Design and development of a 3D-printed back-pressure regulator

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In this communication, we describe the novel design and preparation of a back-pressure regulator that can be used in flow chemistry applications. Using low-cost components that can be readily sourced, a low-cost 3D printer and freeware design software, we developed, and 3D printed a back-pressure regulator that is simple to assemble and resistant to blocking. This device can be used to maintain the pressure of a fluidic system between the pump head to the back-pressure regulator and allows the collector, or collection vessel to be at atmospheric pressure. Ensuring control of pressure within the fluidic system is essential for maintaining consistent flow rates in flow chemistry set ups.

Continuous-flow synthesis is a key technology that brings several advantages in terms or safety, reproducibility and sustainability. There are numerous publications showing the advantages of flow-chemistry when applied to the synthesis of high value compounds.[1] One aspect of our research has been looking into ways we can further integrate flow chemistry methods into medicinal chemistry with relative ease. Recent publications in the field have highlighted the advantage that 3D printing has provided chemists with the ability to design, prototype and print functional devices for laboratory applications.[2,3,4] There are several engineering aspects to consider when making the transition from a traditional batch reactor to a flow system. One essential component a chemist would need is a back-pressure regulator (BPR). This small component is the 'unsung hero' of flow chemistry. It maintains a constant pressure throughout the system from the head of the pump and through the reactor to the BPR itself. (Figure 1).

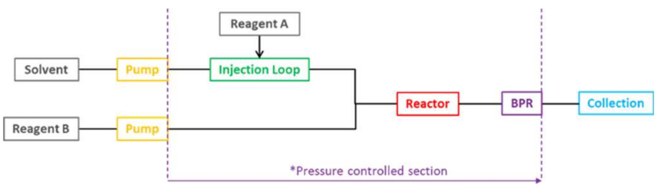

Figure 1. Example diagram of fluidic system highlighting the back-pressure regulator.

Several options are available for the choice of pumps including ones that could be repurposed if required. These include chromatography pumps, HPLC pumps and syringe pumps, although the latter would not be continuous. In addition, we have access to some Syrris Asia pump modules that can be run as a standalone pump with two channels. Our remaining hurdle would then be readily available BPRs. To avoid blocking and to cope with the potential for suspended particulates we opted to design a diaphragm type. We also designed the BPR in two parts for ease of 3D printing and to effectively sandwich a PTFE membrane diaphragm between the two face plates.

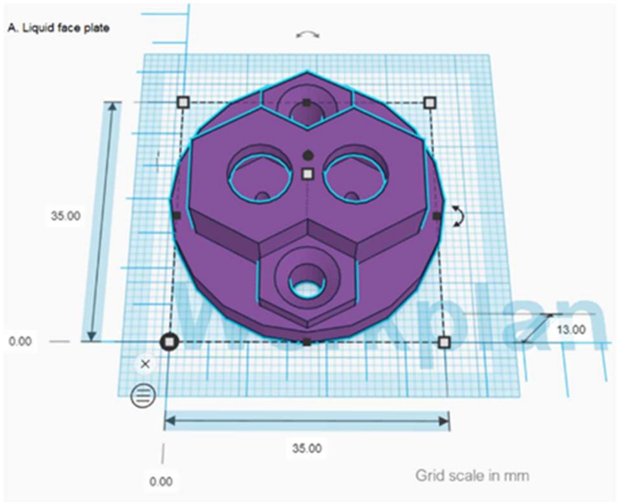

Figure 2. CAD diagram of back-pressure regulator. A; Liquid face plate

Another reason for designing the BPR in two parts, each as a separate face plate, was so that we could insert into the print hex nuts of the appropriate size and thread ready for the fittings to be installed. We could pause the print to allow us to insert the hex nut at the point where the print reached the top of the walls of the nut enclosure, and then resume the print to seal in the nut and complete the build.

We used open-source CAD software Tinkercad® to design both the face plates of the BPR and we used open-source Ultimaker Cura software in conjunction with an Ultimaker3 to print the device. Polypropylene was chosen for its properties and compatibility with the Ultimaker3. Polypropylene (PP) has reasonable resistance to common solvents[5] and the area of the face plate that would be in contact with the solvent was minimised in the design. The PTFE membrane would also provide a protective layer as well as separate liquid from gas in the assembled BPR. The dimensions of the printer table will allow the building of up to 9 of the same plate simultaneously and only require a single pause. Liquid face plate (Figure 2) was designed to accommodate two ¼-28 UNF stainless steel hex nuts which are a standard size and thread matching the fittings from several suppliers. These fittings are suitable for both 1/8th and 1/16th OD tubing. The embedding of the hex nuts avoids the need to build the threads in PP and provides a hard accurate cut thread that can be used to apply force on the ferrule by tightening of the fitting to ensure a leak free seal against the flat bottom of the seating. For practical reasons the underside of the liquid face plate was selected to be built onto the print table ensuring a smooth surface for the membrane to be against. 2 rectangular slots were designed to connect the membrane face to liquid input and output which would also be interchangeable due to the symmetrical design. 2 bolt holes were included to allow M4 countersink hex bolts to secure both plates together. Gas face plate (Figure 3) was designed to accommodate a single M5 nut which would provide the thread for a 4 mm push fit M5 connector that would connect via 4 mm OD tubing to the regulated compressed air or nitrogen supply. 4 mm OD tubing was chosen due its compatibility with pneumatic fittings available from several suppliers. The design of the top side of the gas face plate features a recess for seating of a 9.2 mm ID silicone O-ring and a port in the centre that has a shallow domed recess to allow the diaphragm to be pushed away from the liquid face plate by the back pressure of the input liquid coming from the pump. This shallow recess would allow the pressure of the liquid to push the diaphragm against the gas pressure, allowing the liquid to flow past and allow for small particulates to pass and exit the BPR reducing the chances of blocking.

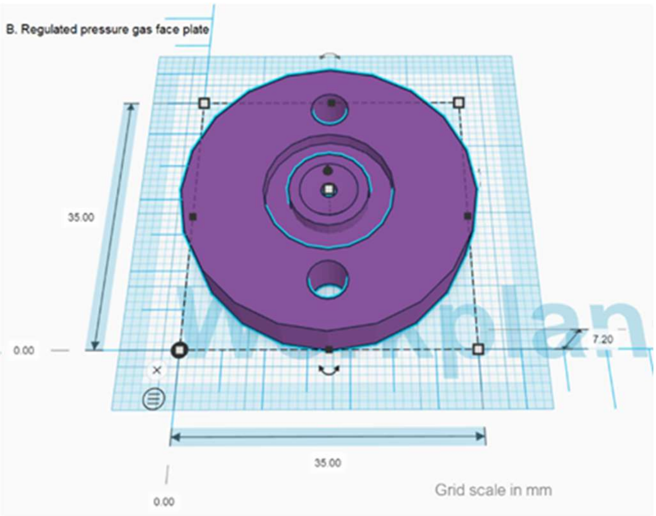

Figure 3. CAD diagram of back-pressure regulator. B; Gas face plate

Assembly and testing

We built 3 prototype BPRs to assess consistency and the time taken for the build. Using one face from one of the BPRs as a template, we marked and cut out the shape of the diaphragm out of 0.1 mm thick PTFE sheet. Holes for the M4 bolts to pass through were also marked using the template and then cut out using 4 mm hollow punch. Similarly, we cut out a gasket layer that would be placed on the gas face side of the membrane and cut out the centre using a 9 mm hollow punch. The BPR was assembled in order (Figure 4) 1; liquid face plate with M4 bolts inserted and used a guide for subsequent layers 2; PTFE diaphragm 3; PTFE gasket 4; gas face plate with silicone O-ring installed. The plates were held in place by 2 x M4 stainless steel wing nuts which were lightly secured to apply a small amount of compression to the silicone O-ring. 5; the straight pneumatic push fit 4 mm OD male M5 adapter was screwed into the gas face plate port to finger tightness.

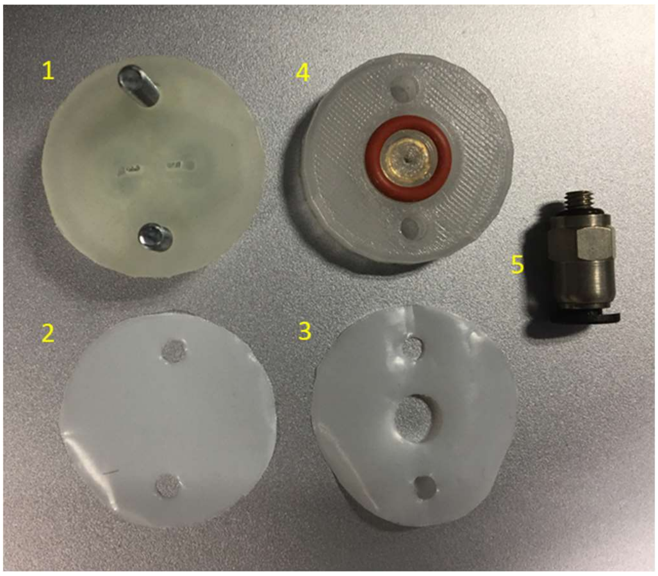

Figure 4. Parts and assembly of the back-pressure regulator

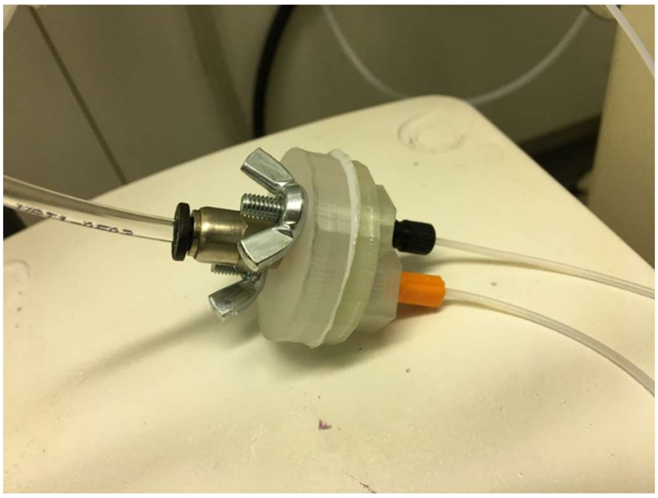

Figure 5. Image of 3D printed back-pressure regulator.

Fittings for liquid input and output were installed into the liquid face plate and the gas face plate push fit was connected to the regulated gas supply suing 4 mm ID tubing (figure 5). The BPR was tested for leaks and performance using tetrahydrofuran and acetonitrile as the solvents. We tested the BPR within a typical operating range, gas pressures of up to 2 bar and flow rates up to 3 mL min^{-1} however we did not establish upper limits for either parameter. STL files that can be used to 3D print the Vernalis BPR can be found here https://github.com/vernalis/3Dprint_files. A list of parts and instructions for assembly are included in the files as well as in the supplementary information.

Conclusion

In summary, we have developed a novel 3D printed back pressure regulator that can be used in a simple flow chemistry set up. This allows a low-cost entry for chemists in a research environment to be able to test flow systems for the synthesis of high value compounds before investing in further automation of the flow chemistry methods.

References

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