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Open Literature Survey

Q2 – 2020

IN THE LITERATURE SURVEY TODAY:

Reported PI technologies vs products/processes
(numbers correspond to papers item#)

[illegible]

1. Rotating Packed Bed / CO₂ removal

A Review

Hydrodynamic characteristics and mass transfer performance of rotating packed bed for CO₂ removal by chemical absorption: A review

By: Zhang, Wei; Xie, Peng; Li, Yuxing; Teng, Lin; Zhu, Jianlu

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Qingdao, Peop. Rep. China

Abstract

Carbon dioxide (CO₂) removal is an important process in natural gas processing. For offshore natural gas, due to the space limitations of offshore platforms, the vol. requirement of CO₂ removal equipment is very strict. Therefore, high-efficient CO₂ removal equipment is needed to meet the processing requirements of natural gas. As a new type of process intensification technol., the rotating packed bed (RPB) is a desirable candidate for removing CO₂ from offshore natural gas due to its good mass transfer performance and considerable size savings. In this paper, the research progress of RPBs is reviewed from the aspects of hydrodynamic characteristics and mass transfer performance. Different research methods have been discussed, and their advantages and disadvantages have been pointed out. The factors that affect the efficiency of CO₂ removal have been analyzed, and operational recommendations have been given. Suggestions for future research are put forward to promote the application of RPBs on offshore platforms for CO₂ removal from offshore natural gas.

PI Classification code number: 2.3.7

Keywords: CO₂ removal ; Rotating packed bed ; Hydrodynamic characteristics ; Mass transfer ; Offshore natural gas

Journal of Natural Gas Science and Engineering, Volume79 Pages103373 Journal;
Online Computer File 2020 CODEN: JNGSA4 ISSN: 1875-5100
DOI:10.1016/j.jngse.2020.103373

2. Membrane / Gas separation

A Review

Membrane engineering: Latest advancements in gas separation and pre-treatment processes, petrochemical industry and refinery, and future perspectives in emerging applications

By: Iulianelli, Adolfo; Drioli, Enrico

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Abstract

The current transformation of our linear and fossil fuels-based economy into a circular economy through the redefined paradigms of the sustainable development is requesting a major role of the renewable sources exploitation and the adoption of alternative technologies able to redesign a new industrial infrastructure not based on the fossil fuel utilization, but involving the concepts of wastes recycle and transformation into added value products. Membrane engineering moves under the principles of the Process Intensification Strategy applied to several industrial sectors, from the chem. and petrochem. industry to refinery, from water desalination and wastewater treatments to agro-food and gas sepn. etc. This review aims to analyze the impact of the membrane gas sepn. technol. in petrochem. industry and refinery, highlighting the progress done on the membrane materials utilized in various industrial gas sepn. processes and discussing on the status of the implementation of membrane based operations in the various gas sepn. industrial fields and related markets. The benefits of their application in terms of improved process efficiency, reduced footprint, environmental protection and lower costs are also proposed. Furthermore, the importance of membrane reactors for fuel processing and membrane based pre-treatments and the integrated membrane gas sepn. systems is also discussed.

PI Classification code number: 3.1.4

Keywords: Membrane engineering ; Gas separation ; Chemical and petrochemical industry ; Gas refinery

Fuel Processing Technology Volume206 Pages106464 Journal; General Review;
Online Computer File 2020 CODEN: FPTEDY ISSN: 0378-3820
DOI:10.1016/j.fuproc.2020.106464

3. Methodology / Process Intensification

A Review

Nonlinear Optimization Strategies for Process Separations and Process Intensification

By: Biegler, Lorenz T.

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Abstract

Advanced nonlinear programming (NLP) strategies based on equation-oriented (EO) process models are leading to significant improvements in computer-aided process engineering. The EO paradigm allows the development of large, integrated optimization platforms that expand the scope of continuous optimization tasks in process engineering. In particular, these platforms deploy significantly faster NLP strategies than in com. simulation tools. Moreover, they exploit exact derivs. and system structure in order to consider much larger and more challenging systems. Finally, they allow the incorporation of much more general models, such as multi-level optimization and complementarity constraints. For process optimization this allows the treatment of extended models for complex phase equil. and process sepn. These advances facilitate the optimization of novel integrated systems that arise in process intensification. Several sepn. case studies are presented that illustrate these optimization concepts and demonstrate their effectiveness for hybrid membrane/distn. sepn. and reactive distn. systems that typify novel systems in process intensification.

PI Classification code number: none

Keywords: Complementarity conditions, Equation-oriented modeling, Nonlinear programming, Process intensification, Process optimization

Chemie Ingenieur Technik PagesAhead of Print Journal; General Review 2020
CODEN: CITEAH ISSN: 0009-286X DOI:10.1002/cite.202000014

A Review

Recent advances in continuous-flow organocatalysis for process intensification

By: De Risi, Carmela; Bortolini, Olga; Brandolese, Arianna; Di Carmine, Graziano; Ragno, Daniele; Massi, Alessandro

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Abstract

Chem. in continuous-flow continues to attract attention from the community of synthetic org. chemists due to its now well-recognized benefits including, inter alia, quick reaction times, operational safety, rapid reaction screening/optimization, enhanced automation with possible addn. of in-line reaction anal., and easy scalability. Coupling of flow chem. to enabling technologies (e.g. unconventional solvents, supported reagents or catalysts, microwave irradiatn., photochem., inductive heating, microreactors) as well as to additive manufg. (AM) technologies (i.e. 3D printing) gives addnl. advantages for throughput and automation, and besides this, unique opportunities are offered by compartmentalization, that allows multistep syntheses to occur reconciling incompatible reaction conditions. Based on all this, continuous-flow may itself be seen as an enabling technol. which leads in the direction of process intensification meeting increasingly pressing sustainability issues (e.g. waste minimization, cost/energy redn.). As part of flow chem., organocatalysis represents an active research area under which there is large opportunity for re-optimizing long-standing reactions or inventing new transformations. Both homogeneous (sol.) and heterogeneous (insol.) org. mols. have been used as catalysts for continuous-flow processing in either achiral or asym. fashion, any issue inherent to a homogeneous approach (high catalyst loading, difficult catalyst sepn.) being typically overcome with the use of heterogenized organocatalysts. This review is aimed at covering the progresses on organocatalysis in continuous-flow from 2016 to early 2020, with special attention paid to the comparison between batch and flow processes for each discussed transformation to substantiate the potential of flow technol. for process intensification.

PI Classification code number: 1.2.7

Keywords: flow chemistry; heterogeneous catalysis; enabling technologies; additive manufacturing; process intensification

Reaction Chemistry & Engineering Volume5 Issue6 Pages1017-1052 Journal; General Review; Online Computer File 2020 CODEN: RCEEBW ISSN: 2058-9883 DOI:10.1039/d0re00076k

5. Microfluidics / Process Intensification

A Review

Miniaturization as One of the Paths to Process Intensification in Chemical Engineering

By: Abiev, R. Sh.

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Abstract

Miniaturization of chem. equipment is one of process intensification methods. The main advantage of microstructured chem. equipment originates from the small cross sizes of microchannels (2-3 mm or less, usually less than 1 mm). Thus, the capillary and viscous forces dominate over the inertial and gravitational forces, leading to the formation of structured flows. The micro-sized reactors, mixers, heat exchangers, extractors, etc., have the following significant advantages: (1) lower mass and heat losses during processing; (2) better temp. control of processes; (3) shorter diffusional paths for mols. and ions; (4) ultimate safety due to a small reaction vol.; (5) much higher heat and mass transfer rates as compared to macrolevel devices; and (6) narrow residence time, consequently, better selectivity and yield. This special issue includes several papers in the field of hydrodynamics and heat and mass transfer in two-phase flows in microchannels.

PI Classification code number: 1.2.7

Keywords: miniaturization, microstructured chemical equipment, microchannels, hydrodynamics, heat and mass transfer, two-phase flows, process intensification, chemical engineering

Theoretical Foundations of Chemical Engineering Volume 54 Issue 1 Pages 1-2 Journal; General Review; Online Computer File 2020 CODEN: TFCEAU ISSN: 0040-5795 DOI:10.1134/s0040579520300016

6. *Microfluidics / Biomolecules purification*

A Review

Separation and purification of biomacromolecules based on microfluidics

By: Vicente, Filipa A.; Plazl, Igor; Ventura, Sonia P. M.; Znidarsic-Plazl, Polona

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Abstract

Seprn. and purifn. of biomacromols. either in biopharmaceuticals and fine chems. manufg., or in diagnostics and biol. characterization, can substantially benefit from application of microfluidic devices. Small vols. of equipment, very efficient mass and heat transfer together with high process control result in process intensification, high throughputs, low energy consumption and reduced waste prodn. as compared to conventional processing. This review highlights microfluidics-based seprn. and purifn. of proteins and nucleic acids with the focus on liq.-liq. extns., particularly with biocompatible aq. two-phase systems, which represent a cost-effective and green alternative. A variety of microflow set-ups are shown to enable sustainable and efficient isolation of target biomols. both for preparative, as well as for anal. purposes.

PI Classification code number: none

Keywords: microfluidics; proteins; nucleic acids; ATP separation; purification; process intensification

Green Chemistry PagesAhead of Print Journal; General Review 2020 CODEN: GRCHFJ ISSN: 1463-9262 DOI:10.1039/c9gc04362d

7. *Falling film distillation / Process Intensification*

A Review

A background review on falling film distillation in wetted-wall columns: From fundamentals towards intensified technologies

By: Battisti, Rodrigo; Machado, Ricardo A. F.; Marangoni, Cintia

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Abstract

In response to the worldwide need for more sustainable chem. processes, distn. became target of major efforts for efficiency improvement. Leveraged by process intensification, several technologies have been proposed to reach a more compact, safer, and less energy-intensive equipment. Falling film columns were intensively used for heat and mass transfer research in last century. Noteworthy, studies proposing the falling film technol. in distn. condition highlighted numerous advantages, such as low residence time and simple constructive structure when compared to conventional distn., as well as high transfer rates due to the small thickness that flows in longitudinal direction of the distn. wall. Therefore, this review brings a historical perspective of theor. and exptl. works as well as deposited patents on falling film distn. from the beginning of 20th Century to present. Theor. background and conceptual aspects related to efficiency improvement and process intensification were deeply discussed, aiming to guideline future perspectives in chem. sepns.

PI Classification code number: 1.2.1

Keywords: Falling film distillation ; Wetted-Wall columns ; Separation efficiency parameters ; Constructive column configurations

Chemical Engineering and Processing Volume150 Pages107873 Journal; General Review; Online Computer File 2020 CODEN:CENPEU ISSN:0255-2701 DOI:10.1016/j.cep.2020.107873

A review

Chemical looping beyond combustion - a perspective

By: Zhu, Xing; Imtiaz, Qasim; Donat, Felix; Muller, Christoph R.; Li, Fanxing

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Abstract

A review. As a promising approach for carbon dioxide capture, chem. looping combustion has been extensively investigated for more than two decades. However, the chem. looping strategy can be and has been extended well beyond carbon capture. In fact, significant impacts on emission redn., energy conservation, and value-creation can be anticipated from chem. looping beyond combustion (CLBC). This article aims to demonstrate the versatility and transformational benefits of CLBC. Specifically, we focus on the use of oxygen carriers or redox catalysts for chem. prodn. - a \$4 trillion industry that consumes 40.9 quadrillion BTU of energy. Compared to state-of-the-art chem. prodn. technologies, we illustrate that chem. looping offers significant opportunities for process intensification and exergy loss minimization. In many cases, an order of magnitude redn. in energy consumption and CO₂ emission can be realized without the needs for carbon dioxide capture. In addn. to providing various CLBC examples, this article elaborates on generalized design principles for CLBC, potential benefits and pitfalls, as well as redox catalyst selection, design, optimization, and redox reaction mechanism.

PI Classification code number: none

Keywords: chemical looping, CO₂ capture, catalysis, particle technology, process intensification

Energy & Environmental Science Volume13 Issue3 Pages772-804 Journal; General Review; Online Computer File 2020 CODEN: EESNBY ISSN: 1754-5706 DOI:10.1039/c9ee03793d

A Review

Sewage sludge to bio-fuel: A review on the sustainable approach of transforming sewage waste to alternative fuel

By: Bora, Akash Pratim; Gupta, Dipanshu Prakash; Durbha, Krishna Sandilya

Department of Chemical Engineering, Dhanbad Indian Institute of Technology (Indian School of Mines), Jharkhand, India

Abstract

A review. Bio-fuels are gaining worldwide attention as an alternative fuel option replacing the usage of the mineral diesel derived from conventional fossil sources. However, the high cost attributed by the feedstock made it less competitive with the com. diesel. A widespread research is going on worldwide for the prodn. of fuels from renewable biomass replacing the currently used traditional sources. The high lipid-contg. municipal sewage sludge (MSS) can be considered as a potential feedstock owing to its low cost and abundant availability. The lipids are transformed to biodiesel via transesterification or to bio-oil by pyrolysis. In this review paper, a comprehensive discussion on the various aspects of bio-fuel prodn. from sludge derived lipids along with the key parameters affecting the process and its economics are presented. This review also emphasizes that future studies should focus on the usage of modern process intensification techniques for more efficient prodn. of bio-fuel from renewable biomass.

PI Classification code number: 3.1.2

Keywords: Bio-fuel ; Sewage sludge ; Lipid extraction ; Transesterification ; Heterogeneous catalyst

Fuel Volume 259 Pages 116262 Journal; General Review; Online Computer File 2020
CODEN: FUELAC ISSN:0016-2361 DOI:10.1016/j.fuel.2019.116262

A Review

The Advances in the Special Microwave Effects of the Heterogeneous Catalytic Reactions

By: Li Hong; Zhang Chunyu; Pang Chuanrui; Li Xingang; Gao Xin; Li Hong

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& Collaborative Innovation Center of Chemical Science and Engineering (Tianjin), Tianjin University, Tianjin, China

& TJU Binhai Industrial Research Institute Limited Company, Tianjin, China

Abstract

In the present, microwave field has been widely used in chemical processes as an important means of intensification. The heterogeneous catalysts coupling with microwave has been shown to have many advantages, such as high catalytic performance and stability. Our objective is to focus an up-to-date overview concerning the advances in the special microwave effects of the heterogeneous catalytic reactions including special thermal effect, microwave plasma, enhanced active groups, and the flexibility of structure. This review systematically states the action mechanism and some practical application of microwave-induced catalytic process. Finally, the potential research directions in the field of microwave-induced catalysis are prospected.

PI Classification code number: 2.1.2, 2.1.3, 2.1.4, 2.1.5

Keywords: microwave, catalysis, special thermal effect, plasma, process intensification

Frontiers in chemistry Volume8 Pages355 Journal; Article; (JOURNAL ARTICLE); General Review; (REVIEW) 2020 ISSN:2296-2646 Journal Code:101627988 Switzerland doi: [10.3389/fchem.2020.00355](https://doi.org/10.3389/fchem.2020.00355)

11. Ultrasonic reactors / Process Intensification

A Review

Continuous Ultrasonic Reactors: Design, Mechanism and Application

By: Dong Zhengya; Delacour Claire; Mc Carogher Keiran; Udepurkar Aniket Pradip; Kuhn Simon

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Abstract

Ultrasonic small scale flow reactors have found increasing popularity among researchers as they serve as a very useful platform for studying and controlling ultrasound mechanisms and effects. This has led to the use of these reactors for not only research purposes, but also various applications in biological, pharmaceutical and chemical processes mostly on laboratory and, in some cases, pilot scale. This review summarizes the state of the art of ultrasonic flow reactors and provides a guideline towards their design, characterization and application. Particular examples for ultrasound enhanced multiphase processes, spanning from immiscible fluid-fluid to fluid-solid systems, are provided. To conclude, challenges such as reactor efficiency and scalability are addressed.

PI Classification code number: 2.2.1

Keywords: microfluidics; ultrasound; process intensification; sonochemistry; flow chemistry

Materials (Basel, Switzerland) Volume13 Issue2 Journal; Article; (JOURNAL ARTICLE); General Review; (REVIEW) 2020 ISSN:1996-1944 Journal Code:101555929 Switzerland DOI: 10.3390/ma13020344

12. Photoreactors / Wastewater treatment

A Review

Innovative light-driven chemical/catalytic reactors towards contaminants of emerging concern mitigation: A review

By: Espindola, Jonathan C.; Vilar, Vitor J. P.

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Abstract

Urban wastewater treatment plants (WWTPs) are among the major sources of contaminants of emerging concern (CECs) release to surface water. This is mainly assocd. with the low performance of conventional technologies (e.g. activated sludge, sand filtration and UV disinfection processes) for the removal of residual amts. (ng L⁻¹–µg L⁻¹) of CECs. In this review, a list of CECs commonly detected in the aquatic environments is presented. Light-driven chem./catalytic processes for CECs removal, namely UV/oxidant and photocatalysis, are presented with discussion of their process, advantages, drawbacks, and the main attainments. In this context, process intensification has been gaining high relevance for wastewater treatment purposes due to its potential to overcome the main treatment limitations. Accordingly, an overview of advances to overcome the limitations in light-driven chem./catalytic processes for CECs mitigation was carried out, focusing mainly on the design of novel reactors and devices. Some aspects related to reactor configuration, removal mechanism, devices applied, illumination system, comparison criteria, and catalyst immobilization through implementation of novel reactors designs are also discussed. Regarding the reactor design, several devices exhibit a satisfactory mass transfer due to a large surface-to-vol. ratio or enhanced mixing conditions. However, improvements in photon transfer are still the biggest challenge to be overcome. The irradsn. of the entire reaction soln. and /or catalyst surface has shown to be challenging in many reactor configurations. Nevertheless, the reactor design and treatment process to be applied for CECs removal must be selected according to the site-specific conditions, in order to accomplish CECs mitigation and attain the best reactor performance.

PI Classification code number: 2.2.9

Keywords: Photoreactors ; Process intensification ; Reactor design ; Light induced chemical/catalytic processes

Chemical Engineering Journal (Amsterdam, Netherlands) Volume394 Pages124865
Journal; Online Computer File 2020 CODEN:CMEJAJ ISSN:1385-8947
DOI:10.1016/j.cej.2020.124865

Beyond electrolysis: old challenges and new concepts of electricity-driven chemical reactors

By: Andrzej I. Stankiewicz and Hakan Nigar

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& Faculty of Chemical and Process Engineering, Warsaw University of Technology, Warsaw, Poland

Abstract

With renewable electricity becoming the most widespread, flexible, and accessible form of energy on Earth, electrification of chemical processes presents one of the most promising transition paths to low-carbon footprint, environmentally-neutral manufacturing of fuels and chemicals. The current paper provides a critical perspective on the entire spectrum of chemical and catalytic reactors, in which electricity plays different roles targeting either the reaction mechanism or the thermal energy supply. Related challenges and necessary developments to address those challenges are discussed.

PI Classification code number: 2.1.2, 2.1.5, 2.2.1, 2.2.9, 2.3.4, 2.3.6

Keywords: electrification; electricity driven processes; catalytic reactors; sustainability; process intensification

Reaction Chemistry & Engineering 2020, Vol 5, Pages 1005–1016 DOI: 10.1039/d0re00116c

The resource gateway: Microfluidics and requirements engineering for sustainable space systems

By: Hessel, V.; Sarafriz, M. M.; Tran, N. N.

School of Chemical Engineering and Advanced Materials, University of Adelaide, Australia

Abstract

In this perspective research article, we present a different take on the emerging issue of in-situ resource utilization (ISRU) through proposing technol. disruption as soln. for the engineering complex space systems. At the example of space chem. manufg., we consider microfluidic approaches as prime tool to achieve process intensification. In particular, we propose a blue-sky vision how to develop circular chem. processes in space, how to integrate these, shield in space habitats and connect them to resources and markets via hubs. In the latter context, we pinpoint at the 'Verbund strategy', developed by the world's largest chem. company BASF, to integrate space processes. On a related note, we identify requirements engineering as a tool to assist the development of complex space systems, which demands for teaming up many stakeholders. The trifold circle 'Process-intensification/Circular-processes/Verbund-integration' will be exemplified through own and literature microfluidic applications.

PI Classification code number: 1.2.7

Keywords: Microreactors ; Microfluidics ; Process intensification : In-situ resource utilization ; Space research ; Circular processes

Chemical Engineering Science, Volume225, Pages115774, Journal; Online Computer File 2020 CODEN: CESCAC ISSN: 0009-2509
<https://doi.org/10.1016/j.ces.2020.115774>

15. Structured internals / Process Intensification

Design and conception of an innovative packing for separation column—Part I: Hydrodynamic study on wire intersections

By: Baptiste Dejean, Michel Meyer, David Rouzineau

Laboratoire de Génie Chimique, Université de Toulouse, CNRS, INPT, UPS, Toulouse, France

Abstract

Packed columns are crucial equipment established in the process industry in order to perform several separation operations (e.g. distillation, absorption, etc.). The scientific challenge is to improve the performance of these separation columns. This work aims to develop an innovative wire-based packing, where the liquid flow on the wire will have an interfacial surface greater than the geometric surface of the packing structure. A study of the liquid film behavior on inclined wires and their intersections is carried out based on experimental observations and a numerical simulation. The result is a mapping of the liquid flow regimes favored for the distillation process. Hence, it will be possible to orient the design of the wire-based packing, especially the wire diameter and inclination and the shape of the intersections.

PI Classification code number: 1.2.1

Keywords: Hydrodynamic study ; Liquid flow on wire ; Innovative packing ; Separation column

Chemical Engineering Research and Design, Vol 160 (2020), Pages 11–19
doi.org/10.1016/j.cherd.2020.05.006

16. Structured Internals / Process Intensification

3D-Structured Monoliths of Nanoporous Polymers by Additive Manufacturing

By: Sebastian Hock and Marcus Rose

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Abstract

Recent advances in 3D printing provide great opportunities for the utilization of functional materials in chemical engineering and heterogeneous catalysis. In this work cylindrical monoliths with varying geometries of transport channels are designed and printed by a fused deposition modeling (FDM) 3D printer from thermoplastic polymers. Their hydrodynamic characteristics are investigated. For a proof of concept composite monoliths of microporous hyper-cross linked polymers (HCP) are printed. They contain up to 40 wt% of HCP with an accessible specific surface area of up to 171m²g⁻¹.

PI Classification code number: 1.2.1, 1.2.2

Keywords: 3D printing, Hierarchical porosity, Hydrodynamic properties, Monolith, Porous polymer

Chem. Ing. Tech. 2020, 92, No. 5, 525–531 DOI: 10.1002/cite.201900149

Optimization of the direct synthesis of dimethyl ether from CO₂ rich synthesis gas: closing the loop between experimental investigations and model-based reactor design

By: Nirvana Delgado Otalvaro, Markus Kaiser, Karla Herrera Delgado, Stefan Wild, Jörg Sauer and Hannsjörg Freund

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& Karlsruhe Institute of Technology (KIT), Eggenstein-Leopoldshafen, Germany

Abstract

Reaction kinetic modeling, model-based optimization and experimental validation are performed for the direct synthesis of dimethyl ether from CO₂ rich synthesis gas. Among these disciplines, experimental methods and models are aligned in a stringent way of action, i.e., the same setup and models are applied throughout the whole contribution. First, a lumped reaction kinetic model from the literature is modified and parametrized to fit a vast array of 240 data points measured in a laboratory fixed bed reactor. The data were acquired using a mechanical mixture of the commercial catalysts CuO/ZnO/Al₂O₃ and γ -Al₂O₃. For this setup, a predictive model is derived and applied within dynamic model-based optimization. Here, the single-pass CO_x conversion serves as objective function while the operating conditions and composition of the mixed catalyst bed are the optimization variables. Finally, the optimization results obtained numerically are validated experimentally verifying the identified performance enhancement qualitatively. The remaining quantitative deviations yield valuable insights into model and methodological weaknesses or inaccuracies, closing the loop between kinetic investigations, model-based optimization and experimental validation.

PI Classification code number: 1.2.2, 1.2.4

Keywords: Reaction kinetic modeling; model-based optimization; experimental validation; DME synthesis

React. Chem. Eng., 2020, Vol 5, Pages 949- 960 DOI: 10.1039/d0re00041h

Additive manufacturing of interpenetrating periodic open cellular structures (interPOCS) with in operando adjustable flow characteristics

By: Do, G; Geisselbrecht, M; Schwieger, W; Freund, H.

Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Lehrstuhl für Chemische Reaktionstechnik, Erlangen, Germany

& Anwenderzentrum VerTec, Zentralinstitut für Neue Materialien und Prozesstechnik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Fürth, Germany

Abstract

Structured catalyst supports and structured reactors offer interesting features to address heat and mass transport challenges in catalytic processes. The present work addresses the unique role of so-called interpenetrating periodic open cellular structures (interPOCS) as a geometrically flexible system enabling in operando adjustment of fluid flow characteristics. The interPOCS studied in this work consist of an interwoven structure of two POCS with a defined offset, each based on a diamond unit cell. The specific surface area and porosity, as the structures' influential morphology parameters, were derived as a function of cell size and strut thickness, respectively. Both, POCS and interPOCS of different geometrical parameters were designed via computer-aided design, fabricated by fused deposition modeling and geometrically characterized. The influence of the structure offset and the geometrical dimension on the pressure drop was investigated in detail. From experimental data, the coefficients of an Ergun-type pressure drop correlation were fitted and a two cavity channel model was established to describe the dependency of the pressure drop on the offset position. The possibility of the structure shift in interPOCS represents a highly interesting and versatile option for in operando adjustment in catalytic processes.

PI Classification code number: 1.2.2, 1.2.3, 1.2.4

Keywords: Structured reactor; Pressure drop; Flow field; Flexible flow control; Periodic open cellular structures (POCS); Additive manufacturing

Chemical Engineering & Processing: Process Intensification, Vol 148 (2020) 107786
doi.org/10.1016/j.cep.2019.107786

When sonochemistry meets heterogeneous photocatalysis: designing a Sonophotoreactor towards sustainable selective oxidation

By: Giannakoudakis, Dimitrios A.; Lomot, Dariusz; Colmenares, Juan Carlos

Institute of Physical Chemistry, Polish Academy of Sciences, Warsaw, Poland.

Abstract

The exploration of the synergistic effect in catalysis upon the simultaneous utilization of two sources of power, ultrasound and light, is barely explored and remains a challenging issue. A crucial reason behind this is the difficulty in design and constructing a well-defined sonophotoreactor capable to take advantage of the combination of sonochem. and photochem. assets. Herein, we present our successful reactor and a detailed study regarding how the utilization of ultrasonication can act as process intensification tool for the selective and partial photo-oxidn. of a biomass derived model compd., benzyl alc. The main outcome was the enhanced selectivity in the case of sonophotocatalysis compared to photocatalysis. This selectivity was ascribed to the effects derived from the cavitation phenomena, leading like to hot spots formation and jetting phenomena. Our study can act as a guidance towards understanding the unique effects of ultrasound irradiation as a hybrid process intensification method (HPIM) towards appliance to more complex chem. reactions and manipulation of the nanocatalysts' photoreactivity in catalytic valorization applications.

PI Classification code number: 3.1.2

Keywords: ultrasonic reactor; photoreactor; sonophotoreactor; photocatalysis; hybrid process

Green Chemistry PagesAhead of Print Journal 2020 CODEN: GRCHFJ ISSN: 1463-9262 DOI:10.1039/d0gc00329h

Precipitation of Drug Particles Using a Gas Antisolvent Process on a High-Pressure Microfluidic Platform

By: Arora, Deepali; Sedev, Rossen; Beh, Chau Chun; Priest, Craig; Foster, Neil R.

WA School of Mines-Minerals, Energy and Chemical Engineering, Curtin University, Perth, Australia

Abstract

A high-pressure microfluidic platform was used to mix an org. soln. with carbon dioxide. Complete mixing occurred on board the microchip and allowed controlled pptn. of active pharmaceutical ingredients (APIs). Griseofulvin was pptd. from DMF with a tuneable particle size varying between 0.5 and 500 μm . The particle size increased with API concn. (favorable crystal growth) and decreased with driving pressure (efficient mixing promoting nucleation). Two different micromixers were used: CO₂ flowing into the soln. from a side channel (T-junction) and CO₂ entering the mixing channel flanked by two liq. streams (X-junction). Systematically smaller particles were obtained with the T-junction micromixer because of the higher antisolvent concn. The process can be carried out continuously with good control over the operating parameters. It is a step in the miniaturization and process intensification of gas antisolvent pptn. with opportunities for micronizing APIs.

PI Classification code number: 1.2.9

Keywords: microfluidics; high pressure; API precipitation; CO₂ antisolvent

Industrial & Engineering Chemistry Research PagesAhead of Print Journal 2020
CODEN: IECRED ISSN: 0888-5885 DOI:10.1021/acs.iecr.0c01484

Pushing the Limits of SNG Process Intensification: High GHSV Operation at Pilot Scale

By: Guilera, Jordi; Boeltken, Tim; Timm, Friedemann; Mallol, Ignasi; Alarcon, Andreina; Andreu, Teresa

Catalonia Institute for Energy Research (IREC), Spain

Abstract

Process intensification leads to a substantially smaller process technol. In this work, we present a combination of an active microsize catalyst and an effective microstructured reactor technol. for CO₂ methanation. The product of the reaction is renewable synthetic natural gas which can be injected into the existing gas infrastructure. The designed process was evaluated at pilot scale (37 kW electrolyzer) in a relevant environment using sewage biogas and a CO₂ waste stream as carbon sources. The desired gas quality was obtained in a 2-step synthesis process at moderate pressure using a decreasing temp. profile ($T = 275\text{--}475\text{ }^{\circ}\text{C}$) and water sequestration. Temp. profiles were adjusted by vaporizing water, compressed air, and heating cartridges. It was obsd. that pressure, carbon feedstock, and GHSV had an impact on the product gas quality. At the min. pressure ($P = 5\text{ bar(g)}$) for direct gas grid injection purposes, the process worked successfully at 31 500 h⁻¹ using upgraded CO₂ and 37 500 h⁻¹ using biogas. This represents a redn. of 4 times the vol. of the com. ref. Accordingly, the limits of CO₂ methanation process intensification were clearly crossed by the combination of reactor and catalyst miniaturization. Carbon dioxide and biogas can be converted to renewable gas in significantly smaller devices.

PI Classification code number: 1.2.4, 1.2.7

Keywords: Power-to-gas, Renewable gas, Synthetic natural gas, Microstructured reactor, Microsized catalyst

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Online Computer File 2020 CODEN: ASCECG ISSN:2168-0485
DOI:10.1021/acssuschemeng.0c02642

22. Supercritical microreactor / NPs production

Process intensification for the synthesis of ultra-small organic nanoparticles with supercritical CO₂ in a microfluidic system

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Abstract

Submicronization of org. compds. is a challenging requirement for applications in the imaging and pharmaceutical fields. A new Supercrit. AntiSolvent process with microreactor (μ SAS) was developed for nanoparticle (NP) synthesis. THF (THF) was used to solubilize a model org. mol., tetraphenylethylene, and supercrit. carbon dioxide (s.c.-CO₂) was used as antisolvent. The soly. of TPE in the THF/CO₂ system was first measured by in situ expts. Then, NPs of TPE were prepd. in various exptl. conditions and characterized by transmission electron microscopy (TEM). Chosen exptl. conditions led to NPs with a mean size of 9 ± 3 nm. Exptl. μ SAS results were compared with size distributions obtained by simulation, to obtain surface tension values, which are difficult to access by expt. alone. Simulations coupling Computational Fluid Dynamics (CFD) and Population Balance Equation (PBE) were performed under turbulent conditions in the high pressure microreactors. This coupled exptl. and theor. approach allowed a deep understanding of the μ SAS process and underlined the superior value of this technique for the prepn. of NPs.

PI Classification code number: 1.2.9

Keywords: Microfluidics ; Supercritical fluid ; Nanoparticle synthesis ; Numerical simulation ; Mixing intensification

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Journal; Online Computer File 2020 CODEN: CMEJAJ ISSN:1385-8947
DOI:10.1016/j.cej.2020.125333

23. Cyclic distillation / Process Intensification

A mass and energy balance stage model for cyclic distillation

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Abstract

Cyclic distn. is an emerging process intensification technol., which can improve sepn. efficiency compared to conventional distn. As most current models only account for the mass transfer, there is a lack of a stage model for cyclic distn. processes, which includes considerations of both mass and energy transfer. Such a model is presented in this article, and using this model, selected case studies, describing binary and multiple component systems with both ideal and nonideal liq. phases, are investigated. The presented stage model allows for the modeling of both mass and energy transfer for a cyclic distn. process and allows for multiple feed locations, as well as side draws. With the energy balances included, the dynamic vapor flow rate can be described. This was shown to have a significant effect on the sepn., esp. for cases where the change in the vapor flow over the column height was high.

PI Classification code number: 4.3.5

Keywords: cyclic distillation, distillation modeling, periodic cycled separation, process intensification

AIChE Journal PagesAhead of Print Journal 2020 CODEN: AICEAC ISSN: 0001-1541
DOI:10.1002/aic.16259

High Productivity Ethanol from Solid-State Fermentation of Steam-Exploded Corn Stover Using *Zymomonas mobilis* by N₂ Periodic Pulsation Process Intensification

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Abstract

Solid-state fermn., featured by water-saving, eco-friendly and high concn. product, is a promising technol. in lignocellulosic ethanol industry. However, in solid-state fermn. system, large gas content inside the substrate directly leads to high oxygen partial pressure and inhibits ethanol fermn. *Z. mobilis* can produce ethanol from glucose near the theor. max. value, but this ethanol yield would be greatly decreased by high oxygen partial pressure during solid-state fermn. In this study, we applied N₂ periodic pulsation process intensification (NPPPI) to ethanol solid-state fermn., which displaced air with N₂ and provided a proper anaerobic environment for *Z. mobilis*. Based on the water state distribution, the promotion effects of NPPPI on low solid loading and solid-state fermn. were analyzed to confirm the different degrees of oxygen inhibition in ethanol solid-state fermn. During the simultaneous saccharification solid-state fermn., the NPPPI group achieved 45.29% ethanol yield improvement and 30.38% concn. improvement compared with the control group. NPPPI also effectively decreased 58.47 % of glycerol and 84.24% of acetic acid prodn. and increased the biomass of *Z. mobilis*. By coupling the peristaltic enzymic hydrolysis and fed-batch culture, NPPPI made the ethanol yield and concn. reach 80.11% and 55.06 g/L, resp., in solid-state fermn.

PI Classification code number: 4.2.1

Keywords: lignocellulosic ethanol ; anaerobic fermentation ; N₂ periodic pulsation ; high productivity ; process intensification ;

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Operation and Optimization of Microwave-Heated Continuous-Flow Microfluidics

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Abstract

Microwave (MW) technol. can be powerful for electrification and process intensification but limited fundamental understanding of scalability and design principles hinders its effective use. In this work, we build a continuous-flow microreactor inside a com. single-mode MW applicator and the corresponding computational fluid dynamics model to simulate the temp. profile. The model is in good agreement with expts. for various microreactor dimensions and operating conditions. The model indicates that MW heating is greatly influenced by reactor geometry as well as the operating parameters. We observe a strong correlation between parameters and develop a gradient boost regression tree model to predict the outlet temp. accurately. This model is then applied to optimize the dimensions and operating conditions to maximize the outlet temp. and energy efficiency, resulting in a Pareto optimal. We demonstrate computationally and exptl. that it is possible to surpass the Pareto optimal and achieve an energy efficiency of ~ 90% or greater at temps. relevant for liq.-phase chem. via salting of the solvent. The present methodol. can be applied to other complex MW reactors. The combined numerical and exptl. approach provides insights into and a framework for scale-up and optimization.

PI Classification code number: 1.2.7, 2.1.2

Keywords: microwave reactor; microreactor; reactor design; CFD

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DOI:10.1021/acs.iecr.0c01650

Propoxylation of fatty amines: Switching from batch to flow

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Abstract

The ethoxylation and propoxylation of fatty amines are important industrial reactions commonly performed in de-intensified semi-batch reactors. The present study aims to intensify these reactions by transferring the process to continuous processing. Therefore, the propoxylation of octylamine, as model system, was performed in a batch reactor and in a micro tubular reactor. The micro tubular reactor operated with a single liq. phase at 15 bar pressure. The batch study found valuable kinetic and soly. information in the temp. range of 120°C-160°C. Moreover, a switch-flow method in the micro tubular reactor combined with inline FTIR gave a more detailed understanding of the reaction kinetics. In the micro tubular reactor, all PO was added in the feed according to stoichiometry, which led to a process intensification factor of 3.7 compared to fed-batch gas phase addn. at max. 2 bar.

PI Classification code number: 1.2.7

Keywords: batch to continuous; octylamine propoxylation; microreactor; process intensification

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Performance of an acoustic settler versus a hollow fiber-based ATF technology for influenza virus production in perfusion

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Abstract

Process intensification and integration is crucial regarding an ever increasing pressure on manufg. costs and capacities in biologics manufg. For virus prodn. in perfusion mode, membrane-based alternating tangential flow filtration (ATF) and acoustic settler are the commonly described cell retention technologies. While acoustic settlers allow for continuous influenza virus harvesting, the use of com. available membranes for ATF systems typically results in the accumulation of virus particles in the bioreactor vessel. Accordingly, with one single harvest at the end of a cultivation, this increases the risk of lowering the product quality. To assess which cell retention device would be most suitable for influenza A virus prodn., we compared various key performance figures using AGE1.CR.pIX cells at concns. between 25 and 50 x 10⁶ cells/mL at similar infection conditions using either an ATF system or an acoustic settler. Prodn. yields, process-related impurities, and aggregation of viruses and other large mols. were evaluated. Taking into account the total no. of virions from both the bioreactor and the harvest vessel, a 1.5-3.0-fold higher volumetric virus yield was obtained for the acoustic settler. In addn., fewer large-sized aggregates (virus particles and other mols.) were obsd. in the harvest taken directly from the bioreactor. In contrast, similar levels of process-related impurities (host cell dsDNA, total protein) were obtained in the harvest for both retention systems. Overall, a clear advantage was obsd. for continuous virus harvesting after the acoustic settler operation mode was optimized. This development may also allow direct integration of subsequent downstream processing steps. Key points: .bul. High suspension cell d., immortalized avian cell line, influenza vaccine.

PI Classification code number: 4.4

Keywords: Cell culture-based . Influenza . Virus . ATF, Perfusion

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DOI:10.1007/s00253-020-10596-x

Identification of the process windows of inclined rotating fixed-bed reactors with concentric tube - A hydrodynamic analysis

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Abstract

The inclined rotating fixed-bed reactor with inner tube is a promising process intensification concept for gas-limited reactions. In order to take full advantage of the reactor concept the installation of an inner concentric displacement tube is proposed to support the wetting intermittency of the whole fixed-bed at stratified flow with different liq. filling levels. The liq. phase distribution is characterized with a capacitance-based wire-mesh sensor, which is designed to cope with org. liq., porous catalyst packings and reactor rotation. The effects of operating conditions and design parameters on flow stratification, liq. filling level and specific pressure drop are analyzed to identify the process windows. Superficial liq. velocity and inclination angle were found to significantly influence the liq. filling level, while rotational velocity and superficial gas velocity have minor effects. Besides, reducing the particle diam. is an effective measure to manipulate the stratification patterns and the assocd. pressure drop.

PI Classification code number: 4.4

Keywords: Inclined rotating fixed-bed ; Hydrodynamic analysis ; Capacitance wire-mesh sensor ; Multiphase reactor

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DOI:10.1016/j.ces.2020.115637

Process intensification education contributes to sustainable development goals.

Part 1

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Abstract

In 2015 all the United Nations (UN) member states adopted 17 sustainable development goals (UN-SDG), as part of the 2030 Agenda, which is a 15-year plan to meet ambitious targets to eradicate poverty, protect the environment, and improve the quality of life around the world. Although the global community has progressed, the pace of implementation must accelerate to reach the UN-SDG time-line. For this to happen, professionals, institutions, companies, governments and the general public must become cognizant of the challenges that our world faces and the potential technological solutions at hand, including those provided by chemical engineering. Process intensification (PI) is a recent engineering approach with demonstrated potential to significantly improve process efficiency and safety while reducing cost. It offers opportunities for attaining the UN-SDG goals in a cost-effective and timely manner. However, the pedagogical tools to educate undergraduate, graduate students, and professionals active in the field of PI lack clarity and focus. This paper sets out the state-of-the-art, main discussion points and guidelines for enhanced PI teaching, deliberated by experts in PI with either an academic or industrial background as well as representatives from government and specialists in pedagogy gathered at the Lorentz Center (Leiden, The Netherlands) in June 2019 with the aim of uniting the efforts on education in PI and produce guidelines. In this Part 1, we discuss the societal and industrial needs for an educational strategy in the framework of PI. The terminology and background information on PI, related to educational implementation in industry and academia, are provided as a preamble to Part 2, which presents practical examples that will help educating on Process Intensification.

PI Classification code number: none

Keywords: Process intensification; Pedagogy; Chemical engineering; Process design; Education challenge; Industry challenge; Sustainability; Entrepreneurship

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Process intensification education contributes to sustainable development goals.

Part 2

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Abstract

Achieving the United Nations sustainable development goals requires industry and society to develop tools and processes that work at all scales, enabling goods delivery, services, and technology to large conglomerates and remote regions. Process Intensification (PI) is a technological advance that promises to deliver means to reach these goals, but higher education has yet to totally embrace the program. Here, we present practical examples on how to better teach the principles of PI in the context of the Bloom's taxonomy and summarize the current industrial use and the future demands for PI, as a continuation of the topics discussed in Part 1. In the appendices, we provide details on the existing PI courses around the world, as well as teaching activities that are showcased during these courses to aid students' lifelong learning. The increasing number of successful commercial cases of PI highlight the importance of PI education for both students in academia and industrial staff.

PI Classification code number: none

Keywords: Industry challenge; Process design; Pedagogy; Process Intensification; Entrepreneurship; Sustainability; Chemical engineering; Education challenge

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