Reaction **Chemistry & Engineering**



EDITORIAL

View Article Online



Cite this: React. Chem. Eng., 2022, 7,

Introduction to the themed collection on digitalization in reaction engineering

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DOI: 10.1039/d2re90011d

rsc.li/reaction-engineering

A transformation of the chemicals industry driven by a need for the design of more efficient and sustainable chemical processes is underway. 1,2 This

rethinking traditional approaches to wet chemistry laboratories, scale-ups, and production.3 Advancement automation with artificial intelligence algorithms have created new opportunities for chemical reactors to synchronously with digital twins, 4-6 and although there has been an upswing in the number of papers on deep learning methods, few have explored their design and application in chemical reaction engineering. Featured in this themed issue, "Digitalization in

Reaction Engineering", are key studies

centered around the convergence of

deep learning methods, data science,

fourth industrial revolution involves

automation, and spectroscopic analysis for reaction engineering.

development of predictive reaction kinetic models, critical for the design of chemical reactors, historically depends on laborious experimentation often generating significant quantities of chemical waste that results in models limited the range of tested conditions. The vast number chemical reactions used in industrial applications7,8 further motivate computational versatility in the methodology, and ideally, one should be able to validate their models from a limited amount of data. An automated, computational approach to reaction

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Federico Galvanin is an associate Chemical professor of Engineering at University College London (UCL). He completed his MS and PhD in chemical engineering at the University of Padova (Italy). After a postdoctoral in Padova, he was appointed as a research associate at UCL where he became a lecturer in 2015. His research interests lie at the interface between mathematical modelling and experimentation and focus

on the use of model-based design of experiments methods for the development of predictive models of complex systems. He has made significant literature contributions to the development of systems engineering methods and software tools for model identification using machine learning, optimal experimental design techniques and their use and integration in autonomous reactor platforms.



Ryan L. Hartman

Ryan L. Hartman is an associate professor in chemical biomolecular engineering at New York University. He completed his BS at Michigan Technological University, a PhD at the University of Michigan, and his postdoctoral training at the Massachusetts *Institute* of Technology, all in chemical engineering. He has served as the Catalysis Engineering Programming Chair of the American Institute of

Chemical Engineers, an executive director of the International Symposia of Chemical Reaction Engineering, and as an advisory board member of Reaction Chemistry & Engineering. His research interests revolve around the design of artificial intelligence with continuous-flow microreactors for the discovery of reaction kinetics and mechanisms.

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network identification could accelerate kinetics development and catalyst selection, while requiring only a handful of experiments for validations (10.1039/ d1re00098e). New approaches to the design of experiments for selecting a "fit for purpose" kinetic model could improve the efficient use of limited data and the design of the next set of experiments advance to early understanding of kinetics (10.1039/ d1re00222h). Catalyst stability, its dependence on the composition and reaction conditions, yielding optimal kinetics are fundamental challenges computer-aided design that experiments can help to discover (10.1039/d1re00441g).

Chemical reactions are without a doubt complex, which only adds to the arduous endeavour designing chemical reactors. Reactor dynamics and phase behaviors have traditionally complicated industrial-scale designs and operations,9 but with recent developments in deep learning methods their transient interplay can be exploited in the laboratory for a faster mapping of the reaction space topology. For instance, synchronous analysis during unsteadystate operation can enable quicker, datarich exploration by comparison to

steady-state experimentation (10.1039/ d1re00350j). On the other hand, Bayesian based self-optimization of gasliquid-solid multiphase reactions can help decipher the influence multivariate conditions for exceptionally complicated reactions, and with improved computational performance over conventional optimization algorithms (10.1039/d1re00397f). For multiphase gas-liquid or liquid-liquid reactions, where the mass transfer rate influences the process, often it is difficult to have an estimate of intrinsic rates and using lumped models tend to bring more empiricism than accuracy as the scale of production increases. Digitalizing such processes with an estimate of all limiting parameters helps reduce the downtime or test time to wait for the desired steady state operations even for sensitive cases where multiple steady states are expected.

This themed issue highlights investigations that have the potential to impact applications across the reaction engineering discipline. Reactions of longstanding industrial significance, such as the Fischer-Tropsch (10.1039/ d1re00351h), multiphase or nanomaterials syntheses and their

designs (10.1039/d1re00247c) can be explored for improved manufacturing efficiencies. Generally speaking, benchtop digitalization integrated with chemical process design, e.g., manufacturing with renewable feedstocks such as biomass (10.1039/ d1re00560j), is a step towards more sustainable chemicals manufacturing and better life-cycle assessments. We would like to thank all authors for their remarkable work, with each contributing insightful concepts that are foundations to the emerging field of digitalization in reaction engineering.

References

- IBM, What is Industry 4.0?, 2022, Available from: https://www.ibm.com/ topics/industry-4-0.
- V. Venkatasubramanian, The promise of artificial intelligence in chemical engineering: Is it here, finally?, AIChE J., 2019, 65(2), 466-478.
- S. Yang, et al., Hybrid Modeling in the Era of Smart Manufacturing, Comput. Chem. Eng., 2020, 140, 106874.
- al., Thakkar, etArtificial intelligence and automation computer aided synthesis planning, React. Chem. Eng., 2021, 6(1), 27-51.



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Amol A. Kulkarni is a scientist in the Chemical Engineering & Process Development Division at CSIR-National Chemical Laboratory, Pune (Since 2005). He is a chemical engineer by training (B.E. and PhD, all from Institute of Chemical Technology, Mumbai). He was Humboldt Fellow at the Max Planck Institute-Magdeburg and later an IUSSTF research fellow at Massachusetts *Institute* of Technology. He works in the area

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María José Nieves-Remacha is Senior Advisor at Lilly Research Laboratories at Eli Lilly and Company. She received her BS from Universidad Complutense de Madrid and PhD and MS in Chemical Engineering from Massachusetts *Institute* Technology (2014). After that, she joined the Dow Chemical Company to work as a Senior Engineer in theReaction Engineering group within the Core R&DDepartment

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- 5 S. J. Qin and L. H. Chiang, Advances and opportunities in machine learning for process data analytics, Comput. Chem. Eng., 2019, 126, 465-473.
- A. Bamberg, et al., The Digital Twin -Your Ingenious Companion for Process
- Engineering and Smart Production, Chem. Eng. Technol., 2021, 44(6), 954-961. C&EN Staff, C&EN's World Chemical Outlook 2022, Chem. Eng. News, 2022, 100(2), https://cen.acs.org/ magazine/100/10002.html.
- 8 C. Council Chemical Industry, 2022, Available from: https:// ukchemistrygrowth.com/chemistry/.
- G. Donati and R. Paludetto, Scale up of chemical reactors, Catal. Today, 1997, 34(3), 483-533.