Electronic Supplementary Material (ESI) for Lab on a Chip.

Electronic Supplementary Information (ESI)

Hydrogel-Enabled Osmotic Pumping for Microfluidics: Towards Sweat Sequestering for Wearable Human-Device Interfaces

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Movies provided (separate files)

Movie S1: This video shows how the notch cut into the hydrogel directs fluid flow towards the microfluidic channel. It is taken in real time from above the microfluidic device. The hydrogel draws fluid through the membrane beneath it and then fills in the void area created by the notch. As the notch fills with fluid, air is pushed through the microchannel first. Once the notch is filled, the fluid then is pumped into the microchannel. The osmotic pressure is large enough to pump the fluid into a hydrophobic microchannel, as can be seen by the greater than 90° contact angle with the channel walls.

Movie S2: This video shows the time-lapse (300x sped up) accumulation of fluid at the outlet of the microfluidic device. The hydrogel disc can be seen on the top of the video with the microchannel leading to the outlet. This device is on the diffusion cell and passively pumping fluid which forms a droplet at the outlet. Glucose was then tested using a commercial glucose meter in this droplet.

Flowrate Calculations from Fluid Front Tracking

Flowrate can be calculated during initial periods of flow by tracking the front of the fluid through the microchannel. Multiple micrographs are taken to track the fluid. Velocity of the fluid front is calculated by dividing the change in coordinates by the time difference in-between images. This provides the average velocity, which can be multiplied by the cross-sectional area of the channel to obtain flowrate. The equation used and an example of images can be seen below.

$$Q = LW\frac{\Delta x}{\Delta \mathrm{t}} = LW\frac{x_{i+1} - x_i}{t_{i+1} - t_i}$$

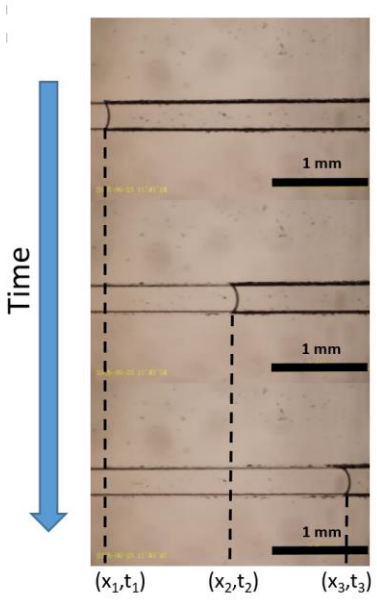

Fig. S1 Micrographs of flow through a microchannel over time. These images are used to calculate flowrate through the microchannels.

Flowrate Calculations from Particle Tracking

The process described for measuring flow rate relies on measuring the maximum velocity of a laminar flow through a square microfluidic duct. In laminar flow, there are well defined models for the velocity profile through a cross section. In a square channel with width ranging from -½W to ½W and height from 0 to H, the velocity can be modeled using the equation below[1].

$$u_x(y,z) = \frac{4h^2\Delta P}{\pi^3 \mu L}\sum_{1,3,5\ldots}^{\infty}\frac{1}{n^3}\left[1 - \frac{cosh\left(\frac{n\pi y}{h}\right)}{cosh\left(\frac{n\pi w}{2h}\right)}\right]sin\left(\frac{n\pi z}{h}\right)$$

The flowrate can be calculated as the product of the average velocity and the cross sectional area. Linear relations can be made between the average velocity in the channel and the maximum flowrate by a correlation value (α), which can be measured experimentally. The maximum velocity is be obtained from the velocity profile at the center of the channel (w=0, h= ½ H). Average velocity can be determined by dividing the flowrate by the cross-sectional area. Flowrate can likewise be determined by integrating the velocity across the cross-sectional area.

$$u_{max} = u\left(0, \frac{1}{2}h\right) = \frac{4h^2\Delta P}{\pi^3 \mu L} \sum_{1,3,5\ldots}^{\infty} \frac{1}{n^3}\left[1 - \frac{1}{cosh\left(\frac{n\pi w}{2h}\right)}\right] sin\left(\frac{n\pi}{2}\right)$$

$$Q = \int_0^h \int_{-\frac{w}{2}}^{\frac{w}{2}} u_x(y,z)dydz = \frac{h^3 w\Delta P}{12\mu L}\left[1 - \sum_{1,3,5\ldots}^{\infty} \frac{192}{(n\pi)^5}\frac{h}{w} tanh\left(\frac{n\pi w}{2h}\right)\right]$$

$$u_{avg} = \alpha u_{max}$$

$$\alpha = \frac{Q}{WHu_{max}}$$

With the channel dimensions used (W=485 µm, H=200 µm), α is found to be 0.51. This value can be used to correlate maximum velocity to average velocity, and therefore the total flow rate. Fluorescent microscopy was used with five micron diameter fluorescent particles. As can be seen in Fig. S2, these particles are small enough that they can easily fit in the region of highest velocity. It can be seen that there is a rather large region in the center of the channel where the velocity is between 90-100% that of the maximum.

Images are captured using a 1 second exposure in fluorescence mode. This long exposure causes moving particles to appear as a streak. The length of this streak (l) corresponds to the distance the particle has traveled during the exposure time (t). Tracking only particles that are located in the center of the microchannel allows the maximum particle velocity to be calculated, which can be used with the above correlations to determine flowrate.

$$Q = \alpha WHu_{max} = \alpha WH\frac{l}{t}$$

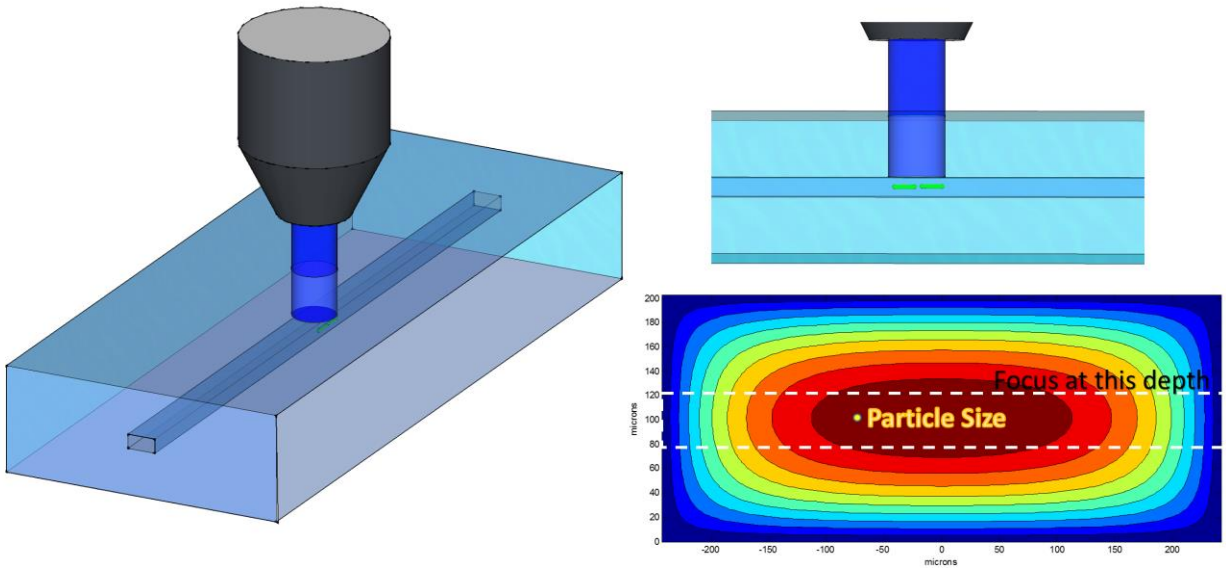

Fig. S2 (a,b) Setup of how we use fluorescent microparticles and a microscope to detect particle motion. (c) A velocity field of laminar flow in a rectangular microchannel. Particles oriented in the center are focused on and are approximated as being at the maximum velocity.

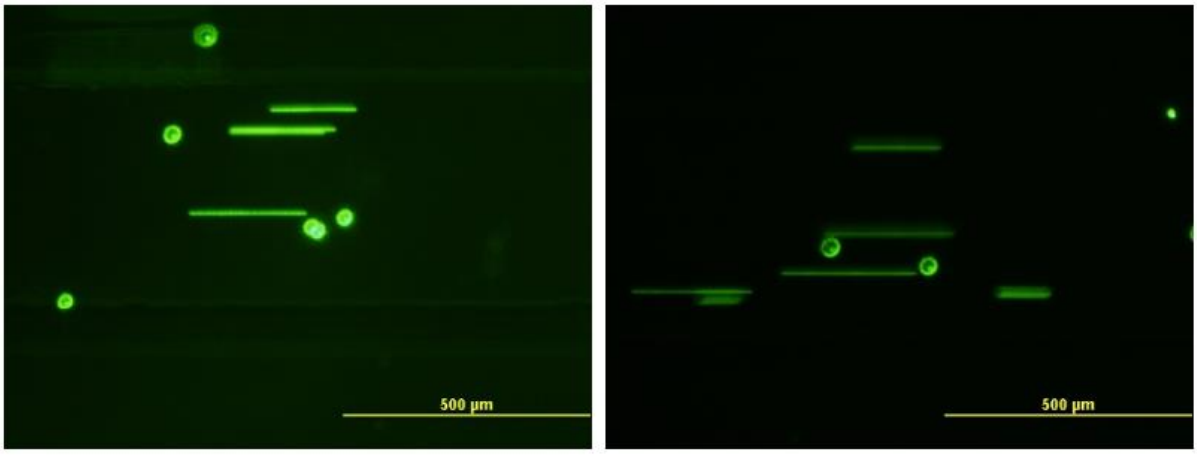

Fig. S3 Example images of flowing particles tracked with long exposures. The length correlates to how fast the particle is moving. The camera is focused in the middle of the microchannel. The circles in the micrographs are particles that are stuck to the walls of the microchannels (which is why they are out of focus).

Comparison of PBS versus artificial sweat pumping

We compared osmotic pumping of PBS versus an artificial sweat simulant in order to validate the use of PBS for our lab testing. Pumping tests were performed using a hydrogel disc equilibrated in 12 M glycerol. Three trials were performed and the average flowrate is plotted below.

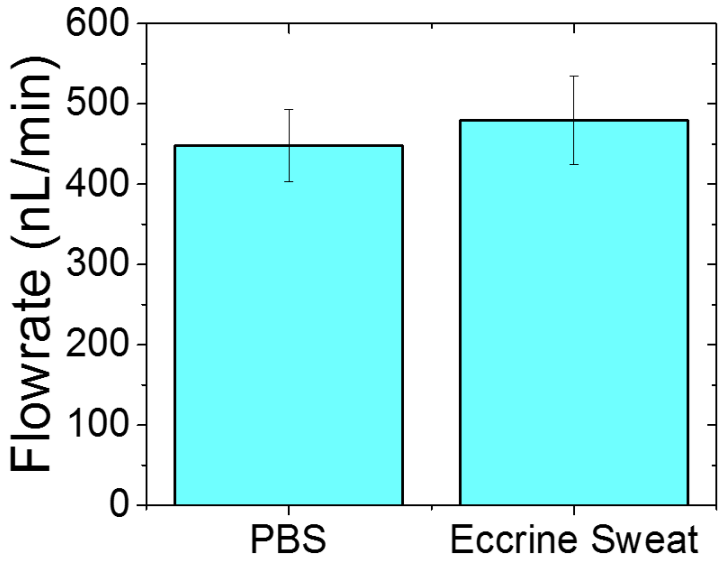

Fig. S4 Comparison of pump rates for hydrogels swelled in 12 M glycerol for PBS and an artificial eccrine sweat solution. These rates fall within each other's margin of error and indicate that there is no significant difference in the pumping rates.

These flowrates fell within the range of error of each other. Therefore we did not record any statistical difference between the pumping rates for the two solutions. These tests also show that pH has no sizeable effect on the pumping mechanism, as the artificial eccrine solution had a pH of 4.5 and the PBS used has a pH of 7.4. These data are in accordance with the expectations and validate the use of PBS in our lab setting for testing, as variations in pH and presence of proteins in solution would have minimal effect on the solution's osmotic strength, which is the basis for the pumping mechanism.