ChE 420/620: Mixing in the Process Industries

Jan-March 2013, Dr. Suzanne Kresta, suzanne.kresta@ualberta.ca

The perfectly-mixed stirred tank is often used in the undergraduate curriculum as an idealized example, along with steady state processes (assumption 2) which operate at equilibrium (assumption 3). None of these three simplifying assumptions are typical of real process operations and the process engineer who assumes that mixing is truly ideal is headed for some nasty surprises. Mixing occurs on many length scales and time scales, where competing rates can determine the success or failure of a process. In practice, stirred tanks are only one of a range of mixing equipment used for a wide range of process needs in many facinating applications. Modern mixing technology requires the control of segregation, rather than blending of miscible fluids, and successful mixing equipment selection and design requires sound engineering analysis of this fundamental process. This course will review mixing applications and design issues using both fundamentals and current research results. Graduate students will also be introduced to the classical literature which forms the foundations of the field.

Dr Kresta has 20 years of research and consulting in turbulent mixing with Agrium, Albian Sands, Corlac, Cray Research, Dow, DuPont, Eastman Kodak, Eastman Chemicals, Epcor, FLUENT, Huntsman, ICI, Lightnin, Merck & Co., Nalco Chemical, Nova, Plastifab, Proctor and Gamble, Raylo Chemicals, Rohm and Haas, SC Johnson Polymers, Sherritt, Sulzer-Metco, Suncor, Syncrude, and Umicore. Co-Editor of the Handbook of Industrial Mixing (Wiley, 2004), and Advances Volume (in preparation).

1. Objectives

By the end of this course, you will:

- ***recognize mixing problems,*** and what information is needed to address these problems
    - o define and give examples of homogeneity, length scales, time scales
    - o identify mixing process objectives
- have an understanding of ***mixing technology***, and be able to apply it for design of equipment
    - o select and size appropriate mixing equipment
    - o rate existing equipment for a new application
- have ***engineering analysis skills*** which integrate fundamentals with practical design
    - o correctly apply design equations to multi-objective problems
    - o identify dominant mechanisms and variables in competing rate problems
    - o (ChE 620) have a working familiarity with the foundations of mixing theory

2. Course Organization

Lectures will be interspersed with discussion periods where assignments are presented and the problem solving process is begun in groups. The assignments are designed to allow students to work with the course material to develop tools for *advanced engineering analysis*. These skills are often needed in industrial applications where the interactions between facets of a process are not perfectly understood. The discussion periods will be a critical component of the course. By the end of the term, we will have drawn on most of the skills and key principles in the undergraduate program, and you should all be better equipped to make the transition from clearly defined textbook problems to industrial practice.

Grades will be distributed between term work and a final exam as follows:

problem definitions (1-3 pages, group submission) **and** (ChE 620) **reading assignments** and discussions	10%	
assignments		20%
midterm (2 hours, open book, open notes)		20%
lab	CR/NCR	
final **exam** (3 hours, open book, open notes) OR (ChE 620) reading project and report		50%

Final grades will be assigned using a combination of the class distribution and absolute percentage results.

During discussion periods you will break up into groups to define and explore the problem and to plan a solution approach for the assignment problems. For each discussion period, one student will act as discussion leader and one as group recorder. At the end of the discussion period, each group will hand in a single page summary of their plan for solving the problem. The problem definition reports will be returned in the next class, graded (1, 2, or 3, with 1 the best) based on a) attendance (0 for an absence), b) quality of the report , and c) peer assessment of contributions (at the end of the course). Assignments will be due 10-14 days after the discussion period. Individual solutions will be required.

Students registered in ChE 620 will be assigned additional problems on the assignments, will have assigned readings from the classical literature to prepare for discussion seminars every 2 weeks, and can expect a different, more theoretical question on the final exam. Graduate students may also choose to write a literature review and report on a specific problem instead of writing the final exam. Those students will present their findings during the last week of class. This choice must be made by January 18.

Textbook: The Handbook of Industrial Mixing, Paul, Atiemo-Obeng and Kresta eds., Wiley, 2004 will be used extensively as a reference with readings identified in the lecture schedule for most lectures. There is one copy in the reference section in the library, and 2 copies are available through on-line collections (Knovel and ebsco reader). It appears that the Knovel version can be downloaded one chapter at a time, and we will not be using the book in its entirety. Previous students from this course recommend the book, but I do not require that you purchase it.

Project Topics: Literature review based on a forward search on any of the 21 classic contributions (some choices will include several papers); book review of several chapters in any of the specialized texts below (the number of chapters depends on the difficulty of the book and the interests of the student); CFD, mean age, and RTD (reactions); Chaos, laminar flow, self-similarity and static mixers; measurement of dissipation in stirred tanks; development of mixing theory as it relates to a research project.

3. Additional References:

Specialized Texts:

Baldyga, Jerzy and John Bourne, 1999, **Turbulent Mixing and Chemical Reactions**, Wiley.

Cullen, PJ, 2009, **Food Mixing, Principles and Applications**, Wiley-Blackwell.

Fox, Rodney, 2003, **Computational Models for Turbulent Reacting Flows**, Cambridge Univ. Press.

Marchisio, Daniele L. and Rodney O. Fox, in press (Apr 30 2013), **Computational Models for Polydisperse Particulate and Multiphase Systems**.

Ottino, Julio, 1989, **The Kinematics of Mixing: Stretching, Chaos, and Transport**, Cambridge University Press.

Tung, Hsien-Hsin, Edward L. Paul, Michael Midler, and James A. McCauley, **Crystallization of Organic Compounds: An Industrial Perspective**, 2009, Wiley.

Classic Mixing Books

Chemineer Mixing Series, 1976, Chemical Engineering.

Davies, J.T., 1972, **Turbulence Phenomena**, Academic Press.

Harnby, N., M.F. Edwards and A.W. Neinow, 1993, **Mixing in the Process Industries**, 2nd ed., Butterworth.

Holland, F.A. and F.S. Chapman, 1966, **Liquid Mixing and Processing in Stirred Tanks**, Reinhold.

Nagata, S., 1975, **Mixing Principles and Applications**, Wiley.

Uhl, V.W. and J.B. Gray, 1966-1985, **Mixing Theory and Practice**, vols. I, II, and III, Academic Press.

Ulbricht, J. and G. Patterson, 1985, **Mixing of Liquids by Mechanical Agitation**, Gordon and Breach.

also a number of excellent texts on turbulence theory, e.g. Pope, Hinze, Tennekes and Lumley. Wyngaard.

4. Course Content

Topics: These six modules encompass the key concepts of mixing science and practice. Applications will be selected according to the interests and background of the class. Graduate level topics are italicized.

1. **Introduction: Characterization of Mixing:**
   Definition of mixing and the control of segregation: concentration, scales, and rates
   Process objectives from the Mega- to the Nano-scale
   Damkohler vs Spatial Statistics
2. **Equipment**
   Types of Equipment
   Design vs. Rating
   Integral measures and local measures of performance: Np, NQ, Mo, ε, P/ρV
   Turbulence vs. diffusion – Kolmogorov and Batchelor
3. **Blending**
   Jets as mixers
   Tanks - turbulent and transitional
   Pipes, T's, and turbulent static mixers
   Laminar static mixers
   Non-Newtonian fluids in tanks: cavern formation and Metzner Otto
   Jet theory, self-similarity, and turbulence scaling – Corrsin and Glauert
4. **Design correlations**
   Dimensional analysis: heat, mass and momentum transfer
   Heat transfer and mass transfer – understanding the form of corrrelations
   Derivation of dimensionless groups from first principles
5. **Multiphase mixing**
   Solids suspension
      Cloud height
      When Zwietering fell apart – Zwietering and HIM1 vs HIM2
   Liquid-liquid mixing
      Scaling of drop size with turbulence – Hinze and Davies
      Phase inversion, high shear mixers
      Case Study: Liquid-liquid emulsion
   Gas-liquid mixing – mixer power vs compressor power
      Bubble break-up, power consumption, gas-liquid mass transfer
   Design and application of mixing test vessels – turbulent scaling vs local mixing
6. **Reactor Design and industrial problem analysis**
   Homogeneous reactor design
      RTD vs local mixing
      Competition between time scales of mixing and reaction –local mixing conditions
      Turbulence and reaction – Corrsin and Bourne
      Case Study: Laminar mixing and reaction with heat transfer
   Problem analysis and process objectives on many scales
   Heterogeneous reactor design
      Case Study: Digester
      Case Study: Fermenter power optimization
      Case Study: Autoclave
   CFD – what you need to know and what you can learn
   Designing an experimental protocol for a new product development campaign