

ChE-408

Process intensification and green chemistry

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Cursus	Sem.	Type
Ing.-chim.	MA2, MA4	Opt.

Language of teaching	English
Credits	3
Session	Summer
Semester	Spring
Exam	Written
Workload	90h
Weeks	14
Hours	3 weekly
Courses	2 weekly
Exercises	1 weekly
Number of positions	

Summary

The first part of the course (~20%) is devoted to green chemistry and life cycle assessment. The remainder focuses on process intensification (fundamentals, detailed description of a few selected technologies, with a special focus on microreactors). Examples and exercises are included.

Content**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

Essentials of Life Cycle Assessment

LCA aims and methodology; LCA metrics (impact categories); example: dimethyl carbonate production

Process Intensification

General principles and benefits; description of selected process intensification technologies (rotating packed beds, thin-film and rotor-stator spinning-disc reactors, oscillatory baffled reactors / crystallizers); moving from batch to continuous

Miniaturization

Characteristic process times; coupling of physico-chemical phenomena; effect of scale on process parameters

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

Mixing in Microchannels

Flow regimes in microchannels; mixing by pure diffusion; mixing time for laminar mixing in a shear field

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

RTD in microreactors

Microchannels; fixed-beds; static mixers; coiled tubes and flow inverters; segmented flow

Heat management in micro- and milli-reactors

Heat transfer in various geometries; thermal sensitivity; multipoint injection

Keywords

Green chemistry and engineering, life cycle assessment, process intensification, micro-structured reactors

Learning Prerequisites**Required courses**

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

Learning Outcomes

By the end of the course, the student must be able to:

- Estimate the "greenness" of a chemical process using the appropriate criteria and metrics
- Choose the best technology for carrying out a chemical reaction based on the relevant physico-chemical, economical and ecological criteria
- Design intensified processes with enhanced performance and sustainability
- Assess / Evaluate the impact of various technologies and operating conditions on key process factors such as heat transfer, mass transfer, mixing time and residence time distribution
- Describe the influence of micromixing on reactor performance and product distribution in homogeneous systems.
- Compute the residence time distribution, heat transfer performance and mixing time in micro-structured devices
- Design thermally safe micro- or milli-flow processes for highly exothermic reactions

Teaching methods

ex-cathedra with integrated exercise sessions

Expected student activities

Take notes during lectures
Participate to exercise sessions

Assessment methods

One final exam (written)

Resources

Bibliography

- 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.
- 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.

Ressources en bibliothèque

- [Process intensification for green chemistry / Boodhoo](#)
- [Sustainable industrial processes / Cavani](#)
- [Green process engineering / Poux](#)
- [Micro process engineering / Hessel](#)
- [Microstructured devices for chemical processing / Kashid](#)

- [Novel process windows / Hessel](#)

Notes/Handbook

Slides in moodle