Review for Midterm Examination

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Mechanical Engineering 370
Thermodynamics

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Outline

- Review for midterm
- Property tables and ideal gases
- Work and paths
- First law for closed systems
- First law for steady open systems
- First law for transient open systems
- Solving general first law problems in various systems using tables and ideal gases

Review, but, first a word about units

- Units and dimensions
- SI units and engineering units
- Extensive, intensive and specific
  - E is extensive, e.g., V, U, H, S, Q, W
  - T and P are intensive
  - e = E/m is specific (e.g. kJ/kg, Btu/lb_m)
- Unit conversions (kPa•m^3 = kJ) (m^2/s^2 = J/kg) (lb_f & lb_m) (psia •ft^3,Btu, lb_m•ft^2 /s^2)

Property Data and Relations I

- Find properties from tables
  - Given T and P, T < T_{sat}(P) or P > P_{sat}(T) is liquid; T > T_{sat}(P) or P < P_{sat}(T) is gas
  - Liquid at P, T approximately saturated liquid at given T
  - When given P or T and e where e may be v, u, h, s, compare e to saturation properties
    - e < e_f(P or T) is liquid; e > e_g (P or T) is gas
    - otherwise compute x = (e – e_f) / (e_g – e_f)
  - Forget all this if you find the state point

Property Data and Relations II

- A practical approach for given T and P
  - Start in the gas (superheat) by finding the table for the given P
    - The first line in the table is saturation conditions
    - Saturation temperature, T_{sat}, is given in parentheses next to the pressure
    - If T < T_{sat} you have a liquid; v(T,P) ≈ v_{sat}(***T***)
      - Similar result for u, and h
    - Otherwise find T in tables
      - May have to interpolate
      - You can interpolate with T_{sat}

Property Data and Relations III

- Ideal gas equations and properties
  - Pv = RT, du = c_vdT, dh = c_pdT,c_p = c_v + R, h = u + RT
  - u, h, c_v and c_p = f(T) only
  - Pick constant heat capacity at average T
  - Handle variable heat capacities by equations or use ideal gas tables for u(T) and h(T)

Basic First Law Terms

- Energy terms (per unit mass): internal, u, kinetic, $\mathcal{V}^2/2$, and potential, gz
- Heat, Q (or q), is energy in transit due only to a temperature difference
- Work, W, is action of force over distance
  - Closed system: $W = \int_{path} P dV$ or $w = \int_{path} P dv$
- Heat added to a system is positive, heat removed from a system is negative
- Work done by a system is positive, work done on a system is negative

Energy Balances

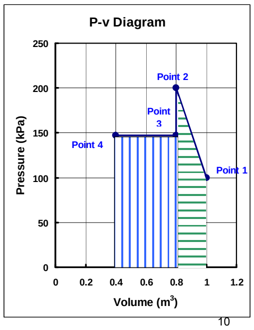
- System energy change = Heat added to system – work done by system + Energy from inflows – Energy outflows
- Usually in kJ (or Btu), but open systems can use power (kW or Btu/hr)
- Can use $q = Q/m$ and $w = W/m$ or equivalent rates: $q = \dot{Q}/\dot{m}$; $w = \dot{W}/\dot{m}$
- Flowing stream terms include flow work to give $h = u + Pv$

Closed Systems

- $Q = \Delta U + W = m(u_{final} - u_{initial}) + \int P dV$
- Integral is area under path
  - Path equation gives P(V) for process
  - Integrate equation or find area
  - Watch sign
- Internal energy depends on state
  - Tables, may have to use $u = h - Pv$
  - Ideal gases: $du = c_v dT$ or u(T) in ideal-gas tables

Work as Area Under Path

- This works if the path has a simple shape
- Here we have a path with three components
- $W = W_{1\text{-}2} + W_{2\text{-}3} + W_{3\text{-}4}$
- $W = (P_1 + P_2)(V_2 - V_1)/2 + 0 + P_{3\text{-}4}(V_4 - V_3)$
- W is zero if V is constant and is negative when volume decreases



Formal Integration of Path

- Analytical path equation examples
  - Isothermal ideal gas: $P = RT/v$
  - Polytropic process: $Pv^n = \text{const}$ ($n \neq k$)
  - Arbitrary: $P = P_1 + a(V - V_1)^2 + \ldots$
- Evaluate $\int P dV$ from V_1 to V_2
- Use P(V)dV for work in kJ (or Btu) or use P(v)dv for kJ/kg (or Btu/lb_m)
- Path equation includes initial and final states and can be solved for these

Closed System Adiabatic Work

- Generally do know an explicit path equation, P(V), for adiabatic process
- However we do know that Q = 0 in an adiabatic process
- If we know the initial and final states we can find W
- From $Q = \Delta U + W$, for $Q = 0$, we have
  - Work equation: $W = -\Delta U = m(u_{initial} - u_{final})$

Open Systems/Assumptions

- General energy and mass balances

$$\frac{dE_{system}}{dt} = \dot{Q} - \dot{W}_u - \sum_{outlet} \dot{m}_i \left(h_i + \frac{\vec{V}_i^2}{2} + gz_i \right) + \sum_{inlet} \dot{m}_i \left(h_i + \frac{\vec{V}_i^2}{2} + gz_i \right)$$

$$\frac{dm_{system}}{dt} = \sum_{inlet} \dot{m}_i - \sum_{outlet} \dot{m}_i$$

- Steady flow: $\frac{\mathrm{dm}_{\mathrm{system}}}{\mathrm{dt}} = \frac{\mathrm{dE}_{\mathrm{system}}}{\mathrm{dt}} = 0$
  - One inlet and one outlet
- Negligible kinetic and potential energies

Steady-Flow Systems

$$\dot{Q} = \dot{W}_u + \sum_{outlet} \dot{m}_o \left(h_0 + \frac{\vec{V}_o^2}{2} + gz_o \right) - \sum_{inlet} \dot{m}_i \left(h_i + \frac{\vec{V}_i^2}{2} + gz_i \right)$$

Mass balance

$$\sum_{outlet} \dot{m}_o = \sum_{inlet} \dot{m}_i$$

First law for ΔKE = ΔPE = 0

$$\dot{Q} = \dot{W}_u + \sum_{outlet} \dot{m}_o h_o - \sum_{inlet} \dot{m}_i h_i$$

For ΔKE = ΔPE = 0, one inlet and one outlet

$$\dot{Q} = \dot{W}_u + \dot{m}(h_{out} - h_{in}) \qquad q = w_u + h_{out} - h_{in}$$

Unsteady Flow Equations

$$\left[m_2 \left(u + \frac{\vec{V}^2}{2} + gz \right)_2 - m_1 \left(u + \frac{\vec{V}^2}{2} + gz \right)_1 \right]_{system} = Q - W_u$$

$$- \sum_{outlet} m_i \left(h_i + \frac{\vec{V}_i^2}{2} + gz_i \right) + \sum_{inlet} m_i \left(h_i + \frac{\vec{V}_i^2}{2} + gz_i \right)$$

$$[m_2 - m_1]_{system} = \sum_{inlet} m_i - \sum_{outlet} m_i$$

Which First Law?

- If the problem mentions the following terms use the first law indicated

Flows, inlet, outlet?	Initial and final states?	Use this first law
No	Yes	Closed System
Yes	No	Steady open system
Yes	Yes	Transient open system

First Law Comparisons

- Closed system: Q = m(u_{final} – $u_{initial}$) + W
- Steady open system, ΔKE = ΔPE = 0, one inlet and one outlet

$$\dot{Q} = \dot{m}(h_{out} - h_{in}) + \dot{W}_u$$

- Transient open system, ΔKE = ΔPE = 0, one inlet and one outlet
- $m_{final} = m_{initial} + m_{in} - m_{out}$
- $Q = m_{final}u_{final} - m_{initial}u_{initial} + W_u + m_{out}h_{out} - m_{in}h_{in}$

The Midterm

- Use equation sheet
  - No books or notes

Practice midterm now available on line

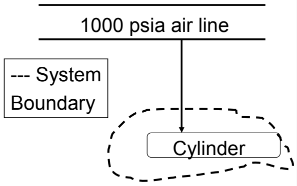
- Problems will be similar to those on quiz and homework assignments
- If you are short of time, show that you know the basic approach to all problems rather than completing all the details of algebra or arithmetic on one or two problems

Tuesday group work on practice midterm

Class Exercise

- A scuba tank with a volume of 1.5 ft^3 is filled from a line with air at 1000 psia and 70°F. The process is so rapid that heat transfer is negligible. The final pressure in the tank is 950 psia. If the cylinder is evacuated initially, what is the final temperature in the tank?
- What kind of system is this?
- What properties do we use?

Diagram and Assumptions



- Define system as cylinder
- Only one inlet
- Q = 0 (given)
- Assumptions:
- Negligible kinetic and potential energy changes
- No useful work (no physical work crosses boundary)

Get the First Law for the System

Negligible ΔKE and ΔPE

Adiabatic

$$\left[m_2\left(u+\cancel{\frac{\vec{V}^2}{2}}+\cancel{gz}\right)_2-m_1\left(u+\cancel{\frac{\vec{V}^2}{2}}+\cancel{gz}\right)_1\right]_{system}=\cancel{Q}-\cancel{W_u}$$

$$\cancel{-\sum_{outlet}m_i\left(h_i+\frac{\vec{V}_i^2}{2}+gz_i\right)}+\sum_{inlet}m_i\left(h_i+\cancel{\frac{\vec{V}_i^2}{2}}+\cancel{gz_i}\right)$$

No useful work

No outlet

One inlet

$$\boxed{\left[m_2u_2-m_1u_1\right]_{system}=m_{in}h_{in}}$$

Mass Balance plus First Law

- Mass balance for this system (m_1 = 0 because cylinder evacuated initially)

$$\left[m_2-m_1\right]_{system}=m_2=\sum_{inlet}m_i-\sum_{outlet}m_i=m_{in}=m$$

- First law from previous page

$$\left[m_2u_2-m_1u_1\right]_{system}=m_{in}h_{in}$$

- Combine mass balance and first law

$$\left[m_2u_2\right]_{system}=\left[m_2\right]_{system}h_{in}\qquad mu_2=mh_{in}$$

$$\boxed{h_{in}=u_2}$$

Use Ideal Gas Relations

$$h_{in}=u_2\quad\Rightarrow\quad h_{in}=h_2-RT_2\quad\Rightarrow\quad RT_2=h_2-h_{in}=\int_{T_{in}}^{T_2}c_p\,dT$$

- Assume constant heat capacity, c_p = 0.240 Btu/lb$_m$·R (page 957)
  - For air, R = 0.06855 Btu/lb$_m$·R

$$RT_2=\int_{T_{in}}^{T_2}c_p\,dT=c_p\left(T_2-T_{in}\right)\quad\Rightarrow\quad T_2=T_{in}\frac{c_p}{c_p-R}$$

$$T_2=\left(529.67\ R\right)\frac{\dfrac{0.240\ Btu}{lb_m\cdot R}}{\dfrac{0.240\ Btu}{lb_m\cdot R}-\dfrac{0.06855\ Btu}{lb_m\cdot R}}=741.4\ R=281.7^{o}\,F$$

Scuba Tank Continued

- How much mass is in the tank?

$$m=\frac{PV}{RT}=\frac{\left(950\ psia\right)\left(1.5\ ft^3\right)}{\dfrac{0.3714\ psia\cdot ft^3}{lb_m\cdot R}\left(741.4\,R\right)}=5.19\,lb_m$$

- How much mass would be in the tank, if the final temperature were 70°F?

$$m=\frac{PV}{RT}=\frac{\left(950\ psia\right)\left(1.5\ ft^3\right)}{\dfrac{0.3714\ psia\cdot ft^3}{lb_m\cdot R}\left(529.67\,R\right)}=7.26\,lb_m$$