VISCOSITY INDEPENDENT PAPER MICROFLUIDIC IMBIBITION

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ABSTRACT

This work introduces capillary flow in paper microfluidics that features a flow rate Q that is constant in time, t, and independent of the viscosity of liquid sample, μ_{liquid}: $Q \neq f(t, \mu_{liquid})$. Compared to conventional paper microfluidics, we enclose the paper in solid walls and add a long and narrow air vent as outlet of the capillary pump, such that the flow rate is dominated by the downstream air resistance. Therefore, the flow rate depends on the viscosity of air rather than that of liquid. This significantly decreases the dependency of lateral flow biosensors on variations of sample fluid.

KEYWORDS: Lateral flow, Viscosity, Capillary pump, Paper microfluidics

INTRODUCTION

Samples of interest for biosensors, e.g. urine and blood, show large person-to-person variations in viscosity: the relative standard deviation in healthy individuals is 10% and 33%, respectively [1, 2], while larger deviations occur in many unhealthy conditions (e.g. ~4× higher for polycythaemia). Moreover, whole blood behaves viscoelastic. Sample pumping time in capillary driven lateral flow devices (LFDs) depends linearly on viscosity ($t_{fill} \sim \mu_{liquid}$); as a result, variations in sample viscosity form a fundamental limitation to the quantitative performance of lateral flow biosensors. Capillary pumps with time independent flow rate, $Q(\mu_{liquid}) \neq f(t)$, can be constructed, e.g. by introducing a large upstream, liquid hydrodynamic resistance [3].

THEORY

Here, we introduce a novel microfluidic paper design (Fig 1) with large downstream, gas hydrodynamic resistance, R_{air}, which provides both time independent flow rate and liquid viscosity independent flow rate. A capillary pump pumps two fluids simultaneously: 1) liquid sample in, through the entrance; 2) air out, through the exit. For a given capillary driving pressure, P_c, the flow rate depends on the hydrodynamic resistances of air, R_{air}, and liquid, R_{liquid}, as: $Q = P_c/[R_{air}(\mu_{air}) + R_{liquid}(\mu_{liquid})]$. Because $R \sim \mu$ and $\mu_{air} << \mu_{liquid}$, previous CP designs resulted in $R_{air} << R_{liquid}$, and thus $Q \approx P_c/R_{liquid}(\mu_{liquid}, t)$.

Our novel design is fitted with a long and narrow vent at the exit, such that $R_{air} >> R_{liquid}$, and thus $Q \approx P_c/R_{air}(\mu_{air})$. Therefore, the device operates nearly independently from the upstream wetted region, hence independent of time and liquid viscosity.

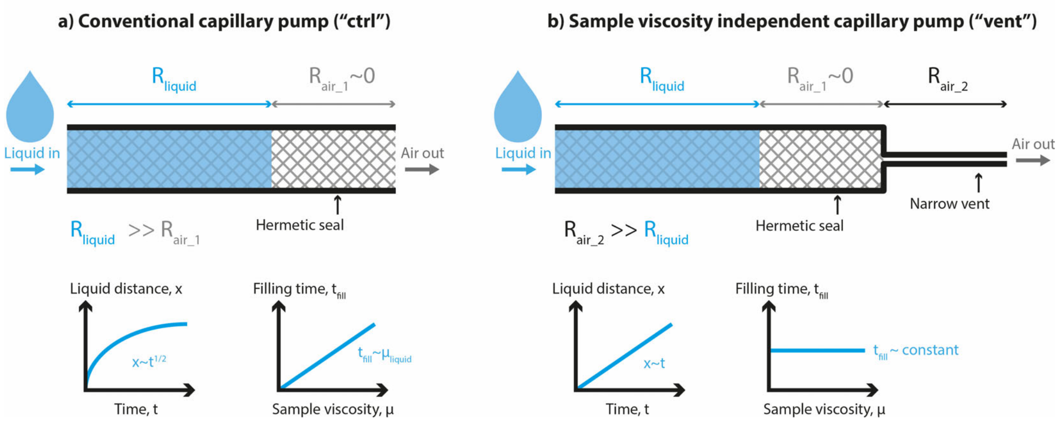

Figure 1: The conventional capillary pump and viscosity independent capillary pump, and their flow behaviour.

EXPERIMENTAL

We built experimental devices (Fig 2) with and without air vent. The devices consist of synthetic microfluidic paper [4], enclosed by a top and bottom layer. The viscosity independent devices are fitted with a 10 cm long 50 µm diameter glass capillary air vent; the control devices are left unchanged, i.e. open to atmosphere at their exit. Dyed mixtures of water and glycerol were prepared, with large viscosity range (1.31 – 6 mPa.s), but near constant surface energy (range 67 – 70 mN/m).

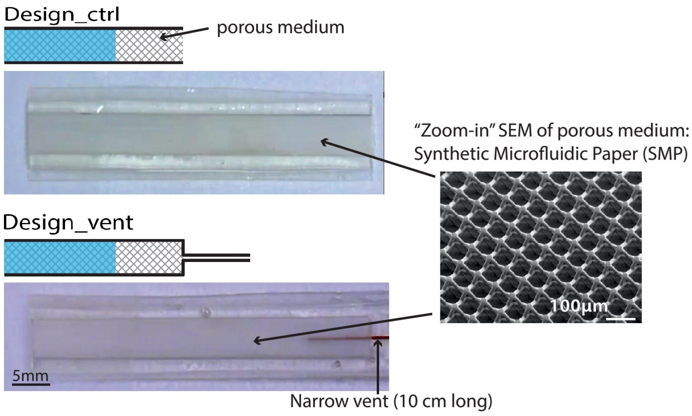

Figure 2: Sketch and real device of the viscosity independent capillary pump and its control.

RESULTS AND DISCUSSION

Fig. 3 shows the total filling time, t_{fill}, for different liquid viscosities, μ_{liquid}, normalized against the filling time of that design for liquid with μ_{liquid}=1.31 mPa.s, illustrating linear dependency for the ctrl devices: t_{fill}~μ_{liquid}, but very weak dependency on viscosity for devices with an air vent: $t_{fill} \neq f(\mu_{liquid})$.

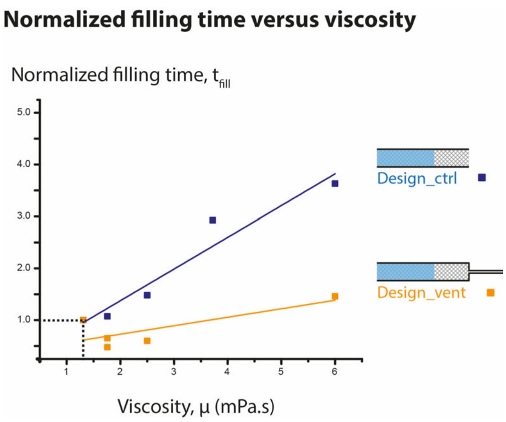

Figure 3: Normalized filling time versus viscosity for the viscosity independent design and for the control design.

CONCLUSION

We introduced microfluidic paper capillary systems that provide a near viscosity independent flow rate.

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