Chemical and Biomolecular Engineering 150A
Transport Processes
Spring Semester 2017

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

Text: Required:
Welty, Rorrer, and Lightfoot, "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 18 — Concept of Continuum Mechanics,
Shell Balance for Statics

January 20 — Barometric Equation,
Manometer Behavior,
Archimedes Principle

Week 2:

January 23 — Plane Couette Flow,
Streamlines,
Stress and Strain,
Newtonian fluids, Viscosity

	Fluxes and driving forces in transport process, Characteristic Time of start up
January 25	Molecular origin of Shear stress and viscosity, Introduction to Non-Newtonian fluids, Control Volumes and Macroscopic Balances, Conservation of Mass
January 27	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

<u>Week 3:</u>

January 30	Microscopic Conservation of Mass, Continuity Equation, Divergence Operator, Concept of Flow Momentum, Conservation of Linear Momentum, Collinear Flow
February 1	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 3	Thrust on Nozzle Bolts, Microscopic Conservation of Momentum

<u>Week 4:</u>

February 6	Cauchy Momentum Equation, Meaning of Gradient Operator, Conservation of Energy
February 8	Classification and Solution of First Order ODEs Conservation of Energy
February 10	First Law in Closed and Open Forms: Energy versus Enthalpy Balances Viscous Heating in a Journal Bearing

<u>Week 5:</u>

February 13	Viscous Heating in a Journal Bearing (Continuation) Importance of Viscous Dissipation Adiabatic Filling of a Gas Cylinder
February 15	Adiabatic Filling of a Gas Cylinder (Continuation)

	Safety in Pressurized Gas Vessels The Entropy Balance Engineering Bernoulli Equation
February 17	Engineering Bernoulli Equation (Continuation) Bernoulli Equation Along a Stream line Macroscopic Mass, Momentum and Mechanical Energy Balances to Calculate Viscous Losses

Week 6:

February 20	Holiday
February 22	Viscous Losses in Fittings and Valves Dimensional Analysis and Scaling Power-Product Method
	MIDTERM: Mid term 6:30-7:30 p
February 24	Mixing Power to a Stirred Tank, Geometric and Dynamic Scaling, Flow in Pipes, Definition of Friction Factor

Week 7:

February 27	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 1	Use of Friction Factors for Pipe Flow, Watering the Lawn, Viscous Losses in Bernoulli Engineering Equation for Pipes and Fittings
March 3	Tank Loading, Piping Networks, Pump Characterization and Sizing

Week 8:

March 6	External Flow, Stokes Flow around a Sphere, Form and Friction Drag, Drag Coefficient Graphs for Various Shapes, Flow Separation and Streamlining,

March 8	Terminal Velocities, Friction Factors in Packed Bed (also in Discussion Sections), Fluidized Beds
March 10	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

<u>Week 9:</u>

March 13	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 15	Substantial Derivative, Navier-Stokes equations: A Rotating Spindle Viscometer
March 17	A Rotating Spindle Viscometer and Cavitation, Non-Newtonian Power-Law Fluid Flow in a Pipe

<u>Week 10:</u>

March 20	Boundary Layer on a Flat Plate, Scaling Behavior, Drag Coefficient
March 22	Adverse Pressure Gradients, Boundary Layer Separation and Streamlining, Turbulent Momentum Transfer Characteristics
March 24	Time Averaging Continuity and Cauchy Momentum, Reynolds Stresses, Eddy Viscosity, Turbulent Boundary Layer on a Flat Plate

<u>Week 11:</u>

March 27	Spring Recess
March 29	Spring Recess
March 31	Spring Recess

<u>Week 12:</u>

April 3	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 5	Steady Conduction Between Two Plates, Boundary Conditions of the First, Second and Third Kinds, Heat Conduction in a Composite Wall
	MIDTERM: Mid term 6:30 – 7:30 p
April 7	Heat Conduction in a Composite Wall, Overall Heat Transfer Coefficient, Concept of Thermal Resistance, Analogy to Electrical Circuits

<u>Week 13:</u>

April 10	Conduction in a Rectangular Fin, Biot Number, 2^{nd} order ODEs with Constant Coefficients, Fin Efficient and Enhancement Factors
April 12	Meaning of Biot Number, An Annular Chemical Reactor
April 14	Transient Heating of a Plate, Isothermal Boundary Conditions, Separation of Variables, Fourier Series Expansions

<u>Week 14:</u>

April 17	Definition of Heat Transfer Coefficient, Bulk or Adiabatic Mixing Cup Temperature, Logarithmic Mean Temperature
April 19	Dimensional Analysis of Convective Heat Transfer, Nusselt Numbers, Heat Transfer Coefficient Correlations
April 21	Thermal Boundary Layer on a Flat Plate, Role of Prandtl Number, Local and Average Heat Transfer Coefficient

<u>Week 15:</u>

April 24	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 26	Double-Pipe Heat Exchanger Design, Overall Heat Transfer Coefficient from Individual Heat Transfer Coefficients, Exchanger Sizing and Duty, Actual Shell and Tube Heat-Exchangers
April 28	Shell and Tube Heat Exchanger Design True-Mean Temperature Driving Force, Extended-Area Heat Transfer
<u>Week 16:</u>	RRR Week

FINAL EXAMINATION:

May 10:	3-6 pm