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

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.

Year 2024/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)

Grading: Two Exams (35% for each)
Homework (30%)
Oral test in class (up to +2 points in the final grade)
Attendance (Absence >3, -2 points each time in the final grade)

TAs: 林威成（Rm 414, Ext. 23482）、陳柏宇（Rm 413, Ext. 33413）
何元佑（Rm 530, Ext. 33480）

TAs' office time: Wednesday and Friday, 12:00~13:00.

Class will end 10 minutes ahead of the regular schedule for Q&A (in English or Mandarin)

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

(Spring/2024)

Chapter 0 Introduction and Basic Vector-Tensor Manipulations (1.5 week)

1. The Gibbs notation & vector-tensor manipulations

Chapter 1 The Concepts of Fluid Viscosity (2.5 weeks)

- Newton's law of viscosity
    1. Definition of viscosity through the Newton's law
    2. Momentum transfer between adjacent layers
    3. Continuum (physical) versus molecular (chemical) perspectives
    4. Kinematic viscosity and momentum diffusivity
- General properties of fluid viscosity
    1. Units of shear rate, shear stress, and viscosity
    2. Typical magnitudes of fluid viscosity for gases and liquids
    3. Temperature and pressure dependences of fluid viscosity
- Stress tensor
    1. Essential consideration for the construction of stress tensors
    2. The generalized Newton's law for viscosity
    3. Use of vector-tensor operation to deduce relevant stress components
- Kinetic theories

    Corresponding-states correlation for finding fluid viscosity

Chapter 2 Shell Balance of Momentum Transfer and Benchmark Problems (3 weeks)

- 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. Applications and assumptions for 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
    3. The Stokes' law for creeping flow

Chapter 3 Equations of Change and Benchmark Problems (4 weeks)

- Equations of continuity, motion, and mechanical energy
  1. Scalar derivations in Cartesian system vs. vector-tensor formulation for general coordinate systems
  2. Physical interpretations of continuity equation and momentum equation
  3. Conservative and non-conservative quantities in mechanical energy equation
- Representation in terms of various time derivatives
  1. Significance of substantial derivatives
  2. Alternative expression of equations of change
  3. The Navier-Stokes equation and various simplifications
  4. Paradox of the incompressible-fluid assumption
  5. The Bernoulli equation and application for compressible fluids

(The Midterm Examination 4/19)

- Couette viscometry and other applications
  1. Solution schemes using the Navier-Stokes equation and utilization as a standard viscometer
  2. Inertial instability and onset of secondary & turbulent flows
  3. Effect of centrifugal force and shape of free surface in a rotating tube
  4. Slowly rotating sphere in an infinite tank
- Dimensional analysis of equations of change
  1. Geometric and dynamic similarities in scale-up application
  2. Selection of characteristic quantities
  3. Retrieval of dimensionless groups as essential physical parameters
  4. Semi-empirical approach guided by dimensionless equations of change: two practical examples

Chapter 4 Stream-Function Formulation and Boundary-Layer Theory (3.5 weeks)

- Time-dependent flows
  1. Momentum transfer by diffusive (molecular) motions—the diffusion equation and notions of momentum diffusivity and boundary layer
  2. Transient shear flow between two parallel plates
- Stream-function formulation
  1. Stream-function reformulation of the Navier-Stokes' equation for 2D flows
  2. Creeping-flow solution for sedimentation of a solid sphere
- Inviscid (ideal) fluids and potential flows
  1. Governing equations for 2D irrotational (potential) flows
  2. Solution schemes based on complex functions
- Boundary layer theory
  1. Complementary to potential flow theory
  2. Prandtl's boundary layer equations and order-of-magnitude analysis
  3. Approximation and exact solutions for flow along a flat plate

Chapter 5 Turbulent Flows (1.5 week)

- 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. The notion of time averaging
  2. Expressions of the turbulent momentum flux and Reynolds stresses
- Miscellany
  1. Four regions of turbulent flow near a wall
  2. A mechanical analogy of the laminar-turbulent transition

(The Final Examination 6/14)