ETA-Lab
Energy Transport Advances

ME-251: Thermodynamics and energetics I
Final Review

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Summary lecture

- <u>Outline</u>

1. Generalities
2. Energy and 1st law for closed systems
3. Energy transfer by heat
4. Thermodynamic properties
5. 1st law for closed and open systems
6. 2nd law and entropy
7. Exergy
8. Applications
9. Mixtures and psychrometry

Basic Concepts and 1st Law of Thermodynamics

- System, surroundings, boundary, closed system, control volume, property, state, process, extensive and intensive property, equilibrium, specific volume, pressure, temperature

1st Law of Thermodynamics

- Closed system

Energy increase is caused by heat input minus work output

$$E_2 - E_1 = Q - W \qquad \frac{dE}{dt} = \dot{Q} - \dot{W} \qquad E = U + KE + PE$$

- Open system

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

Heat input

Control volume work output (excluding flow work)

Enthalpy + KE + PE coming in

Enthalpy + KE + PE going out

1st Law for Open Systems

- Nozzle/diffuser $h_i + \frac{V_i^2}{2} = h_e + \frac{V_e^2}{2}$ Ignoring heat transfer, potential energy change

- Turbine, compressor, pump $W_{cv} = \dot{m}\big(h_i - h_e + +g(z_i - z_e)\big)$

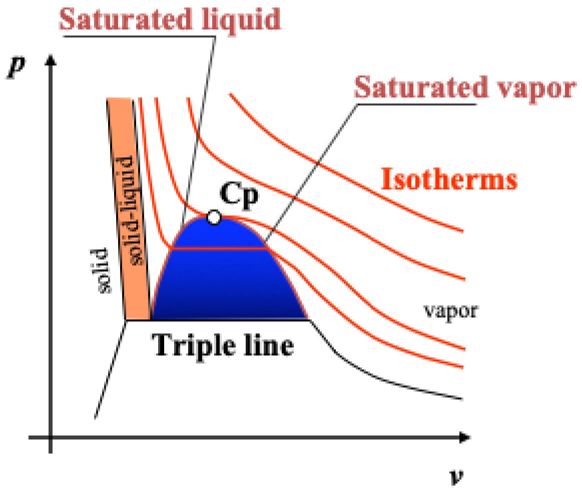
  Ignoring heat transfer and KE change

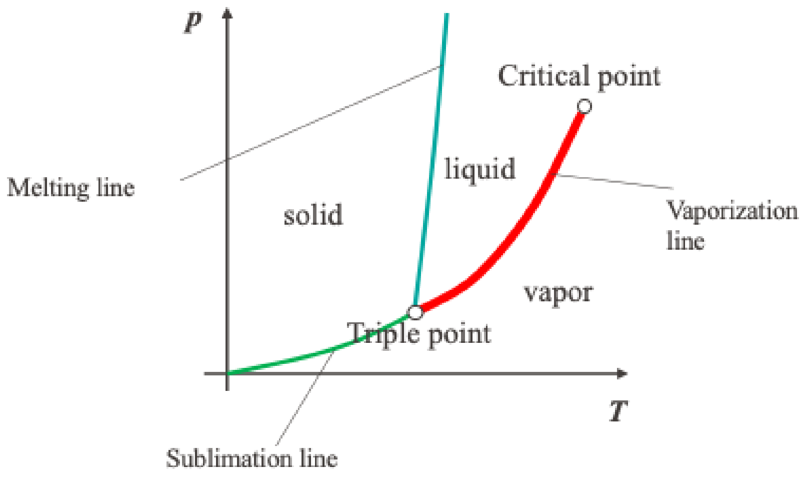
- Heat exchanger $0 = \dot{Q}_{cv} + \sum_i \dot{m}_i h_i - \sum_e \dot{m}_e h_e$ Ignoring mechanical energy change

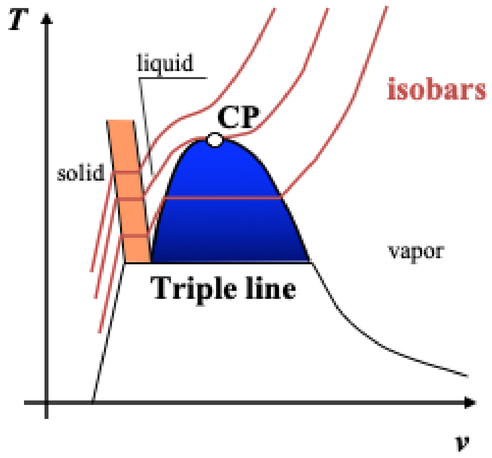
- Throttling device $h_i = h_e$ Ignoring heat transfer and mechanical energy change

Thermodynamic Properties

- p-v diagram
- T-v diagram
- p-T phase diagram
- Steam quality







Evaluation of Thermal Dynamic Properties

	General	Incompressible	Ideal gas, $R = \tilde{R}/M$
u	$u(T, v)$	$u(T)$	$u(T)$
h	$h(T, p)$ *x needed for two phase*	$u(T) + pv$	$u(T) + RT = h(T)$
c_v	$\left.\frac{\delta Q}{\delta T}\right\|_v = \left.\frac{\partial u}{\partial T}\right\|_v$	$c_v(T) = \frac{du}{dT}$	$c_v(T) = \frac{du}{dT}$
c_p	$\left.\frac{\delta Q}{\delta T}\right\|_p = \left.\frac{\partial h}{\partial T}\right\|_p$	$c_p(T) = c_v(T)$	$c_p(T) = \frac{dh}{dT} = c_v + R$
du	$Tds - pdv$	Tds or $c_v(T)dT$	$c_v(T)dT$
dh	$Tds + vdp$	$c_v(T)dT + vdp$	$c_p(T)dT$

For water, $c_v \approx 4.2$ [kJ/kg], $v \approx 10^{-3}$ [m^3/kg]

$c_v \cdot 1[\mathrm{K}] \approx v \cdot 4.2\ [\mathrm{MPa}]$

Evaluation of Thermal Dynamic Properties

	General	Incompressible	Ideal gas, $R = \tilde{R}/M$
s	$s(T,v)$	$s(T)$	$s(T,v)$
ds	$\frac{\delta Q_{rev}}{T}$	$\frac{c_v(T)}{T}dT$	$\frac{c_v(T)}{T}dT + \frac{R}{v}dv$
			$\frac{c_p(T)}{T}dT - \frac{R}{p}dp$

Change in *u, h,* and *s,* can also be further simplified if c_v is assumed to to be constant for incompressible substance or ideal gas (i.e., perfect gas)

2nd Law of Thermodynamics

- Different 2nd law statements, irreversible vs reversible, Carnot theorem and corollaries, Carnot efficiency, Clausius inequality

- Entropy, T-s diagram, isentropic efficiencies

- Closed system

$$S_2 - S_1 = \int_1^2 \left(\frac{\delta Q}{T}\right)_b + \sigma$$

$$\frac{dS}{dt} = \sum_j \frac{\dot{Q}_j}{T_j} + \dot{\sigma}$$

2nd Law of Thermodynamics

- Open system entropy balance

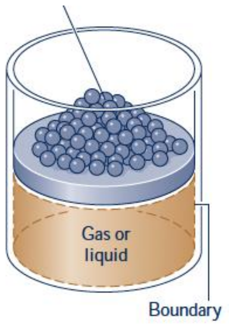
$$\frac{dS_{cv}}{dt} = \sum_j \frac{\dot{Q}_j}{T_j} + \sum_i \dot{m}_i s_i - \sum_e \dot{m}_e s_e + \dot{\sigma}_{cv}$$

- Ideal gas polytropic process: $pv^n = \text{const}$

isentropic, isothermal, constant volume, constant pressure

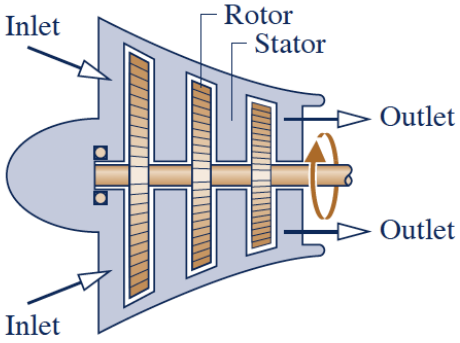
Pdv vs vdP

- Expansion/compression work done by the system



$$W = \int_{V_1}^{V_2} p dV$$

- Control volume work of internally reversible open system



$$\left(-\frac{\dot{W}_{cv}}{\dot{m}}\right)_{\substack{int\\rev}} = h_2 - h_1 - \left(\frac{\dot{Q}_{cv}}{\dot{m}}\right)_{\substack{int\\rev}} = \int_1^2 dh - Tds = \int_1^2 vdp$$