Supplementary Material (ESI) for Lab on a Chip

Supplementary Information

Compressed-air flow control system

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1. Channel geometries

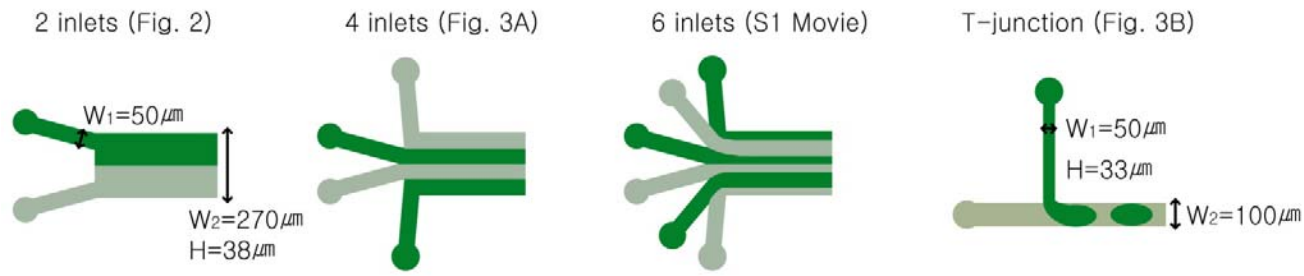


Figure S1. Schematic depicting the four types of channels used in this article. For the three channels generating laminar coflows, the dimensions were all identical; only the number of inlets differed.

2. Estimation of maximum fluid velocity

<u>The following assumptions were made in the estimation:</u>

1. Newtonian, incompressible, fully developed, and laminar flows
2. Negligible surface tension between solutions
3. Viscosity μ is the same (65 cP) in all inlet flow streams.
4. Pressure drop occurs in narrow inlet channels.
5. Negligible PDMS channel deformation for W (channel width) ~ H (channel height)[1]

<u>Basic Equations</u>

For laminar flow in a pipe, the volumetric flow rate Q is given by the following equation[2],

$$Q = \frac{AD_h^2}{32\mu L}(P_{loss}) \quad (1)$$

Hydraulic diameter of rectangular tubes is also given by the following equation[2].

$$D_h = \frac{2ab}{a+b} \quad (2)$$ where a = width of a pipe and b = height of a pipe.

Table S1. Inlet geometry for the channel used in Fig. 2.

Width, W_1	Area, A_1	Hydraulic Diameter, $D_{h,1}$	Length, L_1
50 μm	1900 μm^2	43 μm	4000 μm

Equation Setup

$2Q_{inlet} = \frac{A_1 D_{h,1}^2}{16\mu L_1}(P) = Q_t$ (3)

$U_{max} = 1.5\ U_{avg} = 1.5(Q_t/A_2) = \mathbf{858 \times P}$ (μm/s) (4)

3. Bead Tracking

A 0.02 % solution of 1.6 μm polystyrene beads in PEG-DA 700 was used to measure maximum fluid velocity (U_{max}). The bead velocity was maximum in the center of the channel, and midway between the two walls. After a given pressure was applied, beads in the center of the channel were followed with a 20X microscope objective (Zeiss) with an optivar setting of 2.5X leading to effective magnifications of 50X. Movies of translating beads were taken by a CCD camera that captured images at the rate of 30 fps using an exposure time of 1/500 s. From the frame-to-frame position of beads, bead velocities were calculated using the central difference approximation.

Table S2. Comparison between measured and estimated U_{max}.

P (Psi)	Measured U_{max} (μm/s) (From bead tracking)	Estimated U_{max} (μm/s) (From equation (4))	% Deviation from the estimation
0.5	591	429	37.8 %
1.0	954	858	11.1 %
1.5	1344	1288	4.4 %
2.0	1801	1717	4.9 %
2.5	2374	2146	10.6 %
3.0	2696	2575	4.7 %
3.5	3252	3005	8.2 %
4.0	3642	3434	6.0 %

4. Automation of pulsed-flow operation

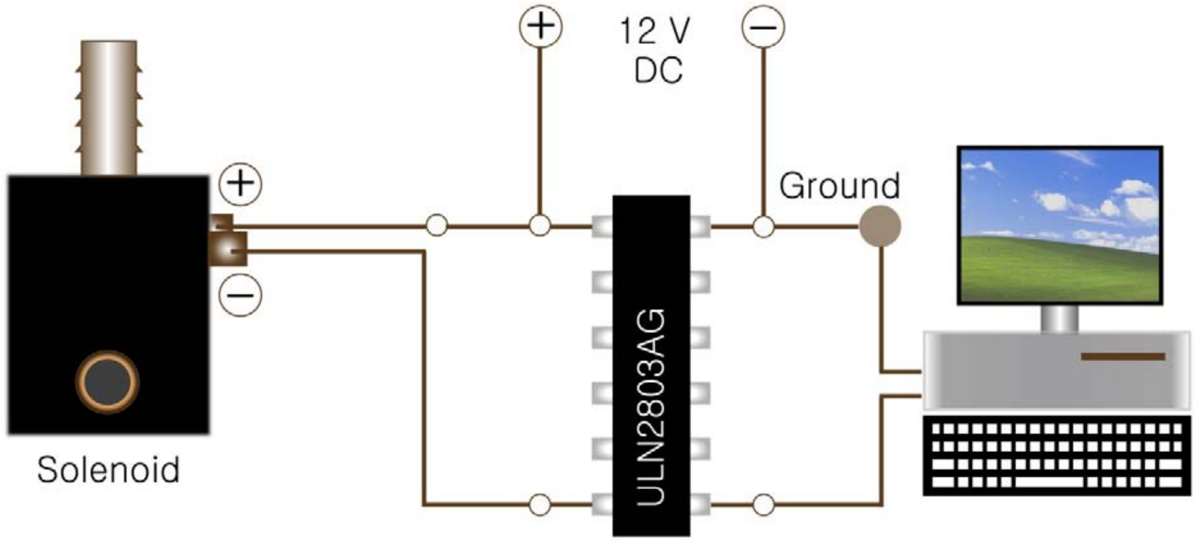


Figure S2. Schematic description of the electrical circuit used for automated control of the three-way solenoid valve via the parallel port connection. A simple GUI was constructed using Python to allow the user to cycle this process automatically through the specification of a flow duration and a stoppage duration.

5. A python script for the automation

A sample code for the GUI used to control the solenoid valve is provided as a separate pdf file.

6. Syringe Setup

In order to compare the response time of our system with that of a syringe setup, we performed additional bead tracking experiments with a two-inlet PDMS microchannel. For the syringe measurements, two Hamilton Gastight Syringes (Model 1701, 10 µL volume) were driven on the same Harvard Apparatus PHD programmable syringe pump, with polyethylene feed tubing

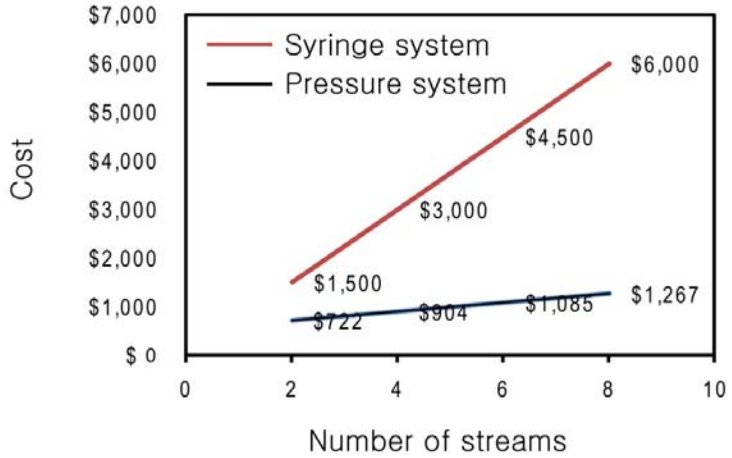
(1/16" I.D. and 1/8" O.D.) connected to the device via plastic adapter units. For the data collected in Fig. 4, the syringe pump was programmed so as to alternate between 1 s of flow at a prescribed flow rate and 1 s of stoppage. For the data collected in Table 1, the syringe pump was driven at a prescribed flow rate for 10 min and then manually stopped; the time required for suspended fluorescent beads to come to a stop was measured.

7. Cost Estimation

Table S3. Cost estimation for the compressed-air flow control system. Estimates are given for versions of the system capable of controlling 2, 4, 6, or 8 streams. Marginal cost of adding an additional stream is ~$90.

Number of Streams	2	4	6	8
Swagelok Needle Valves	$ 60.00	$ 120.00	$ 180.00	$ 240.00
Solenoid Valve	$ 50.00	$ 50.00	$ 50.00	$ 50.00
High-P Pressure Regulator	$ 100.00	$ 100.00	$ 100.00	$ 100.00
Low-P Pressure Regulator	$ 50.00	$ 50.00	$ 50.00	$ 50.00
Digital Pressure Gauge	$ 260.00	$ 260.00	$ 260.00	$ 260.00
PTFE Tape	$ 5.00	$ 5.00	$ 5.00	$ 5.00
PVC Tubing	$ 20.00	$ 20.00	$ 20.00	$ 20.00
Tygon Tubing	$ 10.00	$ 10.00	$ 10.00	$ 10.00
Luer Stubs	$ 7.20	$ 12.00	$ 16.80	$ 21.60
Pipette Tips	$ 9.00	$ 18.00	$ 27.00	$ 36.00
Plastic Syringes	$ 3.00	$ 5.00	$ 7.00	$ 9.00
Circuit Components	$ 20.00	$ 20.00	$ 20.00	$ 20.00
In-Line Pressure Gauges	$ 100.00	$ 200.00	$ 300.00	$ 400.00
Plastic Connectors	$ 7.50	$ 13.50	$ 19.50	$ 25.50
Threaded Male Connectors	$ 20.00	$ 20.00	$ 20.00	$ 20.00
TOTAL	$ 722	$ 904	$ 1,085	$ 1,267

Figure S3. Cost comparison between syringe-based and pressure-based systems. The economic advantage of the pressure-based system is particularly evident in applications that require the control of a large number of streams.



8. Supplementary Video 1

Real-time video showing the manipulation of six coflowing laminar streams. Channel is 38 μm tall and 270 μm wide. Dark streams: 30% PEG-DA, 70% food coloring. Light streams: 30% PEG-DA, 70% water.

9. Supplementary Video 2

Video (0.5X real-time) showing the generation of droplets of different sizes. Droplet size is modulated in a continuous fashion by the gradual closing of the relief valve connected to the dispersed-phase sample arm. Channel is 33 μm tall and 100 μm wide. Dispersed phase: food coloring. Continuous phase: mineral oil.

10. Supplementary Video 3

Real-time video showing pulsed flow operation in a compressed-air flow control system followed by pulsed flow operation with a syringe pump system. Channel is 38 μm tall and 270 μm wide. Stream: 0.02 % solution of 1.6 μm polystyrene beads in PEG-DA.

11. References

[1] Gervais, T., El-Ali, J., Günther, A., Jensen, K.F., *Lab Chip.* **2006**, *6*, 500-507.
[2] M. M. Denn, *Process Fluid Mechanics*, Prentice Hall, New Jersey, 1st edn., **1980**.