AN002: MICROLFLUIDICS – DISC PUMP APPLICATION NOTE

1. INTRODUCTION

The Lee Company's piezoelectric disc pumps are high-performance micropumps operating through ultrasonic acoustic resonance driven by a piezoelectric actuator. This document provides examples of its application to microfluidic control, providing guidance and support to The Lee Company customers in their product development processes. The document is set out as follows:

- Section 3: Basics of Pressure Driven Flow (PDF)
- Section 4: Using the disc pump for PDF
- Section 5: Examples of PDF and pneumatic pumping of liquids.
- Section 6: Support and acknowledgments.

Owing to its operating mechanism, Disc Pump can be controlled with unmatched precision, yet at the same time respond to full-scale set point changes in a matter of a few milliseconds. The compact form factor means it can be tightly integrated into products, increasing portability. All of this contributes to unrivalled real-time control performance in microfluidic applications.

Disc Pump enables the replacement of large, benchtop equipment (e.g. the pumps, regulators and valves required by existing pressure-driven flow systems, which often weigh several kilograms) with a palm-sized, self-contained module that contains the micropump and electronics, together weighing less than 50g. This brings advantages over other miniature pump systems targeting microfluidics, including ultra-smooth liquid flow, rapid response time and a wide dynamic range.

Figure 1: A piezoelectric disc pump

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3. BASICS OF PRESSURE DRIVEN FLOW

With its unique feature set, the disc pumps can be applied to the pressure-driven flow of liquids and offer substantial benefits in terms of improved control, pulsation free flow and rapid response to set point changes.

3.1.Why pressure-driven flow?

The discrete stepping action of the motor and the mechanical play in the drive mechanism that drives the syringe in a syringe pump creates instability in liquid flow. These fluctuations in flow can have a negative impact on microfluidic processes, for example by reducing the consistency of a droplet generation process or the sensitivity of delicate downstream measurements. Syringe pumps therefore require ‘backlash compensation’ algorithms to compensate for the mechanical play in the drive system and these need to be tuned according to the system requirements. Even precision engineered syringe pumps, designed to minimise pulsation, only do so within a narrow band of flow rates.

Pressure-driven flow (PDF) in contrast can deliver truly pulsation-free flow, enabling greater control accuracy and homogeneity within experiments. Further, PDF offers response times several orders of magnitude faster than syringe pumps, streamlining the microfluidic process and making possible new flow control regimes.

Figure 2 below demonstrates the exceptionally rapid response and precise control that a disc pump can achieve relative to the performance of a syringe pump.

Disc Pump vs. Syringe Pump

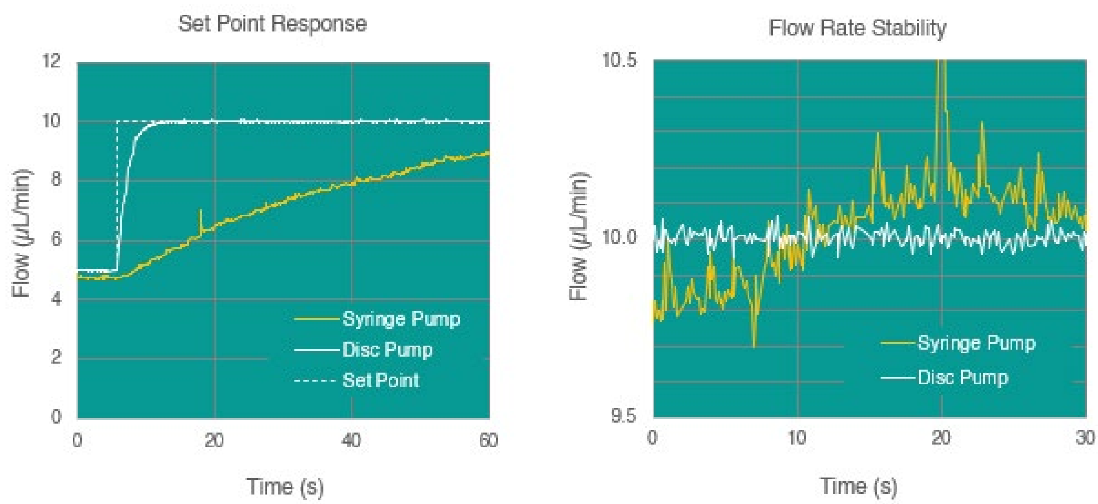

Figure 2. Precise flow-rate control and rapid response enabled by the disc pumps

3.2.How does pressure-driven flow work?

The head space in a closed reservoir is pressurized, driving fluid through an outlet dip tube. The basic configuration is shown in Figure 3. Optional valving can be employed where reversible flow is desired and flow metering can be used where precise, closed-loop control of flow rate is required.

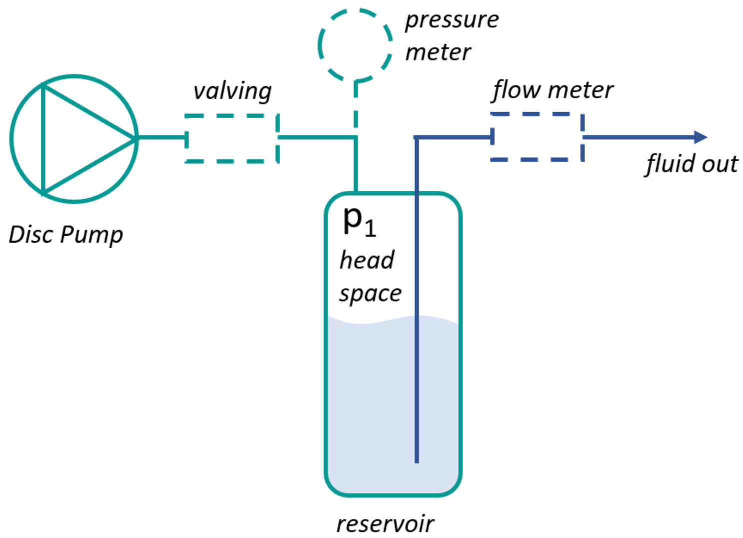

Figure 3. Using a disc pump for pressure-driven flow.

3.3.Why use disc pumps for pressure-driven flow?

The disc pumps have a unique set of attributes that makes it ideal for many PDF systems as it helps to improve microfluidic handling and flow control.

- **Fast response time** – unlike a syringe pump, the disc pump has very little inertia and as such it can react to set point changes much faster, being able to react so quickly means that it can follow pressure profiles with incredible accuracy, this is important as it means the process stability is improved and the likelihood of bubble formation in microfluidic channels is reduced.

- **Pulsation free flow** – The disc pump moves just a few (nl) of air per cycle and as such the resultant air flow is effectively pulsation free. This allows disc pump to create laminar flow streams in microfluidic circuits where fluids mix via diffusion rather than turbulence; and this allows for much better repeatability and system stability. Also, pulsation free flow helps to reduce bubble formation and bubble entrainment.

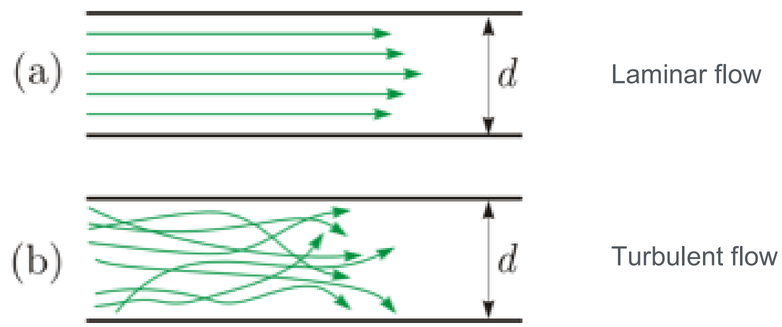

Figure 4. Laminar flow compared to turbulent flow.

- **Flow rate stability** – As the disc pump moves just a few (nl) per cycle and generates a pulsation free flow, the disc pump is precisely controllable and can hold target pressures with incredible accuracy and repeatability, resulting in unrivalled liquid flow stability; as demonstrated in figure 2 above.

- **Compact size** - The disc pump is weighs only 5g (< 1/5 oz) and has a volume of just 7 cm^3 (< 0.5 in^3), supporting the next generation of miniaturised systems.

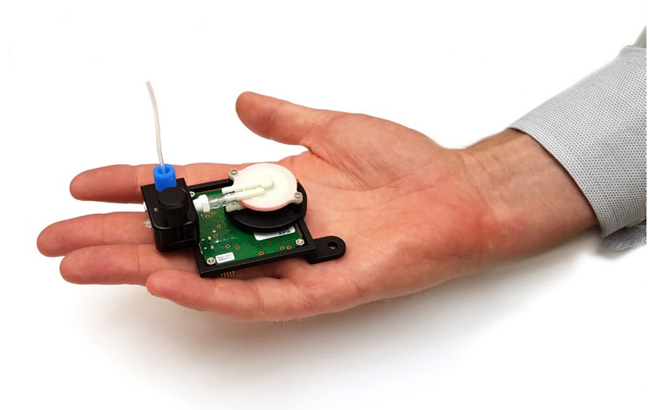

Figure 5. A disc pump in a compact Pressure Driven Flow (PDF) system.

- **Flow rate range** - Unlike conventional pumps, the disc pumps have no stall speed, offering a near-infinite turn-down ratio. This makes it possible to deliver flow rates from nl/min to ml/min range.

- **Versatile function** – The disc pumps can generate positive and negative pressures with unrivalled precision and can therefore in combination with valving, move fluids backwards and forwards through microfluidic circuits or create flow re-circulation as often required in Organ-on-a-Chip (OOAC) systems.

- **Pressure and flow control** – The disc pump systems can be integrated with pressure and flow rate sensors, enabling the changing resistance of the fluidic circuit to be considered and the desired pressure / flow profiles maintained. Please see link to our Vimeo site that shows how a disc pump can very accurately move fluids through a PCR chip, renown for being a difficult chip to work with:

3.4.PDF control options

3.4.1. Open-loop control

In this case, pressure and flow meters are omitted and the rate of liquid dispense is controlled directly by the power applied to the pump, as shown in Figure 6.

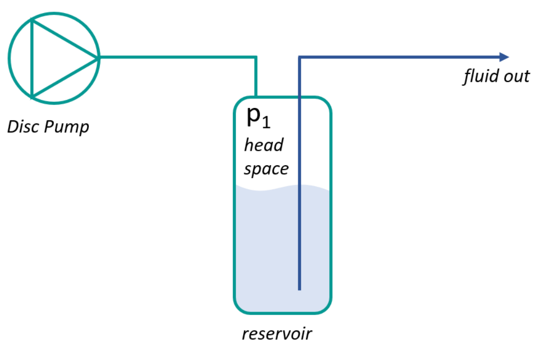

Figure 6. Basic open-loop control of fluid dispense

As the pump's performance can vary from part-to-part and with temperature and age, some form of periodic calibration would be required. Calibration may be achieved by:

1. driving the pump at a known power and known duration
2. measuring the volume or mass of the sample dispensed
3. adjusting the power or duration to deliver the target volume or mass

3.4.2. Closed loop pressure-based control

Variation in flow rate arising from, for example, part-to-part variation and temperature variation may be avoided by controlling the pressure delivered by the pump. In this case the pump is operated in a closed control-loop with a pressure sensor to deliver an accurate liquid flowrate as shown in Figure 7.

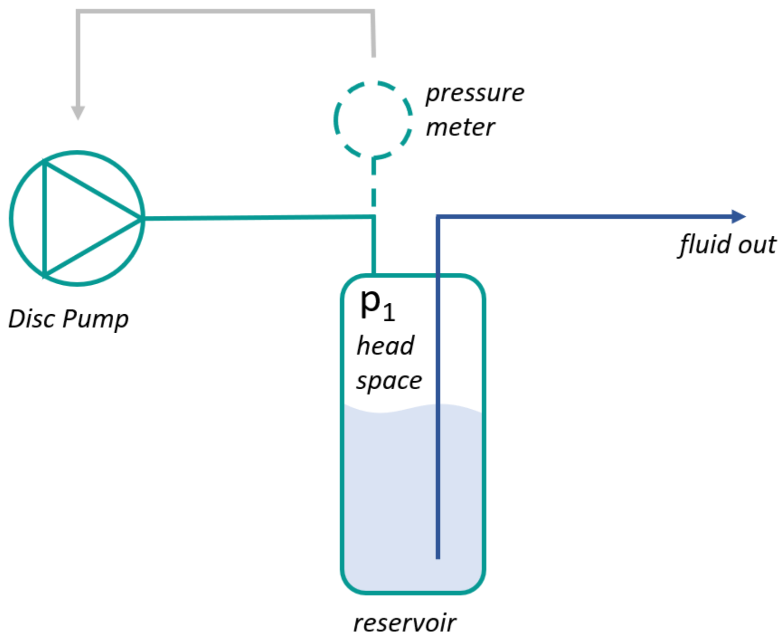

Figure 7. Pressure-based control of liquid delivery

The drive PCB included with The Lee Company's standard evaluation kit includes a pressure sensor, and the board can be configured to operate the pump in closed loop to achieve a particular target pressure.

The drive PCB can also be controlled via an analogue input, or via commands sent over a serial connection, providing users with the ability to implement their own control schemes.

3.4.3. Closed-loop flow-rate control

The disc pumps can be combined with a flow-rate sensor; as shown in figure 8, to deliver precise flow control in a compact form factor, ideally suited for microfluidics products spanning point-of-care diagnostics to droplet-based Digital PCR.

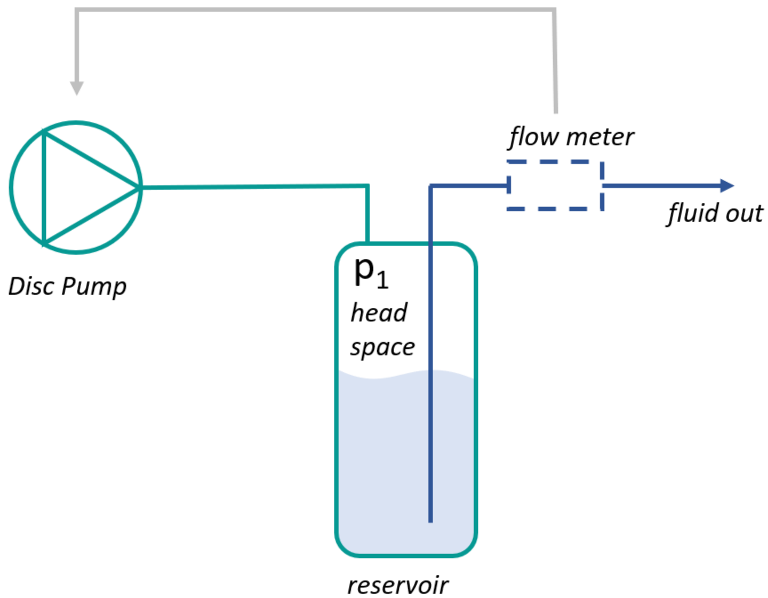

Figure 8. Flowrate based control of liquid delivery.

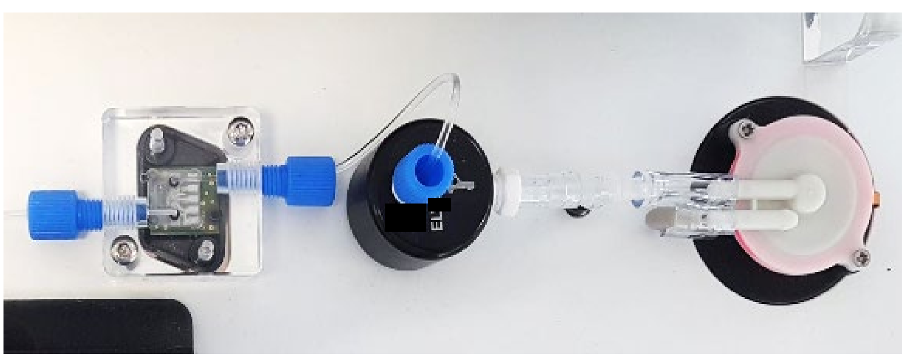

Figure 9. Disc pump integrated with a flow sensor to deliver constant, highly stable flow.

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Figure 9 above shows a system comprising a disc pump and a flow sensor, combined to deliver closed loop control over liquid flowrate.

4. USING DISC PUMPS FOR PDF

The evaluation kit comes complete with all the parts necessary (except for the fluid reservoir) to set up a basic power and pressure-based control systems as highlighted in Section 3.

4.1.System components

The Evaluation Kit components are shown in Figure 10 below. A manual is provided which describes the system components and their function, and this should be read carefully, noting all warnings before proceeding.

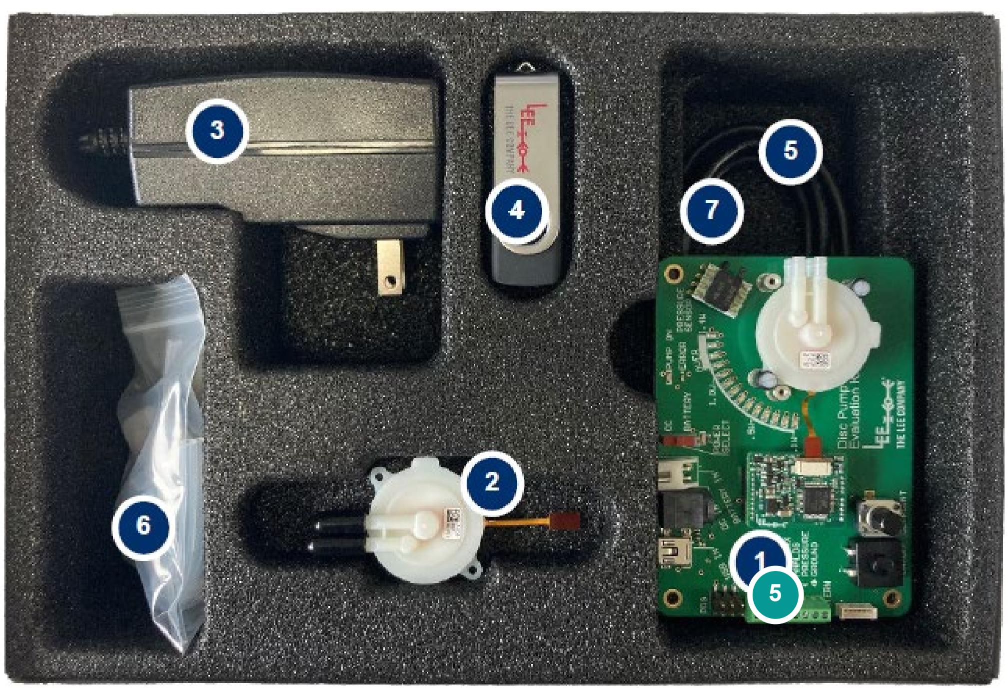


Figure 10: Disc Pump Evaluation Kit Image - kit components and packaging will vary depending on customer order.

Item	Description
1	Motherboard PCB, on which is mounted one of the two pumps included, together with the postage-stamp sized pump drive PCB. This will be packed within an ESD (electro-static discharge) bag.
2	A second pump.
3	Mains power supply. Typically, a region-specific adapter will have been fitted for you. If requested, additional region adapters may be included in the pocket beneath the evaluation kit PCB.
4	USB flash drive containing PC application software and supporting documentation.
5	USB cable, which enables the PC application to communicate with the drive PCB.
6	Accessories including as tubing, luer fittings and filters.
7	Basic instructions (you should also receive a user manual in PDF form)

Figure 10. Evaluation Kit components.

4.2.Getting started

This section shows how to set up the pump to run a basic PDF system, please also refer to the Evaluation Kit manual:

When you receive your Evaluation Kit a pump will already be fitted to the main PCB (see Figure 11).

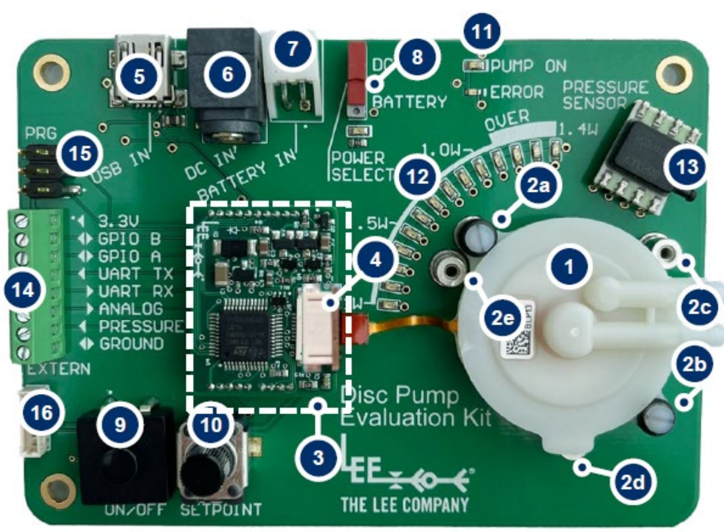


Figure 11. Evaluation Kit Driver board layout.

Item	Details
1	The Lee Company Piezoelectric Disc Pump
2a/b	Pump mounting lugs. Note that whilst Disc Pump operates ultrasonically and is therefore inaudible, there remains vibration of the pump casework. To prevent this vibration causing audible noise, the pump is mounted with compliant O-rings and nylon bolts. When swapping the pump over, be sure to repeat this mounting arrangement.
3	Disc Pump Drive PCB
4	Electrical connection between pump and PCB. The black tab on the connector is hinged and should be lifted into the vertical orientation before inserting or removing the pump flexi tail.
5	USB IN – connect at PC to the PCB with the supplied USB cable to allow the disc pump control software to communicate with the PCB. There is a solder bridge on the underside of the board (SB1) which, when bridged, allows the evaluation system to be powered from USB IN without the need for the mains power adapter. Note that the USB port providing power must be capable of supplying 500 mA or greater.
6	POWER IN – connection for the mains power adapter to power the system.
7	BATTERY IN – optional connection for a single cell 3.7 V lithium-ion battery (not supplied). Pin 1 (marked with a dot) is ground. Note that the motherboard includes a charge circuit that can recharge a lithium battery. With the battery connected and battery power source selected, connect the mains power supply to begin charging. Note that the charge current is limited to 100 mA.
8	Battery / mains power source selector switch; enables selection between mains or battery power. Always ensure a battery is connected when battery power is selected, and a mains power adapter is connected. If a battery is not connected in this state, the system may not function correctly.
9	ON/OFF – pump on/off switch. A single click will toggle the pump on/off. The pump may also be turned on/off by the PC application.
10	SETPOINT – rotary control allowing the system setpoint to be adjusted. By default, this adjusts the drive power supplied to the pump, although it can be configured to control other parameters via the PC application.
11	PUMP ON – green LED indicating the pump on/off state. ERROR – red LED indicating the error state of the system. Errors can be cleared by toggling the pump off and on again, or by power cycling the system. If Error persists, check the contact with the flexi tail and the drive PCB. If contact appears satisfactory but the error light stays on, try installing another pump. If error disappears, the original pump may be faulty or contact may not have been satisfactory previously.
12	Power gauge: array of LEDs to indicate the drive power being supplied to the pump. For continuous operation, The Lee Company recommends that drive power is limited to 1 W. For intermittent use, we recommend a maximum limit of 1.4 W.
13	Differential pressure sensor: when connected to the pneumatic circuit, allows the pressure generated by the pump to be measured and displayed in the PC application. The top barb on the pressure sensor is intended to be connected to positive pressures and the bottom barb to negative pressures. The evaluation system is capable of closed-loop control of the pressure that the pump generates – see 4.4.2 for more information.

14	External signal connections: screw terminal block providing the following connections: 2.5V – output from drive PCB that can be used to power 2.5 V devices (max 10 mA). GPIOA – 2.5V-level digital toggle signal IO for enabling / disabling pumping with an external signal. GPIOB – Reserved for future use. UART T/RX – 2.5V-level serial data transmitted from / received by the PCB. The evaluation system can be controlled by the customer's host PCB/system via these connections. ANALOGUE – 0 to 2.5V analogue input. The evaluation kit can be configured to be controlled by this signal in the PC application. PRESSURE – 0 to 2.5V analogue output representing the pressure measured by the on-board sensor. The mapping is: 0.00 V = -745 mmHg (differential between ports) 1.25 V = 0 mmHg 2.50 V = 745 mmHg
15	PRG – programming header that can be used to programme the drive PCB.
16	External Flow Sensor connector header (See AN007 for set-up, referenced in §6)

- Please note that the pumps included with Evaluation Kits vary by customer request and may be either a mixture of series and/or parallel configurations.
- Confirm that the pump fitted is the correct configuration for your application. The QR code label on the top of the pump indicates the type and configuration. See figure 12.

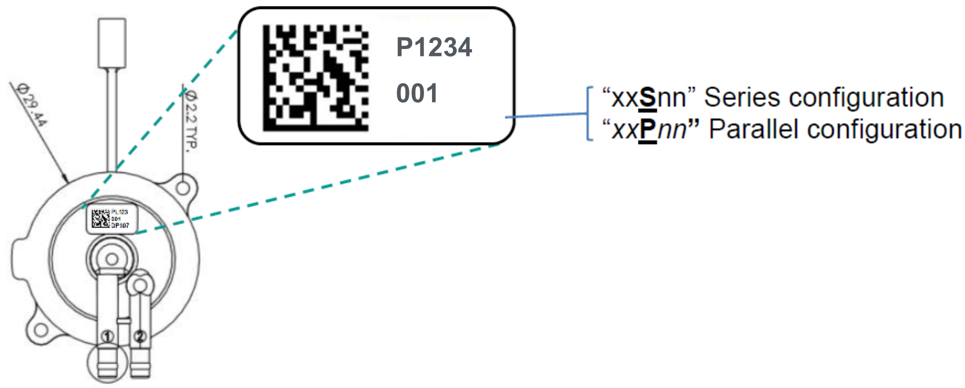
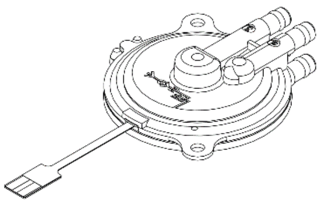
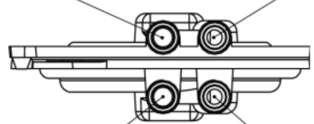


Figure 12. Pump connection details.

- If the pump must be swapped, carefully lift the hinged black tab on the small driver board (marked position 4) into the vertical position. This will release the pump flexi tail.
- With the flexi tail removed, remove the retaining screws (2a and 2b). Note that the pump is mounted with four compliant O-rings and two nylon bolts. Ensure that this mounting arrangement is reproduced for the desired pump.
- It is easiest to connect the pump ports prior to fitting the pump to the board. Therefore, with the desired pump, connect the ports as per Figure 13.





- For series (SDC) configuration pumps:
  - Link ports 2 and 4 ('C' coupler included)
  - Port 3 is inlet & port 1 is outlet

- For parallel (PDC) configuration pumps:
  - Ports 2 and 4 are common inlet*
  - Ports 1 and 3 are common outlet*
  - *Link with included 'Y' coupler

Figure 13. Pump port connections.

- Connect a filter (supplied with the Evaluation Kit) to the inlet of the pump using the tubing supplied (or any other appropriate tubing). This protects the pump from dust ingress.
- Having connected the ports and fitted the filter, fit the pump to the PCB, using the O-rings and bolts.
- With the hinged black tab in the vertical position, fit the flexi tail into position 4. With the tail inserted, lower the black tab to lock the flexi in place.
- Connect the output of the pump to the fluid reservoir (not supplied).
- Connect the pressure sensor (13 on figure 11) to the fluid reservoir as shown in Figure 7. Cut the tubing to length as needed. Please note that the pressure sensor has two barbed ports, connect the upper barb of the pressure sensor to the pneumatic circuit.
- Connect the power supply cable to connector (6 on figure 11) on the drive PCB; or if you are using a battery (not supplied) to (7 on figure 11). Use the toggle switch (8 on figure 11) to select the power source as needed.
- When power is applied to the board, the pump will turn on, press the on/off switch (9) to turn on and off as needed and adjust the power applied to the pump by turning the set point dial (10 on figure 11).

Once powered, the system will load the settings last configured and operate accordingly.

4.3. Using the control application

A bespoke PC application (Disc Pump Control App) is provided to configure and control the Evaluation Kit. Instructions for installing the application are found in the Evaluation Kit manual.

- Once installed, connect the Evaluation Kit to your PC with the USB cable supplied (5).
- Open the “Disc Pump Control App.exe” to run the application.
- Select the COM port from the top-left dropdown menu and click Connect.
- When successfully connected, the application will display the current settings and a live data stream (on the graph).

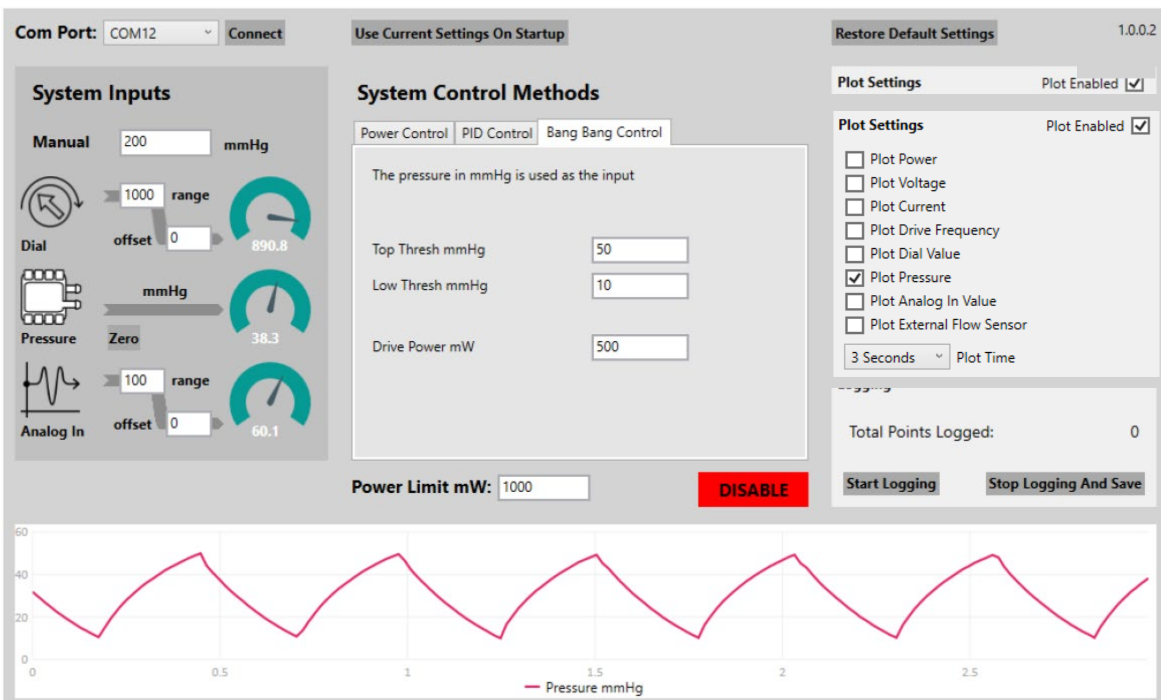


Figure 14. Pump Control Application (example).

The user interface has a panel displaying the System Inputs on the left-hand side – these are: a manual setpoint entered via the software, the setpoint dial on the evaluation kit motherboard, the pressure sensor, also on the motherboard, and a 0 to 2.5 V analogue input signal on the screw terminal block, also on the motherboard. The values for these inputs are displayed under the dials on the user interface.

4.4.Running the pump in PDF mode

4.4.1. Open loop control

This is the most basic control mode and here the pressure applied is adjusted by varying the power input to the pump. Please consult the Evaluation Kit manual for the numerous ways this can be achieved, such as analogue input and manual input through the GUI as shown above.

4.4.2. Closed-loop pressure control

This can be achieved using the PID Control tab within the GUI. See figure 15. PID control mode adjusts the pump drive power until a target pressure is reached.

- ***For positive pressure control*** connect to the outlet of the pump and use positive pressure setpoint targets and positive values for the P, I and D coefficients.
- The pressure sensor reading can be zeroed by clicking the “Zero” button next to the pressure sensor icon. The zero offset can be reset by clicking “Restore Default Settings”

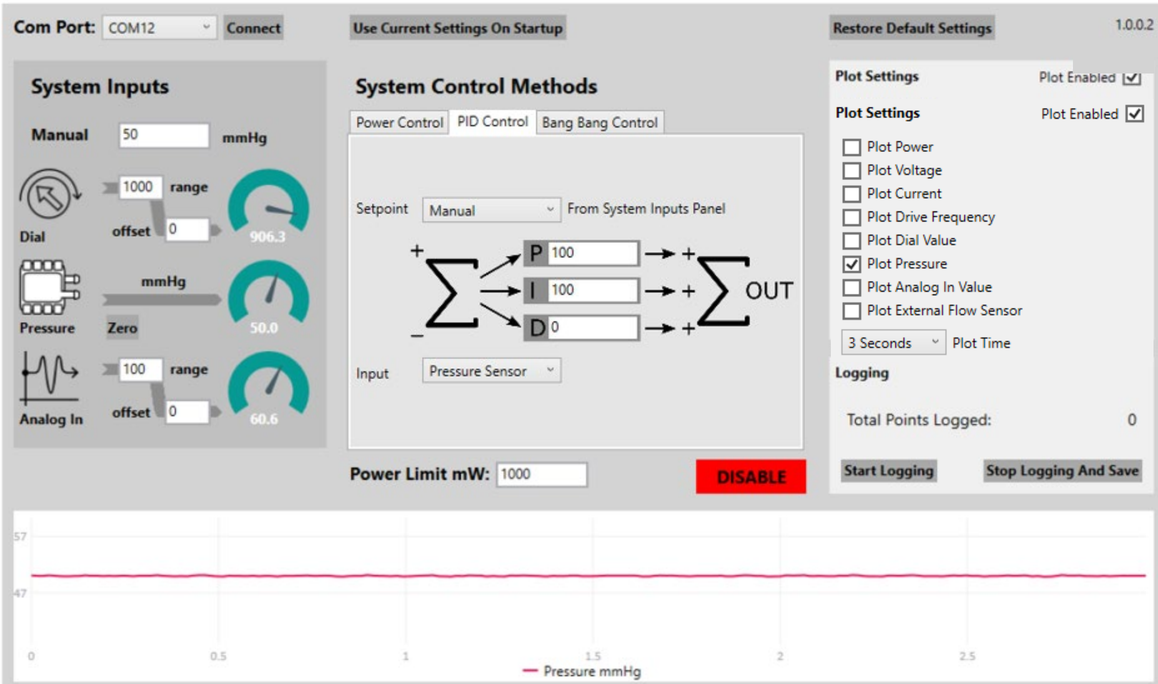


Figure 15: pressure controlled to 50mmHg under PID control mode.

- To change the set point control mode from System Inputs panel, click on the dropdown box and select manual, dial or analogue input.
- If **Manual** is selected, type in the desired set point pressure. In the example shown in Figure 15, the set point is 50mmHg; note how the measured pressure (plotted in red) is held precisely at 50 mmHg.
- If **Dial** is selected, adjust the set point pressure using the Set Point dial (10 in figure 11). The pressure set by the dial will be shown on the meter in the GUI. The mapping can be adjusted with the range and offset values. See figure 16.

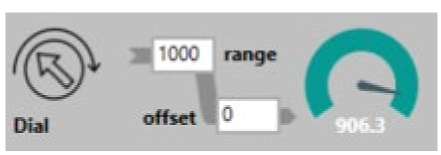


Figure 16: pressure controlled via Dial setting.

- For **Analogue Input**, the set point is controlled by the 0 to 2.5V analogue input supplied on the external connections screw terminal block on the motherboard. The mapping can be adjusted with the range and offset values. See figure 17.

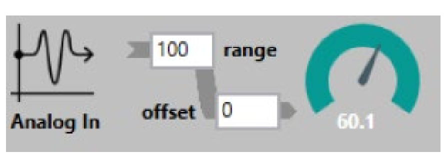


Figure 17: pressure controlled via Analogue Input.

- The set point and measured pressure can be plotted simultaneously to observe the system performance. To do this, check the corresponding boxes in the Plot Settings panel. The plot duration (the amount of data visible in the graph) can also be changed here. See figure 18.

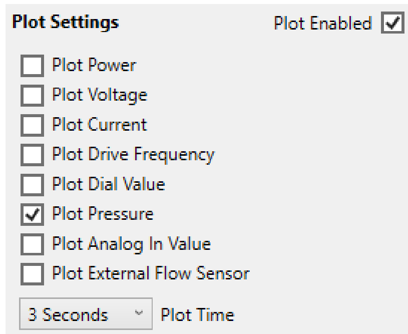


Figure 18: Plot options on GUI.

- Using the methods described previously, **Manual, Dial** and **Analogue Input** it is now possible to control the pressure within the headspace of the reservoir to achieve the desired flow rate within your fluidic circuit.

Please note that the software is configured to automatically protect the pump and so the pressure set point will not always be achievable at values greater than the maximum listed capabilities of the pump. Please refer to pump data

4.4.3. Running the pump in Aspirate PDF mode:

If you are looking to use the pump in aspirate mode and use atmospheric pressure as the motive force to drive the liquid through your fluidic circuit, you will need to connect the circuit to the inlet of the pump.

Please ensure that you have adequate filtration fitted to the inlet and a catch pot system to prevent liquid entering the pump. If liquid enters the pump it will stop working and could be permanently damaged.

For negative pressure control, connect to the inlet to the pump, and use negative pressure setpoint targets and negative values for the P, I and D coefficients.

Once again adjust the set point pressures as needed through the Manual, Dial or Analogue Input functions to achieve the desired flowrates through your fluidic circuit.

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5. PDF EXAMPLES USING DISC PUMP

5.1. Droplet Generation

Two pressure-driven flow systems may be combined to generate liquid-in-liquid droplets, see figure 19.

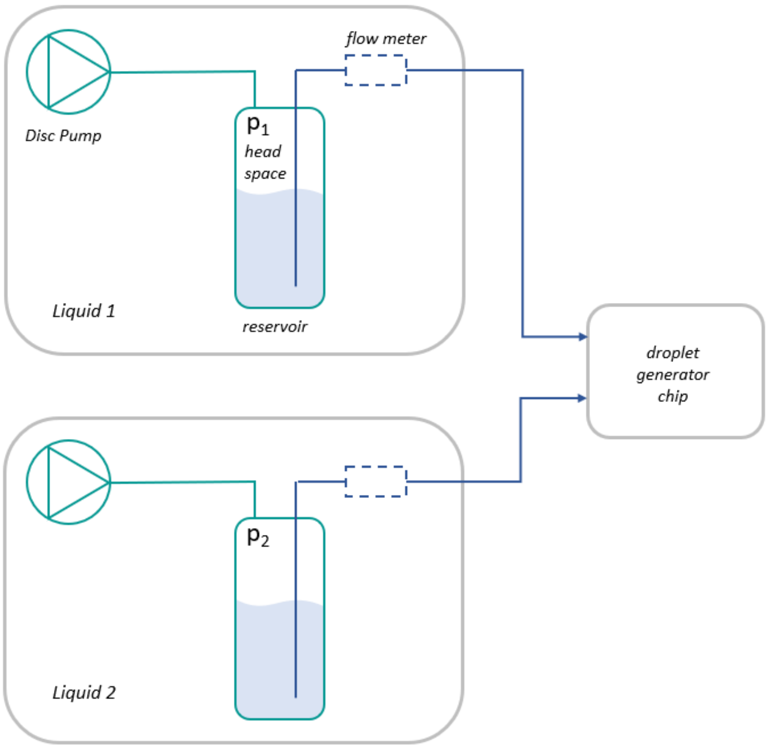

Figure 19. System configuration for liquid-in-liquid droplet generation.

Droplet or digital microfluidics is an emerging liquid-handling technology in POC devices as it enables individual control over droplets. In PCR devices, droplet microfluidics can demonstrate many crucial advantages including absolute quantification, low reagent consumption, rapid heating/cooling, shorter STAT's and portability. Droplets for enzymatic assays can confine molecules and reactions to a small volume (picolitres to nanolitres), thereby reducing the number of mixing and washing steps.

Traditionally, droplets are formed using bulky pressure driven or syringe pump driven flow systems which have limited the ability to extend to POC formats. Disc pump changes all this for POC, through its compact size, infinite control and quiet operation. Figure 20 shows two disc pumps being used to create droplets.

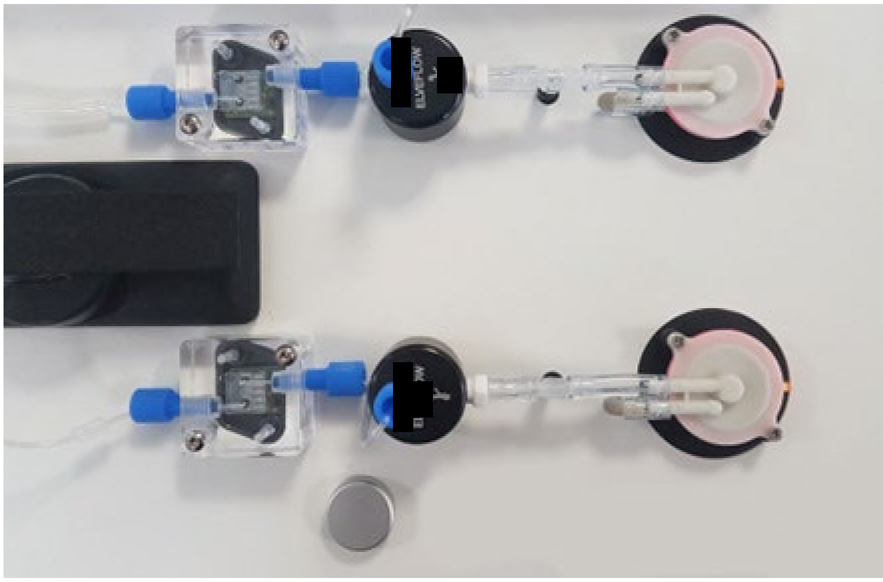

Figure 20.Two disc pumps feeding a droplet generator chip.

The strobe images shown in Figure 21 highlight the stability and controllability of the system through the ability to deliver different droplet diameters and delivery rates.

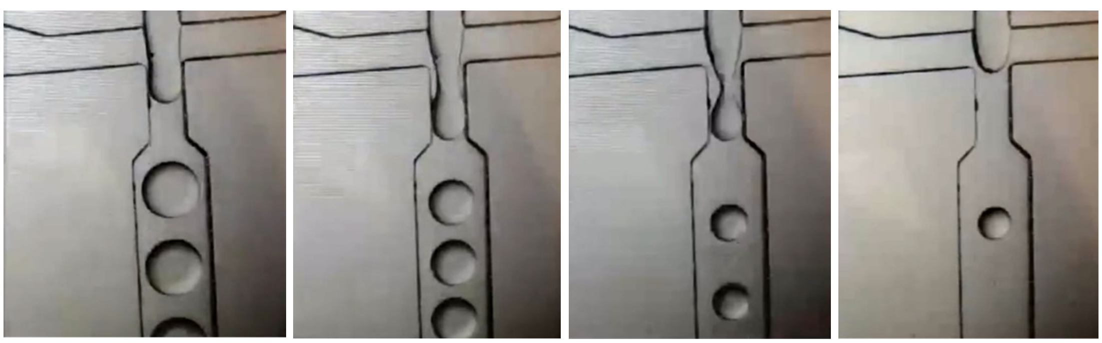

Figure 21. Two closed loop Disc Pump systems generating liquid-in-liquid droplets.

5.2.Laminar flow systems

The disc pump’s ultra-smooth, pulsation-free flow and precise control can be used to set up laminar flow paths in microfluidic circuits. Here fluids mix via diffusion rather than turbulence, the examples below

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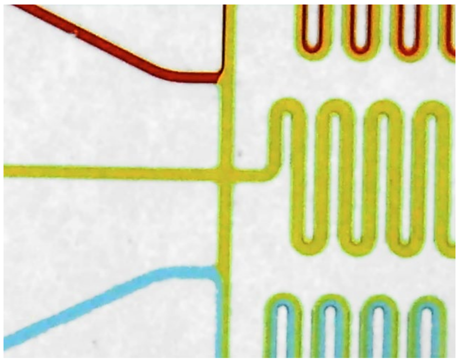
show how different colour liquids can be made to flow side by side in laminar flow paths and how concentration gradients can be produced using a combination of disc pumps.



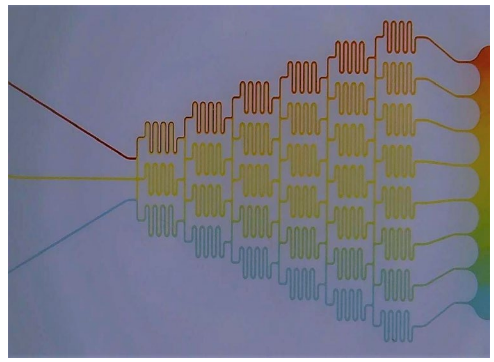


Figure 22. Laminar flow paths and laminar flow in concentration gradient.

The disc pump's ultra-smooth flow and exceptional control can also be used to create droplets of different concentrations. The precise control available with disc pump allows you to control the ratio in the laminar flow streams and therefore create droplets of different concentrations.

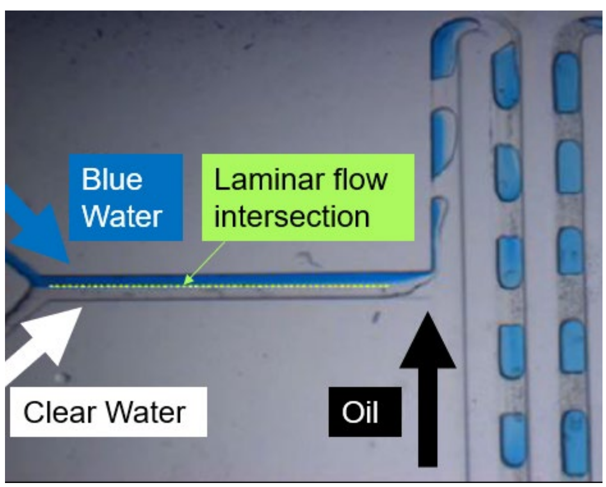


Figure 23. Droplet generation of droplets with different concentrations

5.3.Negative pressure flow control

The disc pump may also be used to aspirate fluids trough microfluidic chips, offering bubble-free, pulsation-free liquid transfer when the microfluidic circuit is connected to the inlet of the pump.

The set up in Figure 24 shows how liquid can be drawn out of a syringe or similar storage blister pack. The control precision and lack of pulsation in the pump allows the liquid flow rate to be controlled with a high degree of accuracy, without oscillation or the entrainment of air bubbles.

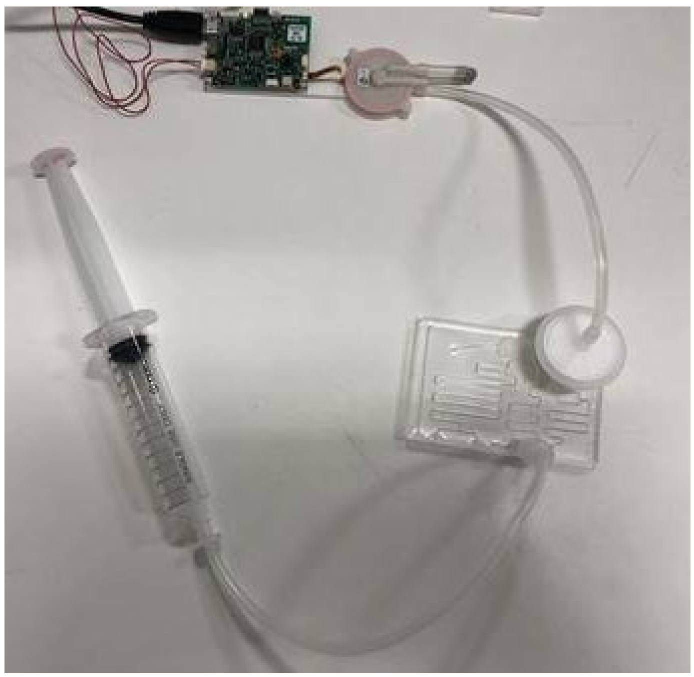


Figure 24. Aspiration of fluid through a microfluidic chip.

5.4.Flow reversal

The disc pump can offer very accurate flow control in PDF with both positive and negative pressure control, this allows a single pump to be used in combination with valves to move fluids backwards and forwards through microfluidic circuits, just by switching between the pressure and vacuum port on the pump.

It is possible to set up flow reversal with a variety of different valve types and designs, the simplest method however is using two 3/2-way valves, one classed as normally closed (NC) and the other normally open (NO), as shown below in Figure 4.

Please note that it is also possible to set up flow reversal using two 3/2-way valves that are both (NC) or both (NO) however please note that the port connections will need to different for each valve.

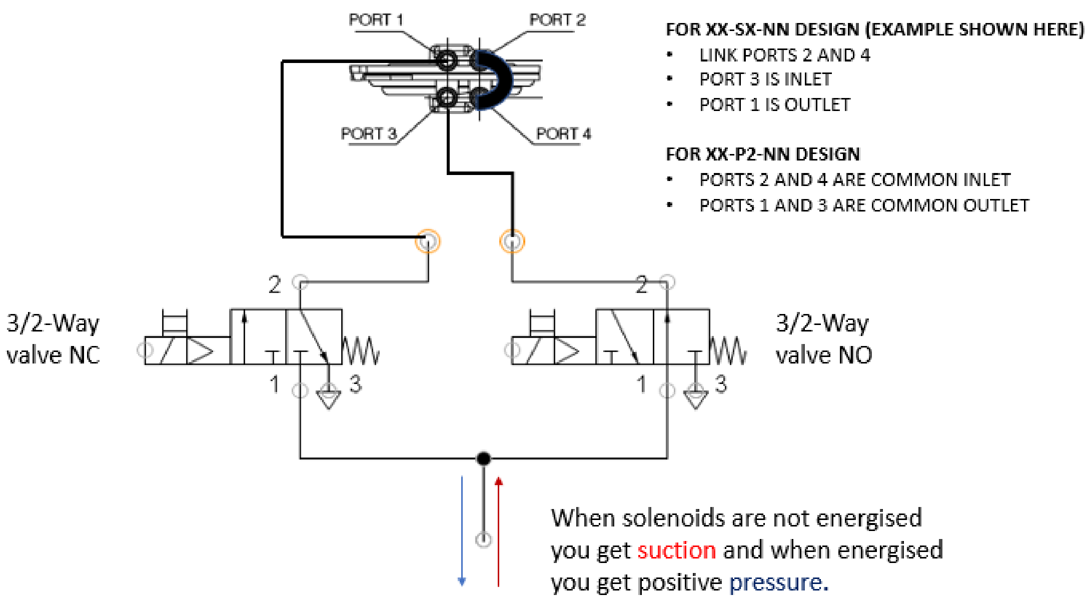


Figure 25. Disc Pump flow reversal using NC and NO 3/2-way valves.

Flow reversal is particularly important in many Point-of-Care (POC) diagnostic systems that need to move fluids very accurately backwards and forwards through their microfluidic circuits.

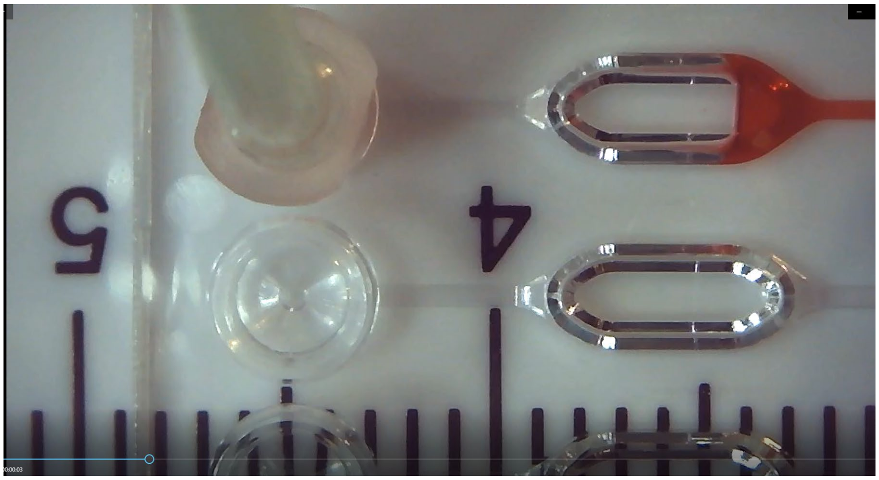


Figure 26. Fluid moving backward and forward through a microfluidic chip, as seen on our website.

5.5.Continuous flow with a PDF set up

PDF re-circulation is possible with the use of some external valves and reservoirs. This is often used in many Organ-on-a-Chip (OOAC) systems that need to re-circulate fluids within their microfluidic systems. The Fluigent L-SWITCH bi-directional six-port valve for example can be used to create continuous flow streams using PDF. In the example below PDF is used to move fluid from one reservoir to another and the flow direction remains constant through the flow unit and chip by the switching of the L-SWITCH valve. A valve on the pump then applies pressure as needed to either reservoir 1 or reservoir 2.

The speed of response, pulsation free flow and flow control, coupled with the compact size of the disc pumps make it an ideal choice for compact OOAC benchtop devices.

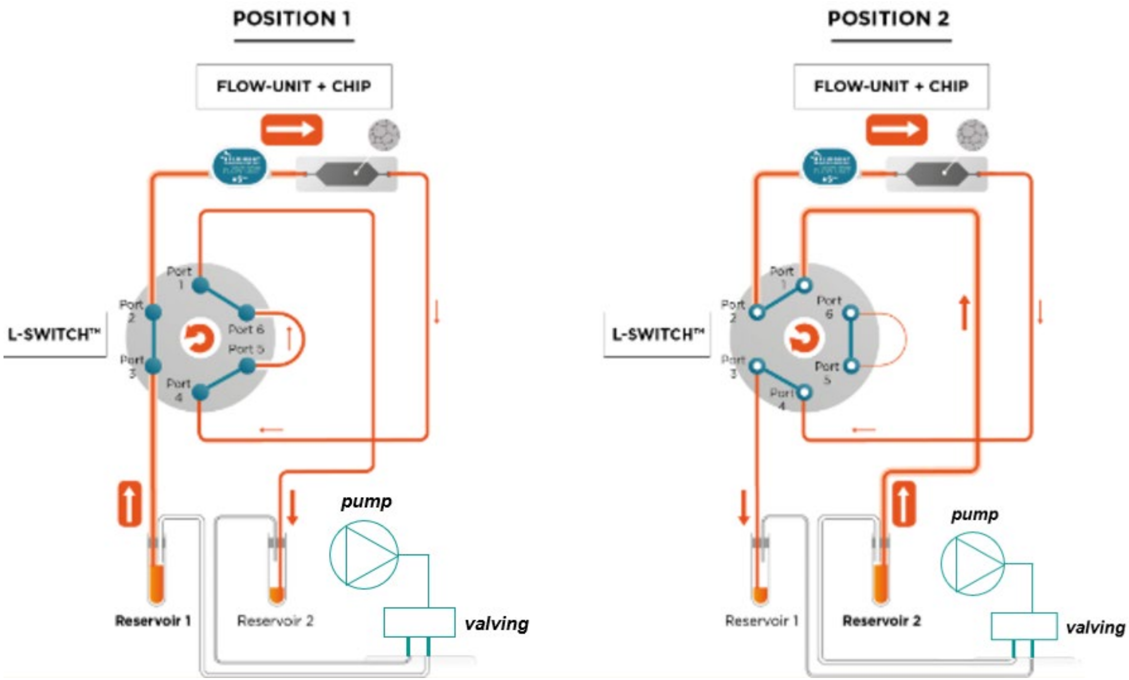


Figure 27: Continuous flow with Fluigent L-SWITCH valve.

5.6.Additional PDF examples and pneumatic pumping systems

As detailed previously disc pump can be used for a large variety of microfluidic applications where stable flow, precise control and compact size and weight and silent operation are important however, in some applications it is unacceptable for the liquid sample to come into contact with pumped (and/or unsterilized) air. Here the precise control of disc pump can be employed to achieve accurate pumping without the liquid contacting the pumped air.

5.6.1. Syringe barrel

One approach is to drive a syringe barrel pneumatically. Optional valving can be used to reverse the pump flow, allowing aspiration/sample collection, and subsequent dispense. Flow rate is measured via a disposable liquid flow meter and fed back to the pump control.

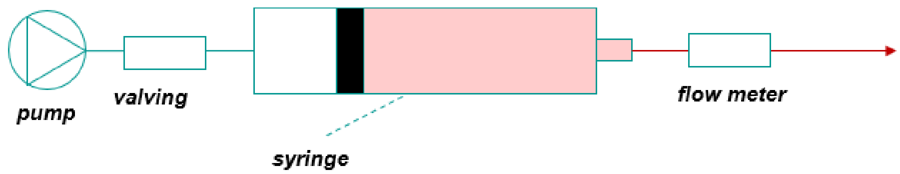


Figure 28: driving a syringe barrel

5.6.2. Bag-in-a-box principle

Another approach used in certain liquid drug delivery applications is a collapsible (non-elastic) bag inside a rigid-walled container. Air pressure from the pump drives fluid from the bag. Again, flow rate is measured via a disposable liquid flow meter and fed back to the pump control.

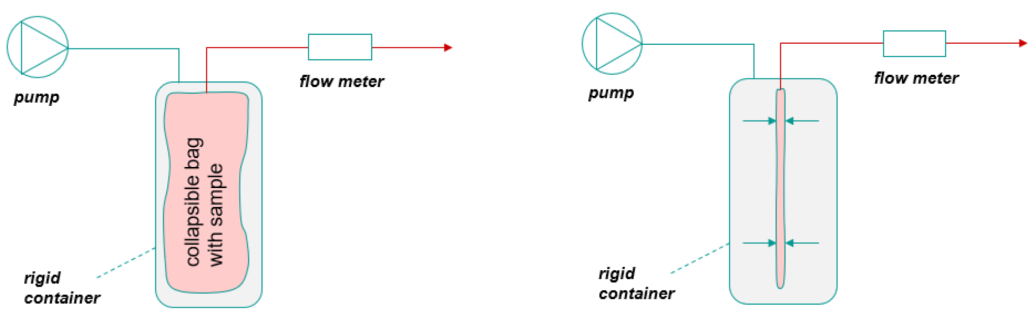


Figure 29: Bag-in-box driven flow.

5.6.3. Flexible membrane with valves

A third approach is to use alternating pneumatic pressure, that switches between pressure and vacuum to drive a flexible elastic membrane. The membrane is linked with an intake and discharge valve and creates fluid pumping. This approach is used extensively for breast pumps, some basic artificial hearts and in kidney dialysis machines.

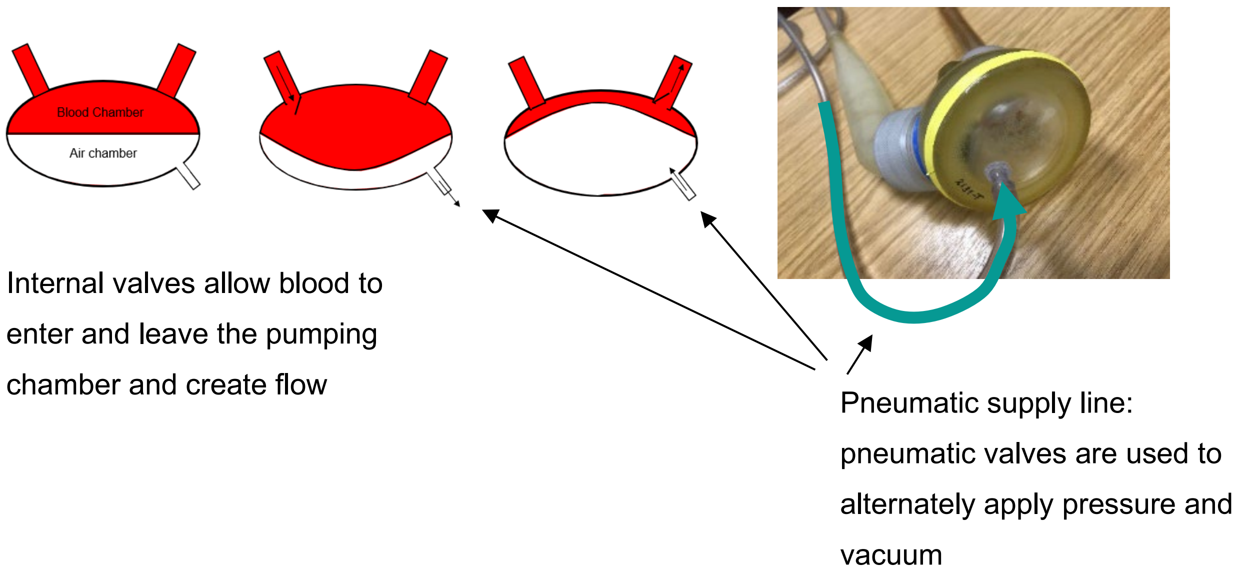


Figure 30: Flexible membrane heart pumpons

6. SUPPORT

6.1. Code snippet library

The Lee Company code snippet library, hosted on GitHub (https://github.com/The-Lee-Company), provides serial communication and control examples in Python for common functions, including turning the pump on and off, setting drive power, closed loop control of pressure and reading back and plotting data. The code snippet library implements the aspects of the communication protocol set out in application note ‘TG003: PSB Serial Communications Guide’ and is intended to support customers after their initial evaluation of our pump technology, as they move on to developing prototypes and products.

6.2. Additional Support

The disc pump section of The Lee Company website provides advice on:

- Getting Started
- Applications
- Development Process

- Downloads (including datasheets, application notes, case studies and 3D models)
- Frequently Asked Questions

Documents related to this application note:

- “TG001: Disc Pump Drive Guide”: a guide on how to drive the disc pump effectively with your own electronics.
- “TG003: PCB Serial Communications Guide”: a serial communications guide, for taking control of the evaluation kit (or smaller drive PCB) with your own hardware.
- “AN007: Microfluidics Driver”: – Prototyping with the Disc Pump Evaluation Kit and Sensirion SLF3x Series Flow Sensor
- “Disc Pump Reference Design Package”: a pack of reference designs for the firmware and drive PCB.

7. REVISION HISTORY

Date	Version	Change
June 2023	R230629	Rebranded.
15th March 2021	R210315	V7 Motherboard
17th July 2020	R200713	Additional information on PDF and examples.
21ST October 2019	R191021	Additional PDF examples.