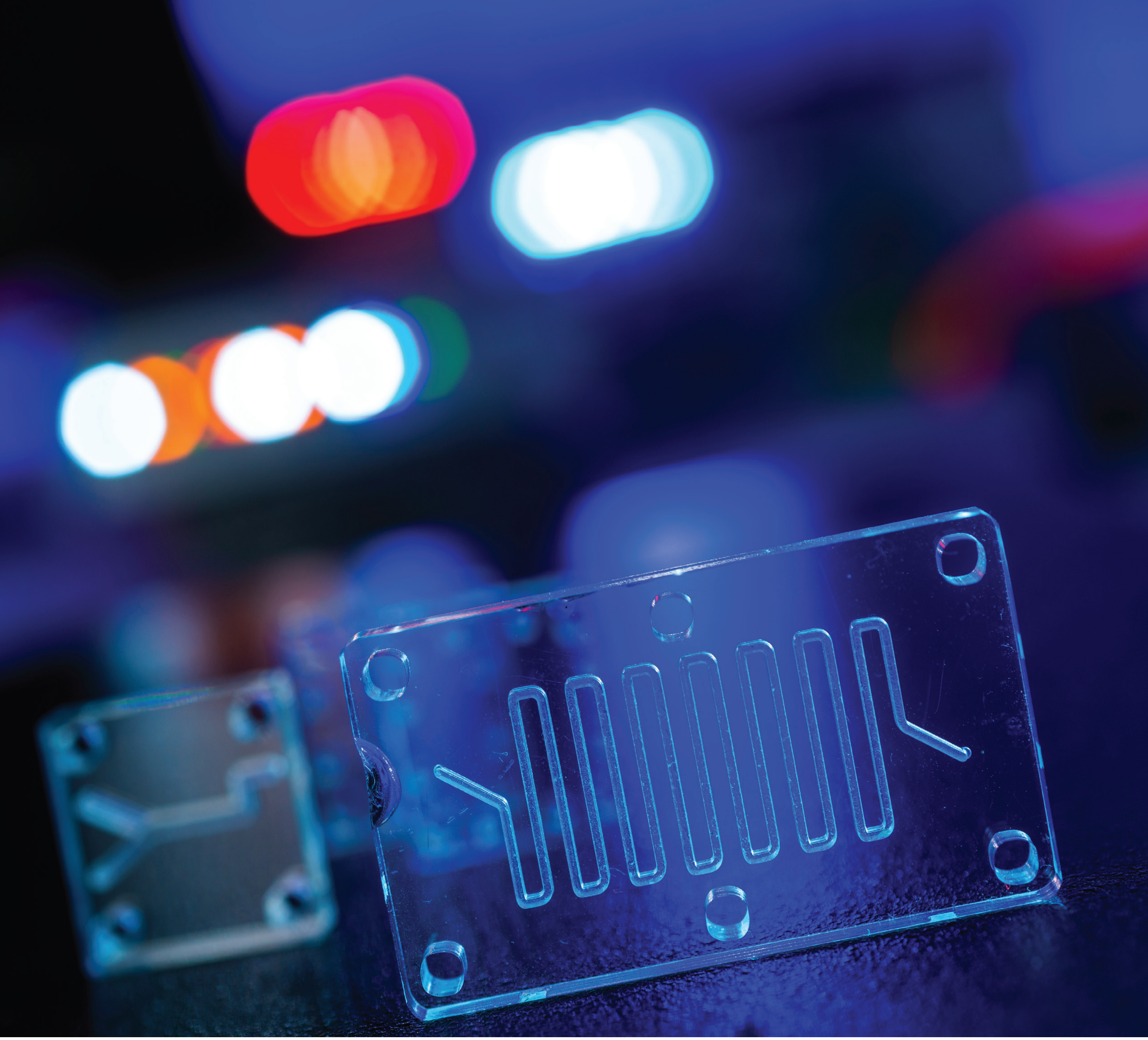

Pressure-Driven Flow Control in Microfluidic Systems

Improving Lab-on-a-chip liquid flow control with digital electronic pressure controllers

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Introduction

Lab-on-a-Chip (LOC) technology, also known as chip-based microsystem, is widely used in multiple industries and applications. It is capable to perform complex analytical tasks with very small sample volumes which can reduce costs and improve efficiency. Additionally, microfluidic systems can be designed to be portable and easy to use making them ideal for point-of-care applications. However, designing a microfluidic system can be challenging as it requires expertise in fluid dynamics to ensure the precise movement of samples, buffers, and reagents throughout the chip for accurate analysis and desired outcomes.

This paper discusses the new trend of Lab-on-a-Chip and three approaches to controlling these critical inputs into lab-on-a-chip-based systems: peristaltic pumps, syringe pumps, and pressure-driven flow control.

Lab-On-Chip Introduction

A Lab-on on-a-Chip (LOC) is a miniaturized device that integrates one or several laboratory analyses into a single microchip. A typical LOC usually consists of a set of microfluidic elements such as valves, pumps, controllers, reaction chambers, and sensors to achieve functions of fluid mixing, fluid manipulation, pressure/flow control, sample preparation, and detection on a miniaturized chip. LOCs have numerous applications in clinical diagnostics. Examples of applications include PCR and DNA sequencing, measurement of blood gases and cholesterol, liquid biopsy, and counting the number of HIV cells in a sample.

LOCs provide several advantages over conventional diagnostic devices. To begin with, LOC devices integrate multiple laboratory functions into a small single chip. This allows for the development of portable and handheld diagnostic devices for the point-of-care testing market which enables rapid analysis and on-site testing, reducing the time and cost by eliminating the need to transfer samples to centralized laboratory facilities. Next, Lab-on-a-chip devices also consume significantly smaller fluid samples compared to conventional testing methods which means less waste, less reagent cost, and less required sample which is very useful when working with limited and precious samples. In addition, LOC systems offer faster analysis and results compared to traditional methods. The chip design allows for precise cell sorting, and the miniaturized flow control system enables fast and controllable fluid flow allowing shorter reaction times and faster processing. Finally, the LOC system is more cost-efficient.

On one hand, the miniaturization aspects of LOC technology can reduce reagent consumption, minimize waste, lower sample consumption, and reduce space requirements. On the other hand, by combining several laboratory analyses into one small platform, LOC system can eliminate the need for separate lab instruments for different analyses, such as sample preparation, sorting, mixing, and detection.

In summary, LOC technology offers numerous benefits over traditional testing methods including smaller size, reduced fluid volume, faster analysis time, greater versatility, and cost-effectiveness.

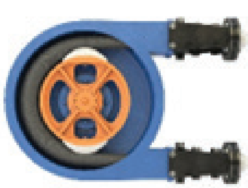
Different technologies to move liquids through the microfluidics system

Peristaltic Pump

Peristaltic pumps are commonly used to generate flow in microfluidics. Peristaltic pumps dispense fluid using a rotating head mechanism. It works by compressing and releasing flexible tubing which generates a pulsatile flow that can be controlled by adjusting the pump speed and tubing size. With this working mechanism, the peristaltic pump is connected in line with the reservoir where the liquid flow can be pushed from the tubing entrance to the exit. The peristaltic pump's main advantage is using interchangeable tubing as the only wetted material which limits the risk of contamination as the liquid is only in contact with the tubing. Peristaltic pumps can also be relatively inexpensive compared to other types of pumps. Additionally, if the microfluidic system requires a switching function between pushing and pulling sample liquid through the fluidic system, the liquid flow can be reversed by changing the polarity of the electrical connection.

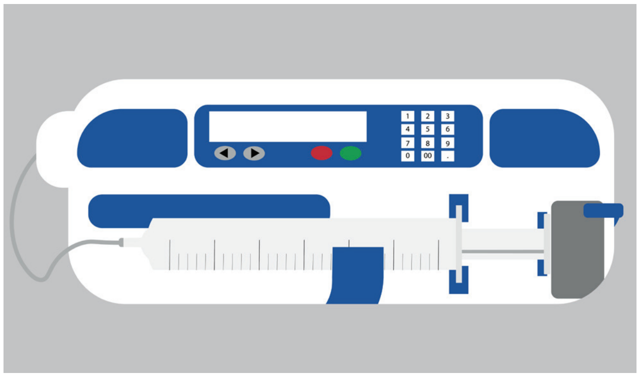
While there are advantages to using a peristaltic pump for controlling microfluidic flow, it is important to point out that there are also certain drawbacks associated with its use.

For example, as the fluid volume is displaced by compressing of the peristatic tube, it is difficult to determine the exact perfusion volume since it depends on the tube materials, sizes, wear, and operating temperature conditions. Additionally, peristaltic pumps generate pulsatile flow which adds vibrations and noise to the system reducing the flow accuracy and precision. Moreover, the tubing used in peristaltic pumps can wear out over time which may require frequent replacement and maintenance.



Syringe pump

Syringe pumps have been commonly utilized in microfluidic systems to control the flow rate of fluids. The syringe pump employs a motor to drive the movement of the syringe plunger which then pushes the fluid through the microfluidic chip. This mechanism allows for accurate manipulation of flow rates and volumes resulting in stable flow performance. By adjusting the speed of the pump motor, the flow rate of the fluids can be accurately and precisely controlled. Moreover, with syringe pump driven flow control in a microfluidic system, the amount of dispensed liquid can be determined for the experiment. Additionally, syringe pumps are relatively easy to set up and operate making them accessible to a wide range of users.



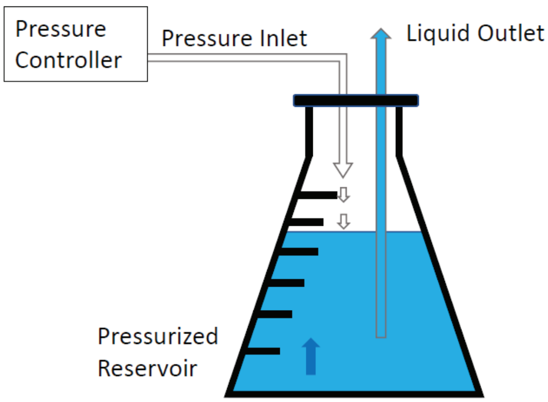
Nevertheless, there are a few disadvantages to consider. To start with, the volume of fluid dispensed by the syringe pump is limited by the syringe tube size; therefore, syringe pumps are not suitable for high flow rate systems as it is also difficult to refill the syringe. Moreover, due to the step-by-step motor of the syringe pump, pulsation for some syringe pumps is still unavoidable leading to a decrease in flow stability. Lastly, syringe pumps may have a residual volume in the syringe and tubing leading to potential contamination and accuracy reduction.

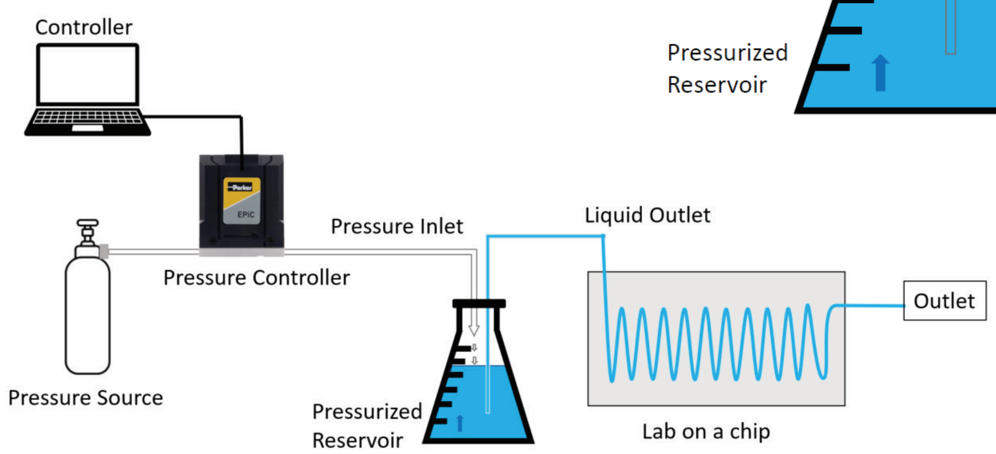
Pressure-driven flow control in microfluidics

Pressure-driven flow control in microfluidic systems has gained increasing popularity in recent years. This method relies on the application of gas pressure to move the fluid through the chip and control its flow rate. In the LOC devices, the fluid is introduced into the microchannel system via an inlet port to a reservoir or bottle. A pressure-regulating device applies gas pressure to the fluid reservoir. As the reservoir is pressurized, the gas pushes on the fluid surface promoting the fluid to flow through the outlet; therefore, by controlling the input gas pressure of the fluid container, precise control over liquid flow into the microfluidic chip can be achieved. This technique is commonly referred to as air-over-liquid control.

Pressure-driven flow controllers provide numerous advantages. First, it offers exceptional accuracy. To reduce the deviation between the target and actual pressure output, a closed-loop control system with feedback of output pressure is established in the pressure-driven flow control ensuring precise control over the fluid flow. Additionally, pressure-driven flow controllers offer active and real-time adjustment of pressure within a system. It is continuously monitoring and regulating the pressure to maintain the desired outcome; therefore, a very stable flow can be achieved without pulsations. Moreover, utilizing gas pressure to control the liquid flow rate offers the advantage of reducing the risk of contamination. By isolating the liquid from the controller devices, the potential for cross-contamination is minimized leading to improved quality and reliability of clinical diagnostic and analytical results.

While pressure-driven flow control offers many benefits, it also has some drawbacks to consider. First, pressure-driven flow control does require a gas pressure source such as a gas pump or gas cylinder. Furthermore, in situations where a microfluidic system necessitates a switching function between pushing and pulling sample liquid through the fluidic channels, pressure controllers alone may not be able to reverse the gas flow. However, this functionality can be achieved by incorporating pneumatic switching valves into the setup. Finally, it is important to note that system backflow can have an impact on pressure stability. If the volume downstream of the pressure controller is insufficient, turbulent flow may occur leading to backflow entering the pressure controller outlet and causing pressure instability; however, this issue can be easily resolved by increasing the volume downstream of the pressure controller ensuring a more stable pressure environment within the system.





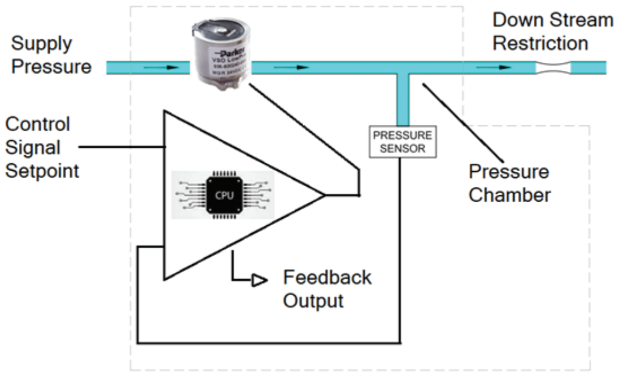
Peristaltic Pump vs. Syringe Pump vs. Pressure-Driven Flow Control

Peristaltic pumps, syringe pumps, and pressure control systems all have their benefits and drawbacks. A peristaltic pump can be a lower cost option, but the stability and precision performances are limited. Syringe pumps are easy-to-use and have been used for a long period, but they present slow response time, flow oscillation, volume limitation, and are usually costly. Pressure-driven systems enable both pressure and flow rate control and are an excellent option for applications that require fast response time and high stability, accuracy, and precision. But a pressure-driven flow control system does require a gas pressure source, and backflow can impact the performance if the volume downstream of the pressure controller is insufficient.

	Peristaltic Pump	Syringe Pump	Pressure Controller
Flow Stability	Low	Medium	High
Response time	High	Low	High
Precision	Low	Medium	High
Volume Limitation	No	Yes	No
Fluid recirculation	Yes	No	No
Injection of small volume sample	Bad	Good	Good
Pressure control	No	No	Yes
Noise	High	Low	Low
High flow rate control	Yes	No	Yes

Introduction to the use of Electronic Pressure Controller for Pressure-Driven Flow Control in Microfluidic System

Electronic pressure controllers offer effective, precise, and high-resolution control. A typical electronic pressure controller with a digital control system consists of a valve, a pressure sensor, fittings, a manifold, and a control system. Electronic pressure controllers are closed-loop systems which means they must be able to measure downstream pressure via a feedback loop that automatically adjusts to maintain a setpoint. When the output of the regulator senses that pressure has dropped below the setpoint, the controller will open and allow more flow to go through to raise the pressure. This dynamic pressure-control process continuously monitors and regulates the pressure to maintain the desired pressure output. It is an active and real-time control system that allows for dynamic changes in pressure level to process flow in the microfluidic system.



The figure shows a typical digital electronic pressure controller. The control system uses a microprocessor to integrate the setpoint signal with the current output pressure signal from the sensor. It will drive the valve until the output pressure equals the setpoint.

Introducing the EPiC Digital Electronic Pressure Controller

EPiC: Key Features at a Glance

HIGH ACCURACY: The high accuracy of ±0.25% FS (Full Scale) and resolution of 0.02% FS provide the capability for precise and accurate control of flow rates in microfluidic systems. This level of accuracy allows for precise manipulation of fluid flow rates ensuring reliable and reproducible results in various microfluidic applications.

HIGH STABILITY: The pressure stability of ±0.2% FS offered by EPiC ensures consistent and pulseless pressure control resulting in a smooth and constant flow rate within a microfluidic system. This will help eliminate fluctuations and variations in flow contributing to improved accuracy, reproducibility, and reliability of tests and processes conducted in microfluidic applications.

FAST RESPONSE TIME: EPiC provides a fast response time of less than 100ms. This rapid response time ensures quick adjustments to pressure levels enabling precise and timely control of fluidic flow rates. With such critical characteristics, EPiC facilitates optimal performance and reliable results in various microfluidic applications.

ADJUSTABLE CONTROL: EPiC offers adjustable PID (Proportional-Integral-Derivative) control for optimal performance ensuring accurate results for specific application requirements. The PID parameters can be adjusted and fine-tuned to achieve optimal control performance, responsiveness, and stability in the microfluidic system. This flexibility empowers users to control algorithms according to their specific needs enhancing the overall efficiency and effectiveness of pressure-driven flow control.

Lab-on-a-Chip is an exciting new technology that is enabling many benefits for new clinical diagnostic, analytical chemistry, and life science instrumentation.

Given the new entrant of air-over-liquid control and related benefits to ensure a fast response, highly stable, accurate and precise fluid control performance within the microfluidic system, Parker's Precision Fluidics Division has successfully launched the EPiC Pressure Controller which utilizes this approach to manipulate fluids within LOC devices.

To learn more about this product, scan below.

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