Additive Layer Manufacturing of Catalytic Static Mixers for Continuous Flow Reactors

Versatile technique provides economic and practical advantages to the flow chemist

Christian H. Hornung, Shravan Singh, Simon Saubern*
CSIRO, Bag 10, Clayton South, Melbourne, Victoria 3169, Australia

*Email: simon.saubern@csiro.au

With a design guided by computational fluid dynamics (CFD), additively manufactured from base metals and coated with metal catalysts using cold spray technology or electroplating, catalytic static mixers are used to replace fixed bed columns in continuous flow reactors. We have shown their versatility in gas-liquid hydrogenations and homogeneous transfer hydrogenations and review here their preparation, stability and wider use in catalytic transformations using flow reactors. Additive manufacturing provides complex mixer structures that can be retrofitted to existing reactor geometry and reduces manufacturing costs by removing abrasive blasting steps in the mixer fabrication process. The rough surface profile of the mixers aids with high metallurgical bonding of the catalyst coating, as shown by the low catalyst leaching levels reported here.

Flow Chemistry – Economic Benefits

Over the last decade, much attention has been focused on continuous flow reactors as a process intensification method to reduce costs. Because of the efficient heat transfer into or out of the narrow tubing used in these reactors, production of by-products is reduced and often eliminated. This in turn leads to less need for purification steps, reducing waste streams and power consumption for a process. Others have noted improved safety aspects such as no vapour headspace, reduced over-all footprint and lower initial capital expenditure as additional economic benefits to using flow reactors (1–5). Reactions at elevated temperatures or pressures that might once have been the domain of specialist toll manufacturers could now be brought in-house with dedicated process lines (6, 7).

Continuous flow hydrogenations were some of the earliest reactions investigated in flow reactors (8–10), resulting in the manufacture of dedicated hydrogenation units from several manufacturers (11, 12). However, these solutions continued to use cartridges or packed columns, essentially fixed-bed reactors.

Hydrogenations – Fixed-Bed Reactor Limitations

Fixed-bed reactors have been a mainstay of catalytic reaction processing for many decades. While easy to construct and implement, they suffer from a number of shortcomings when designing a continuous flow process (1, 9, 13–15). Pressure drop (back-pressure) across a fixed-bed reactor is a major concern when developing a flow process, especially with a viscous medium. This can result in lower throughputs in order to work within the limitations of existing equipment such as pumps, tubing or tubing connectors. Irregular temperature gradients or hotspots are difficult to remove, especially when scaling to larger production units.
**Catalytic Static Mixers – Overview: Design, Print, Coat**

CSIRO has been pursuing a new approach that uses established tubular reactor technology retrofitted with purposely designed and additively manufactured catalytic inserts. These are known as catalytic static mixers (CSM) (16). Metal deposition methods such as cold spraying or electroplating are used to coat the base metal scaffold with the catalyst. These metal scaffolds have good mechanical stability, being less brittle than ceramics and more scratch resistant than plastics. They are also compatible with a broader range of solvents and temperatures compared to most plastics and composite materials.

Moreover, the use of additive manufacturing processes means that the CSM can be designed for an existing reactor geometry to optimise surface contact, mixing and flow. Here, two custom built reactors are used for hydrogenations, both previously described in other publications (16–18). These contain stainless steel tubing of 6 mm inner diameter and are heated electrically. The smaller unit houses four CSM with a reaction volume of 14 ml (Mk1 reactor) and the larger capacity reactor houses twelve CSM with a 40 ml reaction volume (Mk2 reactor).

**Computational Fluid Dynamics**

CFD was used to design a mixer with optimised mixing and heat transfer, along with maximum surface area for catalyst deposition. Our simulations for homogeneous liquid and liquid-liquid phases show good performance with low Reynolds numbers typically below 2300. The details of this design and modelling work will be the subject of a forthcoming publication in the fluid dynamics literature.

Three designs were tested:
- D1 (a continuous mesh style)
- D2 (with a helical groove along the length of the CSM)
- D3 (a commercial design from Cambridge Reactor Design Ltd, UK) (16).

**Figures 1 and 2** illustrate the CAD drawing and CFD calculations, respectively, for D1.

**Additive Manufacture**

Base scaffolds were additively manufactured on an Arcam A1 electron beam melting printer using aluminium alloy, titanium alloy (Ti-6Al-4V), cobalt-chromium alloy (CoCr) or 316L stainless steel powder. An electron beam was used to melt and fuse the metal powders, layer-by-layer, into three-dimensional parts (16–17, 19) as shown in **Figure 3**. The finished scaffolds for D1 and D2 are shown in **Figure 4**. The scaffolds were inserted into metal tubes as illustrated in **Figure 5**.

Without the need for additional abrasive blasting to create increased surface roughness, the base mixer could be coated in catalyst using either cold spray coating or electroplating.

**Fig. 1. CAD drawing of CSM design D1, used to determine fluid dynamics**

**Fig. 2. (a) Velocity magnitude; and (b) turbulence energy, from CFD calculations for the design in Fig. 1. Flow from right-to-left**

**Fig. 3. Animation of the Arcam electron beam building up a model by fusing powdered alloy**

**Fig. 4. The scaffolds for D1 and D2 are shown in this figure.**

**Fig. 5. The scaffolds were inserted into metal tubes as illustrated in this figure.**

Without the need for additional abrasive blasting to create increased surface roughness, the base mixer could be coated in catalyst using either cold spray coating or electroplating.
(a) Cold Spray Coating

Cold spray coating is a technique that sprays metal powders at supersonic speeds onto a target resulting in the metal particles bonding to the target substrate. It produces very stable, controlled coatings. A commercial cold spray unit from Plasma Giken Co Ltd, Japan, was used and base scaffolds were coated with base metals (for example, copper and nickel) as well as precious metals (for example, palladium, platinum and gold).

Coating qualities were analysed by scanning electron microscopy (SEM) and optical microscopy (Figures 6(a) and 6(b)) and CSM of high porosity and high metallurgical bonding were used for further investigation in catalytic reactions. This commercial system was subsequently modified with a custom-made target holder to rotate the scaffold at speeds up to 300 rpm (17). This modification improved surface coverage of the catalyst on the accessible surface of the scaffold, as well as increasing productivity in processing multiple scaffolds. For additional characterisation data, see previous publications (16–18).

(b) Electroplating

More traditional electroplating using solutions of copper, nickel, palladium or platinum salts were used to provide very high internal plating of the CSM base scaffold (16–18). An example of the electroplated scaffold with copper is shown in Figure 7.

Fig. 4. Photographic images of CSM designs D1 and D2; the design D3 cannot be disclosed due to commercial confidence – it is available upon request from Cambridge Reactor Design. Reproduced from (16) with permission from The Royal Society of Chemistry

Fig. 5. A CSM of design D1 fitted inside a tube

Fig. 6. (a) SEM image of a cold sprayed Ni coating on an additively manufactured Ti scaffold (Ti-6Al-4V); (b) optical microscope image of a cross section through a cold sprayed Ni coating and scaffold at 50× magnification; (c) SEM image of an electroplated Ni coating on an additively manufactured Ti scaffold; (d) SEM image of an electroplated Pt coating on an additively manufactured Ti scaffold. Reproduced from (16) with permission from The Royal Society of Chemistry

Fig. 7. Cu electroplated mixer of design D2
SEM images (Figures 6(c) and 6(d)) were used to confirm thickness distribution and, together with X-ray tomography at the Australian Synchrotron, to analyse the morphology and porosity of the scaffolds. Preparation and characterisation procedures have been published previously (16–18).

### Gas-Liquid Hydrogenations

The first application looked at heterogeneous hydrogenations combining a substrate in a liquid phase with hydrogen gas. With a continuous flow reactor, it is possible to conduct hydrogenations under pressure, but by reducing the volume of material being reacted at any one time, dramatically improve safety considerations compared with hydrogenations using a regular batch reactor. For this work, electrically heated tubular reactors were used that could hold either four or twelve CSM inserted into 6 mm ID stainless steel tubing. A reactor schematic is shown in Figure 8.

### Substrate Stability

Early experience in additive manufacturing in metal within our group came from creating medical implants such as heels or sternums (20–21). These used a titanium alloy, so this was initially chosen as a substrate for the CSM scaffolds. However, it became clear that this titanium alloy was subject to hydrogen embrittlement after a few exposures to pressurised hydrogen reactions at temperature (22–24) (Figure 9). Therefore, 316L stainless steel was selected as an alternative. This required investigation of new conditions on the electron-beam printing machine, but once these were determined, the problems of CSM scaffold embrittlement were eliminated.

### Hydrogenation Examples – Initial Investigations

Initial investigations looked at the hydrogenation of oleic acid (OA), vinyl acetate (VAc) and cinnamaldehyde (CAL) (see Scheme I for
cinnamaldehyde hydrogenation pathway). Nickel catalyst was applied by cold spray coating and electroplating, as well as platinum catalyst by electroplating, on the titanium alloy, cobalt-chromium alloy and stainless steel (316L) base scaffolds.

While the nickel catalysts generally afforded lower yields and turnover frequencies (TOF) compared to the platinum catalysts, it was apparent that when comparing nickel coated mixers prepared using electroplating to ones prepared using cold-spray, the cold-spray approach resulted in higher values for yields and TOF. We attribute this to the much smoother surface coatings seen in the electroplated mixers which could contribute to reduced surface area on which the substrate can interact with the catalyst. The results for these substrates are shown in Table I.

A broader range of substrates and functional groups was then investigated (17). For example, the individual isomers of nitroanisole and chloronitrobenzene are cleanly reduced to the corresponding aniline, with the exception of p-nitroanisole (Table II).

For substrates such as phenyl acetylene where multiple products could be produced, the reaction parameters could be tuned to select one product over another, for example favouring styrene over ethyl benzene (Table III). The results from other functional groups, such as imines, diazo compounds, ketones, nitriles and various vinyl systems can be seen in previous publications (16–17).

**Active Pharmaceutical Ingredients – Linezolid**

The antibiotic linezolid is used to treat the antibiotic resistant strains vancomycin-resistant enterococci (VRE) and methicillin-resistant *Staphylococcus aureus* (MRSA). Part of the manufacturing process is a reduction of an aromatic nitro group to an amine as illustrated in Scheme II. A challenge with the existing methodology is the removal of the palladium catalyst by filtration upon completion of the hydrogenation and recovery of the catalyst.

By replacing the Pd/C fixed bed reactor with a palladium coated CSM, the reduction step could be completed with high yield (>99%) and no leaching of the catalyst, making this a highly efficient heterogeneous catalytic reactor (25).

![Scheme I. Hydrogenation pathway of cinnamaldehyde (CAL), yielding cinnamyl alcohol (COH), hydrocinnamaldehyde (HCA) and hydrocinnamyl alcohol (HCOH). Reproduced from (16) with permission from The Royal Society of Chemistry](image-url)

Fig. 9. The remains of a titanium alloy CSM after exposure to hydrogenation conditions

<p>| Table I | Table II | Table III |</p>
<table>
<thead>
<tr>
<th>Entry</th>
<th>Substrate</th>
<th>Catalyst</th>
<th>Reaction conditions</th>
<th>Results</th>
<th>Activation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$p_R$, bar</td>
<td>$V$, ml min(^{-1})</td>
<td>G/L</td>
</tr>
<tr>
<td>1</td>
<td>OA</td>
<td>Ni-EP-CoCr-D1</td>
<td>16</td>
<td>0.5</td>
<td>3.60</td>
</tr>
<tr>
<td>2(^a)</td>
<td>VAc</td>
<td>Ni-EP-CoCr-D1</td>
<td>20</td>
<td>0.5</td>
<td>5.00</td>
</tr>
<tr>
<td>3</td>
<td>OA</td>
<td>Ni-EP-Ti-D1</td>
<td>16</td>
<td>0.5</td>
<td>3.60</td>
</tr>
<tr>
<td>4</td>
<td>OA</td>
<td>Ni-CS-Ti-D1</td>
<td>16</td>
<td>0.5</td>
<td>3.60</td>
</tr>
<tr>
<td>5</td>
<td>OA</td>
<td>Ni-CS-Ti-D1</td>
<td>16</td>
<td>0.3</td>
<td>6.67</td>
</tr>
<tr>
<td>6(^b)</td>
<td>OA</td>
<td>Ni-CS-SS-D3</td>
<td>16</td>
<td>0.2</td>
<td>10.50</td>
</tr>
<tr>
<td>7(^c)</td>
<td>VAc</td>
<td>Ni-CS-SS-D3</td>
<td>22</td>
<td>0.5</td>
<td>5.00</td>
</tr>
<tr>
<td>8(^d)</td>
<td>VAc</td>
<td>Pt-EP-Ti-D2</td>
<td>24</td>
<td>0.5</td>
<td>5.00</td>
</tr>
<tr>
<td>9(^e)</td>
<td>VAc</td>
<td>Pt-EP-Ti-D2</td>
<td>16</td>
<td>0.5</td>
<td>5.00</td>
</tr>
<tr>
<td>10(^f)</td>
<td>CAL</td>
<td>Pt-EP-Ti-D2</td>
<td>20</td>
<td>0.5</td>
<td>5.00</td>
</tr>
<tr>
<td>11</td>
<td>OA</td>
<td>Pt-EP-Ti-D2</td>
<td>16</td>
<td>0.5</td>
<td>3.60</td>
</tr>
<tr>
<td>12</td>
<td>OA</td>
<td>X-X-Ti-D1</td>
<td>16</td>
<td>0.3</td>
<td>6.67</td>
</tr>
<tr>
<td>13</td>
<td>VAc</td>
<td>X-X-Ti-D1</td>
<td>16</td>
<td>0.3</td>
<td>5.00</td>
</tr>
</tbody>
</table>

All reactions were conducted at 140°C. For entries 2, 7, 8, 9, 10 and 13, EtOH was used as solvent, for all others EtOAc was used. For entries 2, 7, 8, 9 and 13, the substrate concentration was 2 M, for all others it was 1 M.

\(^a\) $p_R$ was varied between 16 bar and 20 bar resulting in conversions between 8.3% and 14.8%.

\(^b\) G/L was varied between 0.92 and 10.50 resulting in conversions between 1.1% and 55.3%.

\(^c\) $p_R$ was varied between 10 bar and 22 bar resulting in conversions between 12.5% and 73.6%.

\(^d\) $p_R$ was varied between 14 bar and 24 bar resulting in conversions between 57.9% and 92.1%.

\(^e\) Entry 9 was repeated multiple times with and without activation prior to reaction; with activation conversions were between 88.3% and 100.0%; without activation conversions were between 63.5% and 95.1%.

\(^f\) CAL was converted to 88.7%, giving a range of different hydrogenation products: HCOH 16.1%, COH 60.6%, HCAL 7.3%, CAL 11.3%, others 4.6% (See Scheme I).

Reproduced from (16) with permission from The Royal Society of Chemistry.
Table II Hydrogenation of Individual Isomers using Pd-EP-D2 in Mk2 Reactor

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Yields</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="OMe" /> NO2</td>
<td><img src="graph1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="OMe" /> NH2</td>
</tr>
<tr>
<td><img src="image3.png" alt="Cl" /> NO2</td>
<td><img src="graph2.png" alt="Graph" /></td>
<td><img src="image4.png" alt="Cl" /> NH2</td>
</tr>
</tbody>
</table>

Adapted from (17) by permission of the author.

Table III Hydrogenation of Phenyl Acetylene using Ni-CS-D3 and Mk2 Reactor

<table>
<thead>
<tr>
<th>Conc., M</th>
<th>Pressure, bar</th>
<th>Gas/liquid ratio, v/v</th>
<th>Yield, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>12</td>
<td>5</td>
<td><img src="graph3.png" alt="Graph" /></td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>5</td>
<td><img src="graph4.png" alt="Graph" /></td>
</tr>
<tr>
<td>1</td>
<td>24</td>
<td>10</td>
<td><img src="graph5.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

Adapted from (17) by permission of the author.

Scheme II. Making linezolid with a CSM
Leaching of Catalyst – Results of ICP-OES Monitoring

Over the lifetime of the catalysts, some of which were in operation for up to 2000 h, several leaching tests were conducted. For these, usually an extended run with a common substrate such as VAc (scale: 1 l or more, concentration: 2 M) was used and the combined product from this hydrogenation reaction was collected and analysed for conversion and leaching of metals by inductively coupled plasma-optical emission spectrometry (ICP-OES) (18). The leaching results are shown in Table IV.

Deactivation of the catalyst in the first few hours of operation of a VAc reduction using a CSM coated in nickel using cold spray was also briefly investigated (Figure 10). An initial drop in activity was seen, but a plateau was reached after 150 min and only around 5% of initial activity was lost. This points to the need to activate and pre-condition the catalyst before use as experiments without activation generally showed lower activity than those where the catalyst was activated.

Table IV Average Concentrations for Metals Leached from a Nickel Coated and Palladium Coated CSM Measured by ICP-OES. Base Scaffold was 316L Stainless Steel in Each Case (18)

<table>
<thead>
<tr>
<th>Nickel CSM – Cold Spray</th>
<th>Average conc., ppb</th>
<th>Palladium CSM – Electroplate</th>
<th>Average conc., ppb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>27</td>
<td>Pd</td>
<td>&lt;0.18</td>
</tr>
<tr>
<td>Ni</td>
<td>123.1</td>
<td>Cr</td>
<td>25.2</td>
</tr>
<tr>
<td>Fe</td>
<td>408.1</td>
<td>Cu</td>
<td>6.65</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>Mn</td>
<td>0.98</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>Mo</td>
<td>0.35</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>Ni</td>
<td>44.1</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>Fe</td>
<td>32.4</td>
</tr>
</tbody>
</table>

Reprinted from (18) with permission from Elsevier

Fig. 10. Normalised activity levels of Ni cold sprayed onto a stainless steel CSM: VAc (2 M EtOH), H2 (16 bar), 120°C, 1 ml min⁻¹
Homogeneous (Single Phase) Transfer Hydrogenation

We have also looked briefly at transfer hydrogenation using ammonium formate as the hydrogen source. The early results still need to be optimised, but the smaller reactor containing four of the palladium electroplated CSM using design D1 afforded a series of aniline derivatives by selectively reducing the nitro-groups of the compounds shown in Table V. Additional results for other substrates are listed in a previous publication (17).

Fabrication Costs

A typical CSM printed for a 15 cm length of 6 mm ID tubing found in a mid-sized flow reactor currently costs between 10% to 70% of the cost to make a comparable static mixer using conventional manufacturing techniques (prior to coating in catalyst) by removing additional welding steps. This is already exceedingly cheap for what is essentially a custom item, but would scale readily if transferred to a production environment, where costs are expected to decrease further by a factor of 1.5 to 10 when additively manufacturing these devices for mass manufacture.

Additional costs then come from the catalyst load and some typical quantities for a 15 cm × 6 mm CSM are shown in Table VI. It should be noted that the inherent rough surface profile of the additively manufactured mixers removes the need for an intermediate abrasive blasting step, which further saves on fabrication cost.

Future Directions

CSM is one of the products stemming from a continuous flow manufacturing focus in our labs, culminating in the construction of a new 400 m² flow chemistry facility being built onto existing infrastructure at CSIRO’s Clayton, Australia, site. CSIRO will provide manufacturing partners with access to the latest in flow chemistry and process technology so that they can rapidly develop continuous manufacturing processes to synthesise small molecules, polymers and other materials.

We will be partnering with chemical manufacturers in the pharma, fine chemistry, food and polymers spaces to utilise CSM in a variety of applications. We are currently exploring the use of copper, nickel, platinum, gold and ruthenium coatings as catalysts for a variety of chemical transformations such as oxidations, hydrogenations and coupling reactions.

Conclusion

This short review article has examined how CSM have been prepared for use in continuous flow hydrogenation reactors by making use of in-house computational fluid dynamic design capability, metal additive manufacturing and catalyst coating abilities at CSIRO. While 316L stainless steel is the obvious choice of scaffold for most chemistries,

| Table V Examples of Transfer Hydrogenation on Palladium using Ammonium Formate |
|-----------------|-----------------|-------------|-----------------|-----------------|
| Substrate       | Conversion, %   | P, bar      | TOF, h⁻¹       | STY, g l⁻¹h⁻¹ |
| 4-nitrobenzene  | 36              | 20          | 1.72           | 65             |
| 4-nitrotoluene  | 87              | 20          | 4.17           | 176            |
| 4-nitroanisole  | 100             | 12          | 4.76           | 225            |
| 3-nitroanisole  | 20              | 12          | 0.96           | 45             |
| Conditions: 130°C, 0.33 M in MeOH, 1 ml min⁻¹. Adapted from (17) by permission of the author |

| Table VI Typical Loadings of a 15 cm × 6 mm CSM Produced on the Arcam 2000 Printer, Followed by Spray Coating with the Spray&Wipe3000 Unit |
|-----------------|-----------------|-------------|-----------------|
| Base material   | Weight, g       | Metal/Coating method | Weight with catalyst, g |
| Ti alloy – design D1 | 11.3 | Ni / CS | 13.3 |
| SS 316 – design D3 | 15.6 | Ni / CS | 18.9 |
| Ti alloy – design D2 | 16.2 | Pt / EP | 16.6 |
| Adapted from (16) with permission from The Royal Society of Chemistry |
other alloys using titanium, aluminium or cobalt-chrome could also be used. But we found, as have others, that the titanium alloy was not suitable for use in hydrogenation reactions due to its limited stability after prolonged exposure to hydrogen.

Either cold-spray technology or electroplating may be used to coat the CSM scaffolds with metal catalysts, with little leaching being observed after several months for either technique. SEM studies indicated that the former method produces a rougher coating and thus higher surface area, while the latter method coats more of the internal surfaces of the scaffold.

The CSM performed well in gas-liquid hydrogenations and homogeneous transfer hydrogenations, on a variety of substrates and with improvements in the space time yield (STY) for these reactions. Selective hydrogenation could be achieved by careful tuning of the hydrogenation conditions, allowing, for example, the reduction of phenyl acetylene to either styrene or ethylbenzene. Significantly, the combination of design capability, additive manufacturing in metal and stable catalyst coating has provided a safe alternative to fixed bed reactors for existing hydrogenation continuous flow reactors. We remain excited to see this approach extended to other catalytic reactions in continuous flow reactors.

Acknowledgements

CSIRO would like to thank Bashir Harji of Cambridge Reactor Designs, UK, for the design of our Mk1 hydrogenation reactor. The authors would like to thank Darren Fraser for the animation stills of the Arcam electron-beam printer and the additive manufacturing of the CSM scaffolds, Mike Horne and Bita Bayatsarmadi for electroplating the mixers, Andrew Urban for cold spraying the mixers and Dayalan Gunasegaram for the CFD images of the mixers, all of CSIRO, Australia. Finally, we would like to thank Antoine Avril for the photographs of the disintegrated Ti-mixers and Antony Carafa for data processing of the extended run experiments.

References

12. J. Singh, *Chim. e Ind.*, 2011, **93**, (8), 132
20. ‘CSIRO Produces 3D Heel in World First Surgery’, CSIRO, Canberra, Australia, 22nd October, 2014
21. A. Knight, ‘Cancer Patient Receives 3D Printed Ribs in World-First Surgery’, CSIRO, Canberra,
Australia, 11th September, 2015


The Authors

Christian Hornung is a trained chemical engineer and he currently leads CSIRO’s Centre for Industrial Flow Chemistry, FloWorks. Dr Hornung has several years’ experience working in the flow chemistry and reactor technology area on the interface between chemistry and engineering. He works in multidisciplinary teams involved in the development of new chemical and polymer products and novel reactor solutions, combining additive manufacture with catalysis.

Shravan Singh is an electronic engineer and currently works as Business Development Manager at CSIRO Manufacturing. Prior to joining CSIRO, Shravan worked for himself as an entrepreneur and has years of experience in optical metrology, having worked at leading metrology institutes in South Africa and the USA in technical and management roles. He forms part of a multidisciplinary team at CSIRO that includes intellectual property, commercialisation and legal experts, helping CSIRO researchers translate their work into the market.

Simon Saubern trained originally as an organic chemist and, with a keen interest in high-throughput experimentation, facilitated CSIRO’s early flow chemistry capability. He has several years’ experience working with continuous flow reactors on industrial processes, particularly in the field of polymer synthesis. Dr Saubern is part of the multidisciplinary FloWorks team, evaluating novel technologies applied to synthesising polymers in flow reactors and using statistical methods to optimise reaction conditions.