Mini Review
Volume 9:12, 2022

Fluid Mechanics: Open Access

ISSN: 2476-2296

Open Access

A Novel Pneumatic Valve Serves as the Foundation for an Aliquoting Framework for Centrifugal Microfluidics

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Abstract

New avenues for low-cost point-of-care (POC) diagnostics have emerged thanks to centrifugal microfluidic platforms (CDs). They are now widely used in a variety of diagnostic procedures, including blood plasma separation, serial dilutions, and those requiring polymerase chain reaction steps. The use of CD microfluidic devices makes it possible to transfer a wide range of intricate processes that, in the past, required trained personnel and expensive individual laboratory equipment to the small disc platform. The CD fluidic platforms' portability, ease of use, integration, and robustness necessitate fluid flow control designs that are straightforward, dependable, and scalable.

Keywords: Centrifugal Microfluidics • Microfluidic devices • Fluid flow control

Introduction

For POC diagnostic platforms, centrifugal microfluidic devices (CDs) were successfully implemented. POC systems are platforms that can be used outside of a centralized laboratory, either at the patient's bedside or in a medical office. By accelerating the time to diagnosis and eliminating the need for repeat patient visits if the tests can be performed during the initial doctor's visit, they aid in reducing the turnaround time for patients and doctors to receive the test results, thereby contributing to improved patient outcomes and lowering treatment costs. These POC systems are durable, portable, inexpensive, and simple to use, even for personnel with a moderate amount of training [1].

Since Anderson introduced the centrifugal platform for the first time in 1972, many different processes, such as immunoassays, environmental monitoring, analyte detection, serial dilutions, and a plethora of other ones, now make use of CD technology, which has come a long way. Since Madou and Kellogg introduced the disc-based platform LabCD in the late 1990s, numerous academic and industrial teams have published a steady stream of articles on how to adapt centrifugal microfluidic platforms for a variety of diagnostic applications. These applications range from enzymatic assay analyzers and specialized modules for disc-based immunoassay microarrays to the characterization of pollutants in environmental samples [2].

Literature Review

The advancements in fidelity and dependability of microfluidic valving, a crucial fluidic operation on a spinning disc, supported the active developments and enhancements in CD technology that occurred over the course of the previous twenty years. Fluid flow is controlled, channel paths are turned on and off, specific chambers are isolated, and chambers are opened for the controlled sequential release of reagents. At first, only so-called "passive valves" like siphon, capillary, and hydrophobic valves were used. Most of these passive valves were based on the opposing action of capillary forces (controlled by the material of the disc and the geometry of the microfluidic channels) and centrifugal forces (controlled by the angular velocity of the disc and specific position and geometry of the microfluidic channel) on the CD. They did not require any peripheral equipment to be actuated, were easy to make, and were simple to use. The spin speed, the geometry of the channels and chambers, the location of the vents on the discs (which allow the pressure in various microfluidic chambers to be equal to the ambient pressure), the type of native material on the disc, and the various coatings that are used to alter the wetting angle of the liquid on the surface all affect how passive valves operate. According to their controlling parameters such as spin speed, vent-hole geometry, suction, channel divergence, concentration gradient, presence of siphon channels, and inclusion of dissolvable films.

Researchers and engineers have gradually come to the realization that manufacturing flaws, minute variations in the bill of materials, and the shelf life of materials have an effect on passive valves' reliability and repeatability as CD devices began to be used in commercial applications outside of academia. Active valves were introduced to address issues with passive valves' robust operation. Some external subsystems are used by active valves to trigger and actuate the fluidic channel's opening or closing. The typical active valve actuation mechanisms, such as laser, magnetic, diaphragm-based, electrical, thermal, mechanical, and pH-controlled actuations; and other valve actuation mechanisms are also summarized.

Discussion

At last, there is still one more kind of valves, alleged "crossover valves" that use components of both dynamic and aloof valves. The ferrowax capillary flow-driven valve, the microheater activated valve, and other similarly actuated valves are all examples of hybrid valves. Although the platform's microfluidic system's native capillary forces serve as the foundation for these valves, external equipment (such as a hot plate or laser) is required for their activation. that causes the solid wax plug to become liquid. The fluidic channel is opened and the plug can move once the phase transformation transforms it into a liquid. In comparison to passive valves, active and hybrid valves typically have quicker response times and are more dependable. The operational parameters of valves, such as response times, fabrication routes, and manufacturing cost, are all discussed in detail in the sections that follow. Readers will gain a deeper understanding of how to select the right valve for their particular application thanks to this information. The present basic survey centers around the creation and use of microvalves on outward microfluidic stages. In addition to discussing the virtual prototyping of numerous types of microvalves implemented on centrifugal microfluidic platforms, our work continues and updates more general reviews of microvalves on lab-on-chip platforms.

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Received: 28 November, 2022, Manuscript No. fmoa-23-86621; **Editor assigned:** 30 November, 2022, PreQC No. P-86621; **Reviewed:** 12 December, 2022, QC No. Q-86621; **Revised:** 17 December, 2022, Manuscript No. R-86621; **Published:** 24 December, 2022, DOI: 10.37421/2476-2296.2022.9.264

We hope that by analysing the many valve alternatives on centrifugal platforms, the reader will be able to select the type of valve that is best suited for a specific spin regime and the required application of a future assay. In many cases, the cost and portability advantages of passive valves exceed the reliability shortcomings of active valves. Active valves may become more common on centrifugal assay platforms as they become less expensive to integrate and external actuation devices, such as lasers, do not dramatically raise the platform's cost or weight [3-5].

Based on their actuation mechanisms, the valves have been divided into active, passive, and hybrid categories. For each type of valve, we provide a description of the actuation mechanism. We examine the similarity of the valves to application on divergent stages and report (at whatever point known or conceivable to assess) the additional expense to execute these valves. For a wide range of complex chemical and biological assays, centrifugal microfluidic platforms offer a number of advantages; however, the precise and robust valving capability of CD fluidic devices is necessary for their reliable operation. A comprehensive list of the microvalves that have been reported in scientific publications is provided in this critical review.

Conclusion

The geometry of the fluidic network on the disc and the physio-chemical properties of the disc's materials control the critical burst frequencies of passive valves on CDs, which are actuated by the disc's spin rate, spin direction, or spin acceleration. As a result, changes in the disc's material properties (such as changes in humidity or exposure to air) or the dependability of the action of passive valves is impacted by minute alterations in channel geometry that result from manufacturing flaws. However, in order for the active valves to operate, external force and energy must be applied to the valve. Magnetic force, laser, various heaters, pneumatic force, and other forms of external actuation are just a few examples. Active and passive valve components are combined in the hybrid valves; For instance, the wax is melted by an external heat source and carried by a capillary force toward the fluidic channel that becomes impassable when the wax solidifies.

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How to cite this article: Brook, Mack. “A Novel Pneumatic Valve Serves as the Foundation for an Aliquoting Framework for Centrifugal Microfluidics.” Fluid Mech Open Acc 9 (2022): 264.