



Application Note 002: Application to Microfluidics

1	INTRODUCTION	2
2	DISCLAIMER	2
3	BASICS OF PRESSURE DRIVEN FLOW	3
3.1	Why pressure-driven flow?	3
3.2	How does PDF work?	3
3.3	Open-loop Control	4
3.4	Pressure-based Control	5
3.5	Closed-Loop Flow-Rate Control	6
4	ASPIRATION AND DISPENSE	7
4.1	Manual Control	7
4.2	Automatic Control	7
5	DROPLET GENERATION	8
6	EXAMPLE - SYSTEM SET-UP FOR PDF	9
6.1	System Components	9
6.2	Getting Started	10
6.3	Using the Control Application	10

REVISION HISTORY

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1 INTRODUCTION

Disc Pump is a high-performance piezoelectric micropump operating through ultrasonic acoustic resonance. This document provides examples of its application to microfluidic control, providing guidance and support to TTP Ventus' customers in their product development processes.

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.

The document is set out as follows:

- Section 2: an overview of how Disc Pump may be used for pressure-driven flow
- Section 3: example application to aspiration and dispense of liquids
- Section 4: example application to droplet generation
- Section 5: detailed description of system set-up for pressure-driven flow



Figure 1. A Disc Pump

2 DISCLAIMER

This Application Note is provided "as is" and without any warranty of any kind, and its use is at your own risk. TTP Ventus does not warrant the performance or results that you may obtain by using this Application Note. TTP Ventus makes no warranties regarding this Application Note, express or implied, including as to non-infringement, merchantability, or fitness for any particular purpose. To the maximum extent permitted by law TTP Ventus disclaims liability for any loss or damage resulting from use of this Application Note, whether arising under contract, tort (including negligence), strict

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3 BASICS OF PRESSURE DRIVEN FLOW

Disc Pump can be applied to the pressure-driven flow of liquids, with its unique set of attributes bringing substantial benefits.

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 pulsatility, 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.

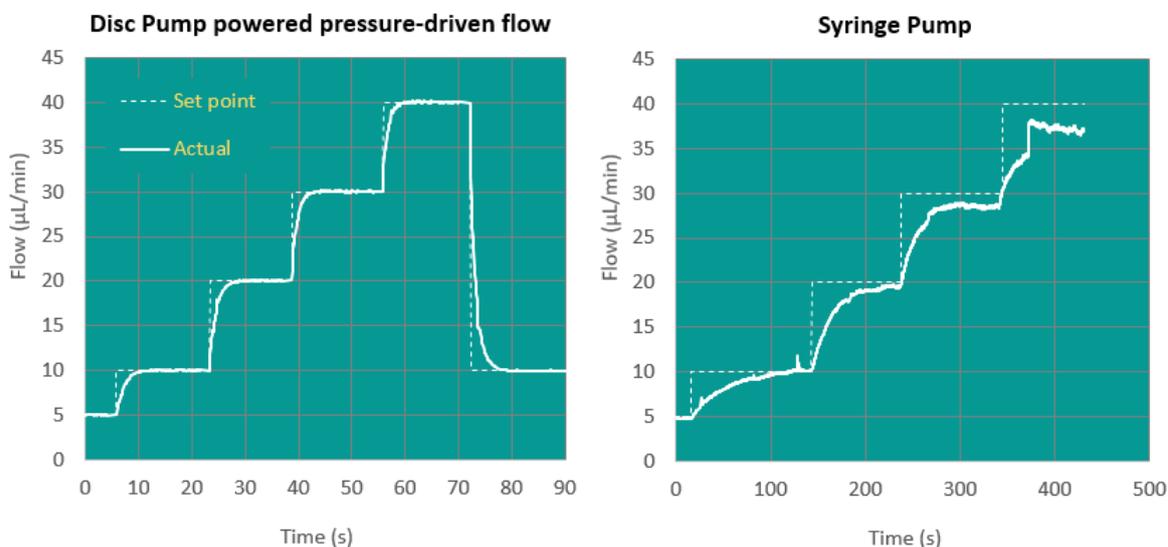


Figure 2. Precise flow-rate control and rapid response enabled by Disc Pump.

3.2 How does PDF 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.

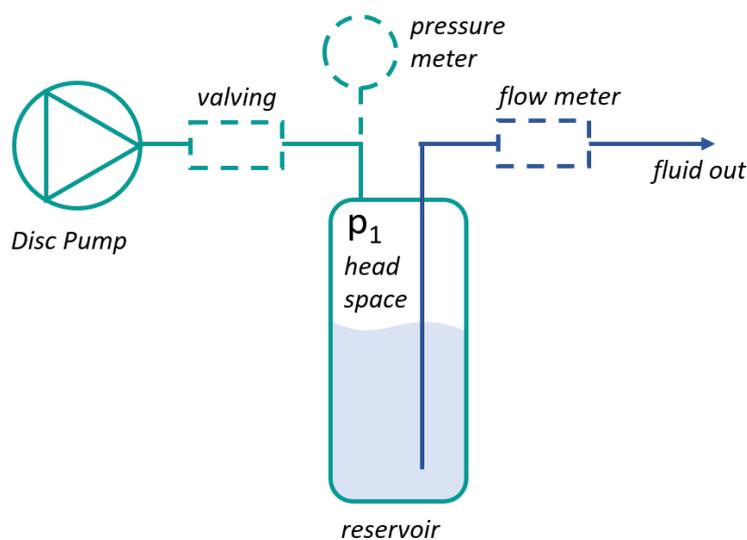


Figure 3. Using Disc Pump for pressure-driven flow.

3.3 Open-loop Control

In this case the pressure and flow meters – and indeed any valving – may be omitted and the rate of liquid dispense controlled directly by the power applied to the pump as shown in Figure 4.

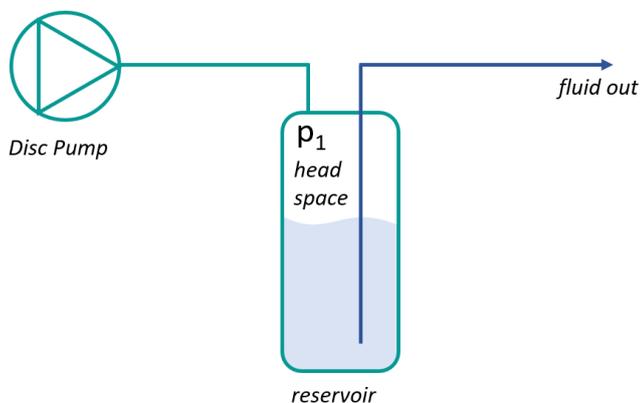


Figure 4. Basic open-loop control of fluid dispense.

As the pump's performance may be part-to-part, temperature, and age dependent, some form of periodic calibration is 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

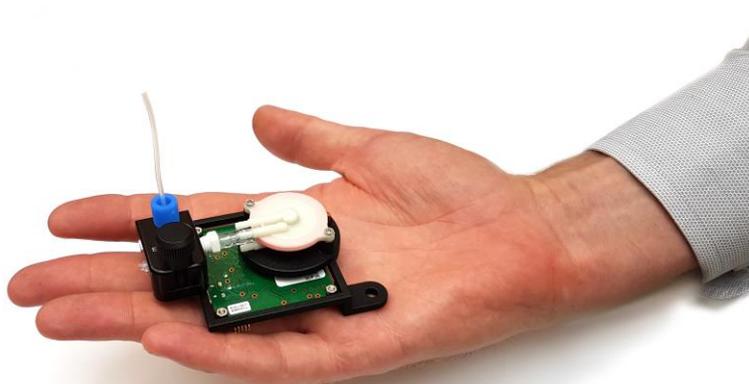


Figure 5. Example of Disc Pump integrated into a miniature pressure-driven flow module.

3.4 Pressure-based Control

Variation in flow rate arising from e.g. 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 flow-rate as shown in Figure 6.

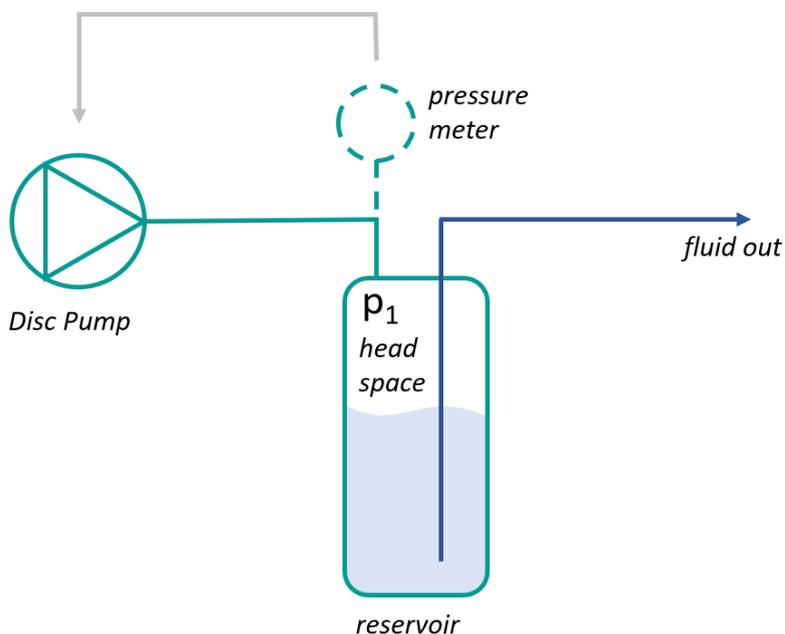


Figure 6. Pressure-based control of liquid delivery.

The drive PCB included with TTP Ventus' 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.

3.5 Closed-Loop Flow-Rate Control

Disc Pump can be combined with a flow-rate sensor; as shown in figure 7, 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.

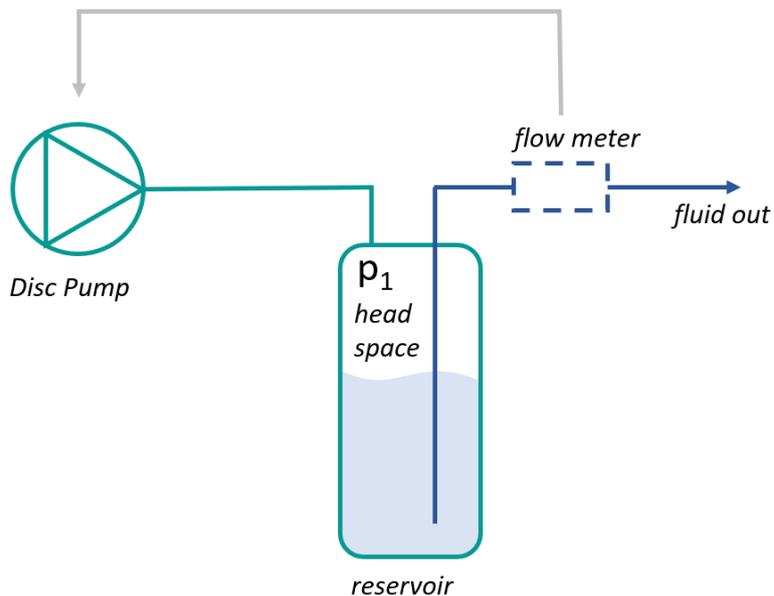


Figure 7. Flow-rate based control of liquid delivery.

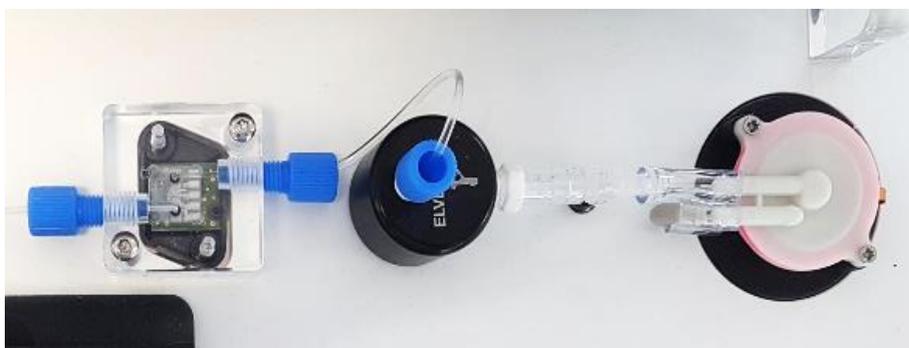


Figure 8. Disc Pump integrated with a Sensirion flow sensor to deliver constant, highly stable flow.

Figure 8 above shows a system comprising a Disc Pump and a Sensirion LPG10 flow sensor, combined to deliver closed loop control over liquid flow-rate.

4 ASPIRATION AND DISPENSE

A Disc Pump may be used to aspirate and dispense fluids using the system shown in Figure .

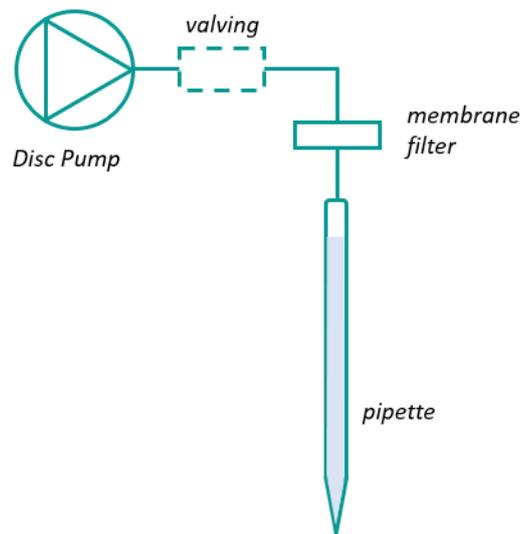


Figure 9. Simple aspiration and dispense system.

4.1 Manual Control

The system above could be operated using manual control of the dispense volume, with the pump enabling the user to control the level of fluid precisely.

4.2 Automatic Control

Automatic aspiration and dispense can be delivered either by periodic calibration or via some form of liquid level, volume or real-time pressure feedback.

Calibration may involve:

1. aspirating by driving the pump at a known power and for a known duration
2. dispensing the fluid and measuring the volume or mass of the sample dispensed
3. adjusting the power or duration to deliver the target volume or mass
4. real-time accurate pressure monitoring for aspiration and dispense actions for given volumes

Any form of liquid sensor – e.g. an optical, acoustic, or capacitive sensor – may be used to control the pump to achieve automatic volume control without the need for periodic calibration.

5 DROPLET GENERATION

Two pressure-drive flow systems may be combined to generate liquid-in-liquid droplets, e.g. for application to Digital PCR.

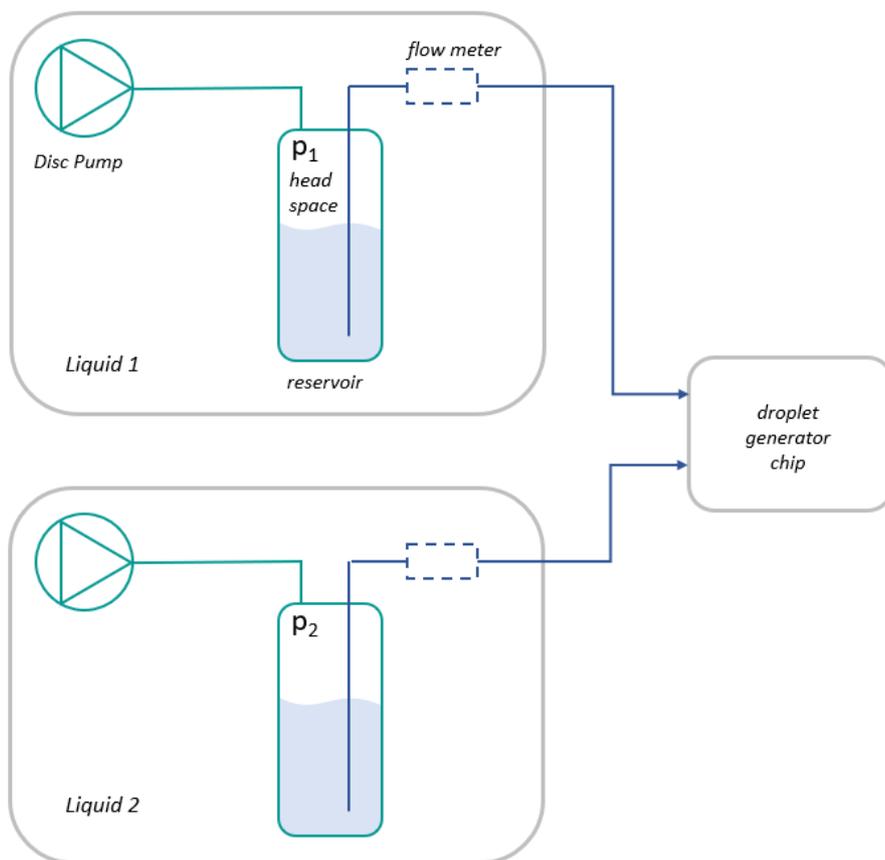


Figure 10. System configuration for liquid-in-liquid droplet generation.

The strobe images shown in Figure 11 highlight the stability and controllability of the system through the ability to deliver different droplet diameters and delivery rates.

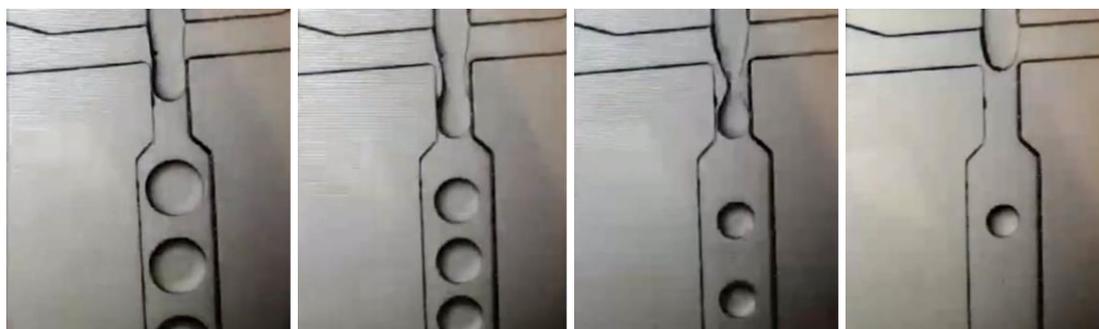


Figure 11. Two closed loop Disc Pump systems generating liquid-in-liquid droplets.

6 EXAMPLE - SYSTEM SET-UP FOR PDF

The evaluation kit comes complete with all the parts necessary (except for the fluid reservoir) to set up a basic pressure-based control system as highlighted in Section 3.4.

6.1 System Components

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



Item	Description
1	Pre-production prototype of the 2 nd generation Disc Pump, which has two moulded cavities (each with a single valve) surrounding a single piezoelectric actuator.
2	Drive PCB (packing in protective ESD bag), which enables various modes of operation and control of Disc Pump and is configured with a dedicated PC application.
3	USB flash drive containing PC application software and supporting documentation.
4	Mains power supply.
5	Mains power supply regional adapter.
6	Micro USB cable, which enables the PC application to communicate with the drive PCB.

Figure 12. Evaluation Kit components.

Note:

A length of 1/16" ID silicon tubing, a filter and a variety of fittings and are also supplied with the kit. These are not shown above.

6.2 Getting Started

To run a basic PDF system, and referring to the Evaluation Kit manual:

- Connect a Disc Pump to the drive PCB
 - Lift the tab gently on the back of the connector P3
 - Insert the ribbon cable on the pump gently into connector P3 (note that the cable is not expected to fully enter the connector or pass through it)
 - Push down the tab on the back of the connector P3
- 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.
- Connect the output of the pump to the fluid reservoir (not supplied).
- Connect the pressure sensor (U7) to the fluid reservoir as shown in Figure . Cut the tubing to length as needed.
- Connect the power supply cable to connector P6 on the drive PCB
- Slide the power switch (SW2) to turn the system on.

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

6.3 Using the Control Application

To control the PCB, a bespoke application (Ventus Pump Control App) is provided with the Evaluation Kit. Instructions for installing the application are found in the Evaluation Kit manual.

Once installed, double-click on the “Ventus pump control app.exe” executable file to load the programme. Open the bottom-left dropdown menu and select the appropriate port.

The application should now be connected and display all the current settings on the GUI, as shown in Figure 13.

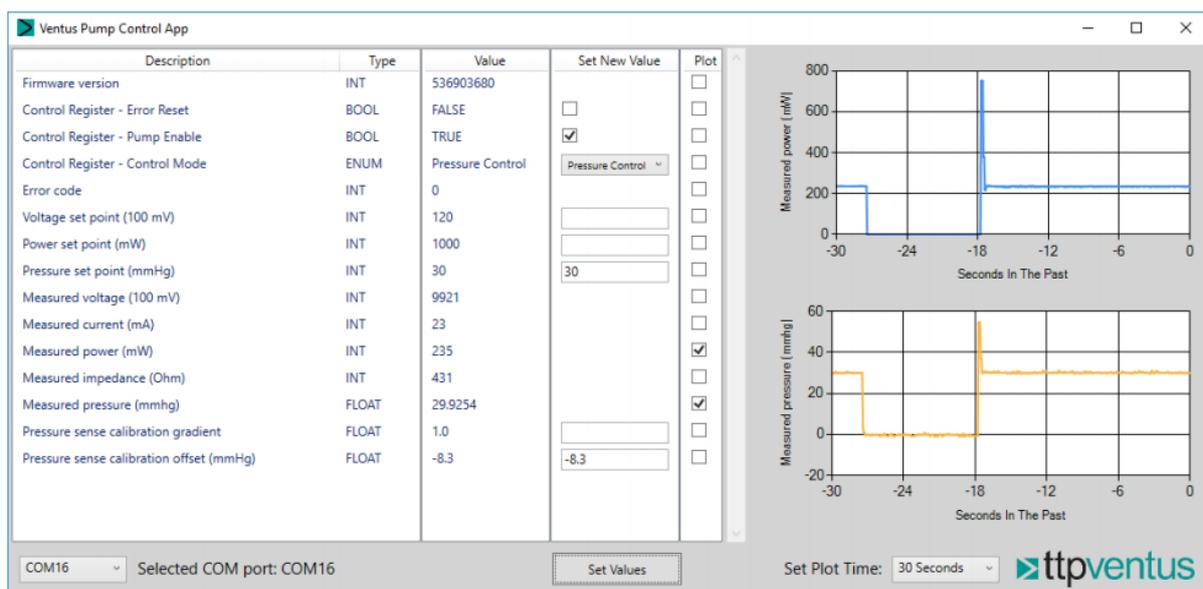


Figure 13. Pump Control Application.

Parameters can be modified by setting the desired value in the “Set New Value” column, and then clicking “Set Values”. Checking a box in the “Plot” column should add a real-time plot to the application, for that value.

Running the pump in PDF mode:

- To change the control mode for pressure-based control, select the desired mode from the “Control Register – Control Mode” combo box. Click on “Pressure Control” and then “Set Values”.
- Check the plot box for both ‘Pressure set point (mmHg)’ and ‘Measured pressure (mmHg)’, and then click on ‘Set Values’
- Calibrate the pressure sensor by adding a figure into the “Pressure sense calibration offset (mmHg)” box in the “Set New Value” Column. This figure will either be positive or negative depending on the “measured pressure (mmHg)” plot with the pump **not running**. The value entered should be the difference between the steady state reading and the zero line. Enter the figure and click ‘Set Values’.
- Check that the Measured Pressure (mmHg) plot is now a steady state zero reading. If not repeat the previous process until a steady state zero is achieved.



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. This is 225 mmHg for the SDC configuration and 112 mmHg for the PDC configuration.

- Enter the desired pressure set point in ‘Pressure set point (mmHg)’ and click on ‘Set Values’.
- Check the “Pump Enable” Control Register checkbox, and then click “Set Values”.
- The pump should now start, and you will see the measured pressure rise to equal the set point pressure.
- To change the required working pressure and ultimately the flow from your reservoir, enter a new figure into the ‘Pressure set point (mmHg)’ box (ideally staying within the limits of the pumps capability as detailed above) and then click on ‘Set Values’. This will now become the new target pressure and the pump will run to achieve that and the flow from your reservoir will alter accordingly.