 27°C$	$T_2 = 150°C$

1st Law: $\underbrace{\Delta KE}_{zero} + \underbrace{\Delta PE}_{zero} + \Delta U = Q_{12} - W_{12}$

$m(u_2 - u_1) = Q_{12} - W_{12}$

We can use tables or shortcuts

$m = \frac{P \forall}{R T}$ using state 1: $\frac{1 J}{1 N \cdot m} \bigg| \frac{1 N}{1 Pa\, m^2}$

$$m = \frac{150 kPa}{298.15 K} \bigg| \frac{0.1 m^3}{} \bigg| \frac{Kmol \cdot K}{8.314 KJ} \bigg| \frac{28 kg}{Kmol}$$

$m = 0.1695 Kg$

Method 1 (Tables)

@ $T_1 = 300K$ $\quad \bar{u}_1 = 6{,}229 \frac{KJ}{Kmol}$

@ $T_2 = 423 K$ $\quad \bar{u}_2 = 8796 \frac{KJ}{Kmol}$

TABLE A-23 (interpolation)

$$Q = m(u_2 - u_1) + W$$

$$= 0.1695 Kg \left| \frac{(8796 - 6229) KJ}{Kmol} \right| \frac{Kmol}{28.01\ Kg} \bigg| + 20 KJ$$

$$\boxed{Q = 35.5 KJ}$$

Method 2 (Assume Constant C_v)

$T_{avg} = 361.5 K$ $\quad C_v = 0.745 \frac{KJ}{Kg\,K}$ $\quad$ Table A-20 pg 925

$$\Delta u = C_v \Delta T$$

$$Q = m(C_v \Delta T) + W$$

$$= 0.1695 Kg \left(0.745 \frac{KJ}{Kg\,K} \left(123\ K \right)\right) + 20 KJ$$

$$\boxed{Q = 35.5 KJ}$$

3.15 Polytropic PROCESS Relationships

$PV^n = \text{constant}$ Polytropic

$-\infty < n < \infty$

$$W = \int P\,d\forall = \frac{P_2\forall_2 - P_1\forall_1}{n-1} \qquad n \neq 1$$

$$= p_1 V_1 \ln\left(\frac{V_2}{V_1}\right) \qquad n = 1$$

Now, ONLY FOR IDEAL GASSES:

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{(n-1)}{n}} = \left(\frac{V_1}{V_2}\right)^{n-1}$$

$$\int_1^2 p\,d\forall = \frac{mR(T_2 - T_1)}{1-n} \qquad n \neq 1$$

$$mRT \ln\left(\frac{V_2}{V_1}\right) \qquad n = 1$$

Work in terms of Temperature

EXAMPLE

CO_2 gas @ $T_1 = 530°R$

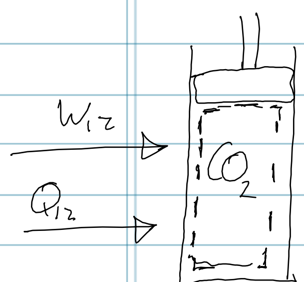
$P_1 = 15$ psi

$\forall = 1 ft^3$

Compressed to $\rightarrow$ via $pv^{1.2} = \text{constant}$

Work to gas $= 45 \frac{BTU}{lb_m}$

FIND: T_2 [°R] & Q [BTU/lb]



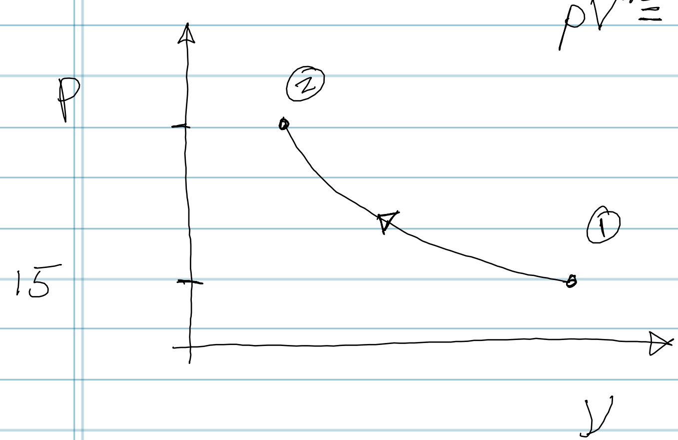
STATE 1

$T_1 = 530°R$
$P_1 = 15$ psi
$\forall = 1 ft^3$

STATE 2

$T_f =$

$pv^{1.2} = P_2 V_2^{1.2}$



$$\cancel{\Delta KE} + \cancel{\Delta PE} + \Delta U = Q_{12} - W_{12}$$

$$\int_1^2 p\,dV = \frac{mR(T_2 - T_1)}{1-n} = W_{12}$$

$$T_2 = \left(\frac{1-n}{R}\right)\frac{W}{m} + T_1$$

$$T_2 = \left(\frac{1-1.2}{1545\,ft\,lb_f}\right) lbmol\,°R\ \frac{44.01\,lbm}{lbmol}\left|\frac{-45\,BTU}{1\,lbm}\right|\ \frac{778\,ft\,lb_f}{1\,BTU}\right| + 530$$

$$T_2 = 729.5°R$$

TABLE A-23E

@ 530°R $\quad \bar{u}_1 = 2916.1 \frac{BTU}{lbmol}$

@ 729.5°R $\quad \bar{u}_2 = 4394.0 \frac{BTU}{lbmol}$

$$\frac{Q}{m} = (u_2 - u_1) + \frac{W}{m}$$

$$\frac{Q}{m} = \left(\frac{\bar{u}_2 - \bar{u}_1}{M}\right) + \frac{W}{m}$$

$$\frac{Q}{m} = (4394.0 - 2916.1)\frac{BTU}{\cancel{lbmol}}\left|\frac{\cancel{lbmol}}{44.01\,lbm}\right. - \frac{45\,BTU}{lbm}$$

$$\frac{Q}{m} = -11.412\,\frac{BTU}{lbm}$$

Thursday Oct 4th, 2012

PROBLEM STRATEGY: CH 1-3

1. Define Problem (sketch)
   ↳ system boundry
   ↳ W, Q crossing boundry

2. Draw Pv & PT Diagram

3. Fix the states → two properties per state
   ↳ list knowns and unknowns at each state

4. Conservation of Energy

5. Write constitutive equations

$$W = \int P \, d\forall$$

$$\Delta U = m(u_2 - u_1)$$

$\Delta KE, \Delta PE$, Ideal gas law

↳ $\Delta u = C_v \Delta T$

$\Delta h = C_p \Delta T$

Compressibility

Polytropic

6. Identify knowns and unknowns → Identify Property look-ups

7. CALCULATE (rigor can save you time!!!)

Chapter 4

Here we begin open systems.

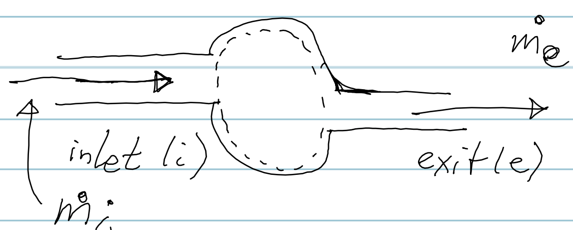
CLOSED SYSTEM		Open System
Conservation of Mass	m = constant ✓	Chapter 4
Conservation of Energy	$\Delta KE + \Delta PE + \Delta U = Q - W$ ✓	Chapter 4
	Chapter 2	

1/2 semester

2nd Law	Chapter 5 & 6	Chapter 5 & 6

Control Volume Analysis (open systems)

4.1 Conservation of Mass



Conservation of Mass

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

$\frac{dm_{cv}}{dt}$ → rate of change (of mass) in control volume

$\dot{m}_i$ → mass flow rate-in

$\dot{m}_e$ → mass flow rate-out

Multiple in's & outs.

$$d\,m_{cv}/dt = \sum \dot{m}_i - \sum \dot{m}_e$$

For 1-D Flow (Pipe Flow)

$$\dot{m} = \underset{\text{density}}{\rho} \cdot \underset{\text{Area}}{A} \cdot \underset{\text{velocity}}{V}$$

$$\dot{m} = \frac{AV}{v}$$ → specific volume

Conservation of Mass:

$$dm_{cv}/dt = \sum_i \rho A_i V_i - \sum_e \rho A_e V_e$$

If we have steady-state:

$$dm_{cv}/dt = 0 \qquad \text{(no storage)}$$

We now get:

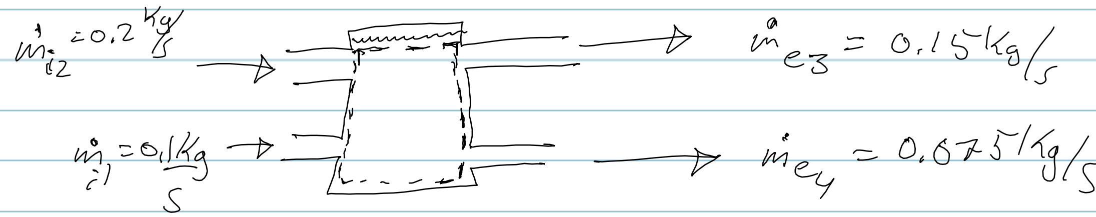
$$0 = \sum_i \dot{m}_i - \sum_e \dot{m}_e$$

Not Steady-State: Transient Analysis

$$\frac{dM_{cv}}{dt} \neq 0$$

$\Rightarrow$ start-up / shut-down (transient effect)
$\Rightarrow$ emptying or filling containers

Example:



Is this steady state?

Conservation of mass:

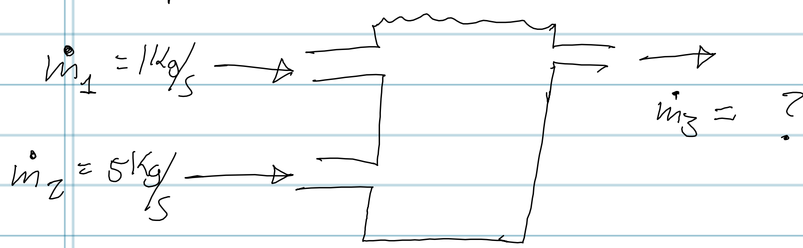
$$\sum_i \dot{m}_i \overset{?}{=} \sum_e \dot{m}_e$$

$$\dot{m}_1 + \dot{m}_2 - \dot{m}_3 - \dot{m}_4 \overset{?}{=} 0$$

$$\text{"} \qquad \text{"} \qquad = 0.075\ \frac{kg}{s} //$$

$\hookrightarrow$ not steady state, transient //

EXAMPLE:

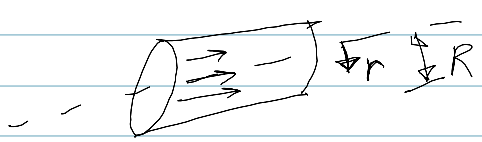


Assume: ▫ steady state (also ~~not~~ overflowing)

$\therefore \quad \dot{m}_3 = 6\,\mathrm{Kg/s}$ // b/c $\dot{m}_1 + \dot{m}_2 - \dot{m}_3 = 0$

✓ ✓ ↑ ✓

EXAMPLE



$V = 1\,\mathrm{m/s}$

$A = \frac{\pi}{4} D^2$

given: steady state

$D = 0.2\,\mathrm{m}$

Find: $\dot{m}$

$$\dot{m} = \frac{\pi (0.2\,\mathrm{m})^2}{4} \left(\frac{1\,\mathrm{m}}{\mathrm{s}}\right) \left(\frac{1{,}000\,\mathrm{Kg}}{\mathrm{m}^3}\right)$$

$$\dot{m} = 31.4\,\frac{\mathrm{Kg}}{\mathrm{s}} \;//$$

Now imagine velocity is a function of radius.

$$V(r) = \left(1 - \frac{r^2}{R^2}\right)$$

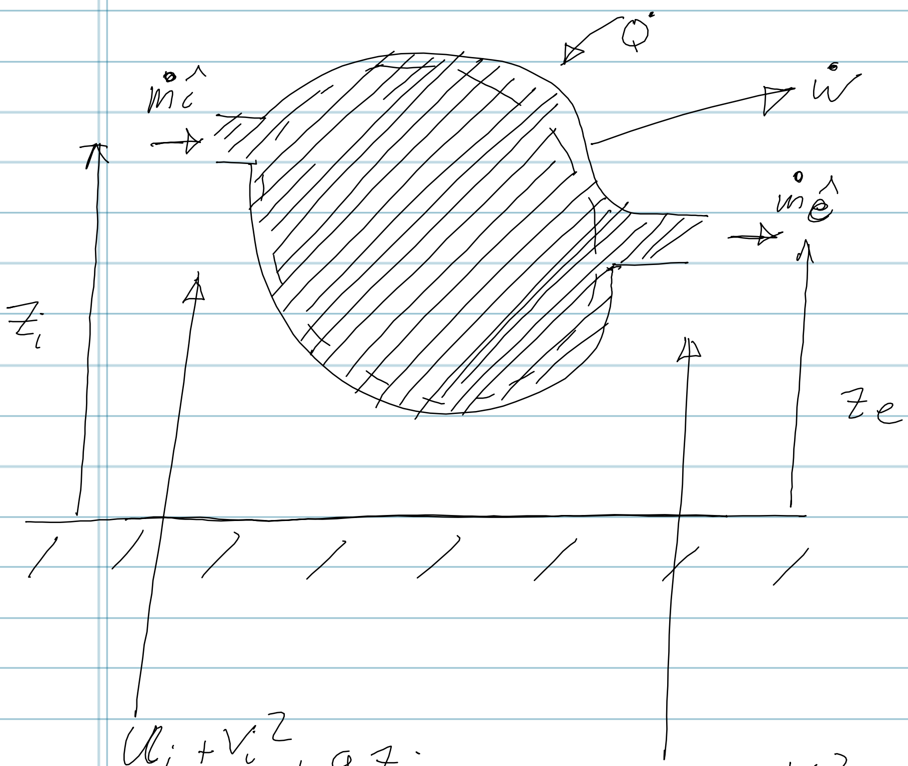
$$A = \pi r^2$$

$$\dot{m} = \int \rho \cdot V \cdot dA \quad \Rightarrow \quad dA = 2\pi r\, dr$$

$$\dot{m} = \rho \int_0^R \left(1 - \frac{r^2}{R^2}\right) \cdot 2 \cdot \pi \cdot r\, dr = 2\pi\rho \int_0^R \left(r - \frac{r^3}{R^2}\right) dr$$

$$\boxed{\dot{m} = 15.71\,\mathrm{Kg/s}} \;//$$

Conservation of Energy in Open Systems



$u_i + \frac{V_i^2}{2} + g z_i$

$u_e + \frac{V_e^2}{2} + g z_e$

1-inlet & 1 Exit

internal energy, Kinetic Ergy, Potential energy

$$\underbrace{dE_{cv}/dt}_{\text{rate of change of energy in the control volume (c.v.)}} = \dot{Q} - \dot{W} + \dot{m}_i \left(u_i + \frac{V_i^2}{2} + g z_i\right)$$

$$- \underbrace{\dot{m}_e \left(u_e + \frac{V_e^2}{2} + g z_e\right)}_{\text{rate of energy transfer out of system (c.v.) based on mass flow}}$$

enthalpy change $\rightarrow$ open system

Flow Work

$\hookrightarrow$ defines the work done by Fluid

$$\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \dot{m}_i\left(u_i + p_i v_i + \frac{V_i^2}{2} + g z_i\right)$$

$$- \dot{m}_e\left(\underbrace{u_e + p_e v_e}_{h_e} + \frac{V_e^2}{2} + g z_e\right)$$

$h = u + P_v$

So; Now (open systems have Δenthalpy)

$$\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \dot{m}_i\left(h_i + \frac{V_i^2}{2} + g z_i\right)$$

$$- \dot{m}_e\left(h_e + \frac{V_e^2}{2} + g z_e\right)$$

4.5 Open systems @ STEADY STATE

Conservation of mass.

if $\frac{dm_{cv}}{dt} = 0$ STEADY STATE

Conservation of Energy $\frac{dE_{cv}}{dt} = 0$

Reduced Equations

$$0 = \sum_i \dot{m}_i - \sum_e \dot{m}_e$$

$$0 = \dot{Q}_{cv} - \dot{W}_{cv} + \sum_i \dot{m}_i \left(h_i + \frac{V_i^2}{2} + g z_i\right) - \sum_e \dot{m}_e \left(h_e + \frac{V_e^2}{2} + g z_e\right)$$

One in-let, one out-let, $\dot{m}_i = \dot{m}_e$ (steady)

$$0 = \dot{Q}_{cv} - \dot{W}_{cv} \quad \dot{m}\left[(h_1 - h_2) + \frac{V_1^2 - V_2^2}{2} + g(z_1 - z_2)\right]$$

(careful w/ 1 & 2, here it's inlet & outlet)

Tuesday Oct 9th, 2012

4.5 Analysis of Control Volume @ Steady State

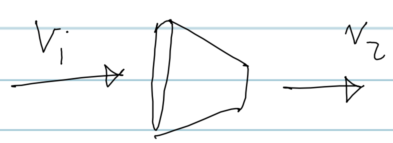
$$\frac{dm_{cv}}{dt} = 0 \qquad\qquad \frac{dE_{cv}}{dt} = 0$$

Conservation of Mass $\quad \sum_i m_i = \sum_e m_e \quad$ 4.6 pg 175

4.18 pg 175 Conservation of Energy

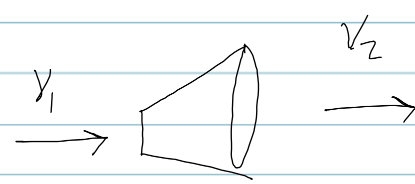
$$0 = \dot{Q}_{cv} - \dot{W}_{cv} + \sum_i \dot{m}_i \left(h_i + \frac{V_i^2}{2} + g z_i\right) - \sum_e \dot{m}_e \left(h_e + \frac{V_e^2}{2} + g z_e\right)$$

4.6 Nozzles and Diffusers



Nozzle

$V_2 > V_1$



Diffuser

$V_2 < V_1$

EXAMPLE

Air enters an uninsulated nozzle @ STEADY STATE

760°R w/ neglidgable velocity

EXIT:

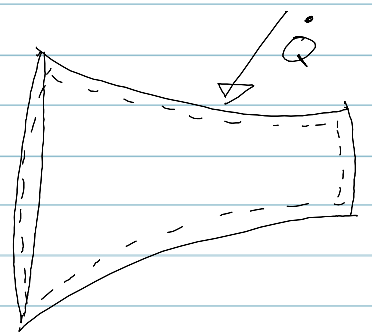
520°R @ V = 1,500 ft/s

Assume: Ideal Gas behavior and neglect Potential Energy

FIND: $\frac{Q}{m}$ (heat transfer per unit mass) $\left[\frac{BTU}{lbm}\right]$

AIR

T = 760°R
V = 0



T = 520°R
V = 1,500 ft/s

STEADY-STATE FORM

Conservation of Mass

$$\underbrace{\frac{dm_{cv}}{dt}}_{0 \text{ (steady state)}} = \dot{m}_1 - \dot{m}_2 \quad \therefore \quad \dot{m}_1 = \dot{m}_2$$

Conservation of Energy

$$\underbrace{\frac{dE_{cv}}{dt}}_{0 \text{ (steady state)}} = \dot{Q} - \underbrace{\dot{W}}_{0 \text{ nozzle/diffuser}} + \dot{m}_1\left(h_1 + \underbrace{\frac{V_1^2}{2}}_{0 \text{ (given)}} + \cancel{g z_1}\right)$$

$$- \dot{m}_2\left(h_2 + \frac{V_2^2}{2} + \cancel{g z_2}\right)$$

neglect (given)

Simplify Conservation of Energy

$$0 = \dot{Q} + \dot{m}\left[(h_1 - h_2) - \frac{V_2^2}{2}\right]$$

$h_1(T_1)$ → ideal gas

$h_2(T_2)$

$$-\frac{\dot{Q}}{\dot{m}} = h_1 - h_2 - \frac{V_2^2}{2}$$

$$\frac{\dot{Q}}{\dot{m}} = (h_2 - h_1) + \frac{V_2^2}{2}$$

$h_1 = 182.08 \ \frac{BTU}{lb}$ TABLE A-22E

$h_2 = 124.27 \ \frac{BTU}{lb}$

$$\frac{Q}{m} = \left(-57.81 \ \frac{BTU}{lb}\right) + \frac{1}{2}(1{,}500 \ ft/s)^2 \left|\frac{lbf \ s^2}{32.2 \ ft \ lbm}\right|\frac{1 \ BTU}{778 \ ft \cdot lbf}$$

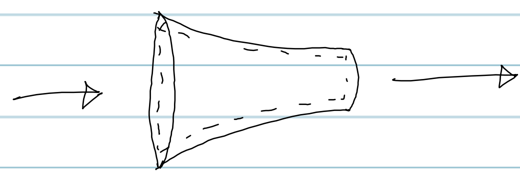
$$\boxed{\frac{Q}{m} = -12.9 \ BTU/lb}$$

EXAMPLE

Steam enters a nozzle @ $\frac{1}{2}$ MPa & 200°C. IT leaves @ 0.15 MPa & V = 600 m/s

(NOZZLE is well insulated)

FIND: T_f



$T_e = ?$

$P_e = 0.15$ MPa

$V_e = 600$ m/s

$T_i = 200°C$

$P_i = 0.5$ MPa

$V_i = 50$ m/s

Assume: steady state

Cons. Mass: $\underbrace{\frac{dM_{cv}}{dt}}_{\text{zero for steady state}} = \dot{m}_i - \dot{m}_e$

Cons. Energy: $\underbrace{\frac{dE_{cv}}{dt}}_{\text{zero for steady state}} = \dot{Q}_{cv} - \dot{W}_{cv} + \dot{m}_i\left(h_i + \frac{V_i^2}{2} + g z_i\right) - \dot{m}_e\left(h_e + \frac{V_e^2}{2} + g z_e\right)$

"well-insulated"

nozzles & diffusers

neglected

$\dot{m}_i = \dot{m}_e$
(cancel)

simplifying

$$\left(h_i + \frac{V_i^2}{2}\right) = \left(h_e + \frac{V_e^2}{2}\right)$$

TABLE A-4)

$h_i = 2855.4 \frac{kJ}{kg}$

$\therefore h_e = h_i + \frac{1}{2}(V_i - V_f)$

$h_i(T_i, P_i)$

$h_e(T_f, P_f)$

$h_e = 2855.4 \frac{kJ}{kg} + \frac{1}{2}(50^2 - 200^2) \cdot \frac{1}{10^3}$

$h_e = 2676.65 \frac{kJ}{kg}$ $\Longrightarrow$

TABLE A-4

@ $P = 1.5$ bar

$h_{SAT} = 2693.6 \frac{kJ}{kg} > h_e \; 2676.65 \frac{kJ}{kg}$

$\therefore$ 2-phase

Table A-3

$h_f = 467.11 \frac{kJ}{kg}$

$h_g = 2693.6 \frac{kJ}{kg}$

$T_{SAT} = 111.4°C$

(quality will be close to 1)

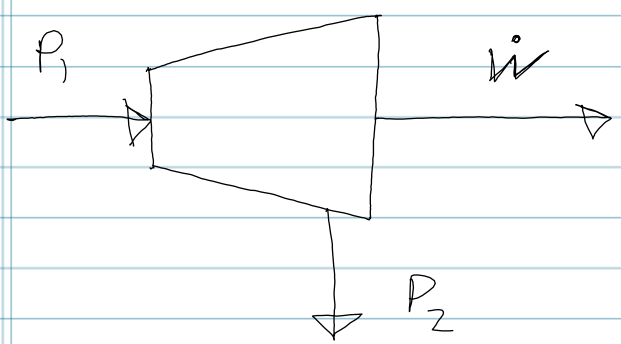
$$X = \frac{h - h_f}{h_g - h_f}$$

$$= \frac{2676.65 - 467.11}{2693.6 - 467.11}$$

$$\boxed{\begin{aligned} T_e &= 111.4°C \\ X &= 0.99 \end{aligned}}$$

$\rightarrow$ b/c we are in 2-phase region

4.7 Turbines



$P_2 < P_1$

$\dot{W} > 0$

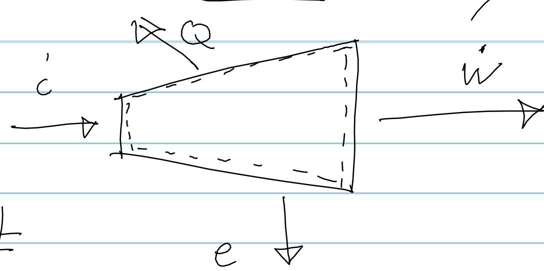
generally desired

EXAMPLE Mass flow rate of Steam is 1.5 Kg/s

Heat transfer from the turbine is 8.5 Kw

Assume: steady state

FIND: WORK



inlet:	exit
$P_i = 2 MPa$	$P_e = 0.1 MPa$
$T_i = 360°C$	$x = 1.0$

$$\frac{dM_{cv}}{dt} = \dot{m}_i - \dot{m}_e = 0$$

"steady"

$$\frac{dE_{cv}}{dt} = \dot{Q} - \dot{W} + \dot{m}_i\left(h_i + \frac{V_i^2}{2} + gz_i\right) - \dot{m}_e\left(h_e + \frac{V_e^2}{2} + gz_e\right)$$

"steady"

zero

assumed here

$\Longrightarrow$

$h_i (T_i, P_i)$

$h_e (P_e, X_e)$

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

Simplify

$$0 = \dot{Q} - \dot{W} + \dot{m}(h_i - h_e)$$

@ $P = 20\,bar$ $T = 360°C$

Table A-4 ∴ $h_i = 3159.3 \frac{KJ}{Kg}$ → pg 896

1 bar $x = 1.0$

@ $h_e = 2675.5 \frac{KJ}{Kg}$ → pg 895

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

$$\dot{W} = -8.5\,KW + 1.5 \frac{\cancel{Kg}}{s} (3{,}159.3 - 2{,}675.5) \frac{KJ}{\cancel{Kg}}$$

$$\boxed{\dot{W} = 717.5\,KW}$$

IF $V_i = 50\,m/s$ $V_e = 290\,m/s$

$$0 = \dot{Q} - \dot{W} + \dot{m}\left(h_i + \frac{V_i^2}{2}\right) - \dot{m}\left(h_e + \frac{V_e^2}{2}\right)$$

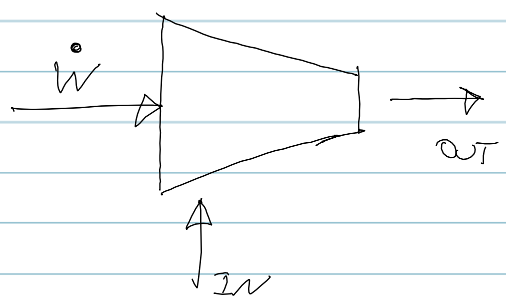
$$\dot{W} = 656\,KW$$

Thursday Oct 11th, 2012

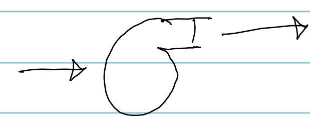
4.8 Compressors & Pumps

Compressors: Do Work on Gas

Pumps: Do Work on Liquid



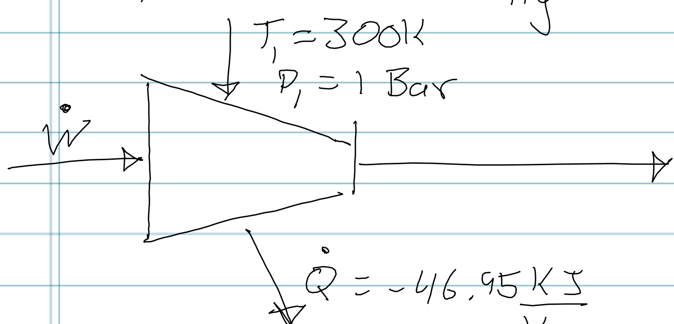
$P_2 > P_1$



Example: Air is Compressed w/ $Pv^{1.27} = C$

$\dot{Q} = -46.95 \frac{kJ}{kg}$ (To the surroundings) Find: $\dot{W}$

$\dot{m} = 4 kg/s$



$P_2 = 6$ bar

$T_2 = ?$

1. Cons Mass
2. Cons Energy

1. $\cancel{\frac{dM_{cv}}{dt}} = \dot{m}_1 - \dot{m}_2 = \dot{m}$

K.E. neglected

$$2.\ \cancel{\frac{dE_{cv}}{dt}} = \dot{Q} - \dot{W} + \dot{m}_1\left(h_1 + \cancel{\frac{V_1^2}{2}} + \cancel{gz_1}\right) - \dot{m}\left(h + \cancel{\frac{V^2}{2}} + \cancel{gz_2}\right)$$

neglect

$$\dot{W} = \dot{Q} + \dot{m}(h_1 - h_2)$$

$h_1(T_1, P_1)$ $\quad h_2(P_1, \ \ )$ now what?

...

IF we assume an ideal gas

w/ the Polytropic information we know

$$\longrightarrow \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{(n-1)}{n}} \quad \text{(all is known)}$$

pg 141 Eq 3.56

$T_2 = 439.1\,K$

TABLE A-22 pg 927

@ 300 K $\quad h = 300.19 \frac{KJ}{Kg}$

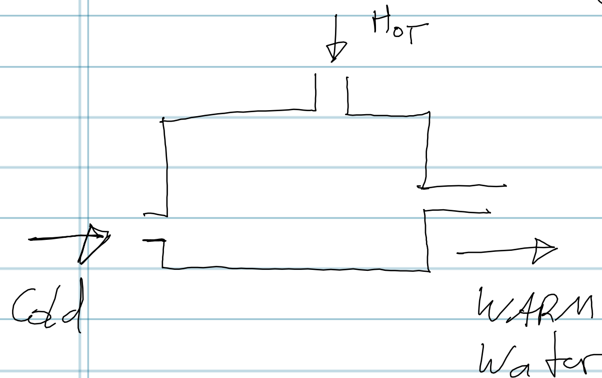
@ 439.1 K $\quad h = 440.69 \frac{KJ}{Kg}$

$$\dot{W} = \dot{Q} + \dot{m}(h_1 - h_2)$$

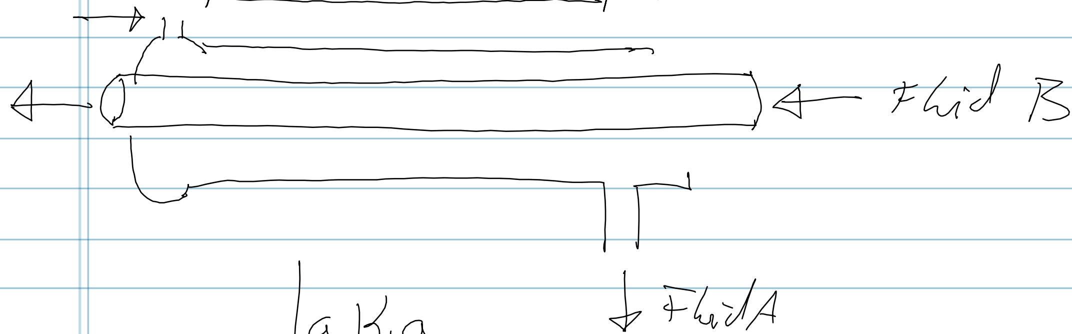
$$= -46.95 \frac{KJ}{KG} \Big| \frac{4\,Kg}{s} + \frac{4\,Kg}{s}(300.19 - 440.7)\frac{KJ}{KG}$$

$\dot{W} = -750\,KW$

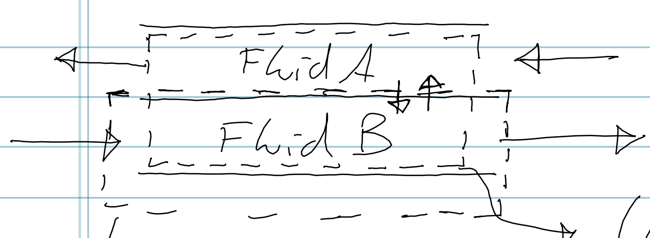
4.9 Heat Exchangers



Pipe within a Pipe



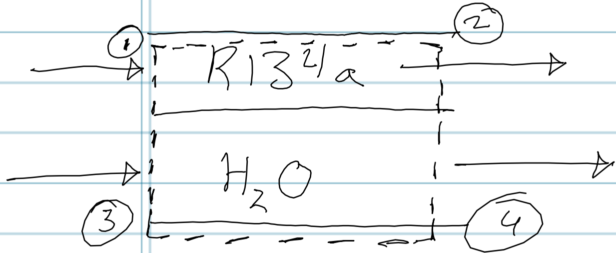
a.k.a.



Control Volume option 1 (Both Fluids)
(No Work, No Q)

Control Volume option 2 (One Fluid)
(There we will have Q)

EXAMPLE



@ 1 $P_1 = 10$ Bar
$T_1 = 80°C$

@ 2 Liquid
$P_2 = 9$ Bar
$T_2 = 34°C$

$\dot{m}_R$ (refridgerant) $= 0.16 \frac{Kg}{s}$

@ 3 $T_3 = 10°C$ 4 $T_4 = 20°C$

FIND: $\dot{m}_{H_2O}$ [Kg/s]

1. Conservation of Mass $\cancel{\frac{dM_{cv}}{dt}} = \dot{m}_1 - \dot{m}_2 + \dot{m}_3 - \dot{m}_4$

assume steady   in   in

No mixing: $\dot{m}_1 = \dot{m}_2 = \dot{m}_R$
$\dot{m}_3 = \dot{m}_4 = \dot{m}_{H_2O}$

2. Cons. of Energy

no work   neglected

$$\cancel{\frac{dE_{cv}}{dt}} = \dot{Q} - \cancel{\dot{W}} + \sum_i \dot{m}_i \left(h_i + \cancel{\frac{V_i^2}{2}} + \cancel{g z_i} \right) - \sum_e \dot{m}_e \left(h_e + \cancel{\frac{V_e^2}{2}} + \cancel{g z_e} \right)$$

steady

zero based on control volume situation

$$0 = \dot{m}_R h_{R_1} + \dot{m}_w h_{w_3} - \dot{m}_R h_{R_2} - \dot{m}_w h_{w_4}$$

$$\dot{m}_R (h_{R_1} - h_{R_2}) = \dot{m}_w (h_{w_3} - h_{w_4})$$

$h_{R_1}(T_1, P_1)$ $\qquad$ $h_w(T_3, ?)$

$h_{R_2}(T_2, P_2)$ $\qquad$ $h_w(T_4, ?)$

$$\Delta h = C_p \Delta T$$

C_p & C_v are constant when fluid is incompressible

$$C_p = 4.179 \frac{KJ}{Kg\,K}$$

A-19 pg 924 @ 300K

$$h_{w_3} - h_{w_4} = 4.179 \frac{KJ}{KGK} \underbrace{(-10K)}_{T_3 - T_4}$$

$$= -41.79 \frac{KJ}{Kg}$$

R134a

INLET	EXIT
@ P = 10 BAR $\quad$ T = 80°C	@ P = 9 BAR $\quad$ T = 34°C
$h_{R_1} = 313.20 \frac{KJ}{Kg}$ $\quad$ A-12	(liquid)
	$h(T,P) \approx h_f(T) + v_f(T)[P - P_{sat}]$
	Eq 3.13 pg 119

$$h(T,P) \approx h_f(T) + v_f(T)\left[P - P_{SAT}(T)\right] \quad \text{Eq } 3.13$$

$$\left.\begin{aligned} h_f(T) &= 97.31 \ KJ/Kg \\ v_f(T) &= 0.953 \cdot \times 10^{-3} \ m^3/Kg \end{aligned}\right\} \text{Table A-10 \& A-11}$$

$P_{SAT} = 8.625$ BAR @ 80°C

$$h_{R_2} = 97.31 \frac{KJ}{Kg} + 0.853 \cdot 10^{-3} \frac{m^3}{Kg} \left((9 - 8.625) Bar\right)\left(\frac{10^5 N}{BAR \ m^2}\right)\left(\frac{KJ}{10^3 N \cdot m}\right)$$

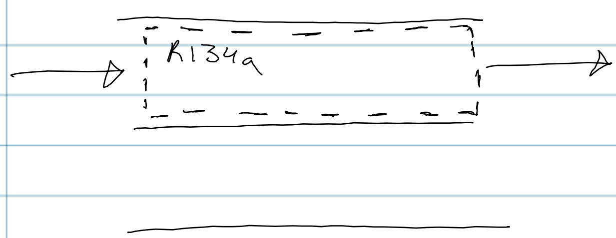
$$h_{R_2} = 97.34 \frac{KJ}{Kg}$$

$$\dot{m}_W = \frac{\dot{m}_R \left(h_{R_1} - h_{R_2}\right)}{-\left(h_{W_2} - h_{W_4}\right)}$$

$$= \frac{0.016 \ Kg}{s} \left| \frac{(313.2 - 97.34) \ KJ}{Kg} \right| \frac{Kg}{(-(-41.79)) \ KJ}$$

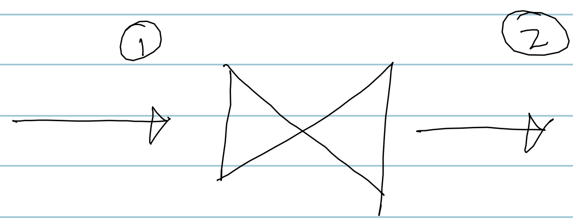
$$\dot{m}_W = 0.0826 \frac{Kg}{s}$$

Now IF They want Q



$$\cancel{\frac{dE_{cv}}{dt}} = \dot{Q} - \cancel{\dot{W}} + \dot{m}_R \left(h_1 - h_2 \right)$$

4.10 Throttling Devices (Valves)



$P_2 < P_1$

→ No Work
→ No Heat Transfer

Cons. of Energy:

$$\frac{dE_{cv}}{dt} = \dot{Q} - \dot{W} + \dot{m}_1 \left(h_1 + \frac{V_1^2}{2} + g z_1 \right) - \dot{m}_2 \left(h_2 + \frac{V_2^2}{2} + g z_2 \right)$$

steady

99% Nope

Never Work

neglected

IF $\Delta KE = 0$

$h_1 = h_2$

Tuesday Oct 23rd, 2012

QUIZ 2 Thursday
Open Book
Closed NOTES

Homework due Next Tuesday
last stuff on Test

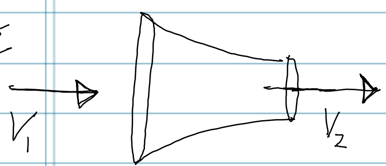
EXAM: Ch 3
Ch 4

Short Review:

SYSTEM

Reduced Conv of Energy

NOZZLE

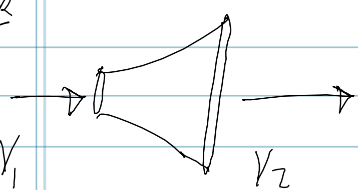


$$0 = \dot{Q} + \dot{m}\left[(h_1 - h_2) + \left(\frac{V_1^2}{2} - \frac{V_2^2}{2}\right)\right]$$

$\dot{Q}$: often canceled

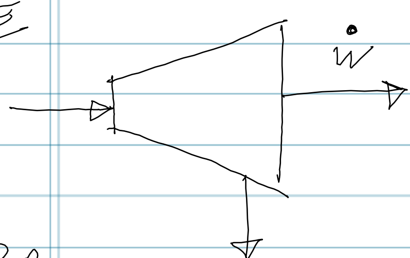
$\dot{m}$: steady state

DIFFUSER



$$0 = \dot{Q} + \dot{m}\left[(h_1 - h_2) + \left(\frac{V_1^2}{2} - \frac{V_2^2}{2}\right)\right]$$

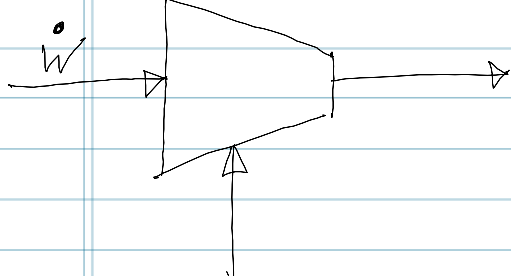
TURBINE



$$\dot{W} = \dot{m}\left(h_1 - h_2 + \frac{V_1^2}{2} - \frac{V_2^2}{2}\right)$$

often: $\dot{W} = \dot{m}(h_1 - h_2)$

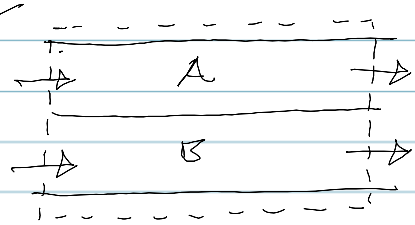
Compressor/Pump



$$0 = \dot{Q}_{cv} - \dot{W}_{cv} + \dot{m}(h_1 - h_2)$$

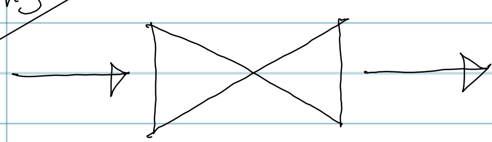
usually

Heat Exchanger



$$0 = \dot{m}_A \Delta h_A + \dot{m}_B \Delta h_B$$

Expansion Valve
OR Throttling - Valve



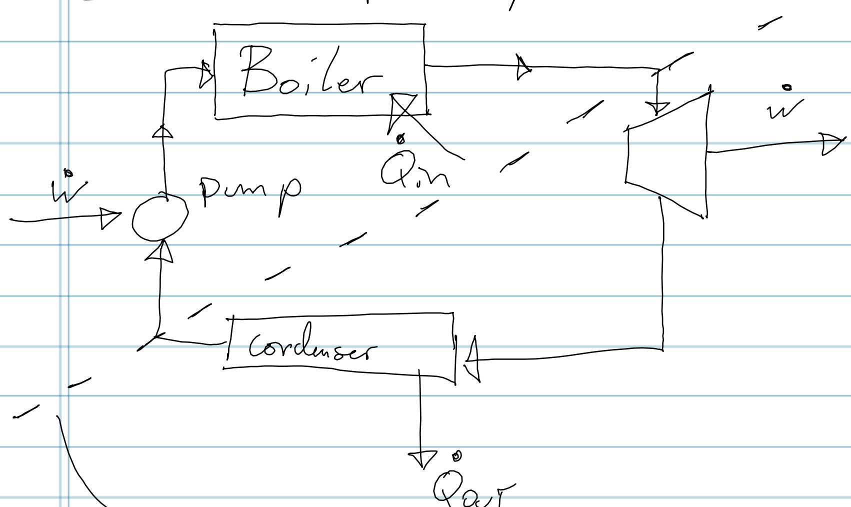
$$h_1 = h_2$$

4.11 System Integration

- Combining Components into a Larger system
- Analysis of total system

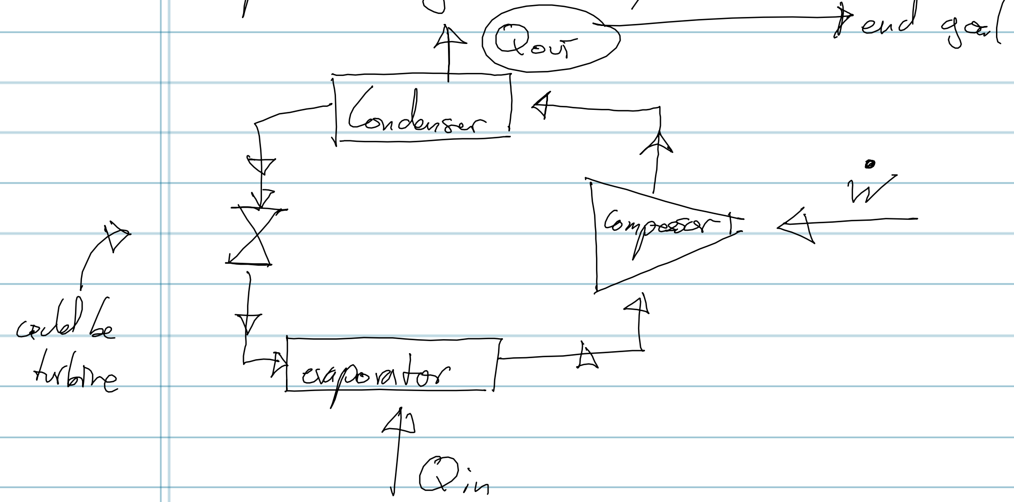
EXAMPLE: Sample Vapor Power Plant

END GOAL

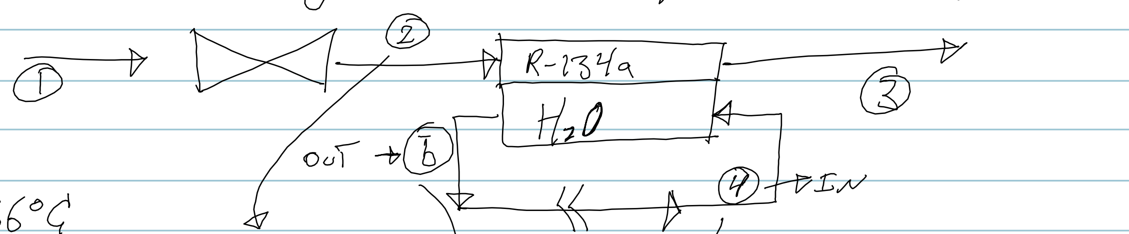


NOTICE The Symmetry

Simple Refrigeration System



EXAMPLE: Throttling valve in series w/ heat exchanger



$T_1 = 36°C$
$\dot{m}_1 = 0.26\ Kg/s$
SAT. LIQUID

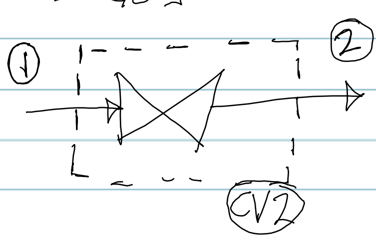
$T_2 = -8°C$

$T_5 = 10°C$
Liquid H_2O

$T_4 = 20°C$
Liquid H_2O

$P_3 = P_2$
Sat. Vapor

FIND: P_2 & $\dot{m}_{H_2O}$
[KPa] [Kg/s]



Consv. Mass

$\dot{m}_1 = \dot{m}_2 = \dot{m}$

$\frac{dM_{cv}}{dt} = \dot{m}_1 - \dot{m}_2$

STEADY

Consv. Energy

$\frac{dE_{cv}}{dt} = \dot{Q} - \dot{W} + \dot{m}(h_1 - h_2)$

steady

zero

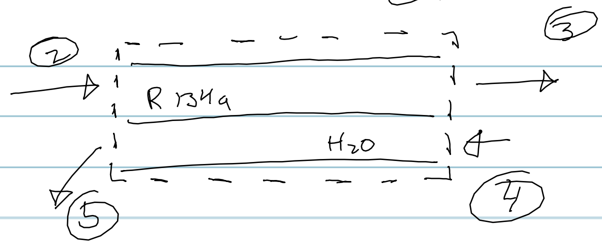
K.E. & P.E. are zero

$\therefore h_1 = h_2$

$h_1(T_1\ X)$
$h_2(T_2\ P_2)$

We will be able to get P_2

CV#1



ASSUME:
No change in Kinetic or Potential Energy

Consv. Mass

$$\cancel{dM_{cv}/dt} = \dot{m}_2 + \dot{m}_4 - \dot{m}_5 - \dot{m}_3$$

Steady

$$\dot{m}_2 = \dot{m}_3$$
$$\dot{m}_4 = \dot{m}_5$$

Consv. Energy

$$\cancel{dE_{cv}/dt} = \dot{Q} - \dot{W} + \dot{m}_R h_2 + \dot{m}_w h_4 - \dot{m}_R h_3 - \dot{m}_w h_5$$

Steady Zero zero

See diagram

$$\dot{m}_R (h_2 - h_3) + \dot{m}_w (h_4 - h_5) = 0$$

$h_3 (P_3 = P_2, X = 1.0)$

$h_4 (T_4, ?)$

$h_5 (T_5, ?)$

→ We assume incompressible fluid b/c it's liquid water & ΔT is "small".

$$h_4 - h_5 = C_p (T_4 - T_5)$$

Lastly;

@ $T_1 = 36°C$, $X_1 = 0$

$h_1 = h_f = 100.25$ KJ/Kg A-10

@ $T_2 = -8°C$, $h_2 = 100.25$ KJ/Kg

$h_f = 39.54 \frac{KJ}{Kg}$ $h_g = 242.54$ KJ/Kg

∴ we are in vapor dome

$P_{sat} = 2.1704$ bar // $= \boxed{217.04 \text{ KPa}}$ //

↳ isobar

$P_3 = P_2 = 2.1704$ bar

$X_3 = 1.0$

$h_3 = h_g = 242.54 \frac{KJ}{Kg}$ //

$C_p = 4.201 \frac{KJ}{Kg\,K}$ @ 288K A-19

15°C

↳ between 10°C & 20°C

interpolated for H_2O

$h_4 - h_5 = C_p \Delta T$

$= 4.201 \frac{KJ}{Kg\,K} (10\text{ K})$

$h_4 - h_5 = 42.01$ KJ/Kg //

$$\dot{m}_w = \dot{m}_R \frac{(h_3 - h_2)}{(h_4 - h_5)}$$

$$= \frac{0.26 \, kg}{s} \times \left(\frac{242.54 - 100.25 \, KJ}{Kg} \right) \left(\frac{Kg}{42.01 \, KJ} \right)$$

$$\boxed{\dot{m}_w = 0.88 \, Kg/s}$$

Quiz on Chapter 3 & Ch 4 (part 1)
up through nozzels & diffusers

Thursday October 25th, 2012

4.12 Transient Analysis "Unsteady / Start-up..."

STATE changes with time

- Time Derivatives are not zero

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

$$\frac{dE_{cv}}{dt} = \dot{Q} - \dot{W} + \dot{m}_i\left(h_i + \frac{V_i^2}{2} + g z_i\right) - \dot{m}_e\left(h_e + \frac{V_e^2}{2} + g z_e\right)$$

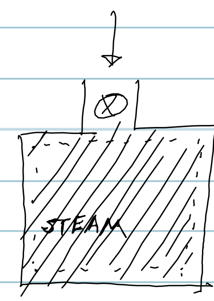
Example: well-insulated tank

$V = 0.4\ m^3$ w/ saturated Vapor

$P_{ini} = 3.5$ bar Valve is opened

STEAM ~~Entres~~ @ 15 bar $T = 320°C$

Flows until Tank is at 10 Bars



STATE 1
$P_1 = 3.5$ bar
$x_1 = 1.0$

STATE 2
$P_2 = 10$ bars

STATE INLET
$P_i = 15$ Bars
$T_i = 320°C$

Cons. of Mass:

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

0

Cons. of Energy:

neglected $\qquad \dot{m}_e = 0$

$$\frac{dE_{cv}}{dt} = \cancel{\dot{Q}} - \dot{W} + \dot{m}_i\left(h_i + \frac{V_i^2}{2} + g z_i\right) + 0$$

well-insulated $\qquad$ assume zero

$\Rightarrow$ (example Continued)

<u>cons. of mass</u>

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

$$\int_{m_1}^{m_2} dm_{cv} = \dot{m}_i \int_0^t dt$$

steady w/ time

$$m_2 - m_1 = \dot{m}_i \cdot t = m_i$$

<u>cons. of Energy</u>

$$\frac{dE_{cv}}{dt} = \dot{m}_i h_i$$

$$\int_{E_1}^{E_2} dE_v = \dot{m}_i h_i \int_0^t dt$$

internal Energy

$$E_2 - E_1 = \dot{m}_i h_i \cdot t$$

$$\underbrace{E_2 - E_1}_{\Delta U} = m_i h_i$$

$$m_2 - m_1 = m_i$$

$$U_2 - U_1 = m_i h_i$$

$$m_2 u_2 - m_1 u_1 = m_i h_i$$

$$\cancel{m_i (u_2 - u_1) = m_i h_i}$$

$u_1(P_1, x_1)$ ✓ ✓

$\rightarrow u_2(P_2, ?)$

$h_i(P_i, T_i)$

$v_1(P, x_1)$

$\rightarrow v_2(P_2, ?)$

$$m_1 = \frac{V_1}{v_1} \qquad m_2 = \frac{V_2}{v_2}$$

<u>STATE 1</u>

$p = 3.5$ bar

$x = 1$

$v_1 = v_g = 0.5243\ m^3/Kg$ } A-3

$u_1 = 2546\ KJ/Kg$

<u>STATE i</u>

$p = 1.5$ bar $T = 320°C$

$h_i = 3081.9\ KJ/Kg$

$$m_1 = \frac{0.4 m^3}{0.5423\ m^3/Kg} \quad \therefore m_1 = 0.763\ Kg$$

$m_2 - m_1 = m_i$ $\qquad$ $m_2 u_2 - m_1 u_1 = m_i h_i$

Substitute

$m_2 u_2 - m_1 u_1 = (m_2 - m_1) h_i$

rearrange

$m_2 = \frac{V}{v_2} \Rightarrow$

$m_2 (u_2 - h_i) = m_1 (u_1 - h_i)$

$\frac{0.4 m^3}{v_2} (u_2 - 3081.9) \frac{KJ}{Kg} = 0.762 Kg \, (2546.9 - 3081.9) \frac{KJ}{Kg}$

$= -407.6 \, KJ$

@ $T = 320°C$ $\quad$ $P = 10 bar$

$V_2 = 0.2678 \, m^3/Kg$

$u_2 = 2826.1 \, KJ/Kg$

@ $T = 310°C$ $\quad$ " "

$V_2 = 0.26285 \, m^3/Kg$

$u_2 = 2809.875 \, KJ/Kg$

@ $312°C$

$V_2 = 0.26384$

$u_2 = 2812.92$

$m_2 = 0.4 m^3 \times \frac{1 \, Kg}{0.26384 \, m^3}$

$m_2 = 1.516 \, Kg$

$\therefore m_2 - m_1$

$\boxed{m_i = 0.754 \, Kg}$ //

Tuesday Oct 30th, 2012 EXAM 2 Monday 6:10 p.m.

Thursday is Review + whatever

Chapters 3 & 4
closed notes
Open Book
Ch3 Map (provided)

Review

CLOSED SYSTEMS:

Consv. of Mass $m = const$

Consv. of Energy $\Delta KE + \Delta PE + \Delta U = Q - W$

OPEN SYSTEMS:

Consv. of Mass

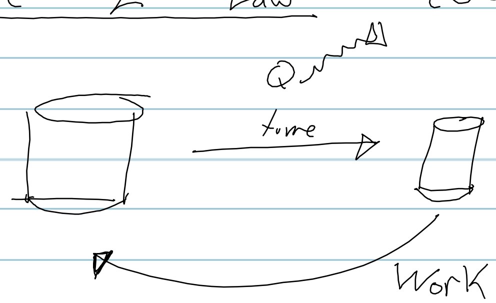
$$\frac{dM_{cv}}{dt} = \dot{m}_i - \dot{m}_e$$

Consv. of Energy

$$\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum \dot{m}_i \left(h_i + \frac{V_i^2}{2} + gz_i\right) - \sum \dot{m}_e \left(h_e + \frac{V_e^2}{2} + gz_e\right)$$

Now, We're headed for the "Second Law"

5.1 The 2nd Law (See Figs 5.1)



IF an object is not at equilibrium with the surroundings there is an opportunity to Do Work,

1. What is the maximum work we can produce
2. What is preventing us from getting maximum work

Does time / (or our ability to measure it) stop at zero K

If left alone all systems will return or reach equilibrium with environment

W/ The Second Law:

1. Predict direction of process

2. Establish equilibrium conditions

3. Determine maximum performance (cycles, engines, etc.)

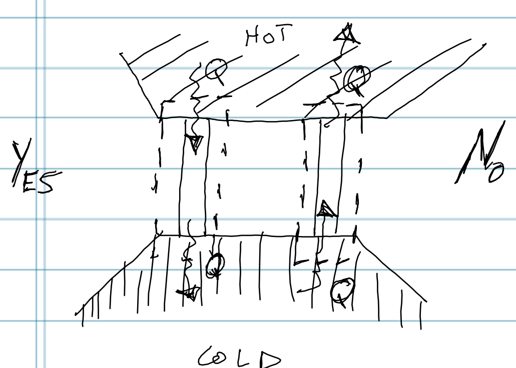
4. Quantify why we don't reach maximum

5. Define absolute temperature scale

6. Define Properties

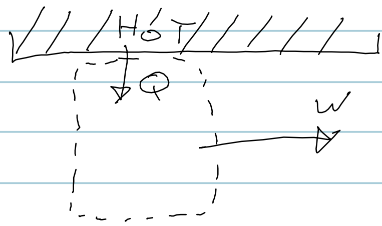
Clausius statement:

"It is impossible for any system to operate in such a way that the sole result would be an energy transfer by heat from a cooler to a hotter body."

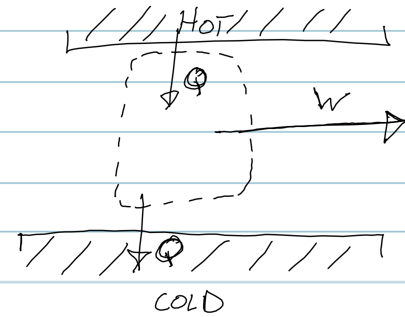


Kelvin-Plank statement

"It is impossible for any system to operate in a thermodynamic cycle and deliver a net amount of energy by work to its surroundings while receiving energy by heat transfer from a single thermal resivour



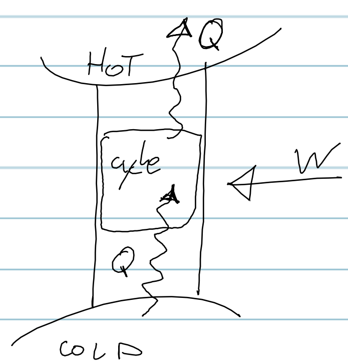
No//



YES//

Thermal Resivour – constant temperature even if Heat is added or removed

(Typically of a "larger scale"...)



"Think of an air (window) conditioner on the Kitchen table."

5.2.3

Entropy Statement of the Second Law

Entropy (S) → Extensive property used for calculations relating to the second Law.

(defined for convienence, how far are we from our environmental conditions)

Mass Balance
Energy Balance
Entropy Balance (IN → OUT)

[change in entropy contained in the system during some time] = [net entropy transferred in system (across sys boundry)] + [amount of entropy produced within the system]

→ friction + ... everything that could account for loss here

entropy is NOT conserved.

(We are always making it)

"It is impossible for any system to operate in a way that entropy is destroyed."

→ maybe an anti-entropy factory recycles the Universes energy

Small-Wooden box with a piston arm that comes in and out

Reversible - If system and surroundings

May be ~~[illegible]~~ restored to initial state

(Perfect Pendulum in Vacuum)

IRREVERSIBLE - If the system and surroundings

Cannot be restored to initial state

Combustion

EXAM 2 REVIEW   Today is Thursday Nov 1st, 2012

→ Monday 6:10 p.m.

*print decision tree

Chapter 3

- Properties & closed systems
- 2 properties to fix state (3 in "dome")

- Enthalpy $h = u + pv$

- Specific Heat

$$C_v = \frac{\partial u}{\partial T}\Big)_v \qquad C_p = \frac{\partial h}{\partial T}\Big)_p \qquad k = \frac{C_p}{C_v}$$

~~So~~;

- Liquids
  - → Tables
  - → incompressible A-19
    - → most useful for Δu, Δh
  - → Liquid Approximation
    - → Fixed Temp

$$h(T, P) \approx h_f(T)$$

2-phase Region

$$x = \frac{u - u_f}{u_g - u_f} \quad \text{OR} \quad u = (1-x)u_f + x u_g$$

Vapor

$$\bar{R} = 8.314 \frac{KJ}{Kmol\ °K}$$

$$R = \frac{\bar{R}}{M} \quad \text{(molecular weight)}$$

Compressibility Factor

$$Z = \frac{Pv}{RT}$$ $Z \approx 1.0$ is ideal

or T_R & P_R

Compressibility charts

Fig A-1

P_R & T_R $\quad v'_R$

IF $Z \approx 1$ (or other conditions) Ideal Gas

$Pv = RT$ Tables

$u = u(T)$, $h = h(T)$ A-22 & A-23

$$C_p(T) = C_v(T) + R$$

$$C_p = \frac{KR}{K-1} \qquad C_v = \frac{R}{K-1}$$

If C_p & C_v are relatively constant (over T) check w/ A-20

$$\Delta u = C_v \Delta T$$
$$\Delta h = C_p \Delta T$$ (very useful/frequent)

Polytropic ideal gas

$$\int P\,dV = mRT \ln\left(\frac{V_2}{V_1}\right) \qquad n=1$$

$$\int P\,dV = \frac{mR\,(T_2 - T_1)}{1-n} \qquad n \neq 1$$

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Chapter 4

	closed sys	Open sys
Consv. of Mass	$m = \text{const}$	$\frac{dM_{cv}}{dt} = \sum_i \dot{m}_i - \sum_e \dot{m}_e$ $\dot{m} = \frac{kg}{s} = \rho \cdot Q = \rho V \cdot A$
Consv. of Energy	$\Delta KE + \Delta PE + \Delta U = Q - W$	$\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum_i \dot{m}_i \left(h_i + \frac{V_i^2}{2} + g z_i\right) - \sum_e \dot{m}_e \left(\text{"} \quad \text{"} \right)$

Nozzles/diffusers: $0 = \dot{Q} + \dot{m}\left(h_1 - h_2 + \frac{V_1^2}{2} - \frac{V_2^2}{2}\right)$

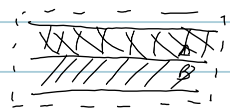
Δ KE is Rarely zero.

Turbines:

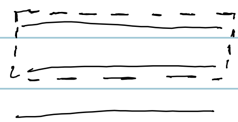
$$\dot{W}_{cv} = \dot{m}(h_1 - h_2)$$

Compressor: $0 = \dot{Q} - \dot{W} + \dot{m}(h_1 - h_2)$

Heat Exchangers:

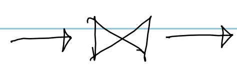


$$0 = \dot{m}_A \Delta h_A + \dot{m}_B \Delta h_B$$



$$0 = \dot{Q} + \dot{m}_A \Delta h_A$$

Throttling Device:



$$h_1 = h_2$$

SYSTEM INTEGRATION

- usually multiple control volumes (think first)
- Use states & Properties between components to relate the equations

Transient Analysis $dM_{cv}/dt \neq 0$ & $dE_{cv}/dt \neq 0$

- show integration
- Watch labeling (be careful)

Tuesday Nov 6^{th}, 2012

5.6 2^{nd} Law For Power Cycles

$$1 > \eta = \frac{W_{cyc}}{Q_H} = 1 - \frac{Q_C}{Q_H}$$ these are magnitudes

Corollaries of the Second Law for Power Cycle
↳ Bonus insights

1. Efficiency is alwayse less than 1
2. $\eta_{real} < \eta_{reversible}$
3. All reversible power cycles operating between the same two thermal resivours have the same thermal efficiency.

$\eta_1 = \eta_2$ if the same resivoirs

5.7 2^{nd} Law For refrigeration & Heat Pump Systems

$$\beta = \frac{Q_C}{W_{cyc}} = \frac{Q_C}{Q_H - Q_C} \qquad \gamma = \frac{Q_H}{W_{cycle}} = \frac{Q_H}{Q_H - Q_C}$$

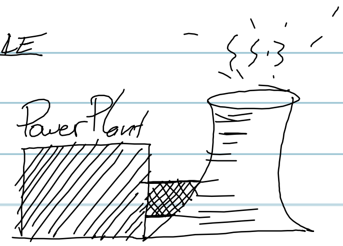
refrigeration

heat pump

5.9 Maximum Performance

$$\eta_{max} = 1 - \frac{T_C}{T_H}$$ (Carnot Efficiency)

EXAMPLE

T_H 500K $\rightarrow$  $\rightarrow T_C = 300K$

$$\eta_{max} = 1 - \frac{300K}{500K} = 0.4$$

Now, we increase boiler temperature Now $T_H = 700K$

$$\eta_{max} = 1 - \frac{300K}{700K} = 0.57$$

$$\beta_{max} = \frac{T_C}{T_H - T_C} \quad \leftarrow \text{Refrigerator}$$

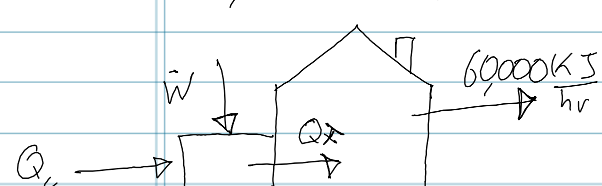
$$\gamma_{max} = \frac{T_H}{T_H - T_C} \quad \leftarrow \text{heat pump}$$

} Temperatures in Absolute

EXAMPLE: Cold outside, Warm inside, Heat Pump @ Steady-state

Motor = 1 KW UNIT heats Home @ 20°C (293.15K) $T_{outside}$ = 0°C (273.15K)

Energy loss through walls etc 60,000 $\frac{KJ}{hr}$ FIND: will the Pump suffice



$$\gamma_{max} = \frac{293K}{293K - 273K} \quad \therefore \gamma_{max} = 14.65$$

$$\gamma_{REAL} = \frac{\dot{Q}_H}{W_{cycle}} = \frac{60{,}000 \frac{KJ}{hr}}{} \quad \text{OR} \quad W_{cyc} = \frac{\dot{Q}_H}{\gamma} = \frac{60{,}000 KJ}{hr} \bigg| \frac{1}{14.65} \bigg| \frac{1 hr}{3{,}600 s}$$

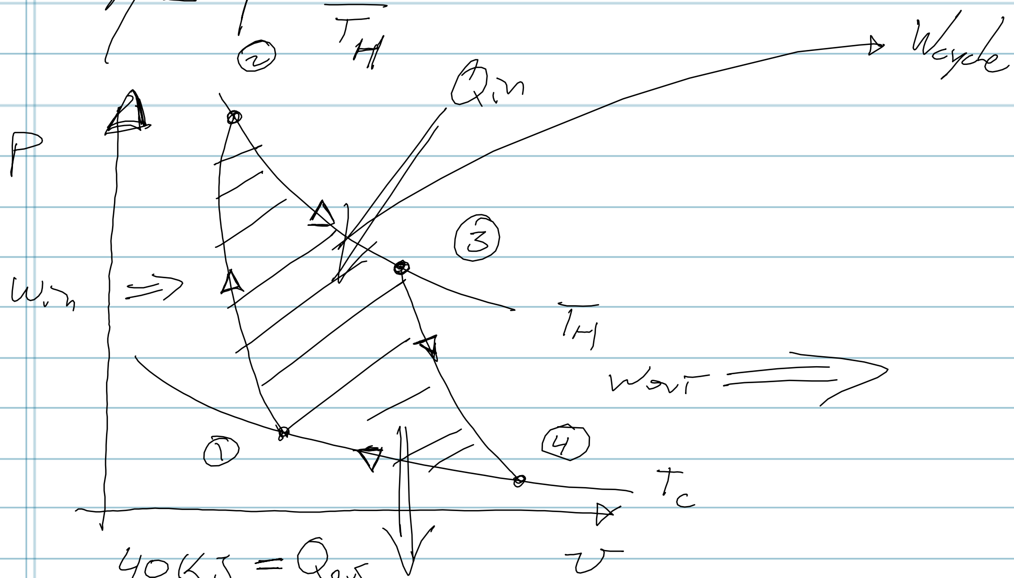
$$\dot{W}_{cyc} = 1.14 KW$$

Therefore, pump is not sufficient

5.10 Carnot Cycle

- → Ideal cycle
- → Piston-Cylinder
- → Entirely reversable

$$\eta = 1 - \frac{T_C}{T_H}$$



EXAMPLE: 1 Kg of AIR in Carnot Cycle $\eta = 0.6$

Heat Transfer to air is 40KJ During Expansion

@ End of Isothermal Expansion $P = 5.6$ Bar & $V = 0.3\,m^3$

Find: a) T_{max}, T_{min} b) Q & W for each process

STATE 1	STATE 2	STATE 3	STATE 4
m = 1 Kg		p = 5.6 BAR V = 0.3 m^3	

Consr of Energy:

$1 \to 2$: NO ΔKE, NO ΔPE, $\boxed{\text{NO } Q}$ Adiabatic

$$Q_{12} - W_{12} = \Delta KE + \Delta PE + \Delta h$$

$$-W_{12} = \Delta h$$

$2 \to 3$: NO " " Q is here

$$Q_{23} - W_{23} = \Delta h$$

$3 \to 4$ " " Q gone

$$-W_{34} = \Delta h$$

$4 \to 1$

$$Q_{41} - W_{41} = \Delta h$$

Also given

$$\eta = 1 - \frac{T_C}{T_H}$$

Since Carnot is "Special perfect Cycle"

Since Air is Ideal Gas (from now on)

$$P_3 V_3 = R T_3$$

$$T_3 = T_H = \frac{P_3 V_3}{mR} \qquad \frac{5.6 \text{ bar} \times 10^5 \frac{N}{m^2}\ 0.3 m^3}{(1 kg)(0.287 \frac{kJ}{kg K})}$$

Also

$$\eta = 1 - \frac{|Q_{41}|}{|Q_{23}|}$$

(Only with Carnot)

$u_2(T_2)$ $u_4(T_4)$

$u_3(T_3)$ $u_1(T_1)$

(only for Ideal Gasses)

$u_2 = u_3$ $u_4 = u_1$

$u_{23} =$ $u_{41} =$

$T_3 = T_H = 584.1 K$

$\therefore T_C = 234.2 K$

via η $Q_{41} = -16 kJ$ (b/c OUT)

$Q_{12} = 0$ $\qquad Q_{34} = 0$

$Q_{23} = 40 KJ$ $\qquad Q_{41} = -16 KJ$

$$\left.\begin{aligned} u_1 &= 167.0 \, KJ/Kg \\ u_2 &= 423.7 \, KJ/Kg \end{aligned}\right\} \text{A-22}$$

$W_{12} = -m(u_2 - u_1)$

$W_{12} = -1 Kg \, (423.7 - 167) \frac{KJ}{Kg}$

$W_{12} = -256.7 KJ$ //

$u_3 = u_2$ ISOTHERMAL

$W_{23} = Q_{23} - m(u_3 - u_2)$

$W_{23} = Q_{23} = 40$ //

$W_{34} = -m(u_4 - u_3) = -1Kg \, (167 - 423.7) \frac{KJ}{Kg}$

$W_{34} = 256.7 KJ$ //

$u_1 = u_4$ Isothermal

$W_{41} = Q_{41} - m(u_1 - u_4)$

$W_{41} = Q_{41} = -16 KJ$ //

Finally;

$$W_{NET} = W_{12} + W_{23} + W_{34} + W_{41}$$

$$W_{NET} = W_{cyc} = 24\ KJ$$ //

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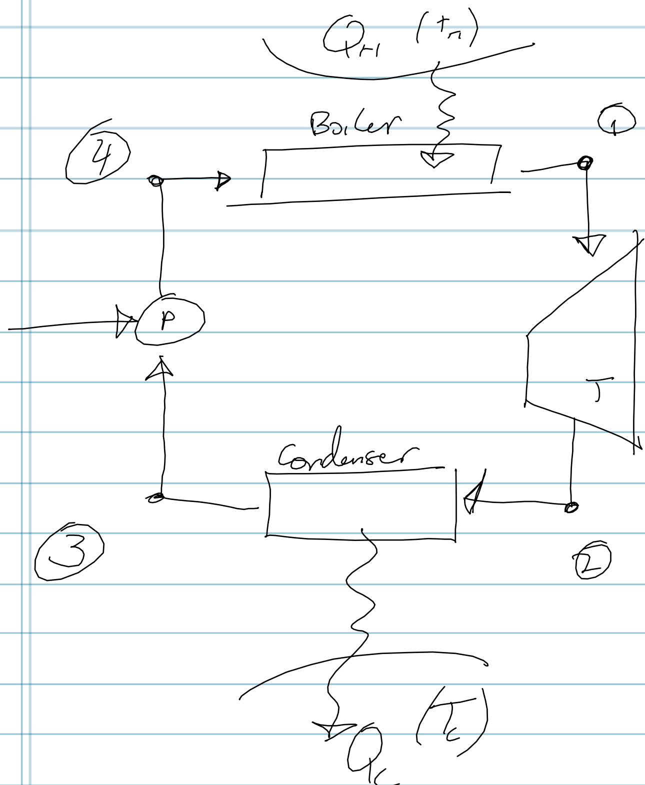
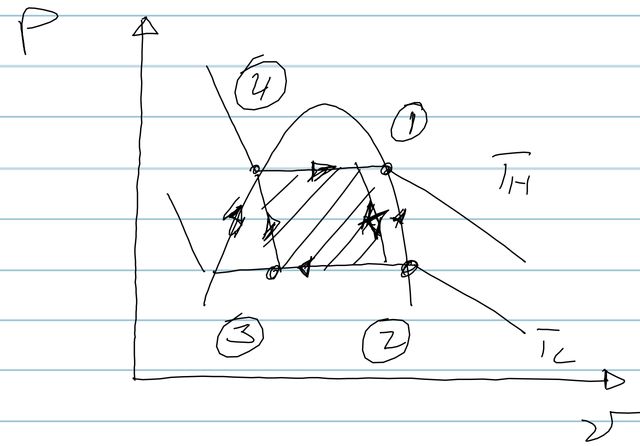
Carnot Cycle in Power Plant





5.11 Clausius Inequality

$$\oint \left(\frac{\delta Q}{T}\right)_b \leq 0$$

Integrate over the boundry (or "surface")

Heat transfer at the boundry

Temperature @ Boundry

This basically talks about an integrand around our control volume along the boundry

Entropy production term

$$\oint \left(\frac{\delta Q}{T}\right)_b = -\sigma_{cycle}$$

$\hookrightarrow$ How big is the inequality

$\sigma_{cyc} = 0$ no irreversibilities (reversible?)

$\sigma_{cycle} > 0$ $\exists$ irreversibilities

$\sigma_{cycle} < 0$ impossible

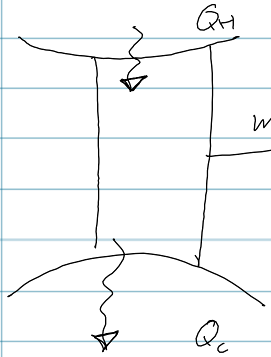
$\hookrightarrow$ OR look at efficiencies to determine impossibility

---

Evaluate Claim $\rightarrow$ A Power Cycle

6 h.p. for heat Addition of $400 \frac{BTU}{min}$

Resivours @ 2,400°R and 1,000°R



First, start w/ real efficiency

$$\eta = \frac{\dot{W}_{cyc}}{\dot{Q}_H} = \frac{6\,hp}{} \left|\frac{min}{400\,BTU}\right| \frac{2545\,BTU}{1\,Hp\,\cancel{Hr}} \left| \frac{1\,\cancel{HR}}{60\,min}\right.$$

$$\eta = 0.636$$

Now; We look at maximum

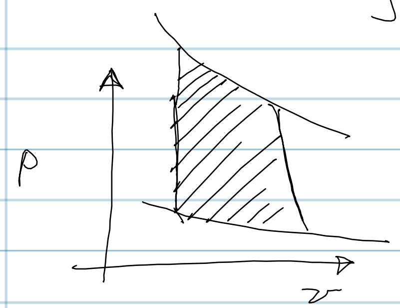
$$\eta_{max} = 1 - \frac{T_C}{T_H} = 1 - \frac{1000°R}{2,400°R}$$

$$\eta_{max} = 0.583$$

$\eta > \eta_{max}$ $\therefore$ impossible

STIRLING Cycle

Robert Sterling (1790 - 1878)



Chapter 6

Entropy → How much work might be possible

S or s in a system [KJ/K, BTU/°R]

specific entropy

6.1.1 Entropy Change

If a process is reversible (IDEAL)

$\sigma_{cycle} = 0$

$$S_2 - S_1 = \left(\int_1^2 \frac{\delta Q}{T} \right)_{\substack{int \\ rev}} \quad \text{OR} \quad dS = \left(\frac{\delta Q}{T} \right)_{\substack{int \\ rev}}$$

VAPOR DATA → In VAPOR DOME

2-phase: $s = (1 - x) s_f + x s_g$

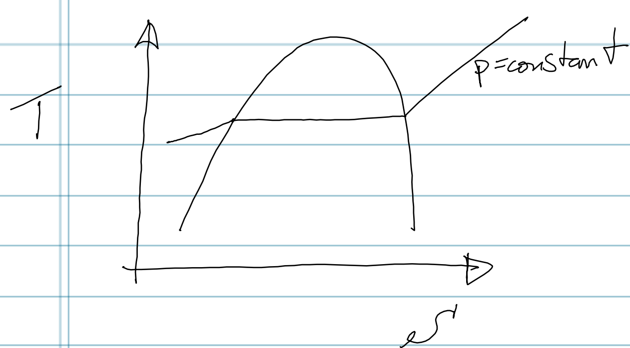
Liquids →

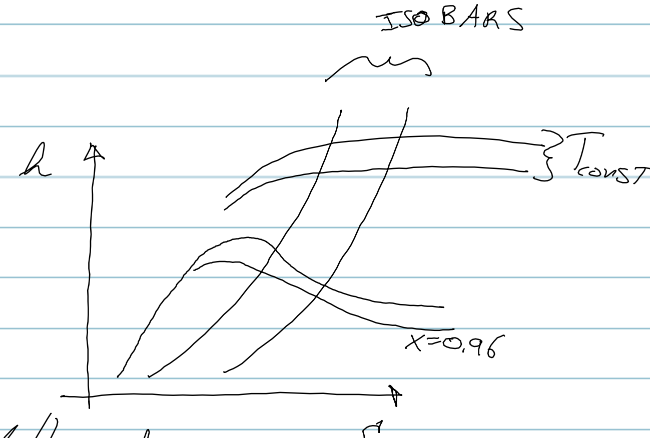
TABLES

$$S(T,P) \approx S_f(T)$$ (since liquid pressure effect becomes minimal)

6.2.5 Graphical methods for ENTROPY

T-S (Temperature - Entropy)





Mollier diagram

6.3 Introducing T ds equations

$$ds = \left(\frac{\delta Q}{T}\right)_{\substack{INT\\REV}}$$

1st law $$(\delta Q)_{\substack{INT\\REV}} = dU + \delta W_{\substack{\cancel{INT}\\REV}}$$

REARRANGE

$$ds = \frac{\delta Q}{T} \quad \text{OR} \quad \delta Q = T\,ds$$

$$\boxed{T\,ds = dU + p\,dV}$$ First T ds equation

Now, with Enthalpy

$$H = U + p\forall$$

$$dH = dU + d(p\forall)$$

$$= dU + p\,d\forall + \forall\,dp$$

REARRANGE

$$\underbrace{dU + p\,d\forall}_{T\,ds \text{ (from before)}} = dH - \forall\,dp$$

$$\boxed{T\,ds = dH - \forall\,dp}$$

Second $T\,ds$ equation

On Unit Mass basis. use lower-case letters

6.4 Entropy for Incompressible liquid

$$du = c(T)\,dT \qquad c_v = c_p = c$$

$$T\,ds = du + p\,dv$$

$$T\,ds = c(T)\,dT + \cancel{p\,dv}$$

zero
incompressible

$$ds = \frac{c(T)\,dT}{T}$$

$$\boxed{s_2 - s_1 = c \cdot \ln \frac{T_2}{T_1}}$$

(incompressible, constant c)

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6.4 Entropy Incompressible (liquid)

$$c_v = c_p = c$$

$$s_2 - s_1 = c \ln\left(\frac{T_2}{T_1}\right)$$

6.5 Entropy Change Ideal Gas

$$T\,ds = du + p\,dv$$

$$ds = \frac{du}{T} + p\frac{dv}{T} \qquad ds = \frac{dh}{T} - \frac{v}{T}dp$$

Ideal Gas: $du = c_v\,dT$
$dh = c_p\,dT$
$pv = RT$

$$ds = c_v(T)\frac{dT}{T} + R\frac{dv}{v}$$

$$ds = c_p(T)\frac{dT}{T} - R\frac{dp}{p}$$

$$s(T_2, v_2) - s(T_1, v_1) = \int_{T_1}^{T_2} c_v(T)\frac{dT}{T} + R\ln\left(\frac{v_2}{v_1}\right)$$

$$s(T_2, P_2) - s(T_1, P_1) = \int_{T_1}^{T_2} c_p(T)\frac{dT}{T} - R\ln\left(\frac{P_2}{P_1}\right)$$

$$s(T_2, p_2) - s(T_1, p_1) = \underbrace{s^\circ(T_2) - s^\circ(T_1)}_{\text{Tabulated}} - R \ln \frac{p_2}{p_1}$$

This is what you use if you can't decide if c_p c_v are constant with temperature

---

IF c_v & c_p are constant

$$s(T_2 v_2) - s(T_1 v_1) = c_v \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}$$

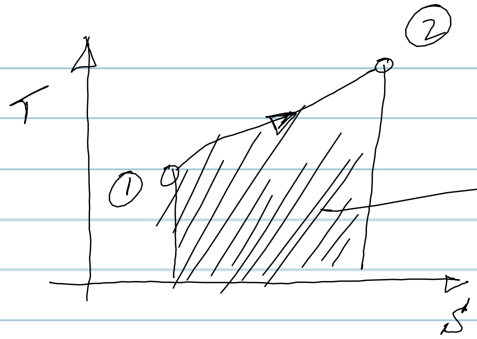
$$s(T_2 p_2) - s(T_1 p_1) = c_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$$

6.6 Entropy Change in Internally Reversable Processes

$$(\delta Q)_{\substack{INT \\ Rev}} = T\,dS$$

$$Q_{\substack{INT \\ Rev}} = \int_1^2 T\,dS$$

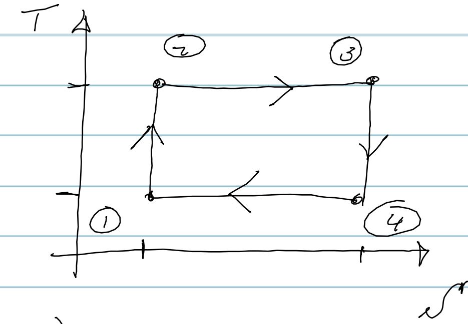
Isentropic - constant entropy process → implies (Adiabatic, reversible)



for internally reversible

$$Q_{\substack{INT \\ REV}} = \int_1^2 T \, dS$$

For Carnot



$$Q_{23} = T_H (S_3 - S_2)$$
$$Q_{41} = T_C (S_1 - S_4)$$

6.7 Entropy Balance for Closed System

$$\underbrace{S_2 - S_1}_{\text{entropy change}} = \underbrace{\int_1^2 \left(\frac{\delta Q}{T}\right)_b}_{\text{entropy in/out}} + \underbrace{\sigma}_{\text{entropy production}}$$

(Transfers w/ heat Q)

→ Caused by all irreversiblities within system

OR

$$dS = \left(\frac{\delta Q}{T}\right)_b + \delta\sigma$$

IF T_b (Temperature @ boundry) IS CONSTANT

$$\boxed{S_2 - S_1 = \frac{Q}{T_b} + \sigma} \rightarrow 2^{ND} \text{ LAW}$$

OR

$$\frac{dS}{dt} = \sum_j \frac{\dot{Q}_j}{T_j} + \dot{\sigma} \rightarrow \text{per unit time}$$

$\sigma \rightarrow > 0$ irreversibilites present

$\rightarrow = 0$ "ideal situation" (reversible)

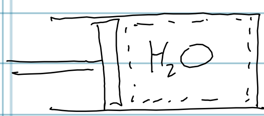
$< 0 \rightarrow$ driving mechanism for eliminating entropy

$\rightarrow$ "impossible"

EXAMPLE: 1 Kg of H_2O @ 160°C, 1.5 bar

Undergoes Isothermal, Internally reversable compression to Sat, Liquid

FIND: W & Q [KJ]



STATE 1

$T_1 = 160°C =$

$P_1 = 1.5$ BAR

STATE 2

$x =$ Sat Liquid

$T_2 = T_1 = 160°C$

Consv. Mass: $m =$ constant

Consv. Energy: $\underbrace{\cancel{\Delta KE} + \cancel{\Delta PE}}_{\text{zero}} + \Delta U = Q - W$

2nd Law: $S_2 - S_1 = \frac{Q}{T_b} + \underbrace{\cancel{\sigma}}_{\text{reversible}}$

STATE 1

@ 160°C 1.5 BAR

$u_1 = 2595.2 \ KJ/Kg$

$S_1 = 7.4665 \ KJ/Kg\,K$

STATE 2

SAT LIQ

$u_2 = 674.86 \ KJ/Kg$

$S_2 = 1.9427 \ KJ/Kg\,K$

So;

$$\Delta U = Q - W \quad \text{and} \quad Q = m \cdot T_6 (S_2 - S_1)$$

$$Q = 1Kg\,(160+273)K\,(1.9427 - 7.4665)\frac{KJ}{Kg\,K}$$

$$\boxed{Q = -2391.8 \ KJ}$$

$$W = Q - \Delta U$$

$$W = -2391.8KJ - 1Kg\,(674.86 - 2595.2)\frac{KJ}{Kg}$$

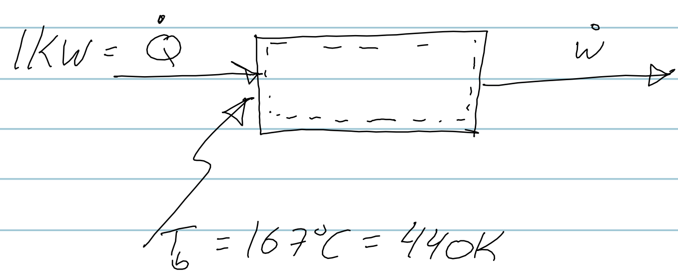
$$\boxed{W = -471.5 \ KJ}$$

EXAMPLE A patent Application Describes a device (steady-state) That recieves heat transfer at a rate of 1KW

At 167°C & Generates electricity

→ T_b (Temperature at the Boundary)

Is Device Possible? (We look at Entropy production)



1st Law: $\frac{dE}{dt} = \dot{Q} - \dot{W}$ So Steady $\dot{Q} = \dot{W}$

2nd Law:

$$\frac{dS}{dt} = \frac{\dot{Q}}{T_b} + \dot{\sigma}$$

$$\frac{\dot{Q}}{T_b} = -\dot{\sigma}$$

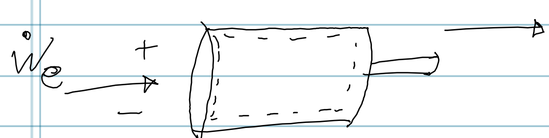
$$\text{So } \dot{\sigma} = -\frac{1{,}000\ J/s}{440K}$$

$$\dot{\sigma} = -2.27\ \frac{W}{K}$$ → 2nd Law violated

6.8 Directionality of Processes

EXAMPLE: steady-state

$\dot{W}_s = 0.5\ Hp$



Draws 4 Amps @ 120 V

$T_b = 120°F$

FIND: Heat Transfer & Entropy Production

1ST Law:

$$\cancel{\frac{dE}{dt}} \xrightarrow{} \text{steady} \qquad \cancel{\frac{dE}{dt}} = \dot{Q} - \dot{W}_s - \dot{W}_e$$

2nd Law:

$$\cancel{\frac{dS}{dt}} \rightarrow \text{steady} \qquad \cancel{\frac{dS}{dt}} = \frac{\dot{Q}}{T_b} + \dot{\sigma}$$

$$\frac{1}{2}hp \times \frac{2545\ \frac{BTU}{hr}}{1\,hp} = 1{,}272.5\ \frac{BTU}{hr}$$

$$\dot{W}_e = 4\,Amps \cdot 120V \left(\frac{1\,W}{1\,A\cdot V}\right) \times \frac{3{,}413\ \frac{BTU}{hr}}{1\,Watt}$$

$$\dot{W}_e = 1{,}638\ \frac{BTU}{hr}$$

$$\dot{Q} = \dot{W}_s + \dot{W}_e$$

OR $\dot{Q} = 1{,}272.5\frac{BTU}{hr} - 1638.2\frac{BTU}{hr}$

so $\dot{Q} = -365.7\ \frac{BTU}{hr}$

$\Longrightarrow$

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Example (continued):

$$\dot{Q} = -365.7\ \frac{BTU}{hr}$$

2nd Law:

$$\dot{\sigma} = \frac{-Q}{T_b} \quad \text{or} \quad \dot{\sigma} = \frac{365.7\ \frac{BTU}{hr}}{580°R}$$

So $\boxed{\dot{\sigma} = 0.631\ \frac{BTU}{hr}}$

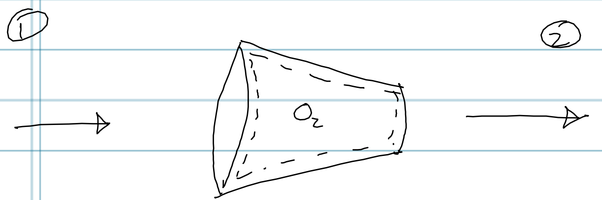
6.9 Entropy Balance For Open Systems / Control Volumes

$$\underbrace{\frac{dS_{cv}}{dt}}_{\text{Rate of Entropy Change}} = \underbrace{\sum_j \frac{\dot{Q}_j}{T_j} + \sum_i \dot{m}_i s_i - \sum_e \dot{m}_e s_e}_{\text{rates of entropy transfer}} + \underbrace{\dot{\sigma}_{cv}}_{\text{rate of entropy production}}$$

EXAMPLE

NOZZLE AT Steady state w/ O_2.

FIND: $\frac{\dot{Q}}{\dot{m}}$ $\dot{\varepsilon}$ ΔS $\dot{\varepsilon}$ $\frac{\dot{\sigma}}{\dot{m}}$



$P_1 = 3.8\ MPa$ $P_2 = 150\ kPa$
$T_1 = 387°C$ $T_2 = 37°C$
$V_1 = 10\ m/s$ $V_2 = 750\ m/s$

Cons. of Mass: $\xrightarrow{\text{STEADY}} \cancel{\frac{dm}{dt}} = \dot{m}_i - \dot{m}_e$ so $\dot{m} = \dot{m}_i = \dot{m}_e$

Cons. of Energy: $\cancel{\frac{dE}{dt}} = \dot{Q} - \cancel{\dot{W}} + \dot{m}_i\left(h_i + \frac{V_i^2}{2} + \cancel{g z_i}\right) - \dot{m}_e\left(h_e + \frac{V_e^2}{2} + \cancel{g z_e}\right)$

STEADY

NO WORK (nozzle)

NO PE

$$\frac{\dot{Q}_{cv}}{\dot{m}} = h_2 - h_1 + \frac{V_2^2 - V_1^2}{2}$$

2nd law: $\cancel{\frac{dS}{dt}} = \frac{\dot{Q}_{cv}}{T_b} + \dot{m}_i s_i - \dot{m}_e s_e + \dot{\sigma}$

STEADY

A-23

@ 660K STATE 1

$\bar{h}_1 = 19870 \frac{KJ}{Kmol}$

$\bar{s}^\circ_1 = 229.430 \frac{KJ}{Kmol\,K}$

$\Omega = 32 \, Kg/Kmol$

@ 310K STATE 2

$\bar{h}_2 = 9030 \, KJ/Kmol$

$\bar{s}^\circ_2 = 206.177 \, KJ/Kmol$

$$\frac{\dot{Q}}{\dot{m}} = (9030 - 19870) \cdot \frac{1}{32} + \left(\frac{750^2 - 10^2}{2}\right) \times \frac{1}{10^3} \, Kilo$$

$$\frac{\dot{Q}}{\dot{m}} = -57.55 \, KJ/Kg$$

$$\Delta s = \frac{1}{\Omega}\left[\bar{s}^\circ_2 - \bar{s}^\circ_1 - R \ln\left(\frac{P_2}{P_1}\right)\right]$$

$$= \frac{1 \, Kmol}{32 \frac{Kg}{Kmol}}\left[(206.17 - 229.430) - 8.314 \cdot \ln\left(\frac{0.15}{3.8}\right)\right] \frac{KJ}{Kmol(K)}$$

$$\Delta s = 0.1131 \, \frac{KJ}{Kg\,K}$$

Hint: Do This explicitly

2nd law:

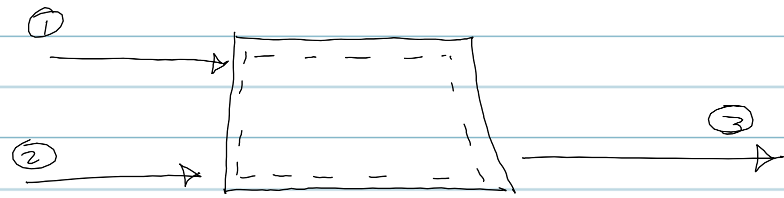
$$\frac{\dot{\sigma}}{\dot{m}} = -\left(\frac{\dot{Q}/\dot{m}}{T_0}\right) + \Delta s = \frac{-57.55 \frac{KJ}{Kg}}{293\,K} + 0.1131 \, KJ/Kg\,K$$

$$\boxed{\frac{\dot{\sigma}}{\dot{m}} = 0.3095 \, \frac{KJ}{Kg\,K}}$$

EXAMPLE

2 Air STREAMS mixing (Ideal gas)

Pressure final is either 1.0 mPa or 1.8 mPa, which one?



$T_1 = 800K$ $\quad$ $T_2 = 650K$

$P_1 = 1.8 MPa$ $\quad$ $P_2 = 1.0 MPa$

$\dot{m}_1 = 1 kg/s$ $\quad$ $\dot{m}_2 = 2 kg/s$

Cons. Mass: $\underbrace{\cancel{dM/dt}}_{\text{steady}} = \dot{m}_i - \dot{m}_e$ $\quad \therefore \dot{m} = \dot{m}_i = \dot{m}_e$

1st Law: $\underbrace{\cancel{dE_{cv}/dt}}_{\text{steady}} = \underbrace{\cancel{\dot{Q}}}_{\text{Insulated (assumed)}} - \underbrace{\cancel{\dot{W}}}_{\text{No work}} + \dot{m}_1 h_1 + \dot{m}_2 h_2 - \dot{m}_3 h_3$

2nd Law: $\underbrace{\cancel{dS/dt}}_{\text{steady}} = \underbrace{\cancel{\frac{\sum \dot{Q}}{T_b}}}_{\text{No } Q} + \dot{m}_1 s_1 + \dot{m}_2 s_2 - \dot{m}_3 s_3 + \dot{\sigma}$

$\dot{m}_3 = 3 kg/s$

STATE 1

$h_1 = 821.95 \frac{KJ}{Kg}$

$s_1^\circ = 2.71787 \frac{KJ}{Kg K}$

STATE 2

$h_2 = 659.84 \frac{KJ}{Kg}$

$s_2^\circ = 2.49364 \; KJ/Kg K$

1st Law:

$$h_3 = \frac{\dot{m}_1 h_1 + \dot{m}_2 h_2}{\dot{m}_3} = \frac{(1 \, Kg/s)(821.95 \, KJ/Kg) + (2 \, Kg/s)(659.84 \, KJ/Kg)}{3 \, Kg/s}$$

$$\therefore h_3 = 713.88 \, KJ/Kg$$

$$T_3 = 700 K$$

Now;

$$\dot{\sigma} = \dot{m}_3 s_3 - \dot{m}_1 s_1 = (\dot{m}_1 + \dot{m}_2) s_3 - \dot{m}_1 s_1 - \dot{m}_2 s_2$$

$$= \dot{m}_1 \underbrace{(s_3 - s_1)}_{\Delta s} + \dot{m}_2 \underbrace{(s_3 - s_2)}_{\Delta s}$$

$$= \dot{m}_1 \left(C_p \ln\left(\frac{T_3}{T_1}\right) - R \ln\left(\frac{P_3}{P_1}\right) \right) + \dot{m}_2 \left(C_p \ln\left(\frac{T_3}{T_2}\right) - R \ln\left(\frac{P_3}{P_2}\right) \right)$$

$$=$$

Tuesday Nov 20th, 2012

HW 12 → Due Next Tuesday 11/27
HW13 → EXAM REVIEW PROBLEMS } EXTRA CREDIT
Due 12/4 (DEAD WEEK)
QUIZ 3 → Next Tuesday 11/27
NO CLASS Thursday 11/29
PROJECTS DUE 12/4 ~~TUESDAY~~

Exam Review Thursday of Dead Week

6.11 Isentropic Processes

↳ constant entropy

Tables: $s_1 = s_2$

IDEAL GAS: (Isentropic)

$$\underbrace{\Delta s}_{\text{zero}} = s_2^\circ - s_1^\circ - R\ln\left(\frac{P_2}{P_1}\right)$$

$$s_2^\circ = s_1^\circ + R\ln\left(\frac{P_2}{P_1}\right)$$

↳ Interpolate For T_2

$$P_2 = P_1 \exp\left(\frac{s_2^\circ - s_1^\circ}{R}\right) \quad \text{OR} \quad \frac{P_2}{P_1} = \frac{\mathrm{Exp}(s_2^\circ(T_2)/R)}{\mathrm{Exp}(s_1^\circ(T_1)/R)}$$

$$\boxed{\frac{P_{r2}}{P_{r1}} = \frac{P_2}{P_1}} \quad (s_1 = s_2,\ \text{air only})$$

NOTE: lower-case "r"

↳ Use for solving for a pressure

Via a similar derivation

$$\frac{v_2}{v_1} = \left(\frac{RT_2}{P_2}\right)\left(\frac{P_1}{RT_1}\right)$$

...

$$\frac{v_2}{v_1} = \frac{v_{r_2}}{v_{r_1}}$$

Constant Specific Heat

$$s_2 - s_1 = c_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{P_2}{P_1}\right)$$

$$= c_v \ln\left(\frac{T_2}{T_1}\right) + R\ln\left(\frac{v_2}{v_1}\right)$$

$$c_p = \frac{kR}{k-1} \qquad c_v = \frac{R}{k-1}$$

$$\boxed{\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}}$$ $(s_1 = s_2)$ k is constant

$$\boxed{\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{k-1}}$$ $(s_1 = s_2)$ k is constant

Finally

$$\boxed{\frac{P_2}{P_1} = \left(\frac{v_1}{v_2}\right)^{k}}$$ $(s_1 = s_2)$ k is constant

Polytropic $\quad P_1 v_1^n = P_2 v_2^n$

$n = k$ isentropic ← NEW

$n = 1$ isothermal

$n = 0$ isobaric

6.12 Isentropic Efficiencies:

Turbine: $\eta_t = \dfrac{\text{Work of Real Turbine}}{\text{Work of Isentropic Turbine}}$

$$\eta_t = \frac{(\dot{W}_{cv}/\dot{m})}{(\dot{W}_{cv}/\dot{m})_s} = \frac{h_1 - h_2}{h_1 - h_{2s}}$$

typically between 0.7 & 0.9

Nozzle: $\eta_N = \dfrac{V_2^2/2}{(V_2^2/2)_s}$

typically 0.95 ish

Compressor: $\eta_c = \dfrac{(-\dot{W}_{cv}/\dot{m})_s}{(-\dot{W}_{cv}/\dot{m})} = \dfrac{h_{2s} - h_1}{h_2 - h_1}$

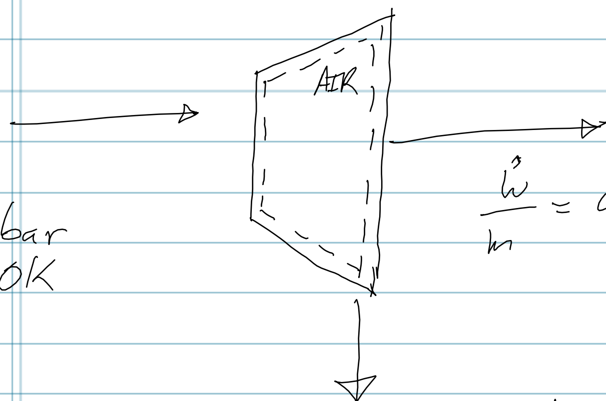
typically between 0.75 & 0.85

EXAMPLE: Insulated Turbine, Air

WORK (measured) = 92 KJ/Kg

FIND: Isentropic efficiency

Q = ZERO; Steady, $\underbrace{\Delta KE \,\&\, \Delta PE}_{\text{Both ZERO}}$



$\frac{\dot{W}}{\dot{m}} = 92\ KJ/Kg$

$P_1 = 4\,bar$
$T_1 = 400K$
$s_1 =$
$h_1 =$

$P_2 = 1\,bar$
$s_2 =$
$h_2 =$

We need to find
$\left(\frac{\dot{W}_{cv}}{\dot{m}}\right)_s$

Cons. of Mass: $\dot{m}_1 = \dot{m}_2 = \dot{m}$

$$W = \dot{m}\,(h_1 - h_{2_s})$$

NOTE:
[Isentropic]

2^{nd} Law

$$\cancel{\frac{ds}{dt}} = \cancel{\sum \frac{Q_j}{T_j}} + \underbrace{\dot{m}s_1 - \dot{m}s_2 + \dot{\sigma}}_{}$$

zero Zero Ideal b/c

$s_1 - s_2 = 0$
$\dot{\sigma} = 0$

Isentropic Ideal Gas:

$$\frac{P_2}{P_1} = \frac{P_{r_2}}{P_{r_1}}$$

STATE 1
$P_{r_1} = 3.806$
$h_1 = 400.98$ " "

STATE 2
$P_{r_2} = 0.9515$
$h_2 = 289.48\ KJ/Kg$

$$\left(\frac{\dot{W}}{\dot{m}}\right)_s = 400.98 - 269.48$$

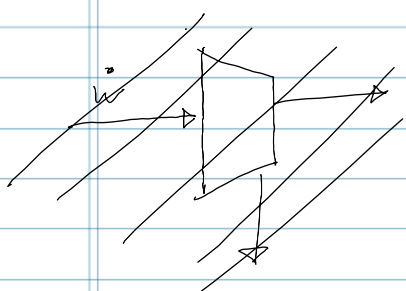
$$= 131.50 \text{ kJ/kg}$$

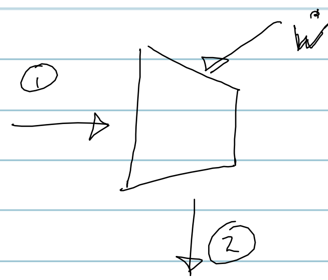
$$\therefore \boxed{\eta_T = \frac{92}{131.5} = 0.70}$$

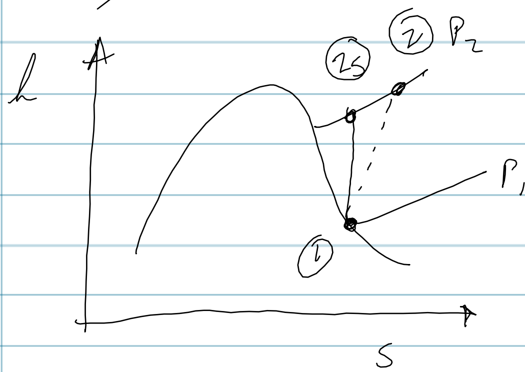
<u>EXAMPLE</u> R134-a (Insulated compressor)

SAT VAP @ 20°F $\qquad$ $P_2 = 20$ psi

<u>FIND</u>: a) minimum work required in $\frac{BTU}{lbm}$
b) exit temperature
c) IF ~~R~~ 134-a exits @ 120°F, find η_c (Isentropic)







Consv. of Mass: $\dot{m}_1 = \dot{m}_2 = \dot{m}$ (1-inlet, 1-outlet)

Consv. of Energy: $\frac{dE}{dt} = \dot{Q} - \dot{W} + \dot{m}(h_1 - h_2)$ Assume: $\Delta KE = 0$, $\Delta PE = 0$

$$\frac{\dot{W}}{\dot{m}} = (h_1 - h_2)$$

2nd Law:

$$\underbrace{\frac{dS}{dt}}_{\text{zero}} = \underbrace{\sum \frac{\dot{Q}}{T_b}}_{\text{insulated}} + \dot{m}(s_2 - s_1) + \dot{\sigma}$$

Isentropic is best case scenario, (Minimum Work)

STATE 1	STATE 2(S)*	STATE 2
$T = 20°F$	$s_2 = s_1$	$T_2 = 120°F$
SAT Vapor	$P_2 = 120 PSI$	$P_2 = 120 PSI$
$h_1 = 104.61$ BTU/lbm	$\boxed{T_{2S} = 98.9°F}$	$h_2 = 121.52$ BTU/lb
$s_1 = 0.2205$ BTU/lbm°R	$h_{2S} = 116.04$ BTU/lbm	

$$\frac{\dot{W}}{\dot{m}} = h_1 - h_{2S} = 104.61 - 116.04 = \boxed{-11.43 \frac{BTU}{lbm}}$$

$$\eta_c = \frac{h_{2S} - h_1}{h_2 - h_1} = 0.676$$

Tuesday November 27th, 2012

→ Think about Study habits

→ Plan studying schedule for finals

Final: Focus on 5 & 6 (Chapters)

→ Tuesday of finals Week (In same Room)
1:30 → 3:30

IMPROVE!!

→ Units
→ Consv Mass
Consv. Energy
2nd Law

→ Reports due Next Tuesday

→ H.W 13 EXTRA CREDIT (Due Next Tuesday)

→ No study Session Next Monday

Thursday Dec 6th, 2012

EXAM 3 REVIEW (FINAL)

CLOSED	OPEN
Conservation of Mass $m = \text{const.}$	$\frac{dm}{dt} = \sum \dot{m}_i - \sum \dot{m}_e$
Conservation of Energy $\Delta KE + \Delta PE + \Delta U = Q - W$	$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_i \left(h_i + \frac{V_i^2}{2} + gz_i\right) - \sum \dot{m}_e \left(h_e + \frac{V_e^2}{2} + gz_e\right)$
2ND Law $\Delta S = \frac{Q}{T_b} + \sigma$	$\frac{dS}{dt} = \sum \frac{\dot{Q}}{T_b} + \sum_i \dot{m}_i s_i - \sum_e \dot{m}_e s_e + \dot{\sigma}$

WORK $= \int P\,d\forall$ $\left\{ \begin{array}{l} \text{constant Pressure} \\ \text{constant } \forall \\ \text{Polytropic} \end{array} \right.$

IDEAL GAS

Heat Transfer
- Conduction
- Convection
- Radiation

PROPERTIES — TABLES
- WATER/STEAM
- R-22, R-134A, Ammonia, Propane,
- Ideal gasses

Ideal Gas Relationships

$$v P = RT$$

for constant C_p or C_v

$$\Delta u = C_v \Delta T$$

$$\Delta h = C_p \Delta T$$

$$\Delta s = C_v \ln\left(\frac{T_2}{T_1}\right) + R \ln\left(\frac{V_2}{V_1}\right)$$

$$= C_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right)$$

Cycles
- Efficiency
- Maximum Efficiency
  - ↳ CARNOT SYSTEMS

Chapter 5 (2^{nd} law)

- PROCESSES Have direction
- IF a system is NOT at equilibrium, it has the potential to do work

2^{nd} law Statements

- Clausius & Kelvin-Plank (equivalent statements)

Temp uphill | Two thermal resiviours

Irreversable & Reversible Processes

2^{nd} law Correlaries

Maximum Performace of Cycle

$$\eta_{max} = 1 - \frac{T_C}{T_H}$$

$$\beta_{max} = \frac{T_C}{T_H - T_C}$$

$$\gamma_{max} = \frac{T_H}{T_H - T_C}$$

Use absolute units on these
↳ (Kelvin)

CARNOT cycle (Ideal cycle)
↳ internally reverseable

Remember which is isothermal or adiabatic

Chapter 6

$$\oint \left(\frac{\delta Q}{T}\right)_b \leq 0 \quad \Rightarrow \text{entropy products}$$

$\sigma = 0$ reversable
$\sigma > 0$ irreversable
$\sigma < 0$ not possible

Entropy Change (Ideal gas)

$$s_2 - s_1 = s^\circ(T_2) - s^\circ(T_1) - R \ln\left(\frac{P_2}{P_1}\right)$$

constant specific heat

$$s_2 - s_1 = c_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right)$$

$$= c_v \ln\left(\frac{T_2}{T_1}\right) + R \ln\left(\frac{v_2}{v_1}\right)$$

Entropy Change, Internally reversable

$$Q_{\frac{int}{rev}} = \int T\,ds$$

Area Under T-S diagram

Entropy Balance, Closed System

$$\underbrace{S_2 - S_1}_{\text{entropy change}} = \underbrace{\frac{Q}{T_b}}_{\text{entropy transfer}} + \underbrace{\sigma}_{\text{entropy production}}$$

Entropy Balance, open System

$$\frac{dS}{dt} = \underbrace{\sum \frac{\dot{Q}}{T_b} + \sum_i \dot{m}_i s_i - \sum \dot{m}_e s_e}_{\text{entropy transfer}} + \underbrace{\dot{\sigma}}_{\text{entropy production}}$$

Isentropic Efficiency (Must have 3 states)

Turbine η_T

nozzle η_N

pump η_C

(Same entropy as 1
Same pressure as 2) Draw T-S diagram!

↳ of course!!!

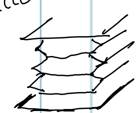
Study

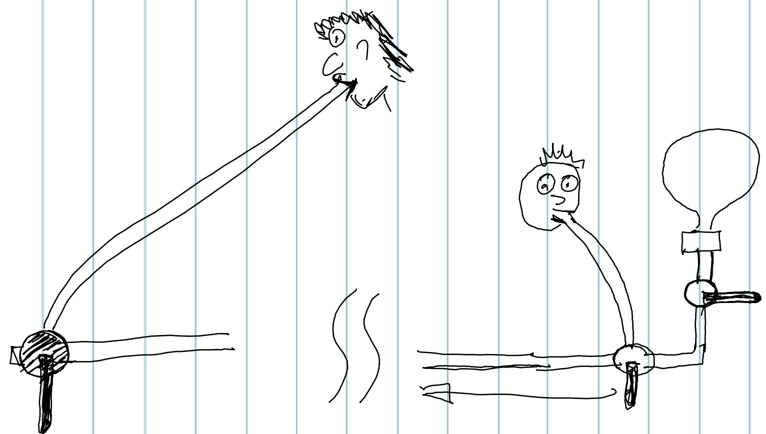
- Work extra problems → (problem 1/day)
- Spread-out reviewing/studying

Chapter 6 is a good spot to study
and try quiz again

① baloon

② accordian





more
closer
to output

∴ No Vacancy in tube