VENTURI-BASED TWO-LAYER MICROFLUIDIC PUMPING SYSTEM

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ABSTRACT

This paper reports a new microfluidic method for pumping fluid and the generation of droplets and bubbles using the Venturi principle, driving flow using pressure without numerous connections or extensive external control systems. The 2-layer devices in PDMS have no moving parts, and can pump fluid at flow rates > 5μl/min.

KEYWORDS: Flow Control, Microfluidic Pumping, Venturi Nozzle

INTRODUCTION

Although syringe pumps are among the most widely used means of controlling flow in microfluidics, they are bulky, expensive, and not suitable for miniaturization [1]. For point-of-care applications such as the generation of microbubbles for diagnostic imaging [2], miniaturization is critical and there is a need for simple methods for creating flow on the chip itself. Chung et al. fabricated a system to reverse liquid motion in a microfluidic device, consisting of a single channel with a Venturi nozzle at each end [3]. The pneumatic control of droplet movement based on the Venturi principle has also recently been reported using an electronically controlled pressure microregulator [4].

THEORY

A Venturi (Fig. 1a) produces a relative vacuum without moving parts and consists of a converging–diverging channel with a sidearm. The fluid (in our case a gas) enters the Venturi at the location with a cross-sectional area A_{in}, pressure P_{in}, and velocity v_{in}. Since the throat of the Venturi A_t is smaller than A_{in}, the gas must travel faster to maintain the same volumetric flow rate. This increase in velocity (Fig. 1b) results in a decrease in pressure at the throat, which follows Bernoulli's equation.

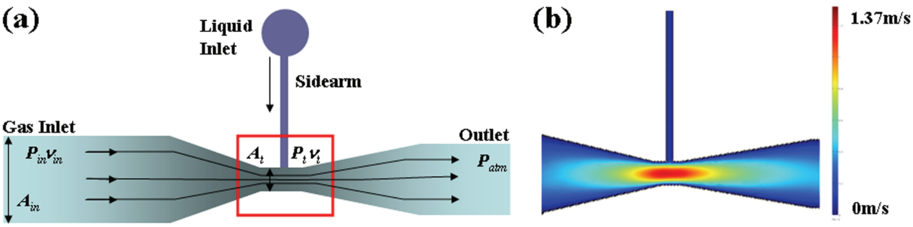

Figure 1. (a) Schematic of Venturi nozzle geometry. The outlet is open to the atmosphere while the sidearm can connect to any arbitrary channel geometry. (b) Simulation showing maximum gas velocity at the Venturi throat.

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Our on-chip fluidic control and production scheme employs the Venturi principle for generating fluid flow. The design has no moving parts, simplifying fabrication without the potential of mechanical failure. One key feature is that the Venturi channel network is above the main flow-focusing channel network. This ensures that the liquid will not enter the top Venturi channel network, allowing for continuous fluid movement in the bottom channel network. The droplet generator design (Fig. 2a) contains two large inlet reservoirs (water & oil) whereas the bubble generator design (Fig. 2b) contains a single large reservoir for the continuous lipid/water phase.

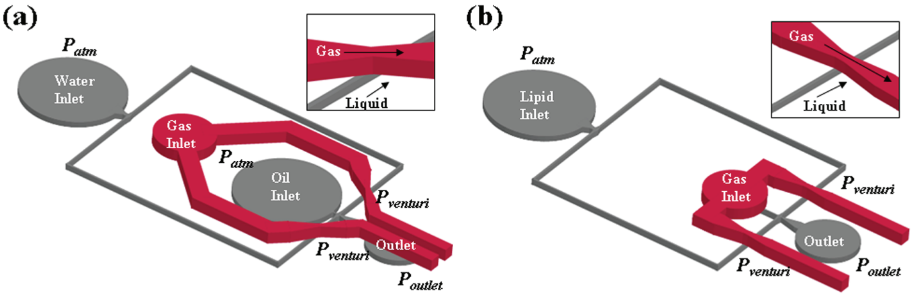

Figure 2. Cross-sectional view of the 2-layer PDMS microfluidic devices with top Venturi channel network highlighted in red and bottom flow-focusing channel network in gray. All channels have a rectangular cross section and a height of 100 µm. The Venturi pump inlet, middle, and outlet channel widths are {500, 167, 333 µm} respectively. The inward and outward declinations are 25^o and 10^o respectively. The devices feature an expanding nozzle with an orifice width of 20-50 µm. The droplet generator (a) contains two liquid inlets and the bubble generator (b) features one liquid inlet. In both cases, Pinlet = Patm > Pventuri > Poutlet.

EXPERIMENTAL

CFD flow simulations were performed with various Venturi nozzle geometries to determine appropriate dimensions for maximizing gas velocity. The dual-layer PDMS devices were characterized by forcing a central stream of nitrogen gas through the top Venturi channel network, creating a pressure gradient in the bottom channel network. For measuring flow rate of the liquid, a straight channel (4 mm and 20 mm) with a single inlet is used. Non-fluorescent polystyrene microspheres 10 µm in size and mixed in DI water are used to calculate velocity.

For flow-focusing applications, the pressure gradient draws the liquid phase(s) from the inlet(s) and through a 20-50 µm orifice, generating droplets or bubbles depending on device. DI water with 2% Tween 20 and triacetin oil (28.0 cP) are used to create oil-in-water droplets. A solution of 10% aqueous glycerol/propylene glycol mixture with the stabilizing lipids DSPC and DSPE-PEG2000-Biotin at a 9:1 molar ratio and concentration of 0.5 mg/mL DSPC is used for bubble production. In either case, the gas is supplied from a pressurized tank via flexible tubing and delivered into the chamber using a micro flow meter. A Nikon inverted microscope and high-speed camera is used to capture images and record movies.

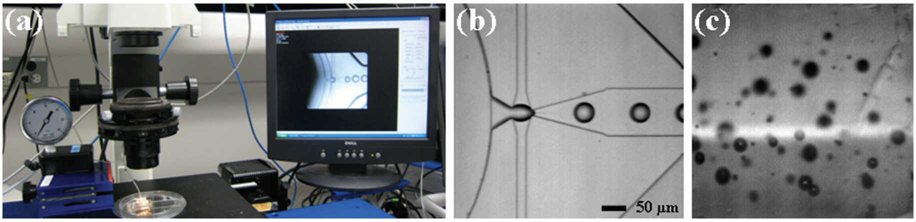

Figure 3. (a) Real photo of setup with only one external source. Brightfield image of (b) oil droplets and (c) lipid microbubbles produced with Venturi pumps.

RESULTS AND DISCUSSION

Incorporating only a single external component, namely a gas source used to drive flow (Fig. 3a), greatly reduces the complexity of the system. For flow-focusing devices, at an inlet gas pressure of 0.1-0.5 psi gauge we can produce monodisperse oil-in-water droplets (Fig. 3b) with generation rates of 6 droplets per second. Lipid-shelled microbubbles were also produced (Fig. 3c). Maximum liquid flow rate for single channel devices was calculated to be 6.3 µL/min when the Venturi sidearm was 2 mm away from the inlet. Increasing the width of the Venturi throat or positioning the sidearm at greater distances away from the inlet(s) reduced the overall liquid flow rate.

CONCLUSIONS

We have developed a simple method based on the Venturi principle to drive fluid flow using pressure gradients in microchannels, generating droplets and bubbles. Since the Venturi pump pulls the discrete phase and continuous phase at fixed ratios depending on the channel geometry, we plan to employ adjustable valves to tune the sizes of generated droplets and bubbles. Future work will involve design optimization and the setup of a truly portable system incorporating a miniature gas canister.

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