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Content Revision Package

Thermodynamics & Heat Transfer (Nanyang Technological University)

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Week 1 : 2nd Law

Possible Assumptions Tutorial 1 :

1. *Steady-state heat transfer*

[Topic : Thermodynamics of HE & Reverse HEs]

1. Thermal Energy Reservoirs

   Q = mc(deltaT)

2. Heat Engines

   Wnet out = Qin - Qout = QH - QL

   HE efficiency = Wnet out / QH = 1 - (QL/QH)

3. Refrigerators & Heat Pumps

   Wnet in = QH - QL

   COPR = (QL) / (QH - QL) = (1)/(QH/QL - 1)

[Topic : Carnot Cycle]

4. The Carnot Cycle

   For Carnot Cycle : QH / QL = TH / TL

5. Carnot HE, Refrigerators & Heat Pumps

   Carnot HE efficiency = 1 - (TL / TH)

   Carnot Refrigerator COP = 1 / [(TH / TL) - 1]

   Carnot HP COP = 1 / [1 - (TH / TL)]

Weeks 2-4a : Entropy

Possible Assumptions :

1. *Tutorial 2 : Entropy change :*
   a. *Assume steady-state*
   b. *Assume constant specific heats*
   c. *Assume isolated system for isolated system problems*
2. *Tutorial 3 : Entropy & Increase of Entropy Principle*
   a. *Assume air is an ideal gas if there is air*
   b. *Assume internally reversible for systems with no irreversibilities*
3. *Tutorial 4 : Entropy in Thermo Devices*
   a. *Steady-state, steady flow*
   b. *Ideal gas with specific constant heats*
   c. *Negligible KE & PE*
   d. *Reversible steady flow for reversible devices*
   e. *Adiabatic for adiabatic devices*

[Topic : Entropy Change & Tds]

1. Entropy of Pure Substances

   delta(S) = S2 - S1 = m(s2 - s1)

2. Entropy Change of Liquids & Solids

   Tds equation : s2 - s1 = Cavg(InT2 - InT1) = Cavg (InT2/InT1)

3. Entropy Change of Ideal Gases

   Know the 2 Tds equations for ideal gas, one for cv and the other for cp

4. Entropy Change for Reversible Processes

   delta(S) = Q / T0 ; T0 is the constant temp

5. Entropy Change for Irreversible Processes

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Addition of the Sgen term to account for irreversibilities, Sgen is only either a positive number (irreversible) or zero (reversible)

6. Entropy Change for Systems

   delta(Ssystem) = Sin - Sout + Sgen

   6.1 Special cases

   Adiabatic : deltaS = Sgen
   Isentropic : deltaS = 0 ; S2 = S1
   Isolated system : deltaS(system) + deltaS(surr) = deltaS(isolated) = Sgen

7. Entropy Change for Flow Control Volumes

[Topic : Steady State Control Volume Devices]

8. Steady State Control Volume Devices

   Know the equation for steady state steady flow devices

9. Reversible Steady Flow Work

   Know the reversible steady flow work equation

10. Polytropic Work in Steady Flow Devices

    Polytropic work in closed system using n
    Isentropic special case of polytropic work (n=k) for ideal gas
    Multistage compression + intercooling : know min. work pressure ratio formula

[Topic : Isentropic Efficiency]

11. Memorise all the h-s diagrams for turbines, compressors and nozzles

Weeks 4b : Gas Mixtures

Possible Assumptions Tutorial 5 :

1. *Steady-state, steady-flow*
2. *Ideal gas mixture with constant specific heats*

[Topic : Composition, PVT behaviour & Properties]

1. Composition of Gas Mixtures

   Molar Mass = Substance Mass / No. of Moles

2. PVT Behaviour

   Dalton + Amagat's Law : Pi / Pm = Vi / Vm = Ni / Nm

Weeks 5-6 : Gas-Vapour Mixtures & Air-conditioning

Possible Assumptions Tutorial 6 :

1. *Steady-state, steady-flow*
2. *Air & water vapour are ideal gases*

[Topic : Air Properties, Temperature Properties & Adiabatic Saturation]

1. Dry & Atmospheric Air

   Enthalpy dry-air : h = CpT ; T is in degrees
   Total Pressure : P = Air Pressure Pa + Vapour Pressure Pv

2. Specific & Relative Humidity of Air

   Specific humidity : omega = mass vapour / mass dry air
   Maximum saturation : Pv = Pg
   Relative humidity : phi = Pv / Pg, ratio of moisture to max.

3. Dew Point Temperature

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Dry-bulb temp : normal temp at atmospheric air
Dew point temp : temp which condensation begins

4. Air-Conditioning Processes
    4.1 Simple Heating & Cooling :
        Process appears as horizontal line on psycho chart
    4.2 Heating with Humidification
        Water spray : temp decreases after humidification due to evaporation
        Steam spray : temp increases
    4.3 Cooling with Dehumidification
        Cooling air past dew point to form condensate with water vapour
        Air is dehumidified when condensate is removed
    4.4 Evaporative Cooling
        Used in desert
        Cool air and increase humidity
    4.5 Adiabatic Airstream Mixing

Week 7 : Heat Transfer Mechanisms, 1-D Heat Conduction, Internal Heat Generation

Possible Assumptions Tutorial 7 :

1. *Thermal conductivity k is constant*
2. *Steady-state heat transfer in 1-direction only*

[Topic : Heat Transfer Mechanisms]

1. Conduction Heat Transfer : Fourier's Law of Conduction
2. Convection Heat Transfer : Newton's Law of Cooling
    a. Newton's law of cooling : Q = hA(deltaT)
3. Radiation Heat Transfer : Net Radiation Exchange
    a. Qrad = emissivity x Boltzman constant x surface area x (Ts^4 - Tsurr^4)

[Topic : 1-D Heat Conduction]

4. Cartesian Coordinates
5. Cylindrical Coordinates

[Topic : Internal Heat Generation]

6. Plane wall
7. Cylinder

Week 8 : Steady-State Heat Conduction & Transient Heat Conduction

Possible Assumptions Tutorial 8 :

1. *Steady-state 1-D heat transfer*
2. *Negligible heat loss through insulation*
3. *Constant thermal conductivity*
4. *No radiation heat transfer*
5. *For thin strip heater : thermal resistance of thin heating element is negligible*

Possible Assumptions Tutorial 9 (Lumped Body) :

1. *Negligible radiation*
2. *Constant heat transfer coefficient over entire surface so lumped analysis can be used*
3. *Constant thermal properties*

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[Topic : Thermal Resistance Networks]

1. Heat conduction in cylinders & spheres
2. Thermal resistance networks
    a. Know the thermal resistance formulas for conduction, convection, cylindrical wall and spherical wall

[Topic : Lumped System Analysis]

3. Know all 4 formulas required for transient lump system analysis problem :
    a. Characteristic length formula
    b. Biot number formula
    c. Time constant tau formula
    d. Time formula

Week 9 : Fundamentals of Convection

- Reynold's numbers :
    a. Flat plate laminar flow : Re < 5 x 10^5
- Know Newton's law of cooling for convection heat transfer
- Friction coefficient : directly related to heat transfer coefficient
    a. Average friction / heat transfer coefficient - know the formula
- Fluid flow classification :
    a. Viscous flow region : flow where frictional effects are significant
    b. Inviscid flow region : regions where viscous forces are negligible compared to inertial or pressure forces
- Fluid viscosity :
    a. Dynamic viscosity (miu)
    b. Kinematic viscosity (v)
- Friction coefficient (Cf) : directly related to heat transfer coefficient & power req.
- Reynold's Number :
    a. Re = [Vavg x D] / v
    b. Re = [rho x Vavg x D] / miu
- Nusselt Number : [Nu x Lc] / k ; Lc = characteristic length, k = thermal conductivity

Week 10 : External Forced Convection

Possible Assumptions :

1. *Steady-state operating conditions*
2. *Smooth cylinder for cross-flow problems*
3. *Might have to assume fully turbulent flow for turbulent problems*

[Topic : Parallel Flow Over Flat Plate]

- Drag force Fd = friction drag + pressure drag
- Reynold's number for flat plate :
    a. Flat plate laminar flow : Re < 5 x 10^5
    b. Reynold's no. at distance x : Re = (V*x) / v
- Nusselt No. for flat plate :
    a. Nu = (h*x) / k
    b. Know how to identify the provided formula for Nusselt no. laminar flow

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        i. (0.664 * Re^0.5 * Pr^1/3)
- Avg friction coefficient (Cf) : know how to use the provided Cf formula for laminar flow over flat plates
- Turbulent flow over flat plates :
    a. Know how to use the provided formulas for avg Nu & avg Cf for turbulent flat plate flow
- Mixed flow over flat plates
    a. Know how to calculate Nu & Cf for mixed flow which is different from pure laminar and turbulent
    b. Mixed flow problem has to be solved in segments, taking flow from start to particular point(s), and mathematically calculating the differences between them to find the properties needed (Refer to lecture note Ex.3 Mixed Flow)
- Special cases of flow over flat plate :
    a. Uniform heat flux
    b. Unheated starting length

[Topic : Cross Flow Over Cylinder & Spheres]
- Critical reynold number : Re = 2 x 10^5
- Cross-flow over cylinders :
    a. Average Nusselt number - use diameter to evaluate the Nusselt number
        i. Nu = (h*D) / k, fluid properties are evaluated at mean temperature
- Cross-flow over spheres :
    a. Average Nusselt number Nu = (h*D) / k
        i. Fluid properties are evaluated at free-stream temperature T(infinite), except for dynamic viscosity of a sphere, which is evaluated at the surface temperature

Week 11 : Internal Forced Convection

Possible Assumptions :
1. *Steady-state operating conditions*
2. *Constant surface temperature for constant surface temp problems*
3. *Constant heat flux for constant heat flux problems*
4. *Negligible heat conduction along pipe*
5. *Negligible work done by viscous forces*
6. *Negligible thermal resistance from pipe outer to inner surface*

[Topic : Reynold’s Number in Pipe Flow for Circular & Non-Circular Pipes]
- Topic assumptions :
    a. Negligible frictional heating during flow, pressure drop is dominant
    b. Significant fluid temperature change is a result of heat transfer
- Reynold’s numbers in tubes :
    a. Laminar : Re < 2300
    b. Turbulent : Re > 10,000
- Reynold’s number formulas :
    a. Circular tube :
        i. Re = 4(mass flow) / miu pi D
    b. Non-circular tube (rectangle) :

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i. Diameter calculation uses the Hydraulic Diameter (Dh) value, which the friction factor is based upon, Dh = [4 x Flow Area] / Wetted Perimeter
ii. Re = [Vavg x Dh] / kinematic viscosity
iii. Recall that kinematic viscosity = dynamic viscosity / density

[Topic : Velocity & Flow Profile Properties]

- Velocity profile :
    a. Hydrodynamic entry length (Lh) : region where velocity profile develops, aka entrance region
- Thermal profile :
    a. Thermal entrance length : thermally developing flow
    b. Thermally fully developed flow : temperature profile of a pipe will always be the same, although mean temp. (Tm) across profiles might be able to change
    c. Bulk mean fluid temperature : used to evaluate fluid properties
        i. Bulk mean fluid temp Tb = 0.5 (Tinlet + Texit)
- Fully developed flow : the flow is both hydrodynamically and thermally developed
    a. Both local friction factor & local convection coefficients remain constant
- Entry lengths in tube flow (memorise the formulas in case not given) :
    a. Laminar flow (Re<2300) :
        i. Hydrodynamic entry length <u>Lh = 0.05 x Re x Diameter (NOT GIVEN)</u>
        ii. Thermal entry length Lt = <u>0.05 x Re x Pr x Diameter (NOT GIVEN)</u>
    b. Turbulent flow (Re>2300) :
        i. Hydrodynamic entry length = thermal entry length = <u>10 x Diameter (NOT GIVEN)</u>

[Topic : Techniques To Solve Internal Flow Problems]

- General thermal analysis techniques : (Stopped at slide 23)
    a. Conservation of energy :
    b. Boundary conditions :
        i. Constant surface heat flux
        ii. Constant surface temperature : use <u>log mean temperature difference</u> to evaluate constant surface temperature problems
- Techniques to find the heat transfer coefficients for internal flow :
    a. For fully developed laminar flow :
        i. Perform energy balance on the volume element
    b. For laminar flow with constant surface heat flux :
        i. apply boundary conditions dT/dx = 0 at point r = 0, and T = Ts at point r = R
    c. For internal laminar flow :
        i. For laminar flow with uniform surface temp : Nu = 3.66
        ii. For laminar flow with uniform heat flux : Nu = 4.36

Week 12 : Radiation Heat Transfer

- Stefan-Boltzmann Law (sigma) : 5.67 x 10^(-8), do all radiation problems in Kelvin
- Connection between black-body radiation rate & total emissive power :
    a. Total Emissive Power : Eb(T) = sigma x T^4

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    b. Black-body radiation rate : Qb(T) = Area x Eb(T) = Area x sigma x T^4

- Real / non-black surfaces : E(T) = epsilon x Eb (T) = epsilon x sigma x T^4
    a. Epsilon shows how well a surface can emit radiation
    b. Shiny surface have low e, dull surface have high e
- Radiation properties :
    a. absorptivity + transmissivity + reflectivity = 1
    b. absorptivity (alpha) = absorbed radiation (Ia) / incidence wave intensity (I)
    c. transmissivity (tau) = transmitted radiation (It) / incidence wave intensity (I)
    d. reflectivity (rho) = reflected radiation (Ir) / incidence wave intensity (I)
- Kirchhoff's Law :
    a. Main concept : radiation absorbed = radiation emitted
        i. alpha x sigma x T^4 = epsilon x sigma x T^4
    b. A large enclosure behaves like a blackbody, for the case of a small object in thermal equilibrium with a large enclosure at constant T :
        i. Irradiation / incident radiation flux G = Eb = sigma x T^4
        ii. Radiation absorbed by small object : alpha x G
        iii. Radiation emitted by small object : epsilon x Eb
- View factor :
- View factor rules :
    a. Reciprocity relation
    b. Summation rule
    c. Superposition rule
    d. Symmetry rule

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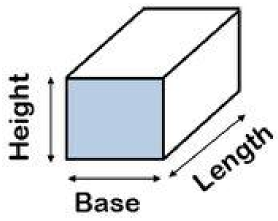
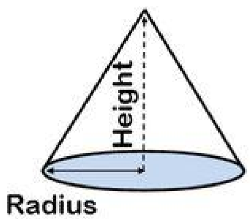
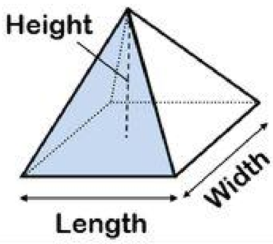
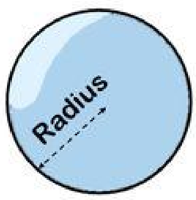
Formula Sheet for Volume www.cazoommaths.com

Shape	Name	Formula for Volume
	**Prism**	Cross– sectional area x length
	**Cone**	$\frac{1}{3}$ x πr^2 x height
	**Pyramid**	$\frac{1}{3}$ x length x width x height
	**Sphere**	$\frac{4}{3}$ x πr^3

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