



HAL
open science

Nature-inspired chemical engineering processes

Vincent Gerbaud, Catherine Xuereb, Marc-Olivier Coppens

► **To cite this version:**

Vincent Gerbaud, Catherine Xuereb, Marc-Olivier Coppens. Nature-inspired chemical engineering processes. *Chemical Engineering Research and Design*, 2020, 155, pp.200-201. 10.1016/j.cherd.2020.01.019 . hal-02543219

HAL Id: hal-02543219

<https://hal.science/hal-02543219>

Submitted on 15 Apr 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.





Open Archive Toulouse Archive Ouverte (OATAO)

OATAO is an open access repository that collects the work of Toulouse researchers and makes it freely available over the web where possible

This is an author's version published in: <http://oatao.univ-toulouse.fr/25847>

Official URL: <https://doi.org/10.1016/j.cherd.2020.01.019>

To cite this version:

Gerbaud, Vincent  and Xuereb, Catherine  and Coppens, Marc-Olivier
Nature-inspired chemical engineering processes. (2020) *Chemical Engineering Research and Design*, 155. 200-201. ISSN 0263-8762

Any correspondence concerning this service should be sent
to the repository administrator: tech-oatao@listes-diff.inp-toulouse.fr

Nature-inspired chemical engineering processes

Nature is fascinating. It is even more awesome when scrutinised from a scientific, mechanistic angle across length scales, down to the nanoscale, unravelling complex structures and patterns. Natural systems consist of a dynamic, complex assembly of interacting components and systems, leading to emergent behaviour, achieving tasks ultimately aiming at survival, which, very roughly, translates into sustaining current activities. Such activities include processing matter and energy, transporting fluids, changing phase state to obtain products of high quality, and communication. The similarity is striking with what processes in chemical engineering are intended for, since they also deal with the processing of matter, energy and data.

The living environment is sometimes cooperative, but it is usually also competitive. To cope with this, natural processes are sober in their usage of resources, creating little waste as a whole, and they have to be responsive to changes in their environment. These features can be qualified as being performant, efficient and resilient to maintain operation within constraints. In chemical engineering, such attributes are highly desirable as well, especially within the context of sustainable growth. They are indeed key drivers for academics and industry to develop any new process or retrofit existing ones.

Hence, under the auspices of the Editorial Board of the Elsevier journal *Chemical Engineering Research and Design*, we have assembled a special issue on Nature-Inspired Chemical Engineering (NICE) with a particular emphasis on products and processes inspired by nature and related to chemical engineering. The term nature-inspired has been preferred over biomimetics, which often alludes to the superior performance of biological components and systems to justify imitation of particular features without sufficient consideration of a different context in applications.

Mimicking natural objects, tools or processes as a 'supreme goal' is misguided, since the constraints and objectives of the natural and chemical engineering domain differ, at least in part. Therefore, NICE questions the goals and desired functions it pursues, in the same way that nature's most crucial processes and tools relate to aims with strategies to cope with environmental changes. Furthermore, nature and chemical engineering, as conventionally applied, do not rely on the same operating strategies. As recalled by [Coppens \(2005, 2012\)](#)

the challenges set by NICE require a fundamental mechanistic understanding of what lies at the core of nature and of how this can be transposed into innovative chemical engineering devices and processes.

The present special issue features seven articles, each with a different focus: review of mechanisms, optimal design of unit apparatuses using these mechanisms, development of structured devices and functional materials, aiming at enhancing transport or reactive phenomena, the development of processes with natural intermediates, and energy applications.

[Yu et al. \(2020\)](#) have reviewed the mechanisms, models and manufacturing processes of an important class of nature-inspired devices: self-cleaning surfaces. These are of industrial importance for chemical engineering whenever adhesion of contaminants is unwelcome, because it reduces functionality or prevents operation. Inspiration comes from a wide range of living systems: geckos, lotus leaves, mosquito eyes, cicada wings, water strider legs, bird feathers, butterfly wings, carp scales, etc. They have identified six key mechanisms that involve a liquid and dry environment. The spreading of self-cleaning devices is correlated with the growing availability of small-scale manufacturing technologies since the mid-2000's, although some lab techniques cannot be upscaled to a profitable process. Modelling is based on equations frequently encountered in chemical engineering but necessitating numerical techniques, because of the locally complicated structure of surfaces. Both static and dynamical studies are performed, and both Eulerian and Lagrangian approaches are used.

[Gerbaud et al. \(2020\)](#) revisit Coppens's classification of three published mechanisms underlying nature-inspired engineering, namely hierarchical transport networks, force balancing and dynamic self-organisation ([Coppens, 2005, 2012](#)), by setting them in a broader framework supported by nonequilibrium thermodynamics, the constructal law and nonlinear control concepts. This opens new perspectives in the development of nature-inspired devices and processes that would be affected by fluctuations and boundary effects on local properties at a small-scale level. At the process unit level, thermodynamic coupling should be exploited both for nonlinear transport enhancement and resilient behaviour to external constraint changes, in combination with nonlinear control

frameworks. At the plant level, they question the opportunity to develop resilient and agile chemical plants based on modular units considered as services and interconnected in a symbiotic network of mass, energy and data exchange. They also discuss the use of optimal control theory and entropy production for nonlinear systems.

Magnanelli et al. (2019) perform a plug flow reactor geometry optimisation by minimising entropy production, a nonequilibrium thermodynamic concept with the help of optimal control theory. In their work, they are inspired by the energy-efficient mass transfer and energy transfer induced by the reindeer nose's complex geometry. Depending on the variables optimised, they find double digit savings, which can be readily realised by a suitable geometry, changing the reactor diameter.

The design of hierarchical porous structures is the scope of the contributions by Cervantes-Martinez et al. (2019), Zhao et al. (2020) and Ye et al. (2019) with the goal of improving transport and/or reactive phenomena in unit operation devices, sometimes by several order of magnitudes. Both meso- and microscale structures are considered. The first two papers study the manufacturing processes, respectively the sol-gel process combined with surfactant templating and crystallisation in a Pickering emulsion, and propose mechanisms and conditions for optimising the structures. Applications of such structures refer to many domains, like electronics, catalysis, adsorption and drug delivery. Ye et al. (2019) develop an analytical method for optimising the hierarchical pore network in lithium-ion battery electrodes.

The development of industrial processes for producing copper selective plated polyimide-based substrates is the focus of the work by Marques-Hueso et al. (2020). The new process reduces waste and toxicity and is taking advantage of a spinach-based visible light sensitive photo-catalyst to induce the fast synthesis of silver nanoparticles on substrates in dedicated areas that can be further plated with copper.

Bearing in mind a noticeable similarity between nature and chemical engineering needs in terms of efficient, low-waste, resilient and performant devices and processes and the potential improvement when implementing natural mechanisms, there is great opportunity and a bright future for nature-inspired chemical engineering.

Acknowledgment

MOC gratefully acknowledges support from the EPSRC via EP/K038656/1 and EP/S03305X/1.

References

Cervantes-Martinez, C.V., Emo, M., Garcia-Gelma, M.-J., Stebe, M.-J., Blin, J.-L., 2019. [Morphosynthesis of porous silica from](#)

- [biocompatible templates](#). *Chem. Eng. Res. Des.* 151, 179–189.
- Coppens, M.-O., 2005. [Scaling up and down in a nature inspired way](#). *Ind. Eng. Chem. Res.* 44, 5011–5019.
- Coppens, M.-O., 2012. [A nature-inspired approach to reactor and catalysis engineering](#). *Curr. Op. Chem. Eng.* 1 (3), 281–289.
- Gerbaud, V., Da Cunha, S., Shcherbakova, N., 2020. A nonequilibrium thermodynamics perspective on nature-inspired chemical engineering processes. *Chem. Eng. Res. Des.*, <http://dx.doi.org/10.1016/j.cherd.2019.10.037>, in press.
- Magnanelli, E., Solberg, S.B.B., Kjelstrup, S., 2019. [Nature-inspired geometrical design of a chemical reactor](#). *Chem. Eng. Res. Des.* 152, 20–29.
- Marques-Hueso, J., Jones, T.D.A., Watson, D.E., Ryspayeva, A., Esfahani, M.N., Shuttleworth, M.P., Harris, R.A.S., Kay, R.W., Desmulliez, M.P., 2020. [Spinach-based photo-catalyst for selective plating on polyimide-based substrates for micro-patterning circuitry](#). *Chem. Eng. Res. Des.* 153, 839–848.
- Ye, G., Tong, W., Liu, X., Song, X., Zhou, J., Zhou, X., 2019. [An analytical method for the optimization of pore network in lithium-ion battery electrodes](#). *Chem. Eng. Res. Des.* 149, 226–234.
- Yu, C., Sasic, S., Liu, K., Salameh, S., Ras, R.H.A., van Ommen, J.R., 2020. [Nature-inspired self-cleaning surfaces: Mechanisms, modelling, and manufacturing](#). *Chem. Eng. Res. Des.*, <http://dx.doi.org/10.1016/j.cherd.2019.11.038>, in press.
- Zhao, X., Duan, H., Gao, S., Shi, Z., Zhu, K., 2020. [Crystal engineering of hierarchical zeolite in dynamically maintained Pickering emulsion](#). *Chem. Eng. Res. Des.* 153, 49–62.

Vincent Gerbaud*

Catherine Xuereb*

Laboratoire de Génie Chimique, Université de Toulouse, CNRS, INP,

UPS, Toulouse, France

Marc-Olivier Coppens**

EPSRC “Frontier Engineering” Centre for Nature Inspired Engineering & Department of Chemical Engineering, University College London, London WC1E 7JE, UK

* Corresponding authors.

** Corresponding authors.

E-mail addresses: vincent.gerbaud@ensiacet.fr (V. Gerbaud),

catherine.xuereb@ensiacet.fr (C. Xuereb),

m.coppens@ucl.ac.uk (M.-O. Coppens)

<https://doi.org/10.1016/j.cherd.2020.01.019>