Chemical and Biomolecular Engineering 150A
Transport Processes
Spring Semester 2020

Objective: To introduce the basic concepts of fluid mechanics and heat transfer necessary for solution of engineering/science problems.

Text: Required:
Welty, Rorrer, and Foster, "Fundamentals of Heat, Mass, and Momentum Transfer," 6th ed., John Wiley (2015).

Recommended:
1. Bird, Stewart, and Lightfoot, "Transport Phenomena," 2nd ed. John Wiley, NY (2002).
2. Denn, "Process Fluid Mechanics," Prentice-Hall, NJ (1980).
3. White, "Fluid Mechanics," 2nd ed. McGraw-Hill, NY (1986).
4. Middleman, "An Introduction to Fluid Dynamics," Wiley, NY (1998).

Description: CBE 150A discusses fluid mechanics and introduces heat transfer: two processes which together with mass transfer (CBE 150B) comprise the field of transport phenomena. Since the transport or movement of momentum, heat and mass is indigenous to all chemical processing, this course is basic to what follows in the curriculum. In other words, this is really a base course of the curriculum. Text coverage is Chapters 1 – 22, excluding Chapter 10. However, lecture material will not necessarily follow the text. Students are expected to have a working knowledge of simple ordinary differential equations and calculus.

COURSE SCHEDULE

Total Lectures: 40

Week 1:

January 22   Concept of Continuum Mechanics,
Shell Balance for Statics

January 24   Barometric Equation,
Manometer Behavior,
Archimedes Principle

Week 2:

January 27   Plane Couette Flow,
Streamlines,
Stress and Strain,
Newtonian fluids, Viscosity

	Fluxes and driving forces in transport process, Characteristic Time of start up
January 29	Molecular origin of Shear stress and viscosity, Introduction to Non-Newtonian fluids, Control Volumes and Macroscopic Balances, Conservation of Mass
January 31	Spatial Averaging, Mass Conservation for Steady Flow in a Sudden Constriction, Transient Emptying of a Liquid from a Tank, Transient Filling of a Gas Cylinder

Week 3:

February 3	Microscopic Conservation of Mass, Continuity Equation, Divergence Operator, Concept of Flow Momentum, Conservation of Linear Momentum, Collinear Flow
February 5	Steady Flow Through a Contracting Bend (Fluid Control Volumes), Atmospheric Pressure on a Control Volume Steady Flow Through a Contracting Bend (Pipe Control Volume)
February 7	Thrust on Nozzle Bolts, Microscopic Conservation of Momentum

Week 4:

February 10	Cauchy Momentum Equation, Meaning of Gradient Operator, Conservation of Energy
February 12	Classification and Solution of First Order ODEs Conservation of Energy
February 14	First Law in Closed and Open Forms: Energy versus Enthalpy Balances Viscous Heating in a Journal Bearing

Week 5:

February 17	Holiday
February 19	Viscous Heating in a Journal Bearing (Continuation) Importance of Viscous Dissipation

Adiabatic Filling of a Gas Cylinder

February 21

Adiabatic Filling of a Gas Cylinder (Continuation)
Safety in Pressurized Gas Vessels
The Entropy Balance
Engineering Bernoulli Equation

Week 6:

February 24

Engineering Bernoulli Equation (Continuation)
Bernoulli Equation Along a Stream line
Macroscopic Mass, Momentum and Mechanical Energy Balances to Calculate
Viscous Losses

February 26

Viscous Losses in Fittings and Valves
Dimensional Analysis and Scaling
Power-Product Method

February 26

MIDTERM: Mid term 6:00p-7:00p, Wednesday (To be confirmed)

February 28

Mixing Power to a Stirred Tank,
Geometric and Dynamic Scaling,
Flow in Pipes,
Definition of Friction Factor

Week 7:

March 2

Dimensional Analysis by Buckingham Pi Theorem,
Fanning Friction Charts,
Reynold's Experiment on Turbulence,
Analytic Forms for Friction Factors in Laminar and Turbulent Flow,
Pipe Roughness, Standard Pipe and Tubing Sizes

March 4

Use of Friction Factors for Pipe Flow,
Watering the Lawn,
Viscous Losses in Bernoulli Engineering Equation for Pipes and Fittings

March 6

Tank Loading,
Piping Networks,
Pump Characterization and Sizing

Week 8:

March 9

External Flow,

Stokes Flow around a Sphere,
Form and Friction Drag, Drag Coefficient Graphs for Various Shapes,
Flow Separation and Streamlining,

March 11   Terminal Velocities,
Friction Factors in Packed Bed (also in Discussion Sections),
Fluidized Beds

March 13   Microscopic Balances,
Shell Balances of Mass and Momentum in Plane Couette Flow,
Continuity Equation, Cauchy Momentum Equation,
Velocity and Shear Stress Profile in Plane Couette Flow,
Boundary Conditions

Week 9:

March 16   General Continuity and Cauchy Momentum Equations
General Relation between Shear Stress and Shear Rate for Newtonian Fluid
Navier-Stokes Equations, Examples: Hagen-Poiseuille Flows

March 18   Substantial Derivative,
Navier-Stokes equations: A Rotating Spindle Viscometer

March 20   A Rotating Spindle Viscometer and Cavitation,
Non-Newtonian Power-Law Fluid Flow in a Pipe

Week 10:

March 23   Spring Recess
March 25   Spring Recess
March 27   Spring Recess

Week 11:

March 30   Boundary Layer on a Flat Plate, Scaling Behavior,
Drag Coefficient

April 1   Adverse Pressure Gradients,
Boundary Layer Separation and Streamlining,
Turbulent Momentum Transfer Characteristics

April 3   Time Averaging Continuity and Cauchy Momentum,
Reynolds Stresses, Eddy Viscosity,
Turbulent Boundary Layer on a Flat Plate

Week 12:

April 6	Heat Transfer Modes: Conduction, Convection, Radiation and Fourier's Law, Heat Transfer Coefficients: Newton's Law, Stefan-Boltzmann Radiation, Boundary Conditions, Microscopic Thermal Energy Balance
April 8	***MIDTERM: Mid term 6:00 – 7:00p, Wednesday (To be confirmed)***
April 8	Steady Conduction Between Two Plates, Boundary Conditions of the First, Second and Third Kinds, Heat Conduction in a Composite Wall
April 10	Heat Conduction in a Composite Wall, Overall Heat Transfer Coefficient, Concept of Thermal Resistance, Analogy to Electrical Circuits

Week 13:

April 13	Conduction in a Rectangular Fin, Biot Number, 2nd order ODEs with Constant Coefficients, Fin Efficient and Enhancement Factors
April 15	Meaning of Biot Number, An Annular Chemical Reactor
April 17	Transient Heating of a Plate, Isothermal Boundary Conditions, Separation of Variables, Fourier Series Expansions

Week 14:

April 20	Definition of Heat Transfer Coefficient, Bulk or Adiabatic Mixing Cup Temperature, Logarithmic Mean Temperature
April 22	Dimensional Analysis of Convective Heat Transfer, Nusselt Numbers, Heat Transfer Coefficient Correlations
April 24	Thermal Boundary Layer on a Flat Plate, Role of Prandtl Number, Local and Average Heat Transfer Coefficient

<u>Week 15:</u>

April 27   Power-Law Dependence of Nusselt Number on Reynolds and Prandtl Numbers
                               Double Pipe-Heat Exchangers: Co and Counter Current Flow,
                               Logarithm Mean Temperature Driving Force

April 29   Double-Pipe Heat Exchanger Design,
                               Overall Heat Transfer Coefficient from Individual Heat Transfer Coefficients,
                               Actual Shell and Tube Heat-Exchangers

May 1   Shell and Tube Heat Exchanger Design
                               True-Mean Temperature Driving Force,
                               Extended-Area Heat Transfer

<u>Week 16:</u>   RRR Week

FINAL EXAMINATION:

May :   To be updated