

ChE-408

**Process intensification and green chemistry**

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Cursus	Sem.	Type
Ing.-chim.	MA2, MA4	Opt.
Minor in Engineering for sustainability	E	Opt.

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

**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](#)
- [Novel process windows / Hessel](#)
- [Micro process engineering / Hessel](#)
- [Microstructured devices for chemical processing / Kashid](#)

- [Green process engineering / Poux](#)

### **Notes/Handbook**

Slides in moodle

### **Moodle Link**

- <https://go.epfl.ch/ChE-408>