Course Name: **Unit Operation and Transport Phenomena I**

單元操作與輸送現象(一)

Instructor: 華 繼 中 教授 （工二館 Rm 412 Ext. 33412)

Textbook: R. B. Bird, W. E. Stewart, and E. N. Lightfoot, 2007, “Transport Phenomena”, 2nd edition, John Wiley & Sons.

Reference: W. L. McCabe, J. C. Smith, and P. Harriott, 2007, “Unit Operations of Chemical Engineering,” 7th edition, McGraw-Hill International Edition.

Year 2021/Spring

Course Outline:

- Vector and Tensor Manipulations (Appendix A)
- Concept of Fluid Viscosity and the Newton’s Law (Chap. 1)
- Mechanisms of Momentum Transfer and Shell Balance (Chap. 2)
- Dynamic Conservation Equations for Isothermal Systems and Benchmark Problems (Chaps. 2,3,4)
- Stream-Function Formulation & Boundary Layer Theory (Chap. 4)
- Turbulent Flows (Chap. 5)
- Interfacial Transport in Isothermal Systems (Chap. 6)
- Macroscopic Balances for Isothermal Flow Systems (Chap. 7)
- Introduction to Non-Newtonian Fluids (Chap. 8)

Grading: Three Exams (1st: 30% 、2nd: 30%、3rd: 40 %)
Homework (+10 %)

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<u>Course Schedule of *Unit Operation & Transport Phenomena (I)*</u>

(Spring/2020)

Chapter 0 Introduction and Basic Vector/Tensor Manipulations (1 week: 2/24~2/26)

1. Overview of transport phenomena: mass, momentum, and heat transfers
2. Continuum (physical) versus molecular (chemical) perspectives
3. The Gibbs notation & vector-tensor manipulations

Chapter 1 The Concepts of Fluid Viscosity (2 weeks: 3/3~3/12)

- Newton's law of viscosity
  1. Definition of viscosity through the Newton's law
  2. Molecular momentum transfer between adjacent layers
  3. Typical magnitudes of fluid viscosity for gases and liquids
- Temperature and pressure dependences of fluid viscosities
  1. Viscosity vs. momentum transfer
  2. Concepts of shear rate and shear stress
  3. Units of shear rate, shear stress, and viscosity
  4. Temperature and pressure dependences of fluid viscosity
- Stress tensor
  1. Notation and significance of tensors
  2. Essential considerations for constructing a stress tensor
  3. The generalized Newton's law for viscosity
- Kinetic theories
  1. Kinetic sources of molecular momentum transfer
  2. Use of corresponding-states correlation to find fluid viscosity
  3. The Lennard-Jones (6-12) potential as a fundamental description of van der Waals forces for simple fluids
  4. Formulas for estimating the fluid viscosity in various particulate systems

Chapter 2 Shell Balance of Momentum Transfer and Benchmark Problems (3 weeks: 3/17~4/9)

- Momentum shell balance & boundary conditions
  1. Steady-state laminar flows
  2. Typical boundary conditions
  3. Shell balance and solution scheme: postulation and posterior check
- Benchmark Problems:
  a. Flow of falling film
     1. Gravity-driven flow

    2. Free surface (stress)
    3. Estimation of the film thickness
    4. Stability criterion based on the Reynolds number
b. Flow through a circular tube
    1. Shell balance in a cylindrical coordinate
    2. Pressure-driven vs. gravity-driven flows
    3. Paradox of the incompressibility assumption in pressure-driven flows
    4. Applications of the Hagen-Poiseuille equation
    5. Essential assumptions for arriving at the Hagen-Poiseuille equation
c. Creeping flow around a sphere
    1. Coordinate transformation and surface integration
    2. The form drag and friction drag on a solid spherical particle
    3. The Stokes' law for creeping flow
    4. The concept of Brownian particles

(The First Examination: 4/16)

Chapter 3 Equations of Change and Benchmark Problems (3 weeks: 4/14~5/5)

- Equations of continuity, motion, and mechanical energy
    1. Scalar deviations in Cartesian system and extension to general coordinate systems
    2. Vector/tensor representations and physical interpretations
    3. Equations of change for conservative/non-conservative quantities
    4. Momentum transfer by convection or diffusion (molecular kinetics/interactions)
- Representation in terms of various time derivatives
    1. The significance of substantial derivatives
    2. Common simplifications of the equation of motion
    3. The Bernoulli equation
- Couette Viscometry
    1. Utilization as a standard viscometer
    2. The centrifugal force and the shape of free surface
    3. Onset of secondary & turbulent flows
- Dimensional Analysis of the equations of change
    1. Selection of characteristic quantities
    2. Correlation relationships constructed using dimensionless parameters
    3. Essential considerations for scale-up application

- Time-dependent flows: the momentum diffusivity (Chap. 4)
  1. Momentum transfer by molecular motions
  2. Concept, expression, and application of momentum diffusivity
  3. Relationship with the notion of boundary layer (and its development)

Chapter 4 Stream-Function Formulation and Boundary-Layer Theory (2 weeks: 5/7~5/19)

- Creeping flows
  1. Construction and merits of the stream-function formulation of the EOM
  2. Physical significance in 2D steady-state flows
- Inviscid (Ideal) fluids and potential flows
  1. The assumptions and governing equations of irrotational (potential) flows
  2. Use of an analytical complex function for describing a potential flow
- Boundary layer theory
  1. Complementary to potential flow theory
  2. The Prandtl boundary layer equations
  3. Exact/Approximation solution schemes

(The Second Examination: 5/21)

Chapter 5 Turbulent Flows (1 week: 5/26~5/28)

- Comparison between laminar and turbulent flows
  1. Velocity profile & pressure drop in circular tubes
  2. 3D characteristics and additional energy dissipation by eddy motions
- Time-averaged equations of change
  1. Expressions of the turbulent momentum flux
  2. The Reynolds stresses
- Turbulent flow in ducts
  1. Four regions of turbulent flow near a wall
  2. Semi-empiricisms for estimating the wall shear stress and average velocity

Chapter 6 Interphase Momentum Transport (1.5 weeks: 6/2~6/9)

- Definition of Friction Factors
  1. Essential information incorporated
  2. Applications for complex flow/geometry problems
- Friction Factors in

  a. Tube flow

  1. Analytical formula for laminar flow

2. Nearly constant *f* (a function of tube roughness only) for highly turbulent flows
3. The concept of hydraulic radius

b. Creeping flow around a sphere

1. Analytical creeping-flow expression & constant *f* under highly turbulent condition

c. Flow in Packed beds

1. The tube bundle model
2. Superficial velocity and void fraction
3. Essential considerations for constructing empiricisms in three different flow regimes

Chapter 7 Macroscopic Balances for Isothermal Flow Systems (1.5 weeks: 6/11~6/18)

- The macroscopic mass, momentum, and mechanical energy balances

1. Basic assumptions of their derivations
2. Utilization in problem solving

- Estimation of frictional loss

1. Definition of friction loss factor
2. Friction loss factor for turbulent flow in straight pipe of uniform cross section
3. Utilization for various obstacles for piping flow

- Steady-state problems

1. Pressure rise in expansion flow & liquid-liquid ejection
2. Orifice manometer and the discharge coefficient

- Unsteady-state problems

1. Torricelli's equation in quasi-steady-state efflux flow
2. Critical damping in manometer

Chapter 8 Introduction to Non-Newtonian Fluids (Flows) (optional)

- Characteristics of non-Newtonian fluids

1. Laminar non-Newtonian flow profile in a circular tube
2. Shear thinning and development of normal stresses in steady-state shear flows
3. Fluid elasticity and memory effect (the Deborah number)

- The generalized Newtonian models

1. Power-law fluid in a circular tube
2. The Maxwell model and rheological constitutive equations

- Polymer kinetic theories

1. Anisotropic chain alignment and entropic forces

2. Bead-spring & dumbbell models

(The Third Examination: 6/23 or 6/25)