



UNIVERSITY OF LEEDS

This is a repository copy of *Electrochemistry in continuous systems*.

White Rose Research Online URL for this paper:

<https://eprints.whiterose.ac.uk/161450/>

Version: Accepted Version

Article:

Nicholls, TP orcid.org/0000-0001-6654-0825, Schotten, C and Willans, CE orcid.org/0000-0003-0412-8821 (2020) *Electrochemistry in continuous systems*. *Current Opinion in Green and Sustainable Chemistry*, 26. 100355. ISSN 2452-2236

<https://doi.org/10.1016/j.cogsc.2020.100355>

© 2020, Elsevier. This manuscript version is made available under the CC-BY-NC-ND 4.0 license <http://creativecommons.org/licenses/by-nc-nd/4.0/>.

Reuse

This article is distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs (CC BY-NC-ND) licence. This licence only allows you to download this work and share it with others as long as you credit the authors, but you can't change the article in any way or use it commercially. More information and the full terms of the licence here: <https://creativecommons.org/licenses/>

Takedown

If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing eprints@whiterose.ac.uk including the URL of the record and the reason for the withdrawal request.



eprints@whiterose.ac.uk
<https://eprints.whiterose.ac.uk/>

Electrochemistry in continuous systems

Thomas P. Nicholls,* Christiane Schotten,* Charlotte E. Willans

School of Chemistry, University of Leeds, Leeds, LS2 9JT, UK

* T.P.Nicholls@leeds.ac.uk

* C.Schotten@leeds.ac.uk

C.E.Willans@leeds.ac.uk

Abstract

The use of continuous flow conditions for synthetic electrochemical reactions exhibits many benefits over more traditional batch conditions. This has resulted in many research groups developing continuous electrochemical reactors and their application. The benefits of continuous flow include increased Faradaic efficiencies resulting in reduced energy consumption, higher selectivities, and lower electrolyte loadings which decreases waste streams and simplifies purification. These improvements are largely derived from the smaller interelectrode gaps employed in continuous systems compared to batch protocols. While this may be perceived as a small change in terms of practical reaction setup, it presents many challenges associated with reactor design and development. This perspective will highlight reactor layouts designed to address some of these challenges.

Keywords

Electrochemistry, continuous flow, reactor development

Introduction

Electrochemistry is a convenient and sustainable enabling technology that provides a complementary approach to traditional chemical methods for the synthesis of functional molecules.[1-9] Electrochemistry is widely regarded as a ‘green’ technology as it allows direct redox manipulations using only electrons as reagents. The use of electrons is intrinsically ‘green’ as stoichiometric chemical redox agents which are often toxic and produce large amounts of by-products is avoided. Despite electrochemistry having been used for centuries,[10] its use for synthetic applications has only recently been adopted by a growing community of synthetic chemists.[3] There are several factors which have prompted this resurgence including the development of new and complementary synthetic methodology and the increasing push to perform synthetic chemistry more sustainably.[3] The use of electrons as reagents allows redox manipulations to be performed in the absence of harsh chemical oxidising and reducing agents. This generally provides greater selectivity derived from the fine control over the applied potential allowing late-stage manipulations of complex molecules.[1, 3, 5]

Continuous systems exhibit several attributes that can be beneficial compared to conventional batch reactors.[11-18] Heat and mass transfer are typically improved through the use of small dimensions. Small

reactor volumes, as well as the ability to generate and immediately consume hazardous or sensitive materials in a closed system result in an increased safety profile.[14] Reproducibility is improved due to inherent control over reaction parameters. Easier scale-up and process intensification make the use of continuous systems attractive to industry.[18] The ability to telescope multiple steps into a single system and to monitor, automate and optimise the process is also desirable.[11, 13, 15, 17]

Synthetic electrochemistry benefits significantly from translation to continuous systems, in fact a number of commercially available continuous electrochemical reactors have been developed as early as the 1980s. [19-26] Specifically, the smaller interelectrode distances typically employed in continuous systems reduces resistance which reduces or removes the need for a supporting electrolyte and simplifies purification. Large surface to volume ratios greatly benefit electrochemistry as it is a heterogeneous process, and provide the possibility of higher currents and thus, higher production rates.

This perspective will focus on the considerations and advantages that affect continuous electrochemical reactor designs. It will showcase the requirement for modularity and versatility when designing in-house fabricated electrochemical flow reactors using four recent examples. In addition, we will outline the approach our group has taken to enable and improve the

synthesis of organometallic complexes using electrochemistry in a continuous system.

Advantages of continuous flow for electrochemical transformations

In the last decade flow chemists, engineers and electrochemists have pursued the development of electrochemical continuous flow reactors and their application in synthetic chemistry.[20-22] Several groups have reported their own in-house fabricated reactors tailored to a specific application,[27-37] with several commercial reactors also being available.[26, 38-43]

We have chosen to highlight four recent examples which demonstrate the strengths of continuous electrochemistry: a) electrocatalysis with inline analysis (Fig. 1A), b) a flexible reactor design to both enable a synthetically useful reactor volume and enable rapid screening in a small reaction volume (Fig. 1B), c) electrochemical generation and consumption of reactive intermediates (Fig. 1C) and d) improved selectivity in a continuous reactor (Fig. 1D).

Ackermann and co-workers developed a rhodaelectro-catalysed alkyne annulation with arylimidates *via* C–H activation in continuous flow (Fig. 1A).[44] The electrochemical methodology enabled the oxidation of a Rh(III) species to Rh(IV) which resulted in a more rapid reductive elimination. In this example, the electrochemical step enables catalyst turnover rather than electrolysis of the substrate directly. This is desirable as only small amounts of electrocatalyst are needed. A key feature of the continuous system is the ability to utilise inline monitoring. Inline NMR monitoring was used in conjunction with various other analyses to propose a sophisticated mechanism. During the optimisation of this method, a PTFE anode compartment was developed containing a porous graphitic felt material. Together with a turbulence promoting electrode spacer, this electrode delivered the best results. The ability to interchange between different electrode materials was only possible as a result of the modular design of the electrochemical flow reactor.

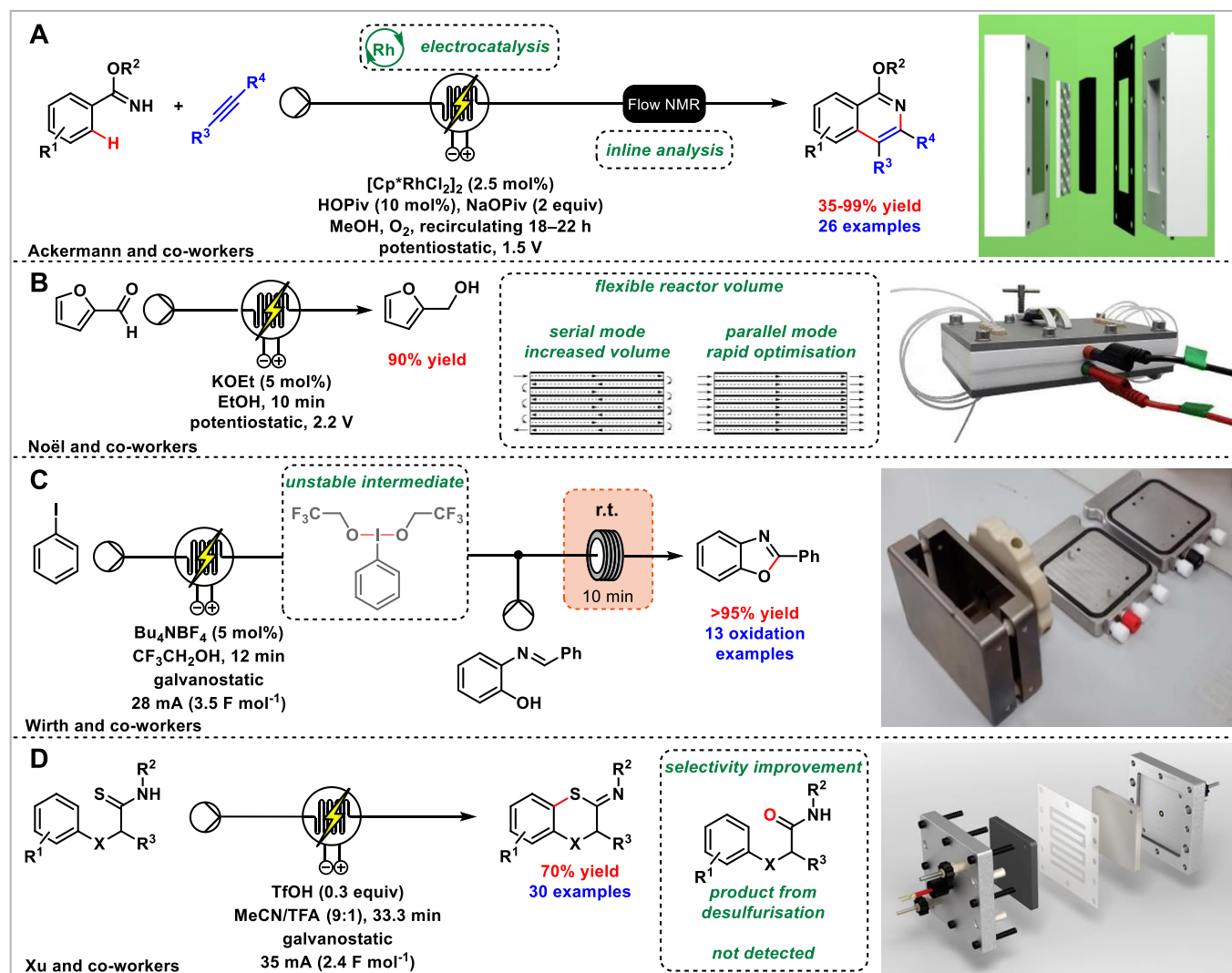
Noël and co-workers developed an indirect electrolysis method for the reduction of furfural with electro-derived hydrogen to deliver furfuryl alcohol under continuous conditions (Fig. 1B).[45] In this process, an electrochemical flow reactor was utilised which consists of eight separate channels. The channels can either be used in parallel and independently of each other in a numbering-up approach, or linked together in series to allow variation of the reactor volume. The electrochemical flow reactor displayed a clear advantage in the rapid optimisation of reaction conditions due to the

ability to perform eight reactions simultaneously within separate reactor channels in the same reactor. After optimisation under both acidic and basic conditions, 55% yield (19% Faradaic efficiency) and 90% yield (90% Faradaic efficiency) were achieved respectively in just 10 minutes residence time. The short reaction time is likely due to the large surface to volume ratio and short diffusion distances enabled by the flow reactor. Noël and co-workers have also utilised this reactor to develop several other useful transformations showcasing the versatility of the reactor design.[36, 46, 47]

Wirth and co-workers reported the electrochemical generation of hypervalent iodine reagents by anodic oxidation of iodoarenes in fluorinated alcohols (Fig. 1C).[48] The development of a continuous methodology is of particular interest as many hypervalent iodine reagents are highly reactive and are not bench-stable. The ability to produce such compounds and directly telescope them into a second reactor is therefore highly desirable. The hypervalent iodine reagents synthesised were telescoped into a second reactor and successfully mediated a range of oxidative transformations. Furthermore, the synthesis of bench-stable hypervalent iodine compounds can be achieved from the fluorinated hypervalent iodine reagents *via* ligand exchange. The group has worked with Vapourtec to commercialise their reactor.[32, 42, 43]

A similar reactor was used by Xu and co-workers to develop an intramolecular dehydrogenative C–S cross-coupling to produce 1,4-benzoxathiins and 1,4-benzothiazines from thioamides (Fig. 1D).[49] Dehydrogenative C–S cross couplings are typically challenging by transition metal catalysis as sulfur is known to poison these catalysts. However, the use of electrochemistry for this transformation is beneficial as transition metals can be avoided entirely. Furthermore, the authors demonstrated that a continuous flow methodology is beneficial over batch electrolysis as unproductive desulfurisation species are avoided (Fig. 1D). Initially, a Pt foil electrode was used as the cathode but this was degraded during the reaction. As such, an in-house fabricated Pt electrode was produced which was found to be more stable under the reaction conditions.

These representative examples demonstrate that modularity and versatility are crucial design features for electrochemical flow reactors. Benefits highlighted include the ability to replace toxic oxidising reagents with electricity, the implementation of inline analysis leading to useful mechanistic information, rapid screening and optimisation of reaction conditions, telescoping highly reactive intermediates directly into a second reactor and improved selectivities due to increased reaction control.



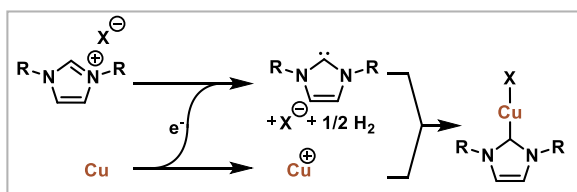
Scheme 1: Representative examples of recent electrochemical methodology that has benefited from translation to a continuous system and the modular reactors that facilitated this translation. A: Metallaelectrocatalysis by Ackermann and co-workers, adapted with permission from Ref. [44] Copyright 2019 American Chemical Society. B: Furfural oxidation by Noël and co-workers, adapted with permission from Ref. [45]. C: Generation of hypervalent iodine reagents by Wirth and co-workers. Reproduced with permission of Ref. [48]. D: Dehydrogenative C–S cross-coupling by Xu and co-workers. Reproduced with permission of Ref. [49].

Development of continuous systems for the synthesis of transition metal complexes

Within our group, we have investigated electrochemistry in search of novel, complementary ways to access inorganic and organometallic complexes. Initially, a batch protocol was developed using a three-necked round bottom flask to reduce imidazolium salts to the corresponding *N*-heterocyclic carbenes (NHCs) while oxidising a sacrificial anode to release metal ions into solution, where the NHC and metal ion combine to form the metal-NHC complex. In this manner, access to Cu(I)-NHC complexes was achieved (Scheme 2).[50] The imidazolium salt acts as both the electrolyte and ligand precursor which allows for a direct, atom efficient and clean method. The only by-product is hydrogen and reaction mixtures are typically clean enough to use directly in catalysis without further purification. As such,

it avoids the use of additional electrolytes, strong bases and the production of alkali metal salts which can complicate down-stream processes. The method is applicable to a range of imidazolium salts including those with base sensitive substituents which are not compatible with traditional syntheses. We have also expanded the scope to other transition metals and salen ligands.[51] Using this batch protocol, typical Faradaic efficiencies were below 50% and the scale was limited to a few millimoles of substrate. A high potential had to be applied as a result of large interelectrode distances. This high potential is in contrast with a mild method and can cause selectivity issues.

To address these issues, we developed a continuous flow protocol to improve the process in terms of mildness, Faradaic efficiency and the ability to scale up.[33] Our first electrochemical flow reactor consisted



Scheme 2: Electrochemical synthesis of Cu(I)-NHC complexes using a sacrificial Cu anode.

of a PTFE plate with a linear flow channel and two copper electrodes (2.5 mm interelectrode distance) placed within the channel. This was encased in stainless steel plates (Fig. 1). The continuous flow reactor successfully delivered the desired Cu(I)-NHC complex, Cu(IMes)Cl using IMes·HCl as starting material, however a significant amount of the bis-NHC complex, [Cu(IMes)₂]Cl, was also produced. This was presumably due to inefficient mixing, so glass beads were introduced to afford passive mixing. Full conversion to the desired mono-NHC complex was achieved with an isolated yield of 82%. This improved the Faradaic efficiency to 98% but also required recirculating the reaction mixture for 80 min at 2.5 V. To the best of our knowledge, this represented the first electrochemical synthesis of metal complexes in a continuous system.

After initial success introducing a continuous protocol, a second generation reactor was developed in which metal electrodes and PTFE flow channel spacers (1 mm) are stacked (Fig. 1).[33] The volume of the reactor can be adjusted to the desired application by introducing more electrodes and flow channels and electrodes can easily be exchanged. Similar to the first generation reactor, the electrodes and spacers are encased in stainless steel plates. This design increases the electrode surface area to volume ratio and facilitates scale up by allowing the volume to be increased while maintaining small interelectrode distances. Due to the decreased interelectrode distance in comparison to the first generation reactor, the potential could be further decreased (1.94 V) making the reactor more efficient and the synthesis milder. Full conversion (94% yield) could now be achieved in a single pass (6 min) without the need for recirculation. The versatility of the methodology was demonstrated by the synthesis of several Cu(I)-NHC complexes. Under these conditions, a calculated 1.07 g (0.265 mmol) of Cu(IMes)Cl could be produced in an hour. The scale of the process is mostly dependent on the flowrate, concentration of reactants and how long the reaction is run for. The stacked design of this reactor enables the volume of the reactor to be increased, which allows for a higher flowrate and a higher throughput. This can be achieved while maintaining the same residence

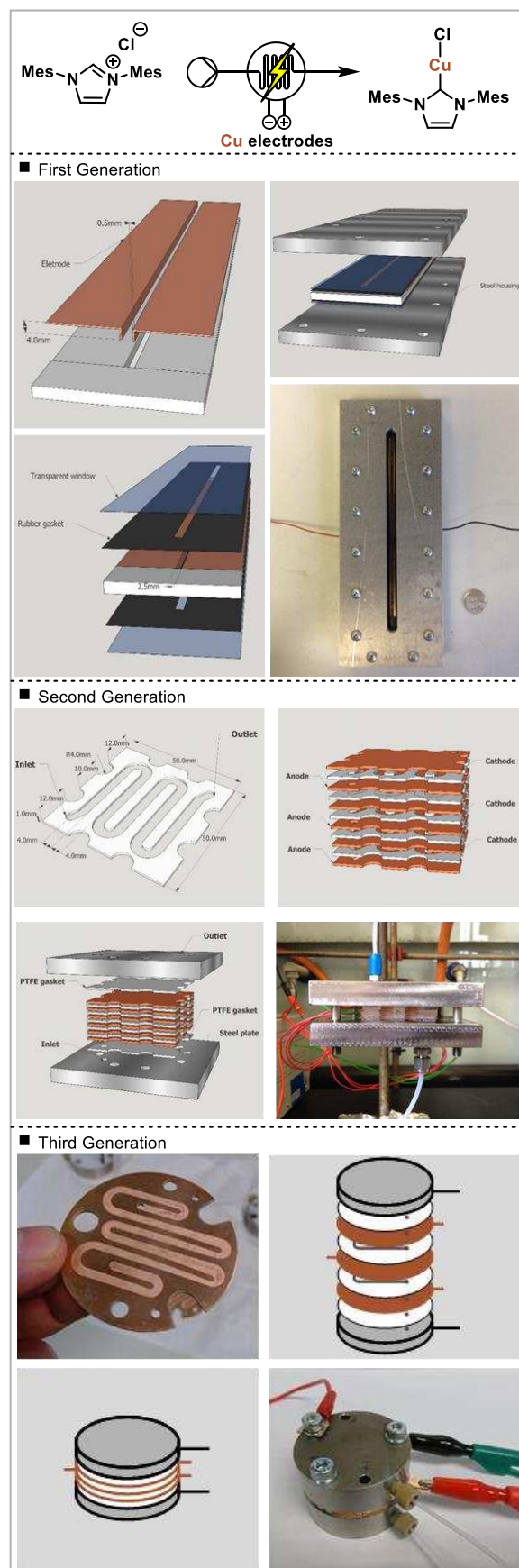


Figure 1: Three generations of electrochemical flow reactors used for the synthesis of transition metal complexes. Adapted from Ref. [33] with permission from The Royal Society of Chemistry.

time, without changing the interelectrode gap and without the requirement to recirculate reaction mixtures. This results in an increased output in the same amount of time. In addition, the reaction stream containing the freshly synthesised complex, Cu(IMes)Cl, was flowed directly into a catalytic hydrosilylation reaction (1 mol% catalyst loading). This method achieved the same yield of silyl ether as with the prepurified catalyst, demonstrating the applicability of this protocol for catalytic purposes. Using this reactor to directly dispense complexes into a catalytic reaction is particularly interesting for the on-demand synthesis of unstable or air-sensitive catalysts.

Next, we developed a third-generation reactor that enables rapid screening of electrochemically derived catalysts (Fig. 1). This required downscaling of the reactor to achieve a minimum reaction volume for high-throughput screening. The reactor is built similarly to the second generation reactor with stacked electrodes and PTFE spacers between two stainless steel plates. Initially, thinner PTFE spacers (0.25 mm) were investigated, however the resistance in the reactor was too low to afford the correct potential range at the desired current. Thus, 1 mm thick spacers were employed. In a layout with two spacers, a total volume of 0.93 mL was realised (*vs.* 4 mL in the second generation reactor). The potential could be decreased further to 1.8 V achieving full conversion to Cu(IMes)Cl (27.3 min residence time). These conditions could also be applied to a range of other imidazolium salts, which is crucial for the capacity of screening. Currently, work within the group is concerned with telescoping of the electrochemical reaction into a catalytic reaction with online monitoring.

Outlook/ perspectives

The use of continuous systems for electrochemical synthesis will be prevalent in the future due to the improved process control and the ability for easy scale-up. This is displayed in the number of recent publications and reviews on the topic. The use of modular and versatile reactors is crucial for this development, allowing a reactor to be optimised for a specific transformation or process. The commercialisation of such reactors will be useful, making them more accessible to the synthesis community. This will help synthetic chemists in adapting this exciting technique for the future.

Funding sources

This work was supported by the EPSRC (grant EP/R009406/1).

Competing interests

The authors declare no competing interests.

References

Papers of particular interest, published within this perspective, have been highlighted as:

* special interest: Pletcher [21], Laudadio [36], Kong [44], Elsherbini [48], Huang [49]
** outstanding interest: Yoshida [19], Chapman [33]

- [1] Sperry JB, Wright DL: **The application of cathodic reductions and anodic oxidations in the synthesis of complex molecules.** *Chem. Soc. Rev.* 2006, **35**:605-21.
- [2] Yoshida J-I, Kataoka K, Horcajada R, Nagaki A: **Modern Strategies in Electroorganic Synthesis.** *Chem. Rev.* 2008, **108**:2265-99.
- [3] Frontana-Uribe BA, Little RD, Ibanez JG, Palma A, Vasquez-Medrano R: **Organic electrocatalysis: a promising green methodology in organic chemistry.** *Green Chem.* 2010, **12**:2099-119.
- [4] Cardoso DSP, Šljukić B, Santos DMF, Sequeira CAC: **Organic Electrocatalysis: From Laboratory Practice to Industrial Applications.** *Org. Process Res. Dev.* 2017, **21**:1213-26.
- [5] Mohle S, Zirbes M, Rodrigo E, Gieshoff T, Wiebe A, Waldvogel SR: **Modern Electrochemical Aspects for the Synthesis of Value-Added Organic Products.** *Angew. Chem. Int. Ed.* 2018, **57**:6018-41.
- [6] Yan M, Kawamata Y, Baran PS: **Synthetic Organic Electrochemistry: Calling All Engineers.** *Angew. Chem. Int. Ed.* 2018, **57**:4149-55.
- [7] Little RD, Moeller KD: **Electrochemistry: Technology, Synthesis, Energy, and Materials.** *Chem. Rev.* 2018, **118**:4483-4.
- [8] Ghosh M, Shinde VS, Rueping M: **A review of asymmetric synthetic organic electrochemistry and electrocatalysis: concepts, applications, recent developments and future directions.** *Beilstein J. Org. Chem.* 2019, **15**:2710-46.
- [9] Kingston C, Palkowitz MD, Takahira Y, Vantourout JC, Peters BK, Kawamata Y, Baran PS: **A Survival Guide for the "Electro-curious".** *Acc. Chem. Res.* 2019:72-83.
- [10] Lund H: **A Century of Organic Electrochemistry.** *J. Electrochem. Soc.* 2002, **149**:S21-S33.
- [11] Webb D, Jamison TF: **Continuous flow multi-step organic synthesis.** *Chem. Sci.* 2010, **1**:675-80.
- [12] Wirth T: **Flow Chemistry: Enabling Technology in Drug Discovery and Process Research.** *Chem. Sus. Chem.* 2012, **5**:215-6.
- [13] Gutmann B, Cantillo D, Kappe CO: **Continuous-Flow Technology—A Tool for the Safe Manufacturing of Active Pharmaceutical Ingredients.** *Angew. Chem. Int. Ed.* 2015, **54**:6688-728.

- [14] Gutmann B, Kappe CO: **Forbidden chemistries go flow in API synthesis**. *Chim. Oggi Chem. Today* 2015, **33**:3.
- [15] Browne DL, Howard JL, Schotten C. **Continuous Flow Processing as a Tool for Medicinal Chemical Synthesis**. *Comprehensive Medicinal Chemistry III*. Oxford: Elsevier; 2017. p. 135-85.
- [16] Plutschack MB, Pieber B, Gilmore K, Seeberger PH: **The Hitchhiker's Guide to Flow Chemistry**. *Chem. Rev.* 2017, **117**:11796-893.
- [17] Baumann M, Baxendale IR: **The synthesis of active pharmaceutical ingredients (APIs) using continuous flow chemistry**. *Beilstein J. Org. Chem.* 2015, **11**:1194-219.
- [18] Hessel V, Kralisch D, Kockmann N, Noël T, Wang Q: **Novel Process Windows for Enabling, Accelerating, and Uplifting Flow Chemistry**. *Chem. Sus. Chem.* 2013, **6**:746-89.
- *[19] Yoshida J-I: **Organic electrochemistry, microreactors, and their synergy**. *Electrochem. Soc. Interface* 2009, **18**:40-5.
Early perspective article describing the synergy between organic electrochemistry and continuous microreactors.
- [20] Atobe M, Tateno H, Matsumura Y: **Applications of Flow Microreactors in Electrosynthetic Processes**. *Chem. Rev.* 2018, **118**:4541-72.
- *[21] Pletcher D, Green RA, Brown RCD: **Flow Electrolysis Cells for the Synthetic Organic Chemistry Laboratory**. *Chem. Rev.* 2018, **118**:4573-91.
Comprehensive review of flow electrolysis cells and the organic transformations that have been enabled by the combination of these technologies.
- [22] Mitsudo K, Kurimoto Y, Yoshioka K, Suga S: **Miniaturization and Combinatorial Approach in Organic Electrochemistry**. *Chem. Rev.* 2018, **118**:5985-99.
- [23] Elsherbini M, Wirth T: **Electroorganic Synthesis under Flow Conditions**. *Acc. Chem. Res.* 2019, **52**:3287-96.
- [24] Fogueiras-Amador AA, Wirth T. **Electrochemistry under Flow Conditions. Flow Chemistry: Integrated Approaches for Practical Applications**: The Royal Society of Chemistry; 2020. p. 153-98.
- [25] Noël T, Cao Y, Laudadio G: **The Fundamentals Behind the Use of Flow Reactors in Electrochemistry**. *Acc. Chem. Res.* 2019, **52**:2858-69.
This perspective describes the basics of electrochemical continuous flow systems and describes several techniques that have been used to optimise specific transformations.
- [26] Marshall RJ, Walsh FC: **A review of some recent electrolytic cell designs**. *Surface Technology* 1985, **24**:45-77.
- [27] Mengaud V, Bagel O, Ferrigno R, Girault HH, Haider A: **A ceramic electrochemical microreactor for the methoxylation of methyl-2-furoate with direct mass spectrometry coupling**. *Lab Chip* 2002, **2**:39-44.
- [28] Küpper M, Hessel V, Löwe H, Stark W, Kinkel J, Michel M, Schmidt-Traub H: **Micro reactor for electroorganic synthesis in the simulated moving bed-reaction and separation environment**. *Electrochim. Acta* 2003, **48**:2889-96.
- [29] Horcajada R, Okajima M, Suga S, Yoshida J-I: **Microflow electroorganic synthesis without supporting electrolyte**. *Chem. Commun.* 2005, **10**:1303-5.
- [30] He P, Watts P, Marken F, Haswell SJ: **Scaling out of electrolyte free electrosynthesis in a micro-gap flow cell**. *Lab Chip* 2007, **7**:141-3.
- [31] Attour A, Rode S, Ziogas A, Matlosz M, Lapique F: **A thin-gap cell for selective oxidation of 4-methylanisole to 4-methoxybenzaldehyde-dimethylacetal**. *J. Appl. Electrochem.* 2008, **38**:339-47.
- [32] Watts K, Gattrell W, Wirth T: **A practical microreactor for electrochemistry in flow**. *Beilstein J. Org. Chem.* 2011, **7**:1108-14.
- **[33] Chapman MR, Shafi YM, Kapur N, Nguyen BN, Willans CE: **Electrochemical flow-reactor for expedient synthesis of copper-N-heterocyclic carbene complexes**. *Chem. Commun.* 2015, **51**:1282-4.
This article describes in detail the development of the first and second generation electrochemical flow reactors described briefly here.
- [34] Gütz C, Stenglein A, Waldvogel SR: **Highly Modular Flow Cell for Electroorganic Synthesis**. *Org. Process Res. Dev.* 2017, **21**:771-8.
- [35] Syntrivanis L-D, Campo FJD, Robertson J: **An electrochemical flow cell for the convenient oxidation of Furfuryl alcohols**. *J. Flow Chem.* 2018, **8**:123-8.
- *[36] Laudadio G, de Smet W, Struik L, Cao Y, Noël T: **Design and application of a modular and scalable electrochemical flow microreactor**. *J. Flow Chem.* 2018, **8**:157-65.
- [37] van Melis CGW, Penny MR, Garcia AD, Petti A, Dobbs AP, Hilton ST, Lam K: **Supporting-Electrolyte-Free Electrochemical Methoxymethylation of Alcohols Using a 3D-Printed Electrosynthesis Continuous Flow Cell System**. *J. Flow Chem.* 2019, **6**:4144-8.
- [38] Green RA, Brown RCD, Pletcher D, Harji B: **A Microflow Electrolysis Cell for Laboratory Synthesis on the Multigram Scale**. *Org. Process Res. Dev.* 2015, **19**:1424-7.
- [39] CRD, <https://www.cambridgereactordesign.com/ammonite/ammonite.html>, (accessed 16/01/20).
- [40] Rivera FF, de León CP, Nava JL, Walsh FC: **The filter-press FM01-LC laboratory flow reactor and its applications**. *Electrochim. Acta* 2015, **163**:338-54.
- [41] Syrris, <https://syrris.com/product/asia-electrochemistry-flow-chemistry-system/>, (accessed 16/01/20).

[42] Folgueiras-Amador AA, Philipps K, Guilbaud S, Poelakker J, Wirth T: **An Easy-to-Machine Electrochemical Flow Microreactor: Efficient Synthesis of Isoindolinone and Flow Functionalization.** *Angew. Chem. Int. Ed.* 2017, **56**:15446-50.

[43] Vapourtec,
<https://www.vapourtec.com/products/flow-reactors/ion-electrochemical-reactor-features/>, (accessed 16/01/20).

*[44] Kong W-J, Finger LH, Messinis AM, Kuniyil R, Oliveira JCA, Ackermann L: **Flow Rhodaelectro-Catalyzed Alkyne Annulations by Versatile C–H Activation: Mechanistic Support for Rhodium(III/IV).** *J. Am. Chem. Soc.* 2019, **141**:17198-206.

An elegant C–H activation protocol that combines electrochemistry, continuous flow, transition metal catalysis and inline analysis.

[45] Cao Y, Noël T: **Efficient Electrocatalytic Reduction of Furfural to Furfuryl Alcohol in a Microchannel Flow Reactor.** *Org. Process Res. Dev.* 2019, **23**:403-8.

[46] Laudadio G, Barmpoutsis E, Schotten C, Struik L, Govaerts S, Browne DL, Noël T: **Sulfonamide Synthesis through Electrochemical Oxidative Coupling of Amines and Thiols.** *J. Am. Chem. Soc.* 2019, **141**:5664-8.

[47] Laudadio G, Bartolomeu ADA, Verwijlen LMHM, Cao Y, de Oliveira KT, Noël T: **Sulfonyl Fluoride**

Synthesis through Electrochemical Oxidative Coupling of Thiols and Potassium Fluoride. *J. Am. Chem. Soc.* 2019, **141**:11832-6.

*[48] Elsherbini M, Winterson B, Alharbi H, Folgueiras-Amador AA, Génot C, Wirth T: **Continuous Electrochemical Generator of Hypervalent Iodine Reagents: Synthetic Applications in Flow.** *Angew. Chem. Int. Ed.* 2019, **58**:9811-5.

An example of telescoping two continuous steps in which the first step generates a hypervalent iodine reagent which mediates the second oxidation step.

*[49] Huang C, Qian X-Y, Xu H-C: **Continuous-Flow Electrosynthesis of Benzofused S-Heterocycles by Dehydrogenative C–S Cross-Coupling.** *Angew. Chem. Int. Ed.* 2019, **58**:6650-3.

An example in which continuous flow electrochemistry improves selectivity of a transformation when compared to batch electrolysis.

[50] Lake BRM, Bullough EK, Williams TJ, Whitwood AC, Little MA, Willans CE: **Simple and versatile selective synthesis of neutral and cationic copper(I) N-heterocyclic carbene complexes using an electrochemical procedure.** *Chem. Commun.* 2012, **48**:4887-9.

[51] Chapman MR, Henkelis SE, Kapur N, Nguyen BN, Willans CE: **A Straightforward Electrochemical Approach to Imine- and Amine-bisphenolate Metal Complexes with Facile Control Over Metal Oxidation State.** *ChemistryOpen* 2016, **5**:351-6.