AN002: LIQUID HANDLING INCLUDING MICROLFLUIDICS – DISC PUMP APPLICATION NOTE

1. INTRODUCTION

The Lee Company's piezoelectric disc pumps, Figure 1, are high-performance gas micropumps. This document details liquid handling applications, including microfluidic control, using pressure driven flow (or air over liquid). There is no direct contact between the liquids and the pumps.

Please note disc pumps cannot pump liquids directly.

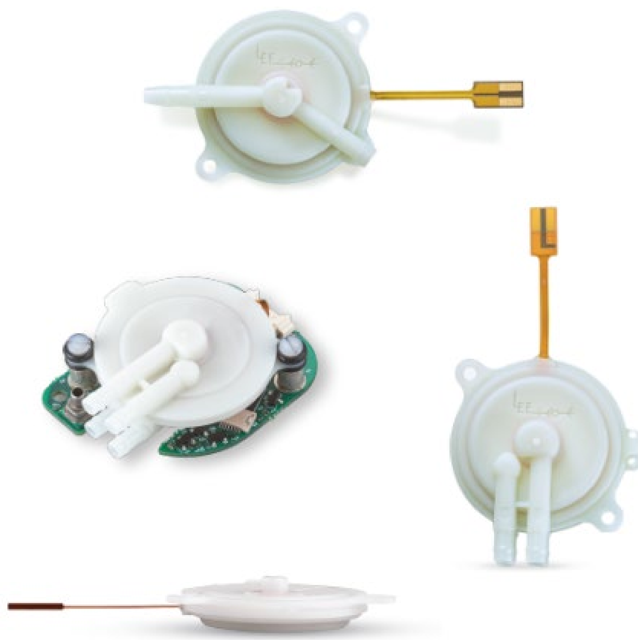

Figure 1. The piezoelectric disc pump models and an example of a Smart Pump Module

Owing to its operating mechanism, the disc pump can be controlled with unmatched precision, at the same time, responding 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. These features contribute to highly precise, real-time control in many liquid handling and microfluidic applications.

Disc pump enables the replacement of bulky equipment (e.g. the pumps, regulators and valves required by existing pressure-driven flow systems) with a palm-sized, self-contained module that contains the micropump and electronics, see Figure 2. This brings advantages over other miniature pump systems targeting microfluidics, including ultra-smooth liquid flow, rapid response time and a wide dynamic range. In addition, disc pump operation is silent, its operating frequency is above the audible threshold.

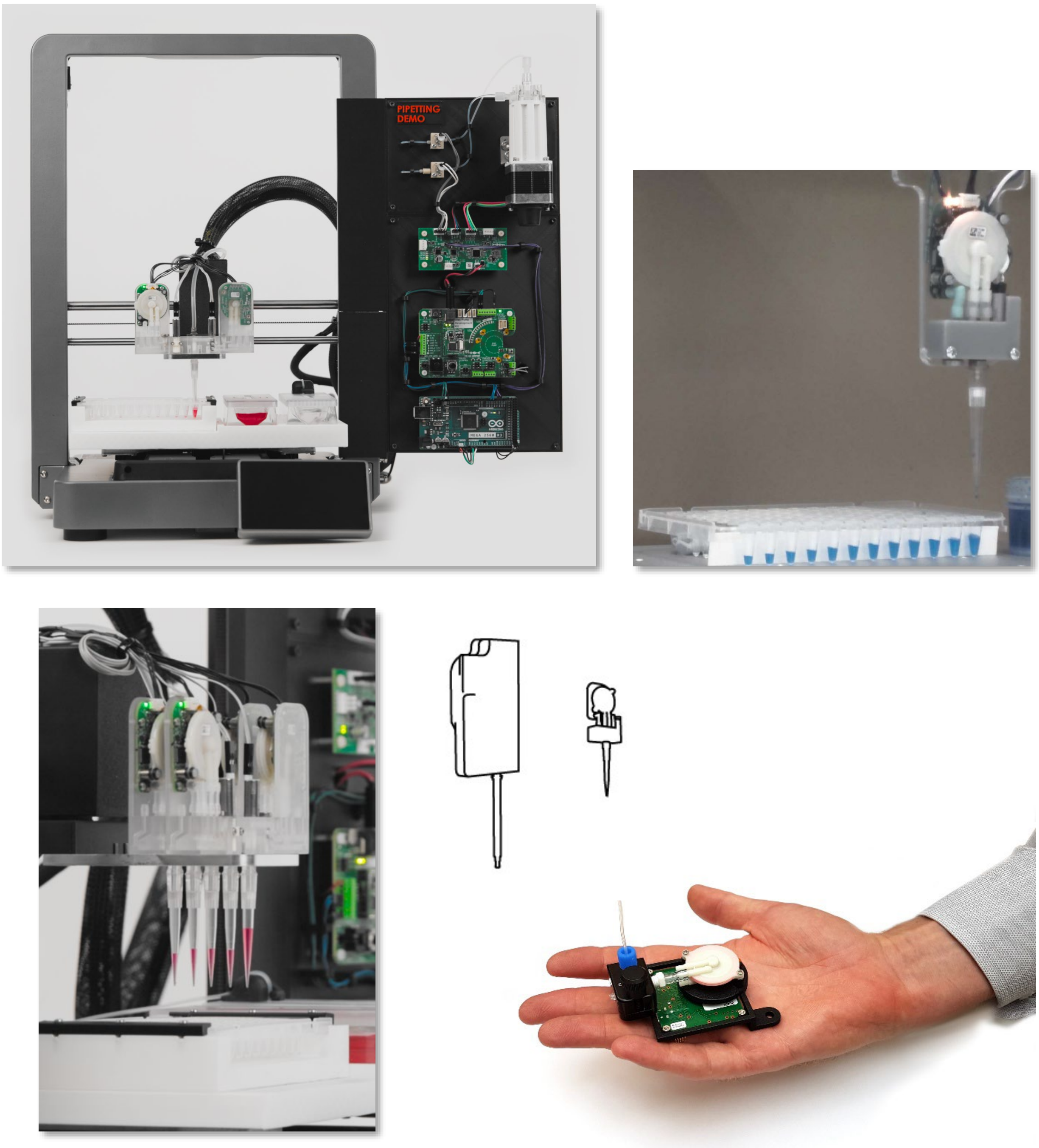

Figure 2. Prototype examples of liquid handling systems using the disc pump.

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: Liquid handling applications
- Section 7: Boosting performance
- Section 8: Support

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3. BASICS OF PRESSURE DRIVEN FLOW

With its unique feature set, disc pumps can be used for 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 over legacy technologies. Click here to view examples of applications enabled by Disc Pump.

3.1.Why pressure-driven flow?

Syringe pumps utilise the stepping action of the motor to control accurately the flow of liquids. However, the resolution of the steps and the mechanical play in the drive mechanism create instability in the liquid flow. Fluctuations in liquid flow can have a negative impact on microfluidic processes, for example by reducing the consistency of droplet generation or the sensitivity of downstream measurements. Syringe pumps therefore require ‘backlash compensation’ algorithms to address the mechanical play in the drive system and need to be tuned according to the system. Even precision engineered syringe pumps, designed to minimise pulsation, only do so within a narrow band of flow rates.

Peristaltic pumps deliver a pulsatile flow. The tubing used is flexible and coiled around a motor driven roller carrier mechanism. The rollers move the liquid by sequentially compressing the tubes. The user sets a flow rate or motor speed which corresponds to the mean value of the pulsatile flow. The amplitude and frequency of the pulsations depend on the internal diameter of the tubing, the number of rollers and their rotation speed.

The flow rate of component peristaltic pumps ranges from 2 μL/min to more than 10 L/min. The technology is also used for much higher flow rates on industrial devices. Peristaltic pumps are broadly used to recirculate as well as to dispense large volumes.

Solenoid/motor driven piston pumps and motor diaphragm pumps, when used, provide pulsatile flow and the pump components are in direct contact with the liquids. The materials in contact with the liquids have to be compatible to maximise reliability and longevity. These technologies generally have the ability to operate at higher pressures than syringe or peristaltic pumps and pressure driven flow using disc pumps. They do not rely on a pressurised system to operate. The Lee Company have fixed and variable volume pumps in its portfolio (https://www.theleeco.com/industries/diagnostics/products/pumps/).

Pressure-driven flow (PDF), also referred to as air over liquid, in contrast can deliver truly pulsation-free flow, enabling greater control accuracy and homogeneity within experiments. PDF also provides response times several orders of magnitude faster than syringe pumps, streamlining the microfluidic process and enabling new flow control regimes.

Figure 3 below demonstrates the exceptional rapid response and precise control that a disc pump can achieve relative to the performance of a syringe pump.

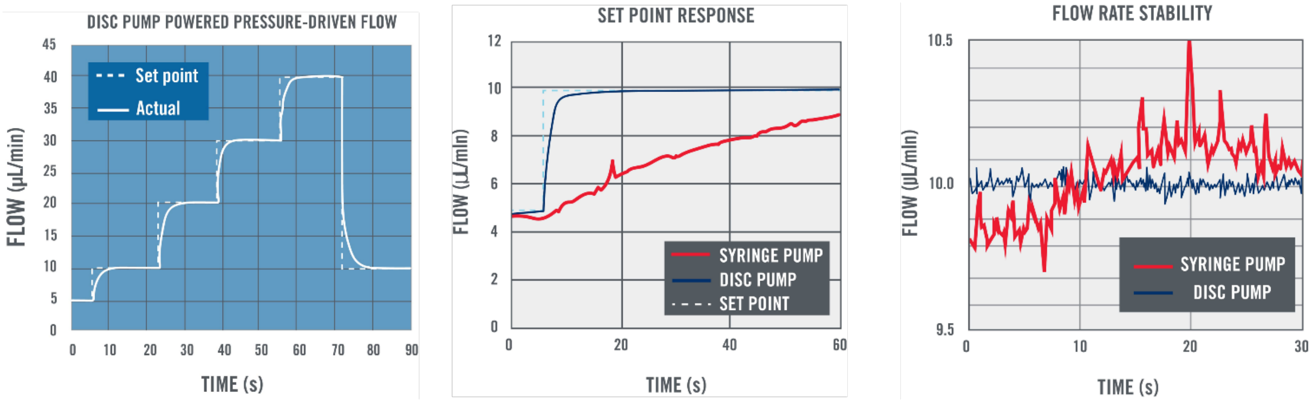

Figure 3. Precise flow-rate control and rapid response enabled by the disc pumps versus a syringe pump

3.2.How does pressure-driven flow work?

The head space i.e. the volume of gas above a liquid in a closed reservoir, is pressurised driving liquid through a tube below the liquid surface. A configuration is shown in Figure 4 with optional valve and sensing concepts depending on the system requirements. Valves can be employed where reversible flow is desired, and flow metering can be used where precise, closed-loop control of flow rate is required.

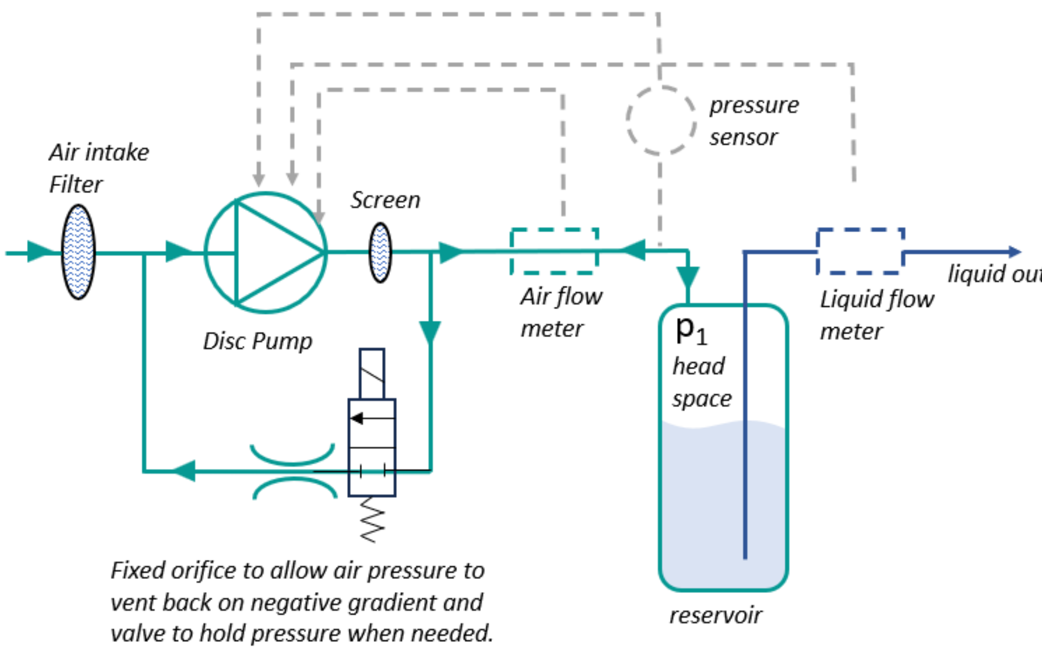

Figure 4. Using a disc pump for pressure-driven flow.

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 for instance, the disc pump has very little inertia and, as such, it can react to set point changes much faster. The ability 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 (Figure 5). Also, pulsation free flow helps to reduce bubble formation and bubble entrainment.

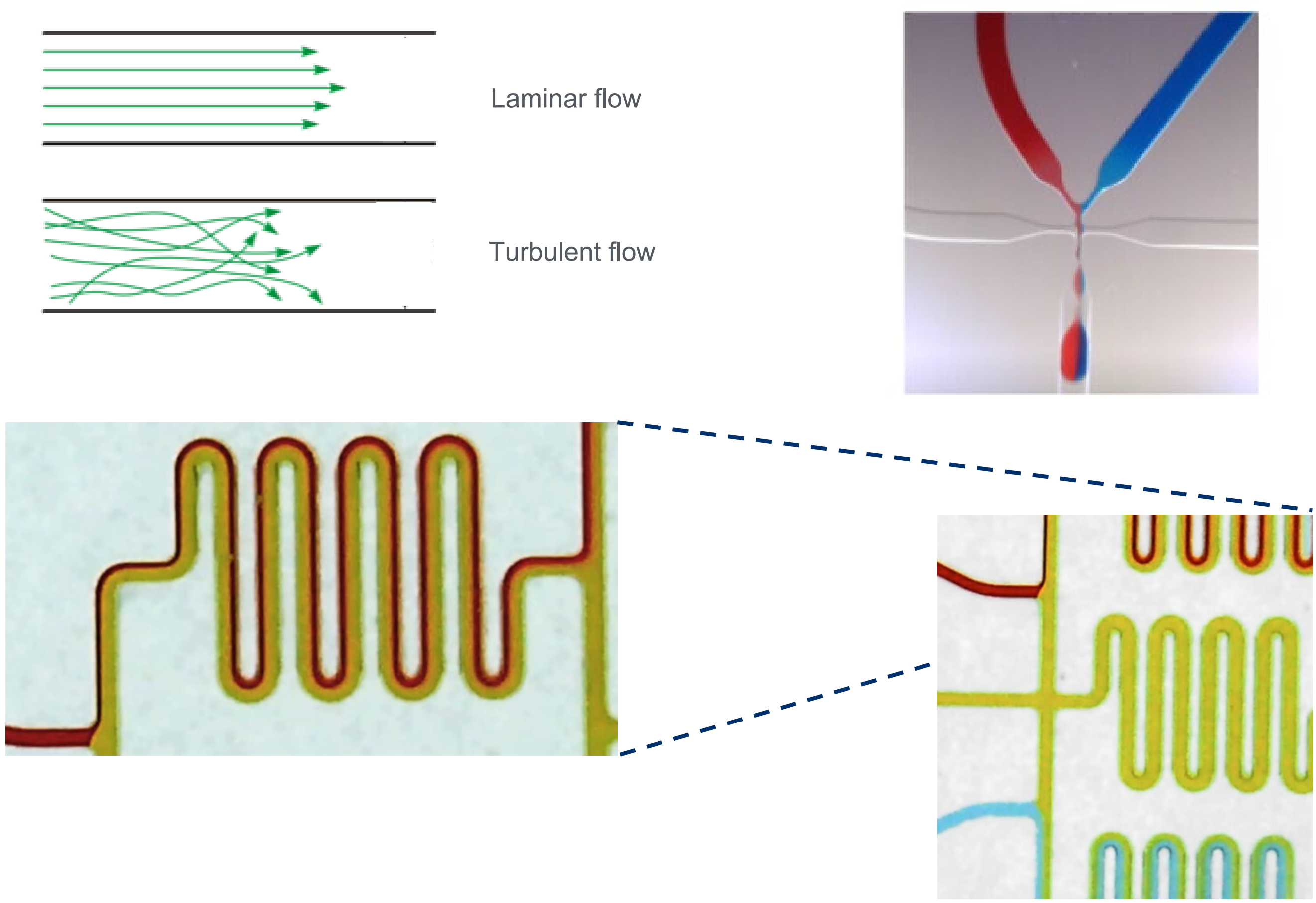

Figure 5. Laminar flow compared to turbulent flow and example of laminar flow achieved using disc pump.

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 (Figure 3).

Compact size - The disc pump 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 6). Figure 6. A disc pump in a compact Pressure Driven Flow (PDF) module for a system.

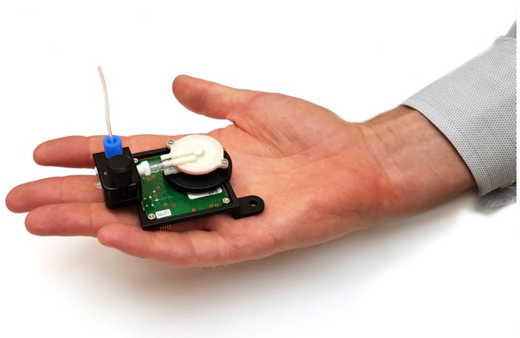

Figure 6. A disc pump in a compact Pressure Driven Flow (PDF) system.

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.

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

4. USING DISC PUMPS FOR PDF

Each disc pump requires its own drive electronics for optimum performance and control. Ultimately device manufacturers can incorporate this function on their system PCB, using the reference design package provided freely. There is a PCBA accessory (UEKA0300000A) or Smart Pump Modules can be used, see Figure 7.

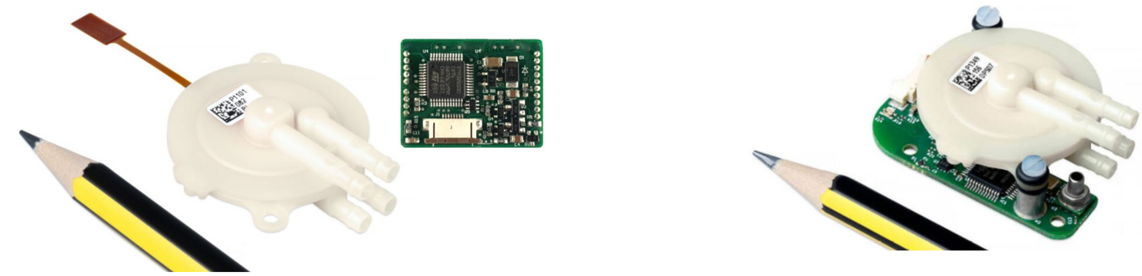

Figure 7: Disc pump, GP Drive PCB (UEKA0300000A) and example of Smart Pump Module

For the purposes of evaluating disc pumps, particularly in combination with other Lee fluid control components, a versatile Development Kit is available (UEKA0500300A).

Figure 8: Piezoelectric Development Kit (UEKA0500300A)

The Development Kit comprises, a motherboard and drive electronics (UEKA0300000A), necessary to run and control a disc pump. This setup can also control Lee solenoid and dispense valves. The motherboard has headers to connect to multiple Smart Pump Modules (SPMs) and an integral pressure sensor.

A variety of pneumatic and control related accessories are also included to facilitate system set up. The appropriate pump/module and valve selections for an application/system can be ordered with the kit.

For pressure driven flow, a reservoir will also need to be sourced separately. The Development Kit is configurable for closed loop control with flow and pressure sensors, for instance. Detailed instructions are provided in the manual (https://www.theleeco.com/disc-pumps/ and here). Flow and differential pressure sensors can be connected but need to be sourced separately.

4.1.System components

The Development Kit components are shown in Figure 8 above. The manual describes the system components and their function, and this should be read carefully, noting all warnings before proceeding. Below is an example of a demonstration system setup, where three channels are individually controlled to deliver liquid to a microfluidic chip using pressure driven flow.

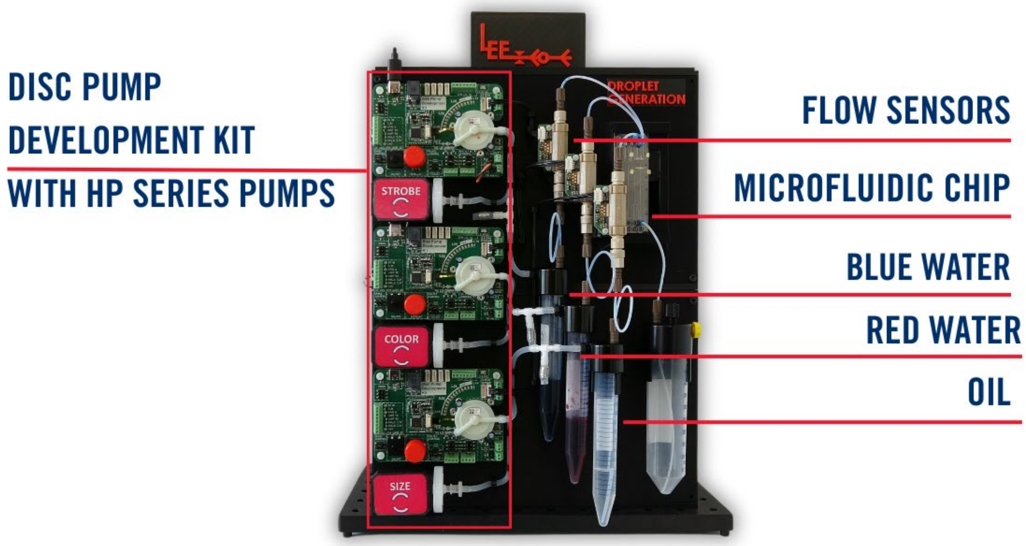

Figure 9. Demonstration system with 3 channels set up with liquid flow sensing for droplet generation

The demonstration system below in Figure 10 provides an example of how forward and reverse flow can be achieved using just one pump with two solenoid valves. This principle can be applied to reservoirs for forward and reverse flow of liquids. See also section 6.6.
Figure 11 shows an example of a forward/reverse flow manifold available as an accessory. This particular example is directly compatible with The Development Kit as it is a 12V version.

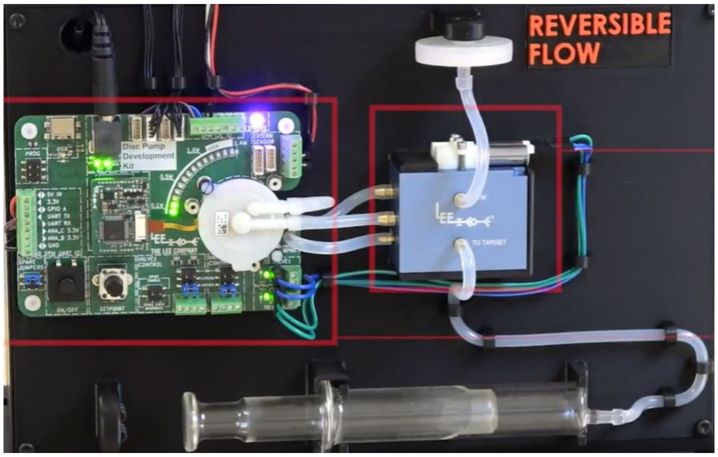

Figure 10: forward and reverse flow demonstration system controlled via the Development Kit

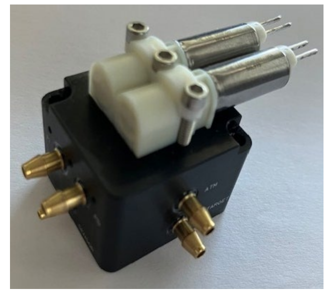

Figure 11: LFMX0534570B is an example of a reverse flow manifold available as an accessory.

5. PDF Examples

5.1.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.

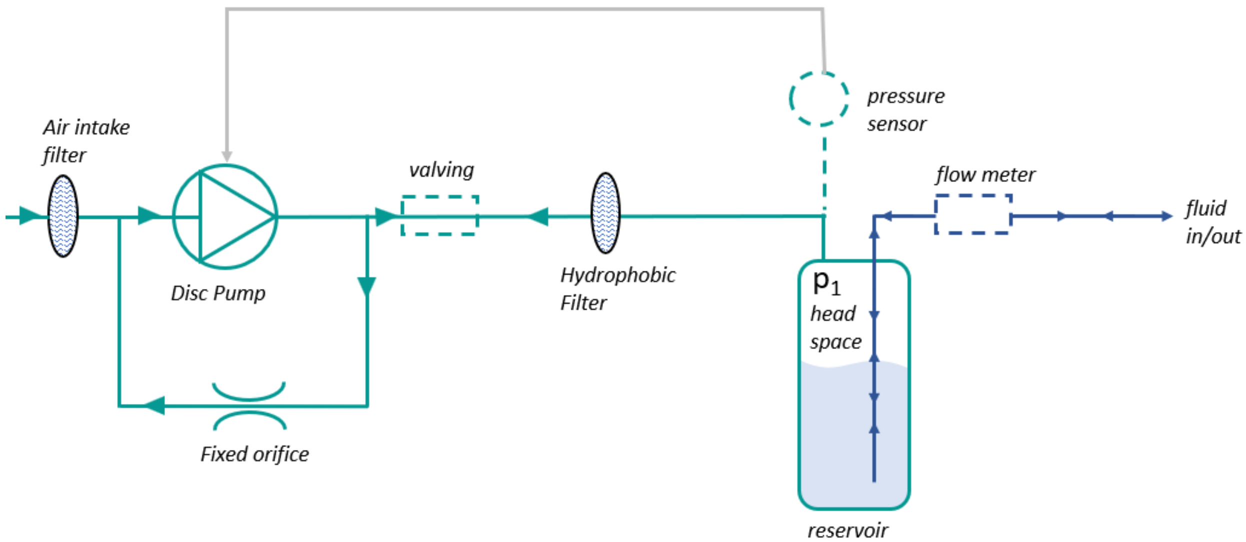

Figure 12: Setup for aspiration

5.2.PDF control options

5.2.1. 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.

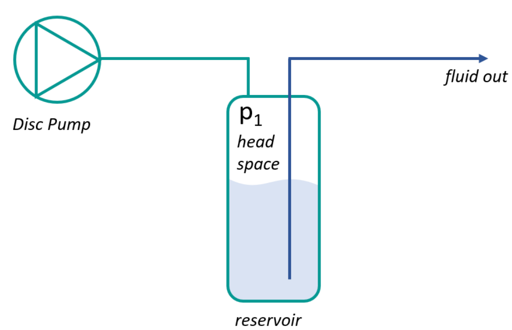

Figure 13. Basic open-loop control of fluid dispense.

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:

- driving the pump at a known power and known duration

- measuring the volume or mass of the sample dispensed
- adjusting the power or duration to deliver the target volume or mass

5.2.2. 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 14.

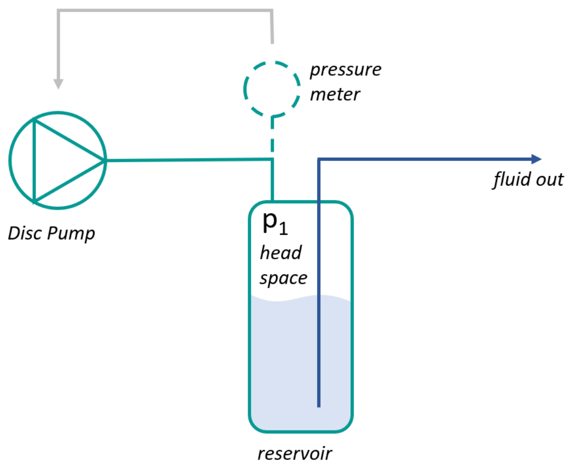

Figure 14. Pressure-based control of liquid delivery

The motherboard included with The Lee Company's Development Kit includes a pressure sensor, enabling the system to operate with closed loop to achieve a particular target pressure. Pressure measurements are received by the Drive PCB and PID control can be used either via the app or using serial commands to modulate the input power to achieve the 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.

5.2.3. Closed-loop flow-rate control

The disc pumps can be combined with a flow-rate sensor; as shown in Figure 15, 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.

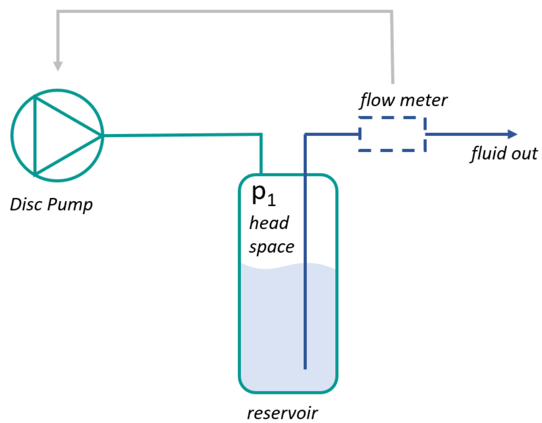

Figure 15. Flowrate based control of liquid delivery.

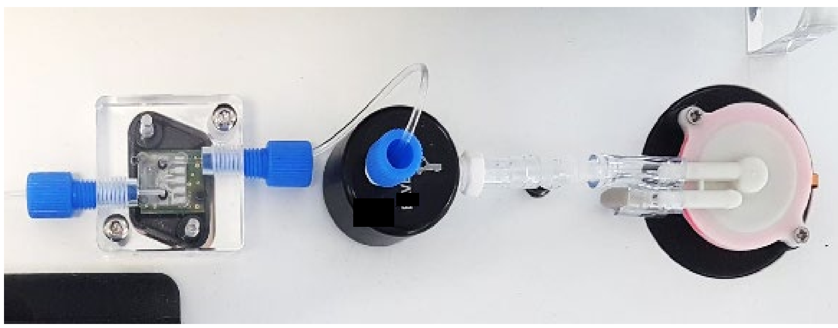

Figure 16. Disc pump integrated with a flow sensor to deliver constant, highly stable flow.

Figure 16 above shows a system comprising a disc pump and a flow sensor, combined to deliver closed loop control over liquid flowrate.

6. Applications using PDF

6.1.Time metered dosing

6.1.1. Simple System

Pressure Driven Flow (PDF) with Disc Pump allows smooth, highly controllable flow of liquid from a sealed reservoir by controlling the pressure in the ‘head space’ above the liquid.

The best control of such systems is achieved using closed loop control of the pump by a measurement of the ‘desired’ property (e.g. flow rate using a flow sensor, liquid level using a level sensor, etc), although such approaches require additional hardware (e.g. flow sensors) which can be undesirable.

A common alternative is pressure-time dispense, where the liquid is moved with a fixed pressure for a fixed time, to achieve a dosing volume which is consistent (assuming constant conditions) and can be calibrated. A drawback to this approach that it is very sensitive to fluid viscosity, system geometry and liquid heights, and can require regular recalibration.

Below is an approach where the drawbacks of pressure-time dosing can be overcome using a Disc Pump driven PDF system.

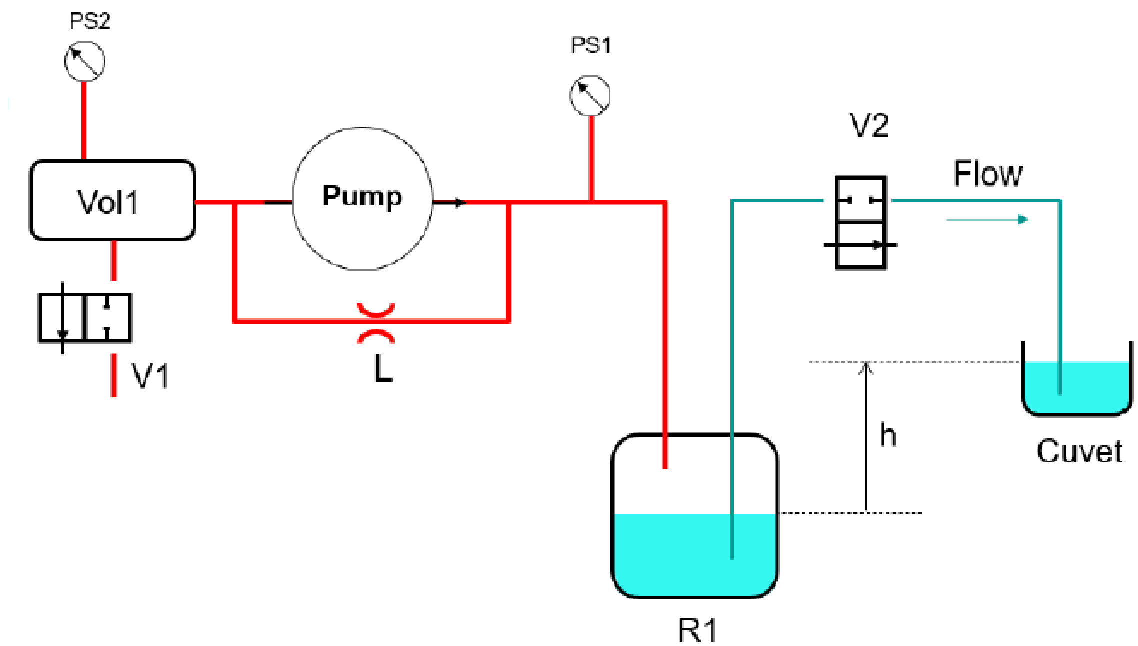

Figure 17: Time metred dosing setup

The schematic above shows a system containing the following features

- A Disc Pump (“Pump”)
- Two pressure sensors (“PS1”, “PS2”)
- One air valve(“V1”)
- One fluid valve (“V2”)
- An orifice (“L”)
- An air volume (“Vol1”)
- A sealed fluid reservoir (“R1”) with a pneumatic connection to the air space and liquid connection to the liquid
- A receptacle or cuvette, at a height h above R1 liquid level

Important notes

- The pneumatic air space needs to be very well sealed when the valves V1 and V2 are closed. For example, to control liquid flow rates ~1ml/min, the air leak rate from the system should be at least 10 times smaller than this (i.e.0.1ml/min) and preferably better for high accuracy
- The size of Vol1 should be selected to provide the appropriate sensitivity but may be typically ~ 5 cc in volume.
- At the end of the dose, the pump will be generating a total pressure of |PA|+|PB|. Values should be selected to ensure this is well within the capability of the pump to avoid unnecessary pump heating (i.e. <0.5W ideally)
- The timings are critical. For fast dosing, timing errors can lead to dosing sensitivity to drive pressures and hydrostatic head height h. Improved accuracy can be achieved by fast response system and slow dispense. See Appendix 1 for details.
- Control approach to dispense a volume Vdisp as shown below
- The drive pressure PA is selected to move fluid at the desired rate and to overcome any hydrostatic forces due to the height difference h. Note, the value of PA affects the rate of dispense but not the volume
- The trigger pressure PB is selected according to the following equation:

$$V_{disp} = \frac{V_{Vol1}(P_{atm} - P_B)}{P_A}$$

A specific document is available for this approach, AN074: Time Metered Dosing using a Volume Control Module. A less complex system is also described in AN059: Time-Metered Dosing (https://www.theleeco.com/disc-pumps/).

Dispensing precise volumes of liquid is useful in a wide variety of industries, whether for scientific research instruments, medical diagnostics, or high-tech industrial applications where accurate and small volumes are needed. Time-metered dosing with constant pressure is a simple solution for precise dispensing of different liquids.

By combining the high level of pressure control provided by the disc pumps, and the ultra-fast and consistent operation of the VHS valves, The Lee Company have built a prototype of a compact, lightweight time-metered dosing system as proof-of concept (Figure 18).

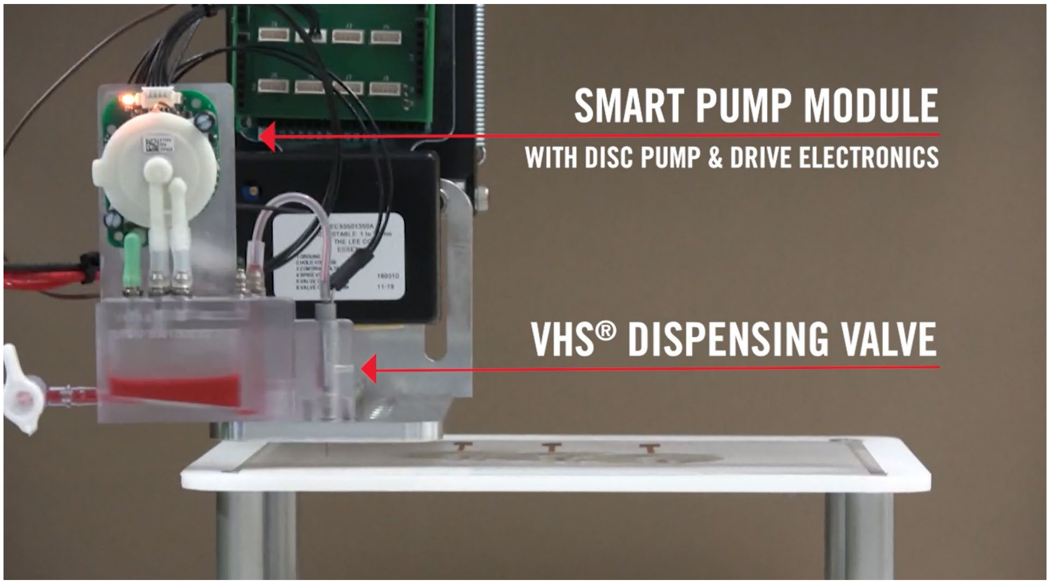

Figure 18. Prototype of time-metered dosing system

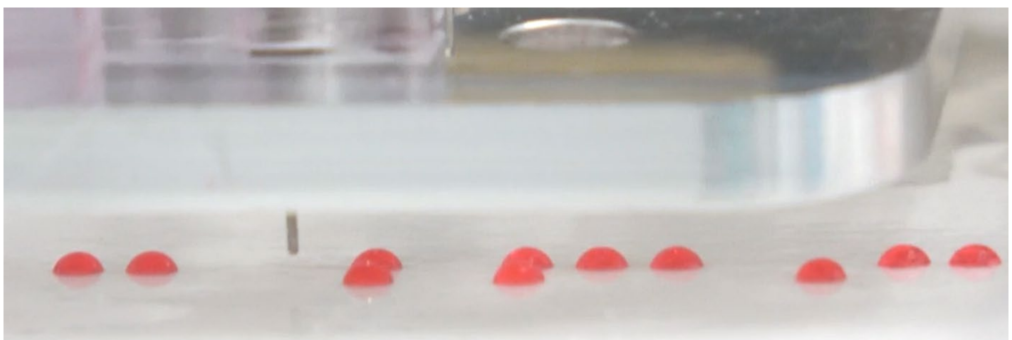

Figure 19. Droplet dispensing demonstration

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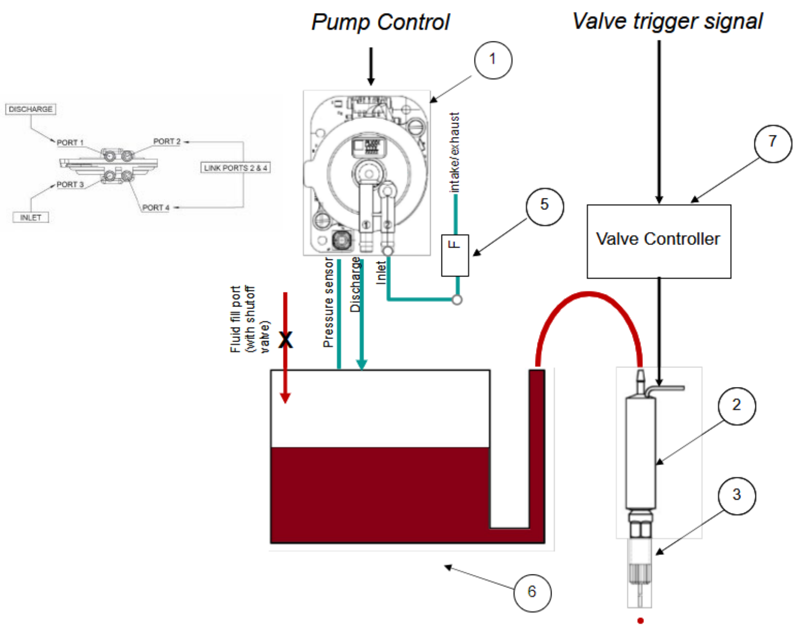


Figure 20. System Schematic A

Component	Description	Product code	Source
1	Smart Pump Module	UBLC5401000A	The Lee Company
2	VHS Valve	INKX0508000A	The Lee Company
3	Dispensing Nozzle	INZA3100914K	The Lee Company
4	Orifice	RPGF2554300S	The Lee Company
5	Filter (maximum 3um pore)	Various	Various
6	Fluid Reservoir	Bespoke SLA	
7	Valve Spike & Hold Driver	IECX0501350A	The Lee Company

Table 1: Prototype Components

Full details are provided in Application Note AN059 (https://www.theleeco.com/disc-pumps/)

6.1.2. Time Metered Dosing using a Volume Controlled Module

The main advantage of the Volume Control Module dispensing over Time-metered dosing is that the dispensed liquid volume is independent of the liquid properties such as viscosity, flow restriction, liquid level, dispensing height. This is beneficial for dispensing applications with liquids that change viscosity with temperature or over time, applications using a single dispensing unit with multiple outputs or high precision applications that are sensitive to minute changes in the dispensed quantity.

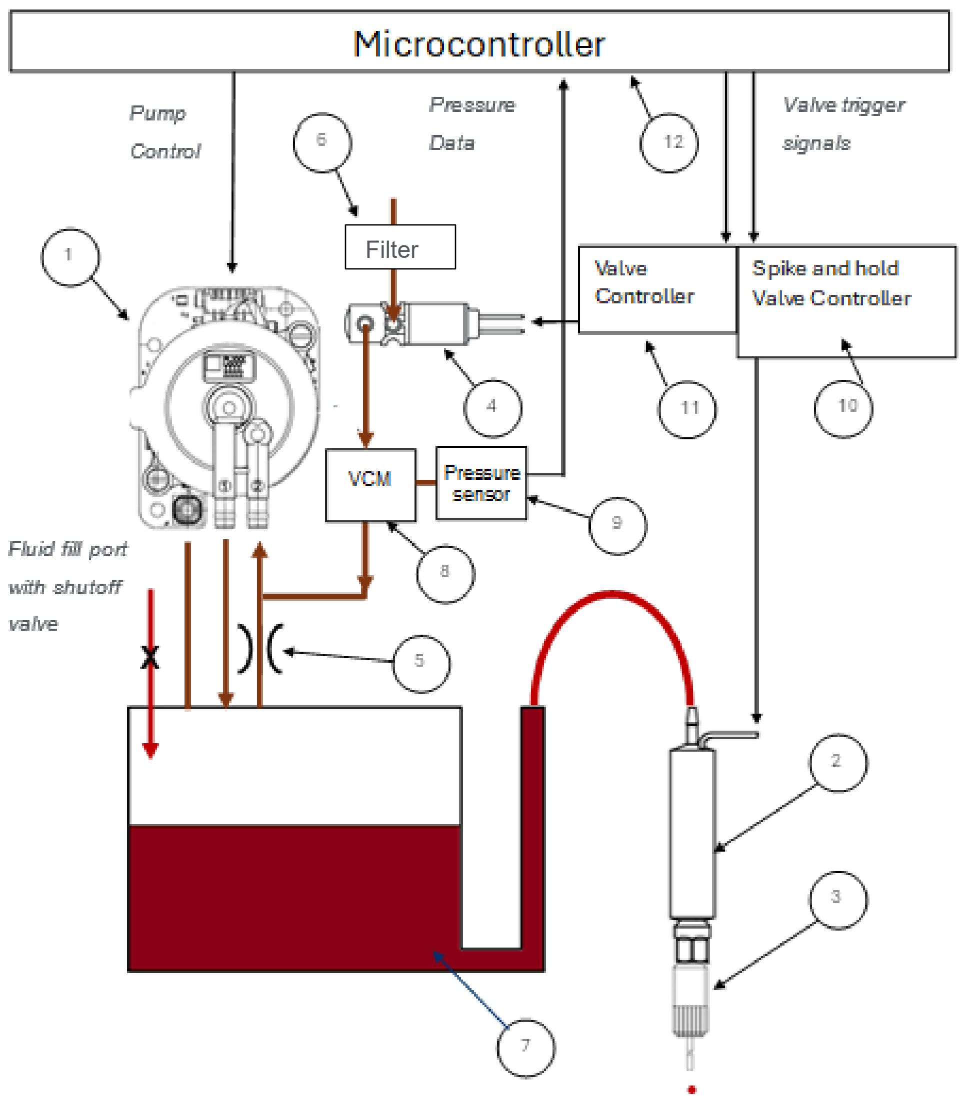


Figure 21: Architecture for Time Metred Dosing using the VCM method

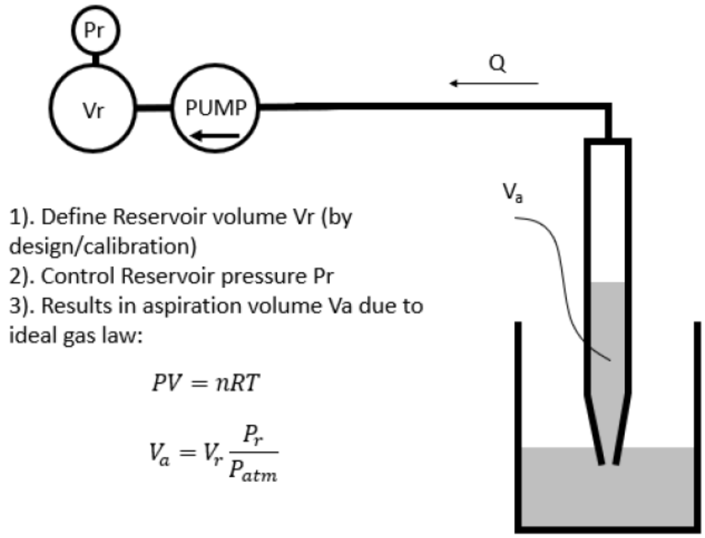
Item	Description	Product code	Source
1	Smart Pump Module	UBLC5400200A	The Lee Co.
2	VHS Valve – for liquid dispensing	INKX 0508000A	The Lee Co.
3	Dispensing Nozzle	INZA3100914K	The Lee Co.
4	HDI Valve – for air intake	LHDA1233115H	The Lee Co.
5	Orifice	RPGF2554300S	The Lee Co.
6	Filter	3µm pore size or less	
7	Fluid Reservoir	Bespoke SLA	
8	VCM control volume	Bespoke SLA	
9	Differential pressure sensor 1psi	HSCDLND001PGAA5	Honeywell
10	Spike and Hold valve controller	IECX 0501350A	The Lee Co.
11	Valve controller	Simple "Basic transistor" valve driver	
12	Microcontroller	Arduino Mega 2560 Rev3	Arduino

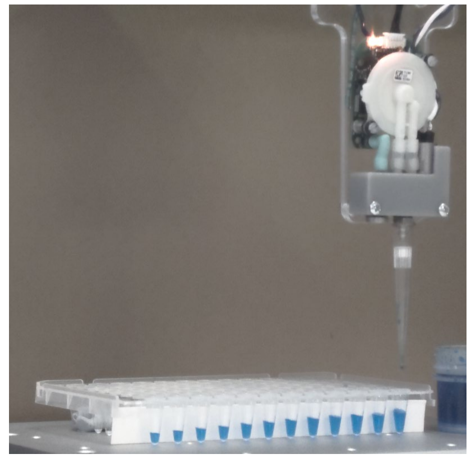
Table 2: Components

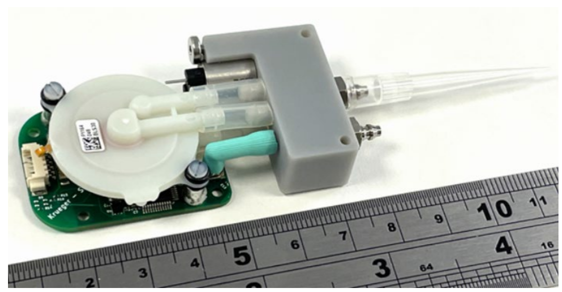
Full details are provided in Application Note AN074 (https://www.theleeco.com/disc-pumps/)

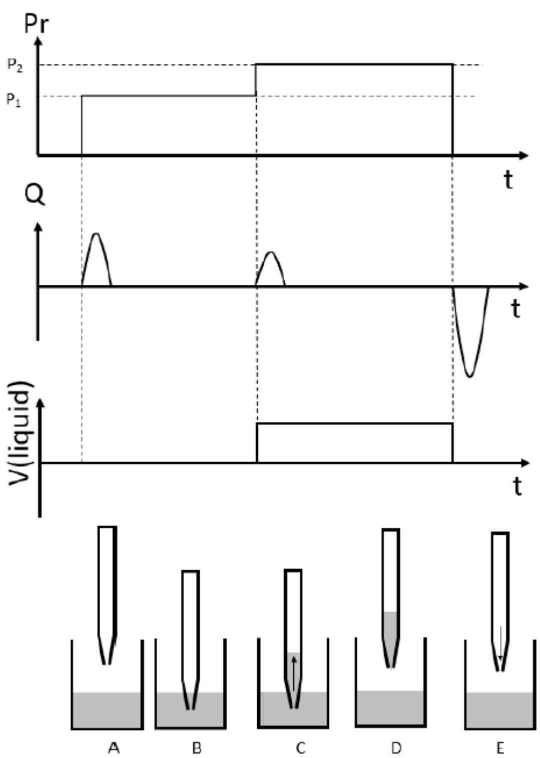
6.2.Pipetting

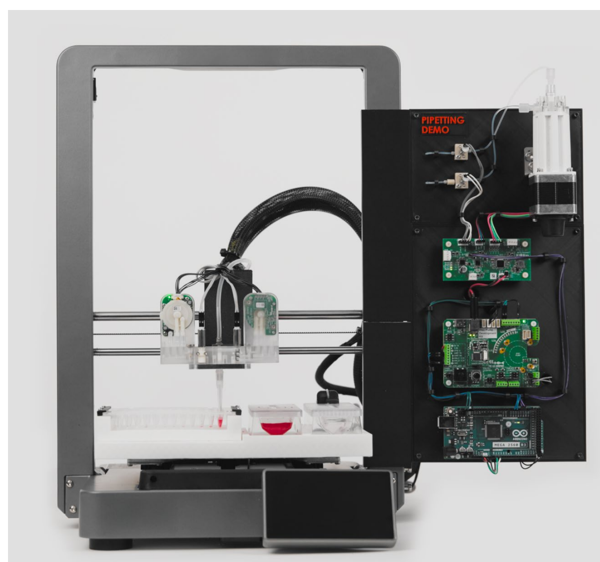
Due to non-pulsatile flow from Disc Pump and its high levels of control, with a suitable pressure sensor, Disc Pump can be used for precise volumetric control, in much the same way as an air displacement pipette. Here, accurate pressure control in a known and fixed volume is used to determine fluid volumes moved using the ideal gas law. A specific document is available for this approach, AN049 Pipetting - Disc Pump Application Note (https://www.theleeco.com/disc-pumps/)











https://www.theleeco.com/insights/pipetting-with-lee-

Figure 22: Volume control via the ideal gas law, used to create liquid handling robot by converting a 3D printer (bottom right)

6.3.Droplet Generation

Two or more pressure-driven flow systems may be combined to generate liquid-in-liquid droplets, see Figure 23. The modified Development Kits demonstrated the ability to dynamically control flow rates to alter the colour combinations and droplet size.

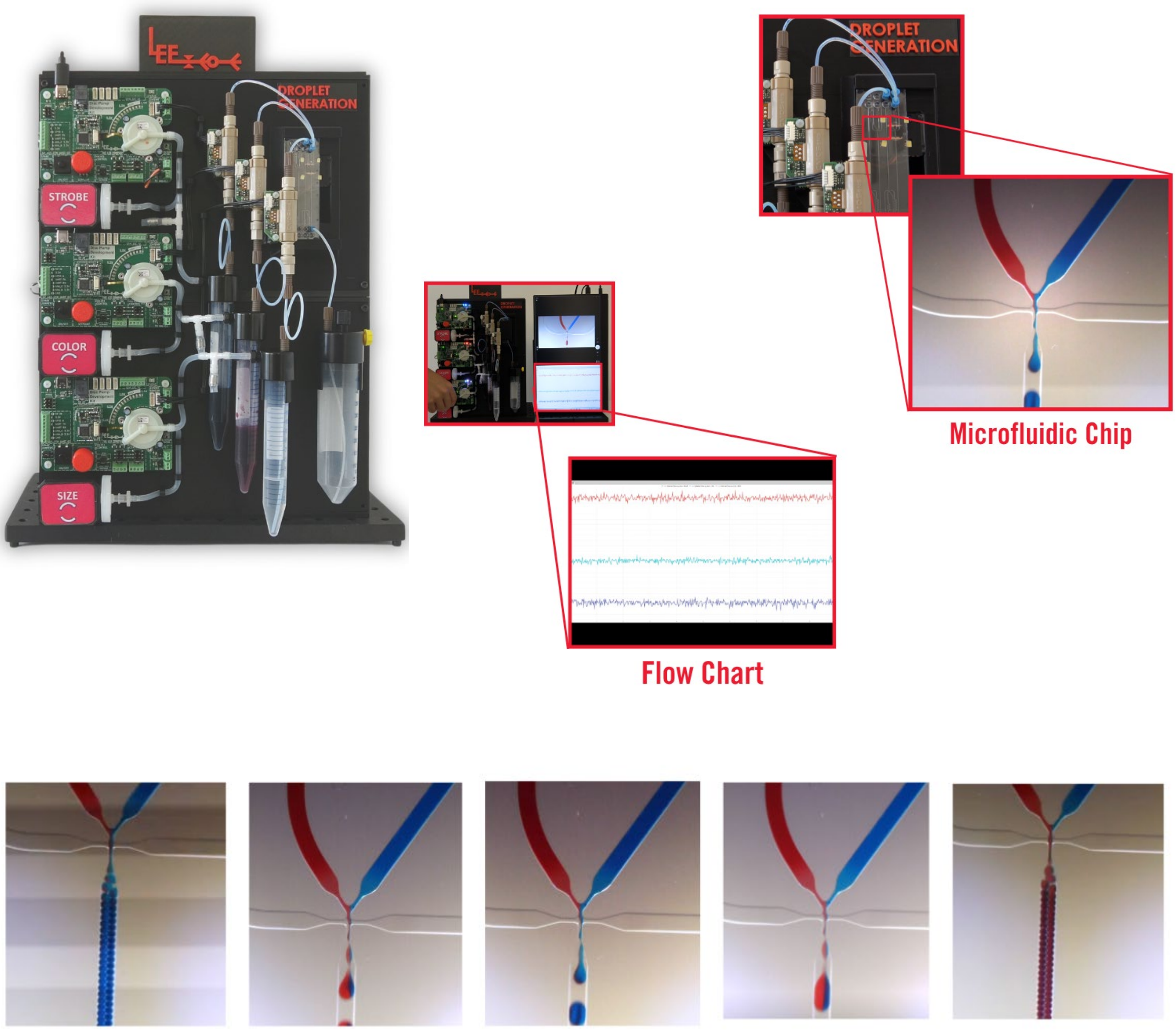


Figure 23. Demonstration system configuration for liquid-in-liquid droplet generation.

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 24 shows two disc pumps being used to create droplets.

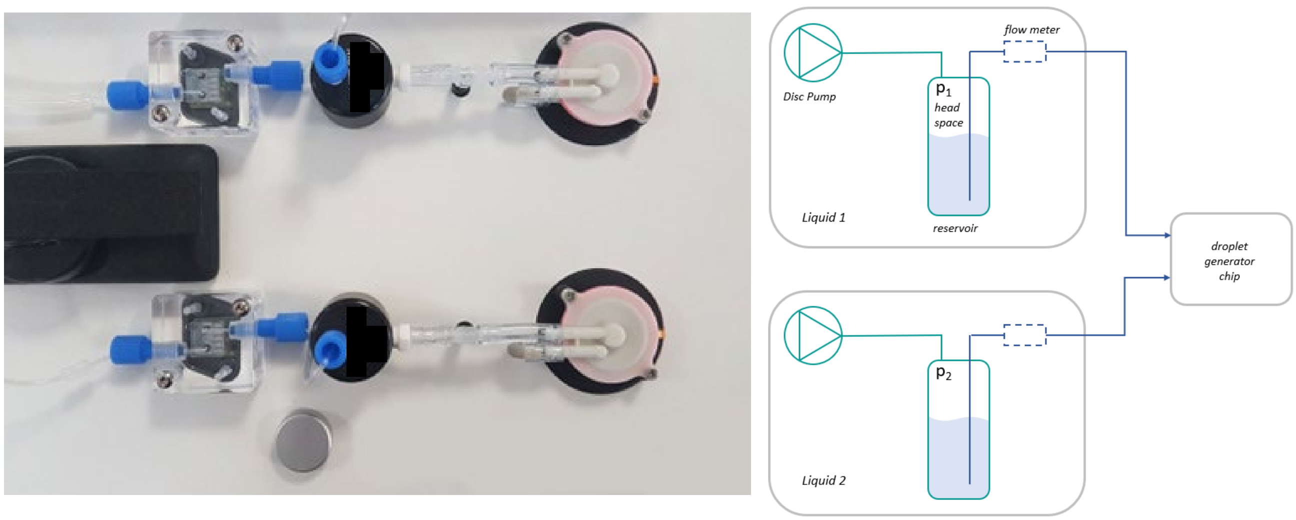


Figure 24. Two disc pumps feeding a droplet generator chip.

The strobe images shown in Figure 25 highlight the stability and controllability of the system through the ability to deliver different droplet diameters and delivery rates.

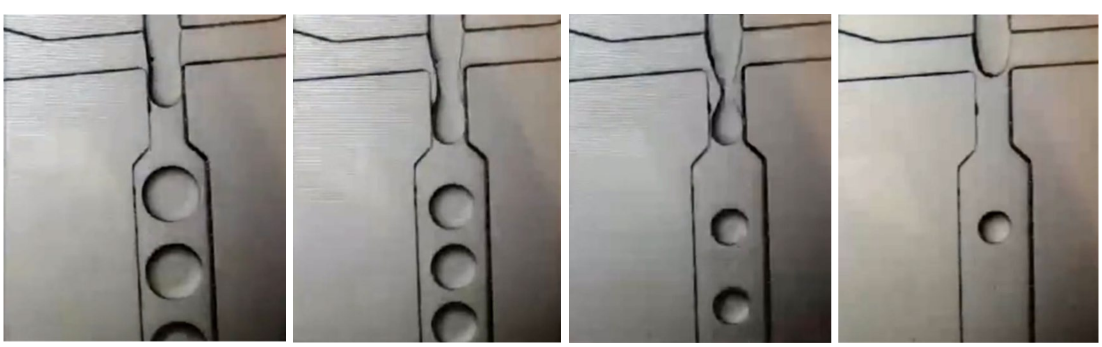


Figure 25. Two closed loop Disc Pump systems generating liquid-in-liquid droplets.

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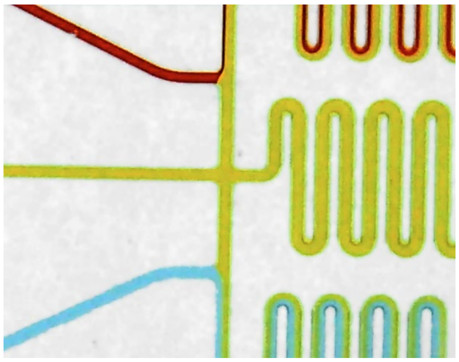
6.4.Laminar flow systems

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 example below in Figure 26, 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.



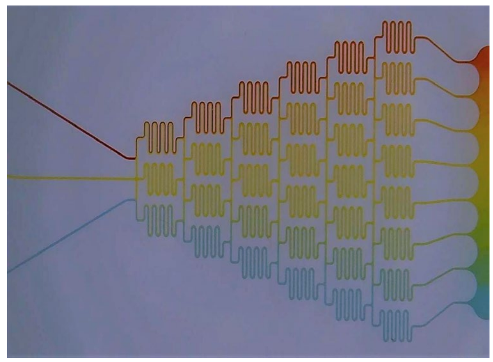


Figure 26. Laminar flow paths and laminar flow in concentration gradient.

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 27.

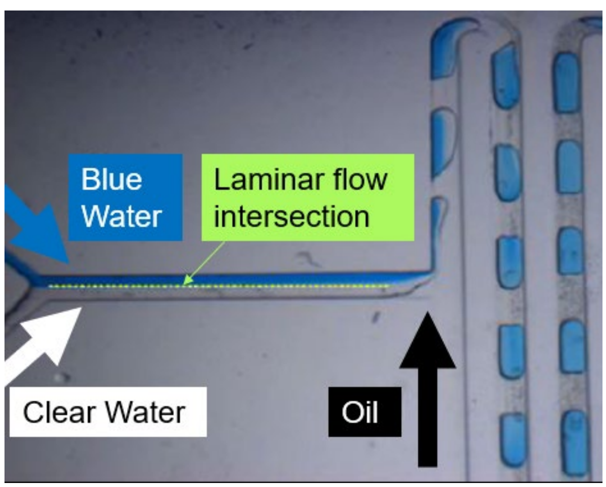


Figure 27. Droplet generation of droplets with different concentrations

6.5.Negative pressure flow control

The disc pump may also be used to aspirate fluids through 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 28 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.

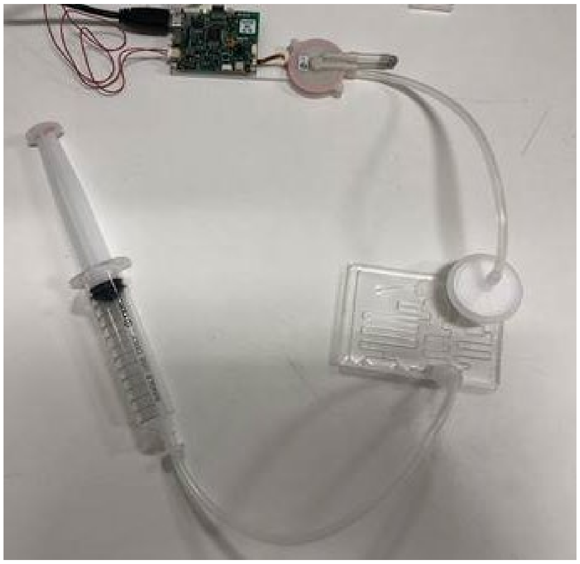


Figure 28. Aspiration of fluid through a microfluidic chip.

6.6.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 28.

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.

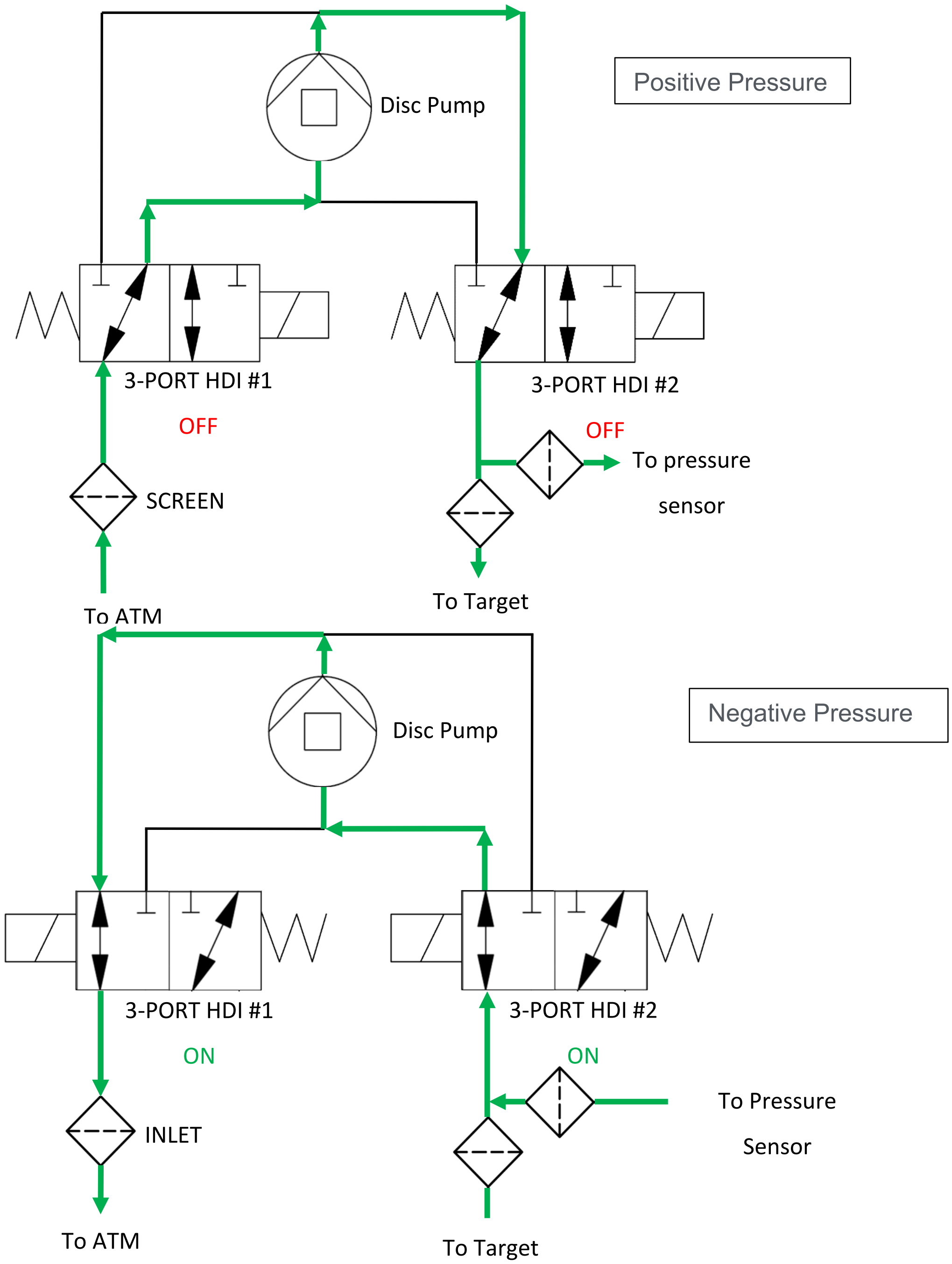


Figure 29. Disc Pump flow reversal using NC and NO 3/2-way valves.

The valves can be individual items connected with tubing and connectors supplied with the Development kit see Figure 30 (left). The Lee Company also has a reverse flow module, LFMX0534570B (right).

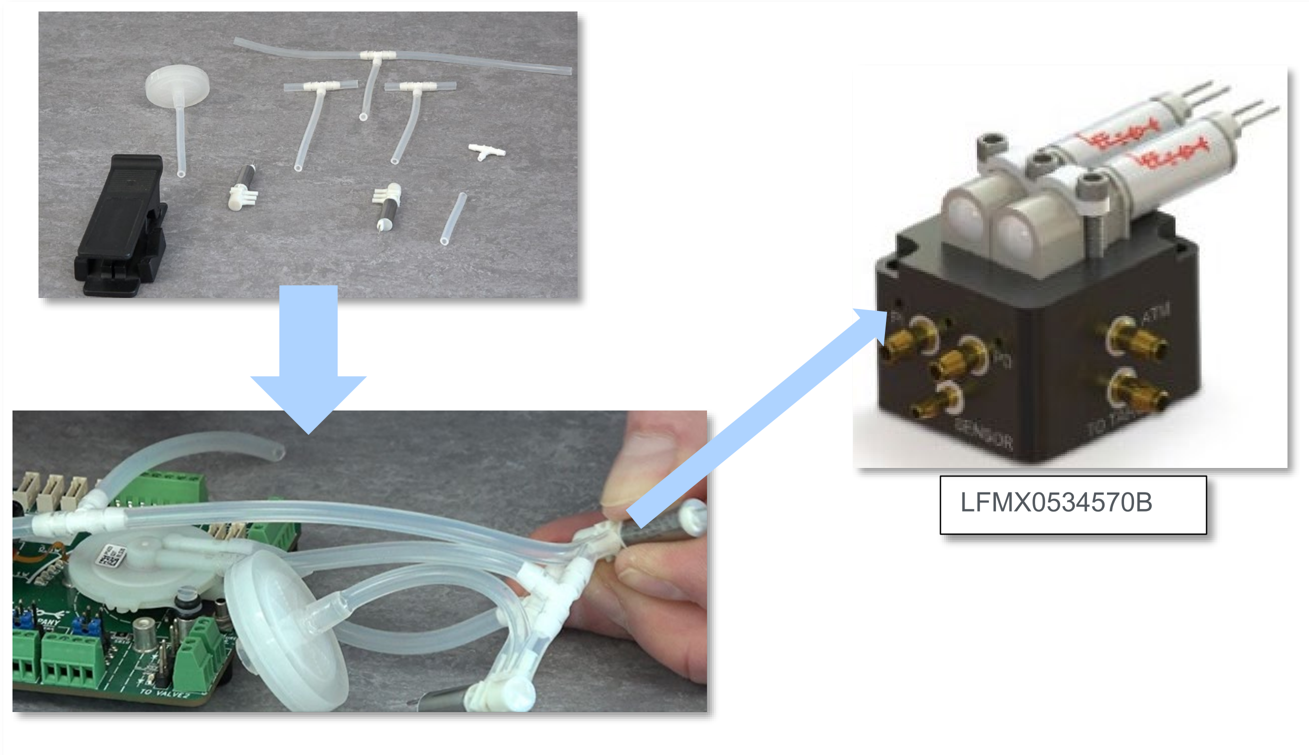


Figure 30. Forward and reverse flow setup with two 3/2 Valves, using tubing and connectors (left), using a Lee manifold (right).

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.

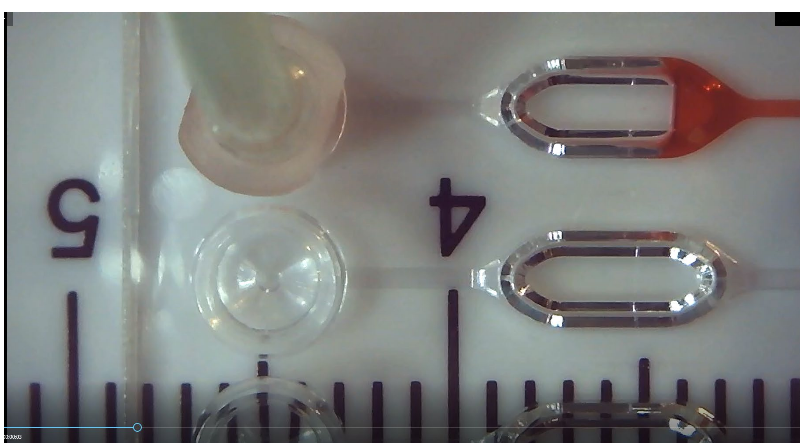


Figure 31. Liquid moving backward and forward through a microfluidic chip, as seen on our website.

6.7.Continuous flow with a PDF set up

PDF re-circulation is possible with the use of external valves and reservoirs. This is often used in Organ-on-a-Chip (OOAC) systems that need to re-circulate fluids. In the example below PDF is used to move liquid from one reservoir to another and the flow direction remains constant through the flow unit and chip by the switching of solenoid valves. A valve downstream of the pump 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.

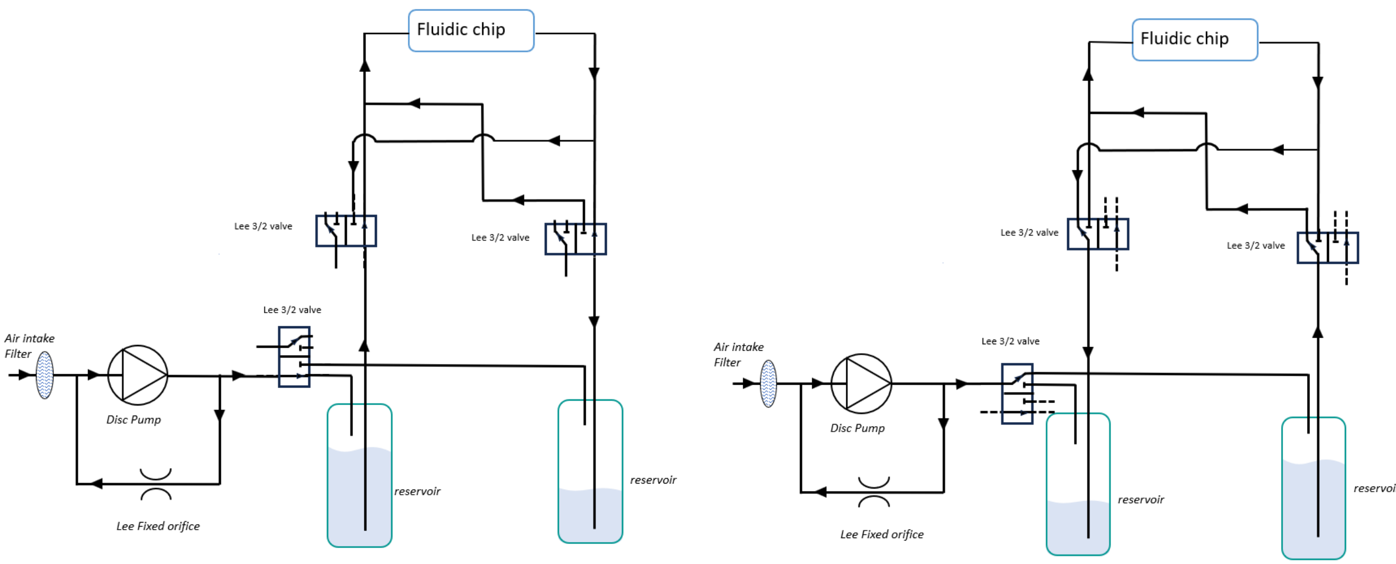


Figure 32: Continuous flow/recirculation with 3/2 Valves.

6.8.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.

6.8.1. 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.

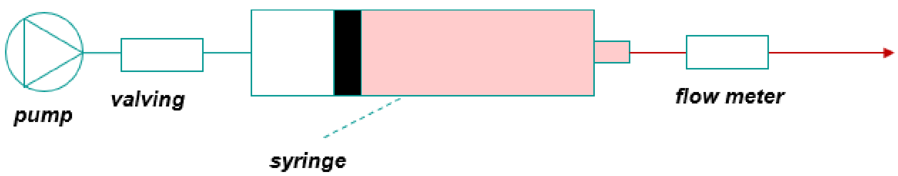
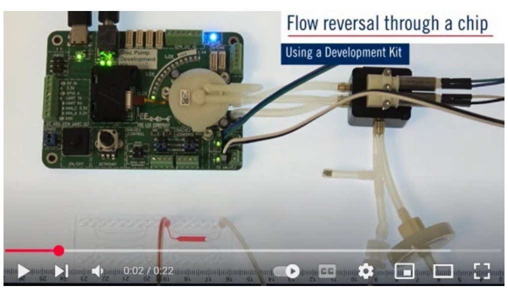
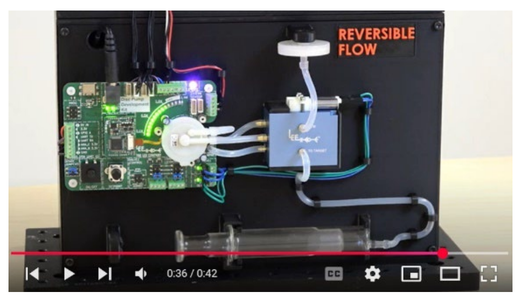


Figure 33: Driving a syringe barrel

VIDEOS	
	
Flow reversal through a chip	Disc Pump Development Kit: Reversible Flow Demo

6.8.2. 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.

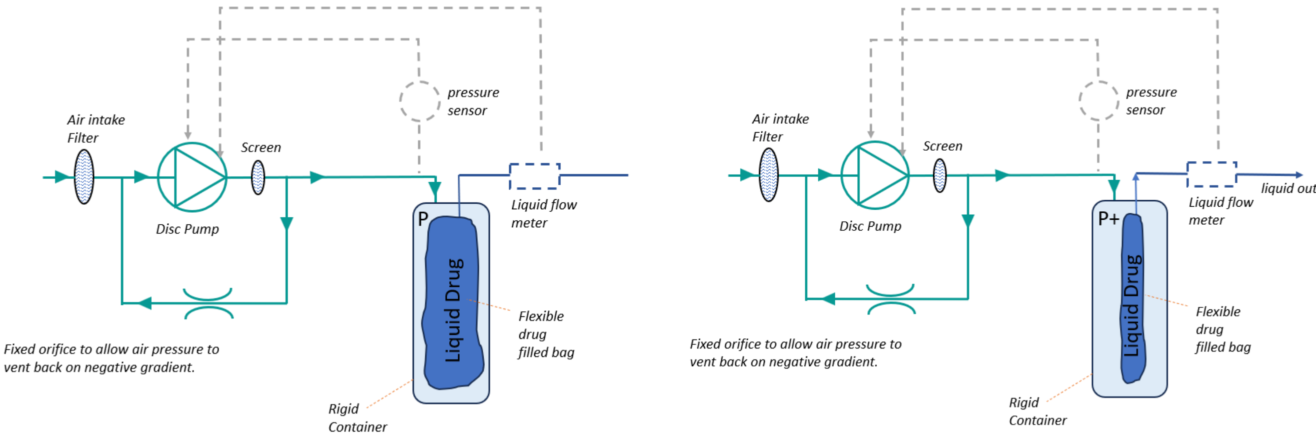


Figure 34: Bag-in-box driven flow.

6.8.3. Flexible membranes with valves and Blisters

A third approach is to use alternating pneumatic pressure, that switches between pressure and vacuum to drive a flexible elastic membranes or blisters. 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.

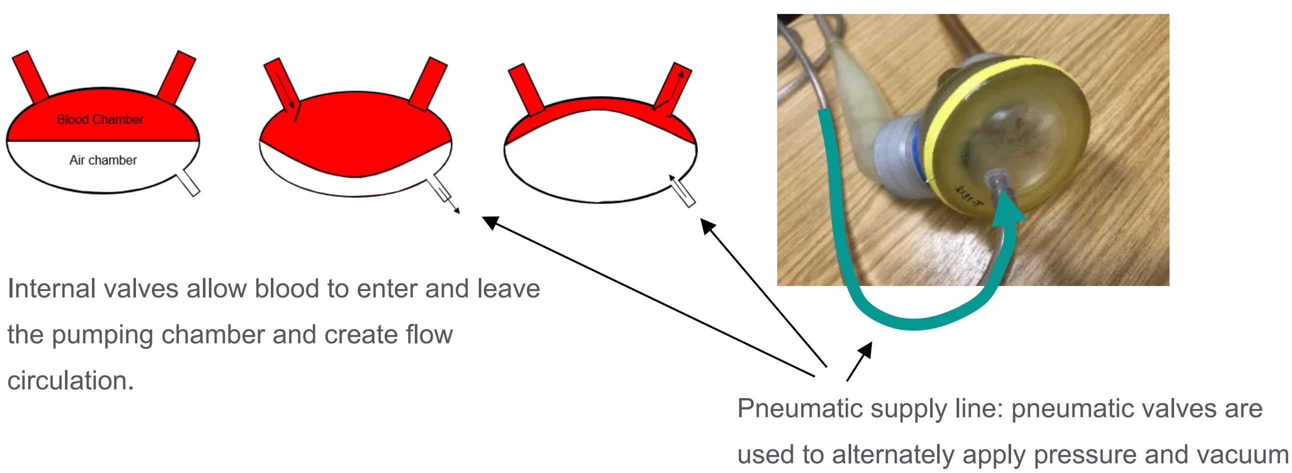


Figure 35: Flexible membrane heart pump on

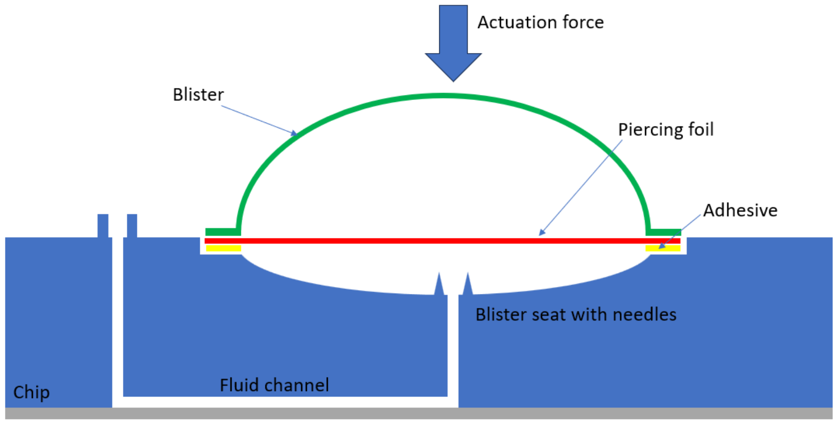
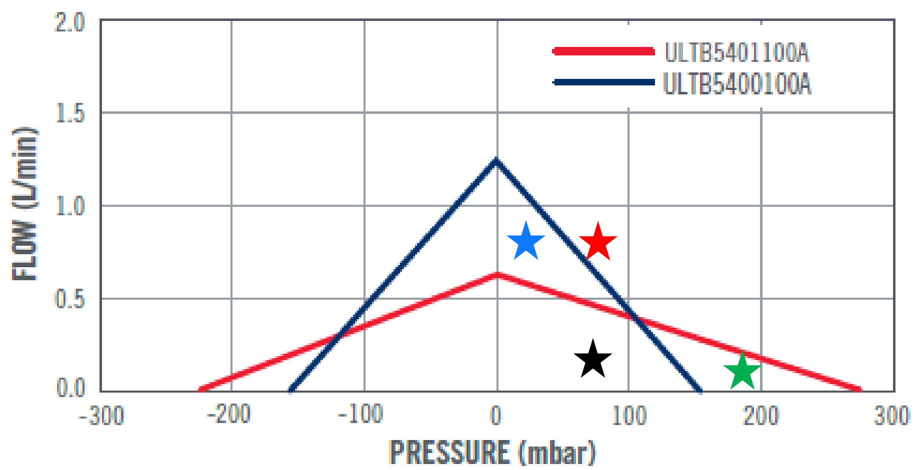


Figure 36: Examples of blisters on microfluidic chips which can be actuated pneumatically

7. BOOSTING PERFORMANCE

Each disc pump has its own operating envelope of performance which is provided in the product data sheet, PDS (https://www.theleeco.com/disc-pumps/). With parallel (higher flow, lower pressure) and series (higher pressure, lower flow) configurations of pumps a broad range of performance can be achieved with single pumps. If performance requirements are not met with a single pump, combinations of pumps or boost circuits can be used.



Black – either pump could work
Blue – ULTB5401100A works
Green – ULTB5400100A works
Red – neither pump works, potential to use more than one pump

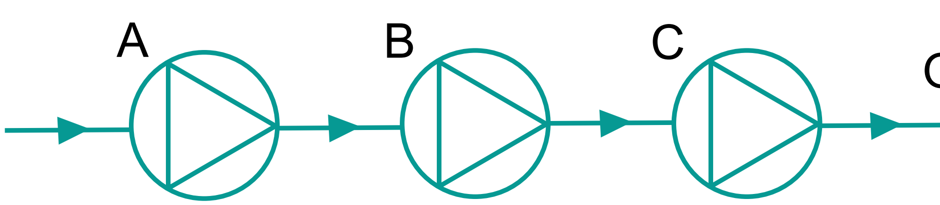
Figure 37: Single pump selection guidance

7.1. Combining pumps

Pumps in series maintain a single pump flow but aggregate pressure:

Q = flow

P = Pressure



Q_A, $P_A+P_B+P_C$

Figure 38: Pump performance with 3 pumps in series

Pumps in parallel maintain pressure but aggregate flow:

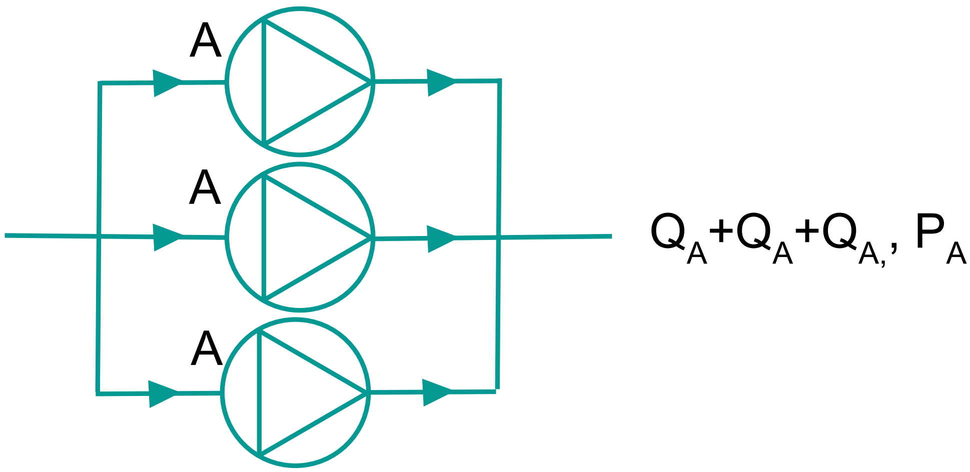


Figure 39: Pump performance with 3 pumps in parallel

A combination of pumps in series and parallel can provide higher flows at increased pressures.

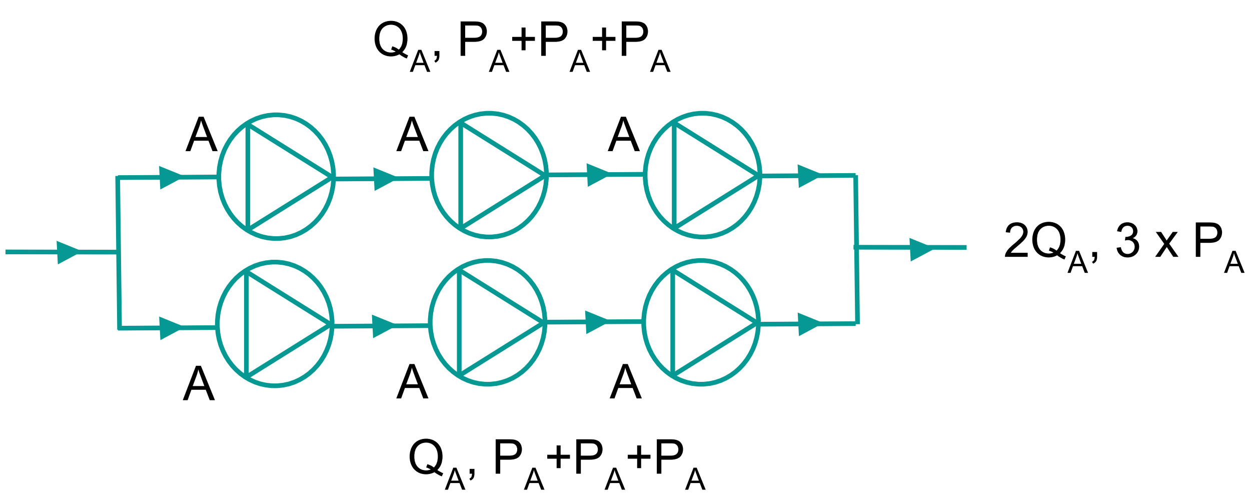
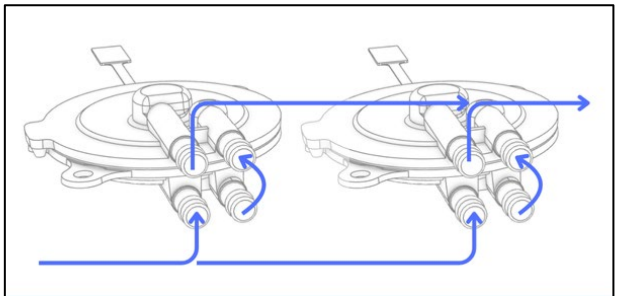
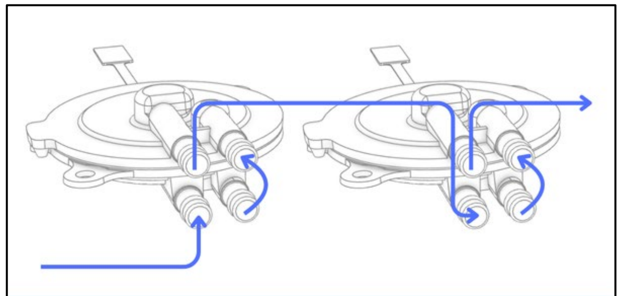


Figure 40: Pump performance with 3 pumps in series in parallel with another 3 pumps in series

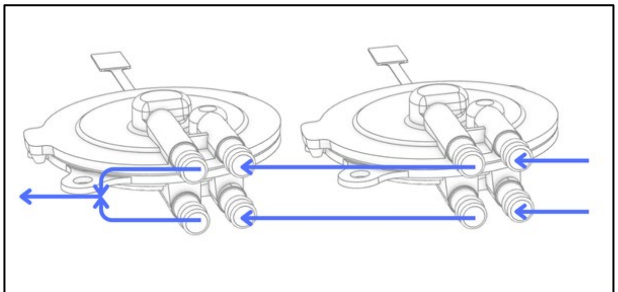
Figure 41 indicates the of routing pneumatic connections for combination of two pumps i.e. two series pumps in series and parallel and two parallel pumps in series and parallel.



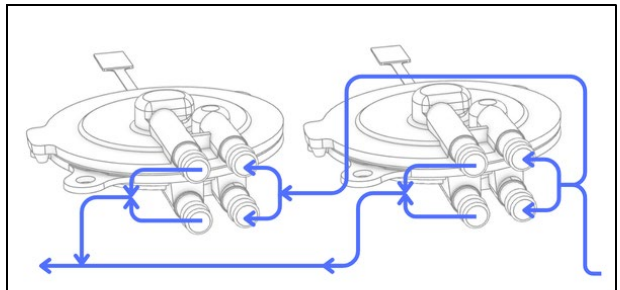
Two series configuration pumps linked in **parallel** for same pressure but higher flows. For example, 2 x UBLB5401200A pumps.



Two series configuration pumps linked in **series** for same flow but higher pressures. For example, 2 x UBLB5401200A pumps.

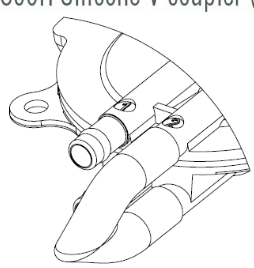


Two parallel configuration pumps linked in **series** for same flow but higher pressure. For example, 2 x UBLB5400200A pumps.



Two parallel configuration pumps linked in **parallel** for same pressure but higher flows. For example, 2 x UBLB5400200A pumps.

UACX0500800H Silicone V coupler (pack of 10)



UACX0500850H Soft Y coupler (pack of 10)

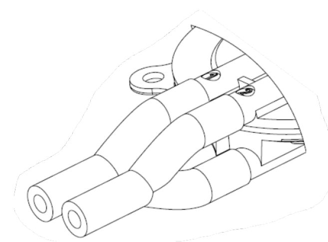


Figure 41: Representation of physical port connections for pump combinations and accessories available

Although it is possible to combine pumps either in series or parallel to achieve the pneumatic performance required, there has been no formal validation via statistically representative reliability testing due to the number of permutations. Achieving additional flow via connecting pumps in parallel will generally not result in an additional thermal effect to be considered. Connecting pumps in series to achieve higher pressures will result in additional heat of compression to be considered with respect to operational life. With intermittent duty the effects will be less influential, so knowledge of the duty cycle (on/off durations and frequency) is important.

7.2.Boost circuits

In addition to connecting pumps via tubing or a manifold it is also possible to use valves and/or reservoirs to:

- boost performance of one or a combination of pumps
- preserve the life of the pumps by running at lower average input powers or operating for shorter run periods
- reduce system operating cycle times by having ready stores of compressed air or vacuum

Reservoirs can be used to store compressed air or a vacuum, charged or evacuated in between operating cycles of a system via solenoid valves. The flow/pressure generated by a pump can be boosted by switching the inlet from atmosphere to the exhaust of another pump. Examples are provided below, however, this is not exhaustive, a Lee Sales Engineer can assist by reviewing customer requirements.

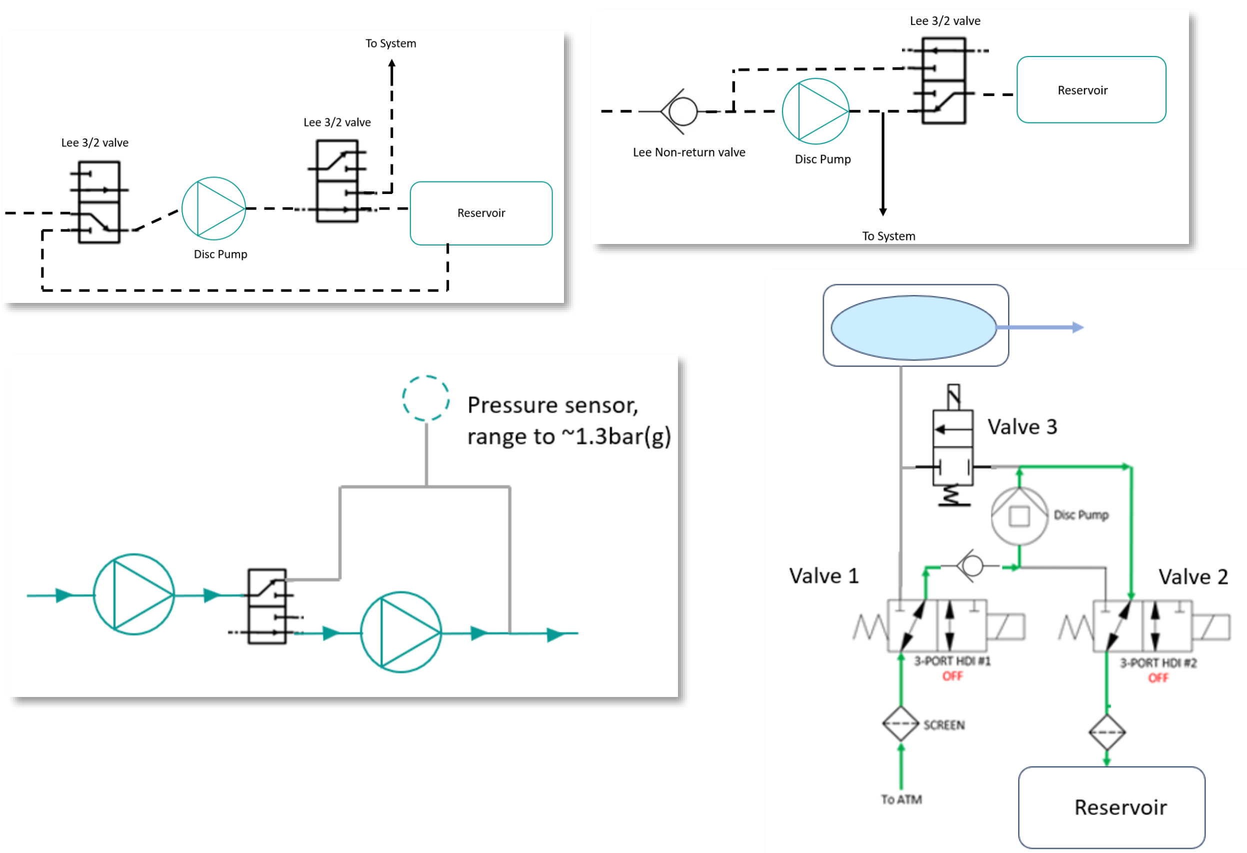


Figure 42: Boost circuit examples

8. SUPPORT

8.1.Support

The Lee Company Website (https://www.theleeco.com/disc-pumps/) provides advice on:

- Getting Started
- Applications
- Development Process
- Downloads (including datasheets, manuals, application notes, case studies and 3D models)
- Frequently Asked Questions

Practical demonstrations involving Disc Pump are provided here (click through).

The Lee Company is happy to discuss next steps beyond prototyping, including system design. If you would like to discuss this with us, or for any other additional support, please contact your Lee Sales Engineer.

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: Pressure driven flow system using liquid flow sensor and closed loop control: – Prototyping with the Disc Pump Development Kit and Sensirion SLF3x Series Flow Sensor
- AN049: Pipetting – Disc Pump Application Note
- AN059: Time Metered Dosing – Disc Pump Application Note
- AN074: Time Metered Dosing using a Volume Control Module
- Disc Pump Reference Design Package: a pack of reference designs for the firmware and drive PCB.

8.2.Additional Support

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

THE LEE COMPANY

9. REVISION HISTORY

Date	Version	Change
September 2025	R240607	Update liquid handling methods
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.