Journal Name

ARTICLE

Review on pneumatic operations in centrifugal microfluidics – electronic supplementary information

Protocol for workflow of tutorial 2

Table 1: Protocol for tutorial two including all relevant frequency and temperature changes without temperature supported pneumatic pumping. The second column indicates the duration of each step. The time required to accelerate or decelerate to the frequencies can be deducted by considering the acceleration or deceleration rate. Heating and cooling is always performed as fast as possible.

Step	Time [s]	Rotational frequency [Hz]	Acceleration Deceleration [Hz/s]	Temperature [°C]	Comment
1	0	0	0	30	Pipette 120 µl into reservoir
2	30	30	10	30	Transfer liquid into siphon channel
3	30	30	0	50	Heat collection chamber to prepare for temperature change rate actuated valving
4	0	5	5	50	Slow down to prepare for temperature change rate actuated valving
5	60	5	0	30	Cool down for siphon priming
6	180	50	10	30	Transfer liquid into pneumatic chamber
7	1	5	30	30	Slow down for pneumatic pumping
8	60	15	1	30	Accelerate to transfer liquid to aliquoting structure
9	60	50	10	30	Transfer liquid from aliquoting into PCR chambers

Table 2: Protocol for tutorial two including all relevant frequency and temperature changes with temperature supported pneumatic pumping. The second column depicts the duration of each step. The time required to accelerate or decelerate to the frequencies can be deducted by examining the acceleration or deceleration rate. Heating and cooling is always performed as fast as possible.

Step	Time [s]	Rotational frequency [Hz]	Acceleration Deceleration [Hz/s]	Temperature [°C]	Comment
1	0	0	0	30	Pipette 120 µl into reservoir
2	30	30	10	30	Transfer liquid into siphon channel
3	30	30	0	50	Heat collection chamber to prepare for temperature change rate actuated valving
4	0	5	5	50	Slow down to prepare for temperature change rate actuated valving
5	60	5	0	30	Cool down for siphon priming
6	120	50	10	30	Transfer liquid into pneumatic chamber
7	60	50	0	60	Heat up to increase pneumatic pumping efficiency
8	1	5	30	60	Slow down for pneumatic pumping
9	60	15	1	60	Accelerate to transfer liquid to aliquoting structure
10	60	50	10	30	Transfer liquid from aliquoting into PCR chambers

Details of network simulation of tutorial 2

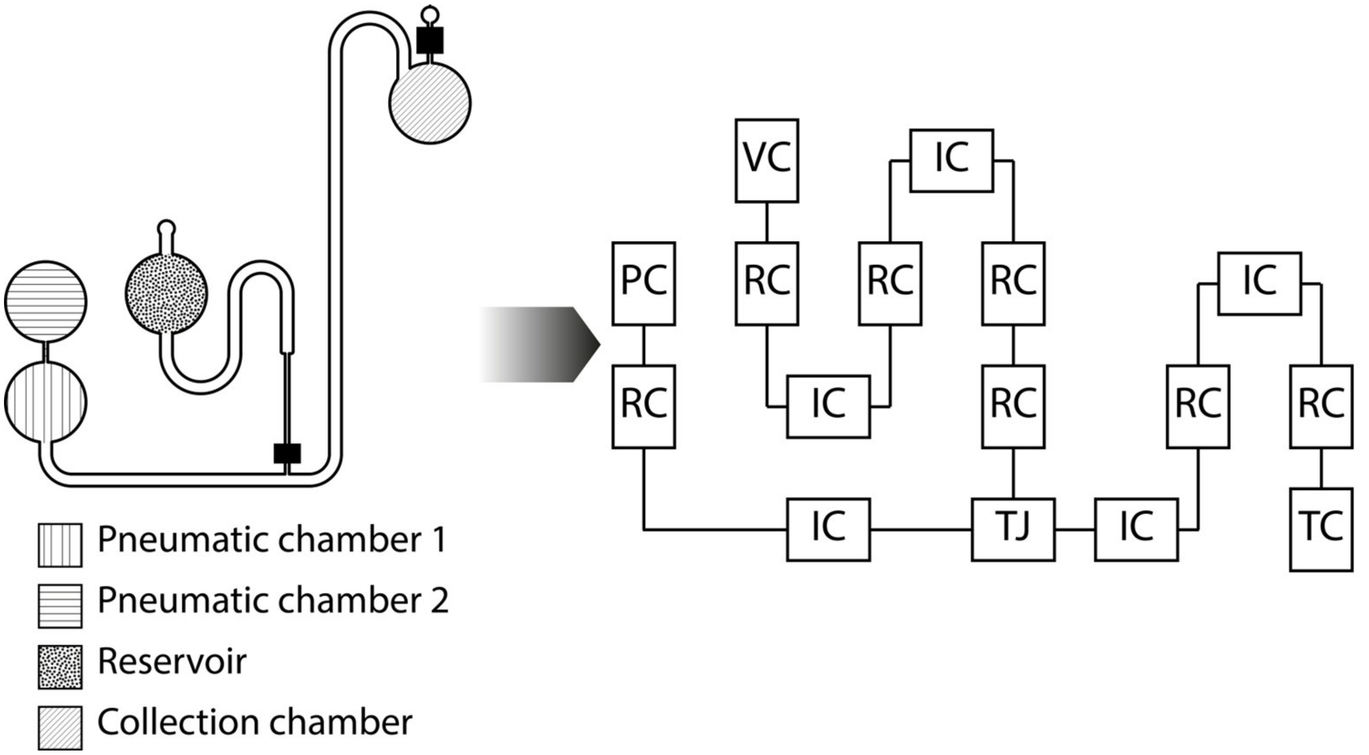

Figure 1: Reprint of Figure 17 of the main manuscript as a basis of the description of Table 3. Elements of the performed network simulation. The system includes radial (RC) and isoradial (IC) channels, vented chambers (VC), pneumatic chambers (PC), two-port chambers (TC) and a T-junction (TJ). Dimensions of each element are defined in Table 3 and
Table 4.

Table 3: Definition of all channels required for the network simulation. A detailed description of the implementation of the elements is given by Schwarz et al..[1]

Radial	Width in µm	Depth in µm	Radial inner position in mm	Radial outer position in mm
RC1	600	600	50.5	53.6
RC2	600	600	42.9	53.6
RC3	600	600	42.9	53.65
RC4	50	50	53.65	60.7
RC5	400	400	59.95	60.5
RC6	400	400	15.2	60.5
RC7	400	400	15.2	19.35
Isoradial	**Width in µm**	**Depth in µm**	**Radial position in mm**	**Isoradial length in mm**
IC1	600	600	53.6	3.6
IC2	600	600	42.9	2.4
IC3	400	400	60.5	13.2
IC4	400	400	60.5	24.1
IC5	400	400	15.2	1.9

Table 4: Definition of all chambers required for the network simulation. A detailed description of the implementation of the elements is given by Schwarz et al..1

Element	Initial liquid volume in µl	Chamber volume in µl	Radial outer position in mm	Starting saturation level	Coefficient for height function $h(V)/mm = P_1(V/\mu l)^{0.5}$	Deformation volume in µl	Venting resistance channel length in mm	Venting resistance channel width and depth in µm
VC1	110	200	50.5	-	P_1 = 3.62527 E-1 P_2 = -2.86439 E-2 P_3 = 1.74467 E-3 P_4 = 1.00398 E-3 P_5 = -1.16025 E-4 P_6 = 3.94963 E-6	-	1	500
PC1	0	402.5	59.9	0.6	P_1 = 2.08416 E-1 P_2 = 1.76683 E-1 P_3 = -7.07995 E-2 P_4 = 1.18286 E-2 P_5 = -8.7594 E-4 P_6 = 2.41629E-5	18.8 at 30 °C, 278 mbar 23.9 at 60 °C, 303 mbar	-	-
TC1	0	1240	19.35	0.6	-	-	21	100

Table 5: Definition of liquid and gas parameters.

Air viscosity	0.19 mPa s
Air density	1.21 kg/m^3
Water density	998.2 kg/m^3
Water viscosity	P_1 = 6.55717 E-3
$\frac{\eta_{H2O}}{mPa\ s} = P_1 \exp(P_2 \left(\frac{K}{T}\right)) + P_3 \exp(P_4 \left(\frac{K}{T}\right))$	P_2 = 1.38681 E+3
	P_3 = 1.48339 E-7
	P_4 = 4.21260 E+3
Atmospheric pressure	1.013 bar

Details on foil deformation of tutorial 2

Table 6: Material parameters for FEM simulation of foil deformations in ANSYS Workbench 18.2.

Parameter	Value @ 25°C	Value @ 60°C	Unit	Comment
Material model	Linear orthotropic	Linear orthotropic	-	The used foil shows orthotropic material behavior due to different molecular orientation during foil extrusion.
Young's modulus x-direction	7,29E+08	3,35E+08	Pa	Young's modulus in axis of extrusion. Determined by tensile-strength experiments of n=12 samples for room temperature. For the 60 °C values a mean drop of -54 % was assumed by evaluating three publications on temperature driven Young's modulus drop of PP: -55%[2], -47%[3] and -60%[4]
Young's modulus y-direction	1,89E+09	8,72E+08	Pa	Young's modulus rectangular to axis of extrusion. Determined by tensile-strength experiments of n=12 samples for room temperature. For the 60 °C values also a mean drop of -54 % was assumed.
Young's modulus z-direction	1,89E+09	8,72E+08	Pa	Young's modulus rectangular to axis of extrusion. Assumed to be identic with y-direction for both temperatures.
Poisson's ratio XY	0,3	0,3	-	Assumed for linear orthotropic polymer.
Poisson's ratio YZ	0,4	0,4	-	Assumed for linear orthotropic polymer.
Poisson's ratio XY	0,3	0,3	-	Assumed for linear orthotropic polymer.

Table 7: Solver parameters for FEM simulation of foil deformations in ANSYS Workbench 18.2.

Parameter	Value	Unit	Comment
Large deflection	On	-	Setting for nonlinear solver.
Mesh sizing	Adaptive	-	Program controlled adaptive meshing of foil membrane.
Foil thickness	53	µm	Determined by foil thickness measurements of n=3 samples.

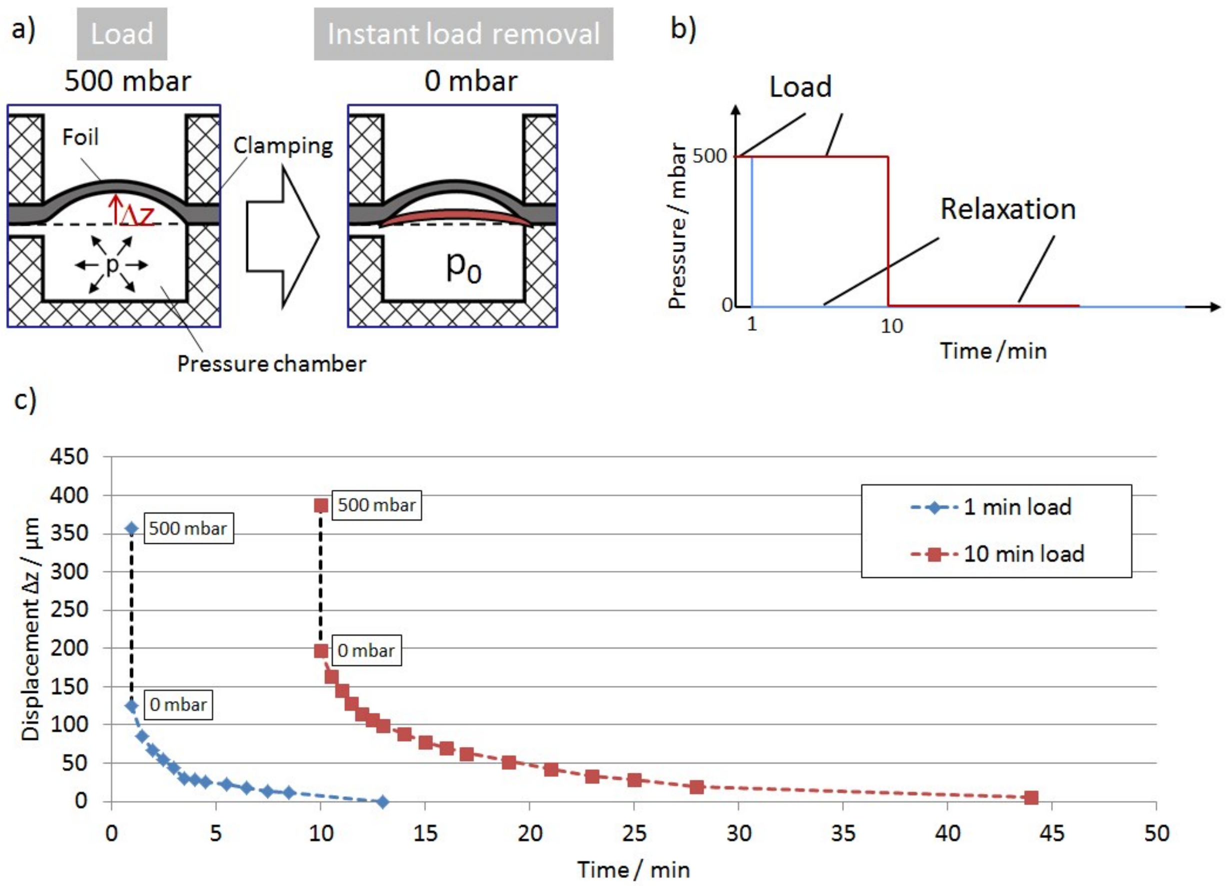

Figure 2: a) Experimental setup for determination of viscoelasticity. A circular foil (D=8 mm) is fixed above a pressure chamber. A syringe pump (Hugo Sachs Harvard Apparatus G Pump 11 Pico Plus Elite) is used to load a defined pressure, measured with an electronic pressure sensor (Greisinger GMH 3181-13). Displacement of the foil is determined by z-stage focussing on a light microscope (ZEISS Axio Imager M2). After instant load removal the residual displacement in z direction is measured frequently. b) Load protocol. c) Displacement curves for 1 min load (blue) and 10 min load (red) clearly show the viscoelastic behaviour of the foil material.

References

1 I. Schwarz, S. Zehnle, T. Hutzenlaub, R. Zengerle and N. Paust, *Lab on a chip*, 2016, **16**, 1873–1885.
2 B. Hartmann, G. F. Lee and W. Wong, *Polym. Eng. Sci.*, 1987, **27**, 823–828.
3 Y. Zhou and P. K. Mallick, *Polym. Eng. Sci.*, 2002, **42**, 2449–2460.
4 C. Maier and T. Calafut, *Polypropylene. The definitive user's guide and databook*, Plastics Design Library, Norwich, N.Y, 1998.