Process Intensification and Green Chemistry

Introduction

EPFL
Master of Science in Chemical Engineering and Biotechnology
Dr. H. Randall

Rev. 1 01/2025

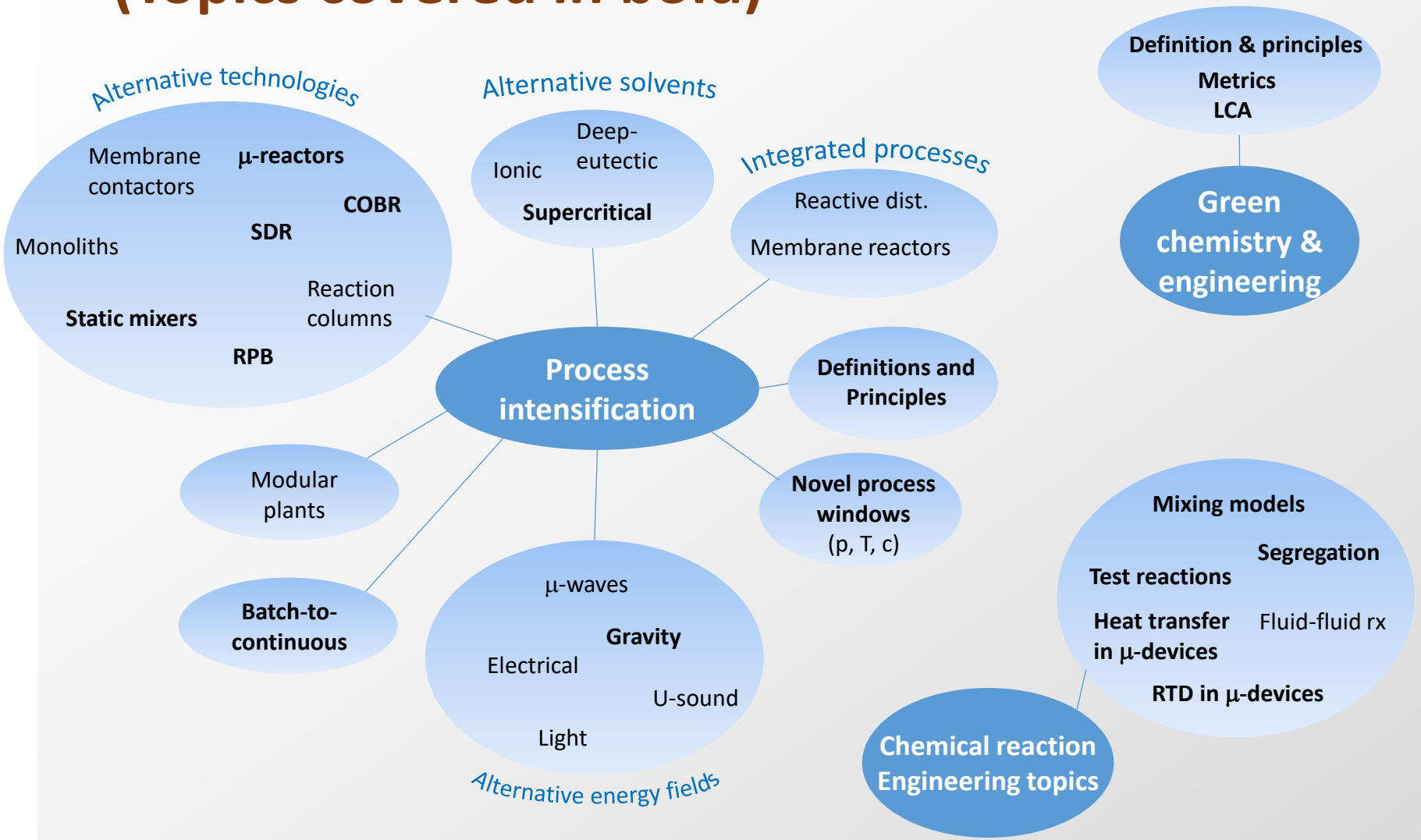
Course objectives

- To give an overview of the benefits and principles of green chemistry and engineering.
- To present some of the main emerging technologies in the field of chemical process intensification.
- To provide some additional background in chemical reaction engineering (e.g., mixing, segregation, RTD and heat transfer in micro-devices).

Required prior knowledge

- Transport phenomena
- Chemical kinetics
- Thermodynamics
- Chemical reaction engineering
- Separation processes
- Thermal safety of chemical processes

Scope of course
(Topics covered in bold)



Course content

1. Elements of Green Chemistry
   - Survey of the chemical industry
   - Green chemistry basics
   - Green metrics: atom economy, reaction mass efficiency, atom efficiency, effective mass yield, carbon efficiency, process mass intensity, energy intensity
   - Industrial examples: phenol and Carbaryl production
   - Green engineering principles
2. Essentials of Life Cycle Assessment
   - LCA aims and methodology
   - LCA metrics (impact categories)
   - Example: dimethyl carbonate production
3. Process Intensification
   - General principles and benefits
   - Description of selected process intensification technologies
     - "Higee" contactors (rotating packed beds)
     - Spinning-disc reactors (thin-film and rotor-stator)
     - Oscillatory baffled reactors / crystallizers
4. Batch-to-continuous
   - Advantages and limitations of batch reactors
   - Advantages and limitations of continuous reactors
   - High pressure processing
   - Criteria for an implementation of continuous processing
   - Examples
5. Miniaturization
   - Characteristic process times
   - Coupling of processes
   - Effect of scale on process parameters

Course content

6. Effect of Mixing on Chemical Reactions
   - Macro-, meso- and micro-mixing
   - Segregation
   - Effect of total segregation on reactor performance
   - Effect of partial segregation on reactor performance and selectivity
   - Experimental mixing time characterization via physical and chemical methods
7. Mixing in Microchannels
   - Flow regimes in microchannels
   - Mixing by pure diffusion
   - Mixing time for laminar mixing in a shear field
8. Microreactors
   - Overview and benefits
   - Passive micromixers: parallel lamination, serial lamination, chaotic mixers and segmented flow
     - Flow regimes, mixing principles & examples
   - Active micromixers: pressure disturbance, electrokinetic
   - Commercial systems
   - Industrial examples
9. RTD in microreactors
   - Microchannels, fixed-beds, static mixers, coiled tubes and flow inverters, segmented flow
10. Heat management in microreactors
    - Heat transfer in various geometries
    - Thermal sensitivity
    - Multipoint injection

Miscellaneous

- **Team**
  - harvey.randall@dsm-firmenich.com
  - Patrick.kelley@epfl.ch
- **Course material**
  - Slides and articles (placed in moodle)
  - Some modifications to slides might be done during the semester (we will inform you on any significant changes)
  - Exercises (placed in moodle before the course)
  - Exercise solutions (placed in moodle after the exercise session)
  - 3 quizzes (as homework, ungraded)
  - Course recordings (Kaltura, slides + audio only – no video, link: see moodle)
- **Course organization**
  - 2 periods of course + 1 period exercises per week
  - Hybrid (live in room CHB2355 + via Zoom. Zoom links placed in moodle)
  - 1 final written exam
    - Closed book, formula sheet (two A4 sheets, recto-verso)
    - Mix of theoretical questions (multiple choice, true or false) and short problems

Important comments

- **About the exercise sessions**
  - It is important to try solving the exercises by yourself.
  - The solutions often seem obvious once you read them.
  - Trying to find the solution by yourself is more difficult but will develop your problem-solving skills and your creativity in a way that just reading the solutions won't.

  → Simply reading the solutions is insufficient
- **About the course slides**
  - Slides are only intended to be a support for the course.
  - They contain pictures, charts, tables and equations, but no full explanations.
  - The latter are provided orally during the course.
  - The exam will contain some theoretical questions, the answers to which are not necessarily written in the slides but explained orally during the course.

  →Simply looking at the slides is insufficient

Bibliography (key books)

- Stankiewicz , A. and J. Moulijn. **Re-engineering the Chemical Processing Plant: Process Intensification**. 2004. Marcel Dekker, New York.
- Reay, D., C. Ramshaw and A. Harvey. **Process Intensification - Engineering for Efficiency**: **Sustainability and Flexibility**. 2008. Elsevier Ltd.
- Hessel, V., A. Renken, J.C. Schouten and J.-I. Yoshida (eds.). **Micro Process Engineering—A Comprehensive Handbook.** 2009. Wiley-VCH.
- Poux, M., P. Cognet and C. Gourdon. **Green Process Engineering: From Concepts to Industrial Applications**. 2015. CRC Press.
- Boodhoo, K. and A. Harvey. **Process Intensification for Green Chemistry: Engineering Solutions for Sustainable Chemical Processing.** 2013. John Wiley & Sons Inc.
- Kashid, M., A. Renken and L. Kiwi-Minsker. **Microstructured Devices for Chemical Processing.** 2015. Wiley-VCH.
- Poux, M., P. Cognet and C. Gourdon. **Green Process Engineering**. 2015. CRC Press.
- Pena-Pereira, F. and M. Tobiszewski. **The Application of Green Solvents in Separation Processes**. 2017. Elsevier.
- Anastas, P.T. and J.C. Warner. 1998. **Green Chemistry: Theory and Practice**. Oxford University Press, New York.
- Hessel, V., Kralisch, D. and N. Kockmann. **Novel Process Windows**, 2015. Wiley.
- Cavani, F., G. Centi, S. Perathoner, F. Trifiro, **Sustainable Industrial Processes. Sustainable Industrial Chemistry**, 2009, Wiley-VCH.