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

DNA separation and enrichment using electrohydrodynamic bidirectional flows in viscoelastic liquids

Hubert Ranchon[1,2], Rémi Malbec[1,2], Vincent Picot[3], Audrey Boutonnet[3], Pattamon Terrapanich[1,2], Pierre Joseph[1,2], Thierry Leïchlé[1,2], Aurélien Bancaud[1,2]

Supplementary Information

Supplementary Figure S1: Bulk rheological measurements of 2% PVP solution (MW 360 kDa). The graph shows the elastic modulus G' (red dataset) and loss modulus G'' (green dataset) as a function of the oscillatory frequency. The black solid lines correspond to the fit of the data with the Maxwell model with relaxation time of 15 ms. The inset represents the steady shear viscosity as a function of the shear rate. Experiments were carried out with the AR1000 from TA Instruments.

Supplementary Figure S2: The six histograms represent the velocity of Lambda and ϕX174 (left and right panels, respectively) conveyed in 2 µm thick channels for three different pressure drops of 100, 200, and 300 mbar. The channel length is 2 cm, the concentration of PVP is set to 2%, and the potential difference varies in the range 0-50 V, as indicated in the insets. These histograms have been obtained by bright field single particle velocimetry, as described in ref. 25 of main text.

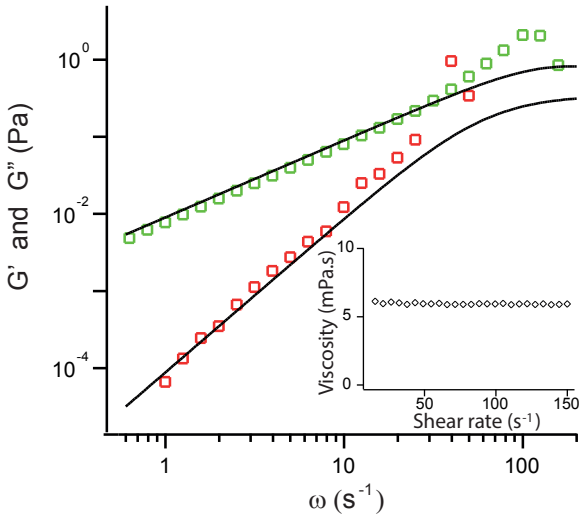
Supplementary Figure S3: (A) The four micrographs correspond to the DNA molecular weight markers used in this study, as uploaded from the manufacturer website. **(B-C)** The electrophoregrams were recorded in one microfluidic chip of 2 µm in thickness **(C)** or in a capillary of 50 µm in diameter **(B)**. The sample is the kb ladder extend in capillaries and the kb ladder in microchannels. The PVP concentration is set to 2%. The electric field and the pressure difference are adjusted to define optimal separation conditions. Note in Fig. S3C that low flow velocities enable us to improve the separation of high MW molecules, while high flow rates are adequate for the

separation of low MW molecules (green and blue rectangles, respectively). The electrophoregram shown in the middle panel of Fig. 3B in main text corresponds to that outlined with a red rectangle in Fig. S3C.

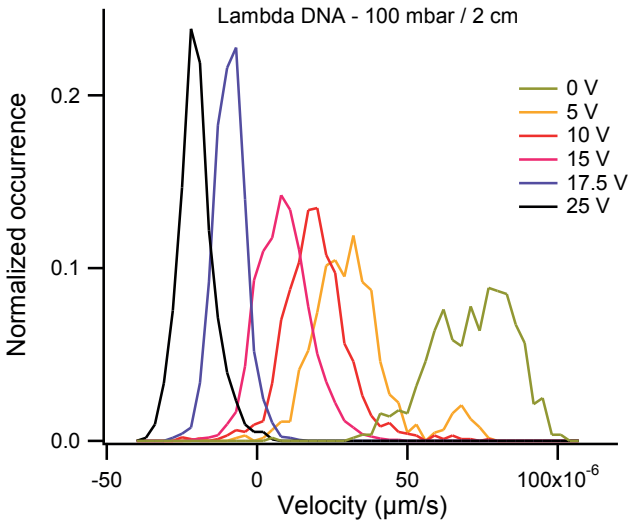
Supplementary Figure S4: (A) In the actuation parameter space (v_0,E), we plot the stagnation points for two DNA sizes of 4 and 5 kb , and superimpose guides to the eye. The smaller MW of 4 kb molecules requires higher settings in (v_0,E) to arrest their motion. This data has been obtained by measuring the position of the bands of 4 and 5 kb in a constriction of 2 μm in thickness and with a 2% PVP solution. The values of the electric field and flow velocity were inferred using the COMSOL simulation described in Fig. 4A of main text. **(B)** The plot shows the enrichment factor over time for the band of 300 bp in the micrograph shown in the right panel of Fig. 4D. **(C)** The dataset represents the optimal enrichment factor recorded for an isolated 100 bp band in a 2 μm constriction during the first 2 seconds of the acquisition. Note that the signal of the camera saturates after 2.5 sec with these optical settings.

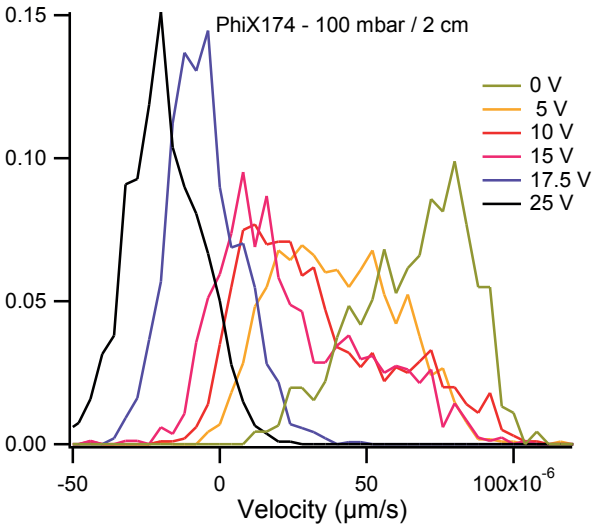
Supplementary Video S1: The video represents the 100-bp DNA ladder accumulation dynamics in a constriction of 2 μm in height for a pressure drop of 2 bars and an electric field of 33V. Real time appears on the upper left corner. The electric field is turned on after 5 s and shut down after 45 s.

Supplementary Video S2: The same DNA sample is conveyed in a constriction of 1 μm in thickness. The electric field is set to 75 V and the hydrodynamic flow field to 7 bars.

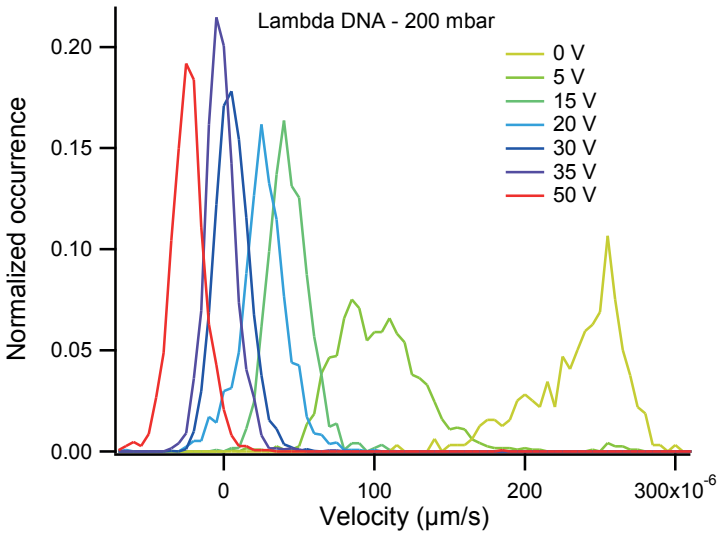

G' and G" (Pa)
10^0
10^-2
10^-4
1
10
100
ω (s^-1)
Viscosity (mPa.s)
10
5
0
50
100
150
Shear rate (s^-1)

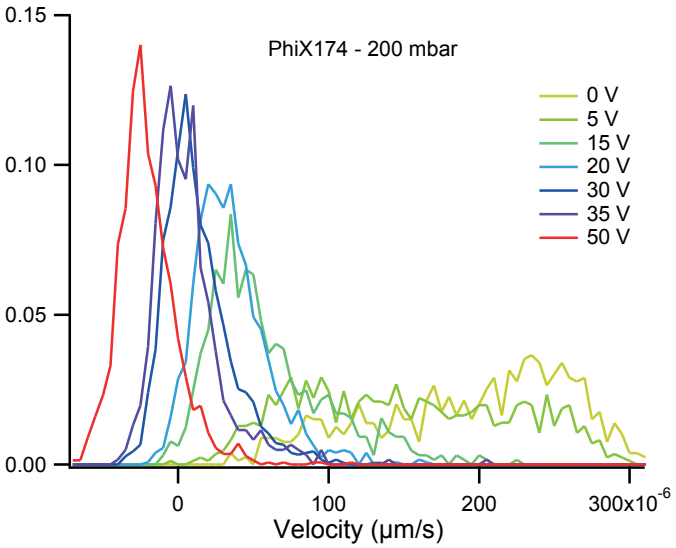
A


Lambda DNA - 100 mbar / 2 cm
Normalized occurrence
0.2
0.1
0.0
-50
0
50
100x10-6
Velocity (µm/s)
0 V
5 V
10 V
15 V
17.5 V
25 V

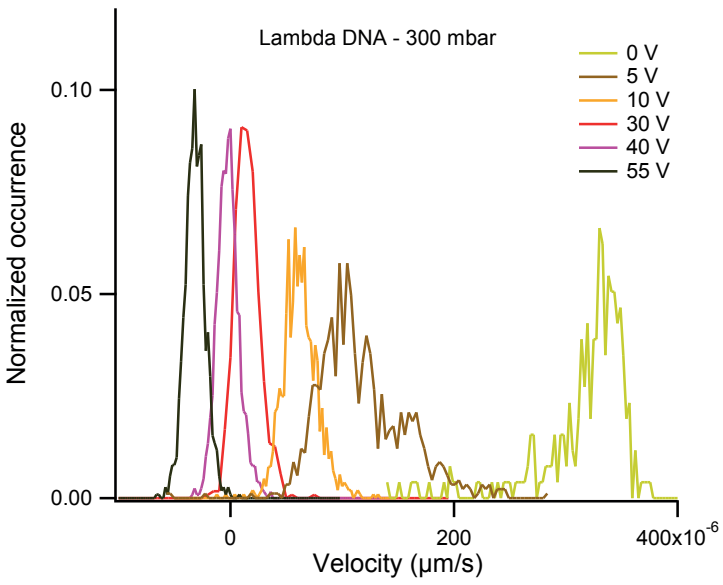

PhiX174 - 100 mbar / 2 cm
0.15
0.10
0.05
0.00
-50
0
50
100x10-6
Velocity (µm/s)
0 V
5 V
10 V
15 V
17.5 V
25 V

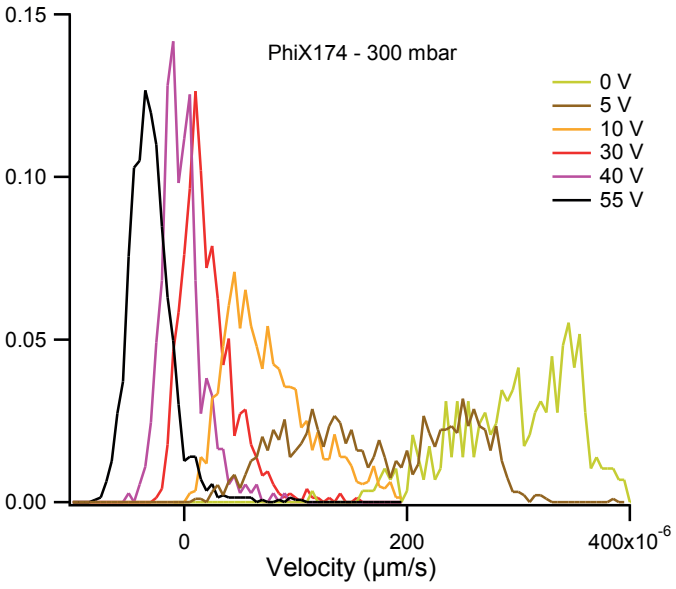
B


Lambda DNA - 200 mbar
Normalized occurrence
0.20
0.15
0.10
0.05
0.00
0
100
200
300x10-6
Velocity (µm/s)
0 V
5 V
15 V
20 V
30 V
35 V
50 V

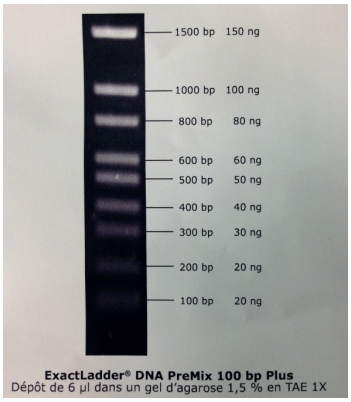

PhiX174 - 200 mbar
0.15
0.10
0.05
0.00
0
100
200
300x10-6
Velocity (µm/s)
0 V
5 V
15 V
20 V
30 V
35 V
50 V

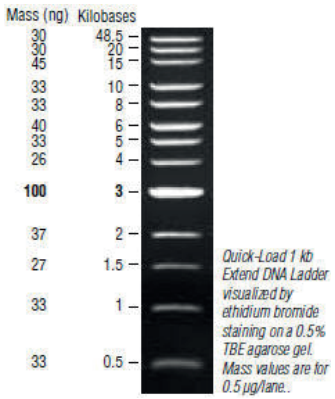
C

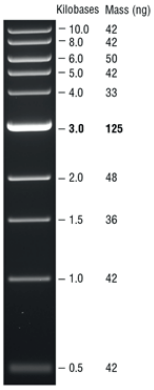

Lambda DNA - 300 mbar
Normalized occurrence
0.10
0.05
0.00
0
200
400x10-6
Velocity (µm/s)
0 V
5 V
10 V
30 V
40 V
55 V

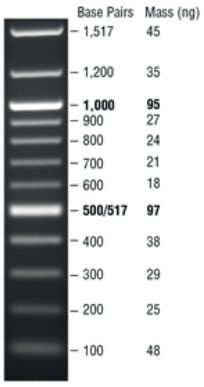

PhiX174 - 300 mbar
0.15
0.10
0.05
0.00
0
200
400x10-6
Velocity (µm/s)
0 V
5 V
10 V
30 V
40 V
55 V

A

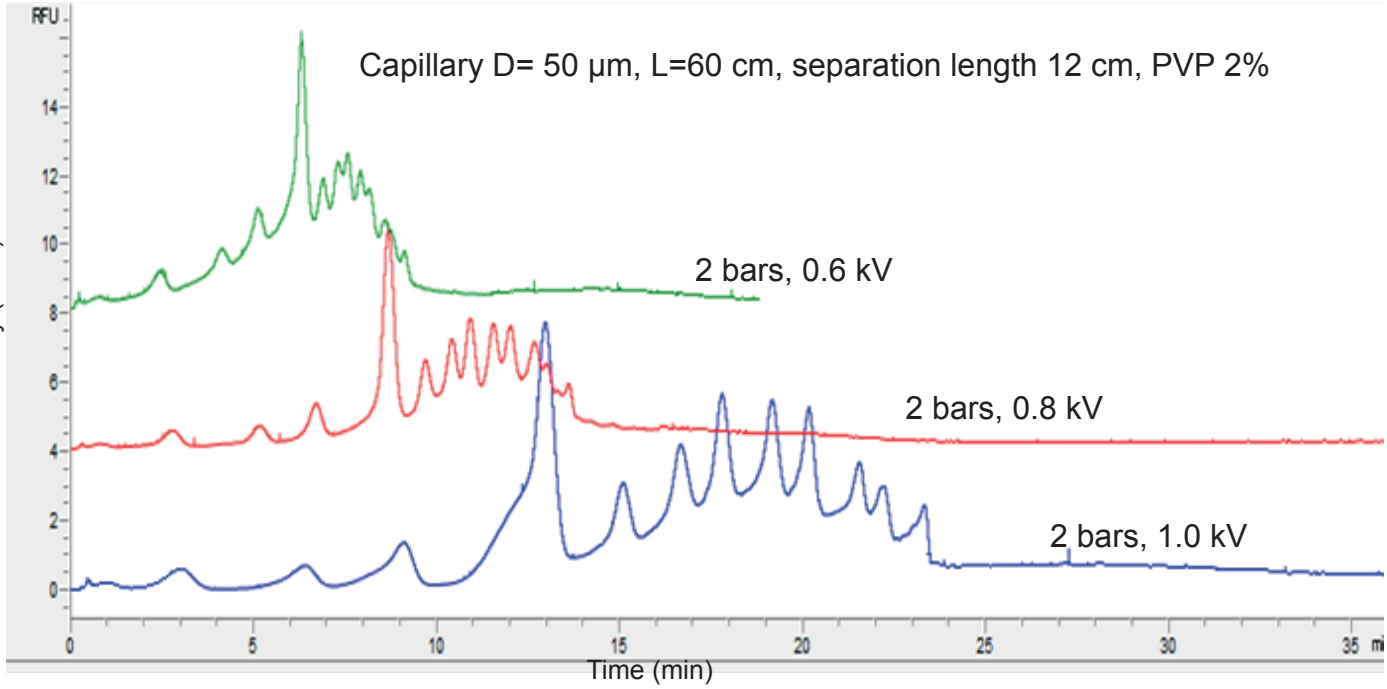

1500 bp 150 ng
1000 bp 100 ng
800 bp 80 ng
600 bp 60 ng
500 bp 50 ng
400 bp 40 ng
300 bp 30 ng
200 bp 20 ng
100 bp 20 ng
ExactLadder® DNA PreMix 100 bp Plus
Dépôt de 6 µl dans un gel d'agarose 1,5 % en TAE 1X


Mass (ng) Kilobases
30 48.5
30 20
45 15
33 10
33 8
40 6
33 5
26 4
100 3
37 2
27 1.5
33 1
33 0.5
Quick-Load 1 kb Extend DNA Ladder visualized by ethidium bromide staining on a 0.5% TBE agarose gel. Mass values are for 0.5 µg/lane.

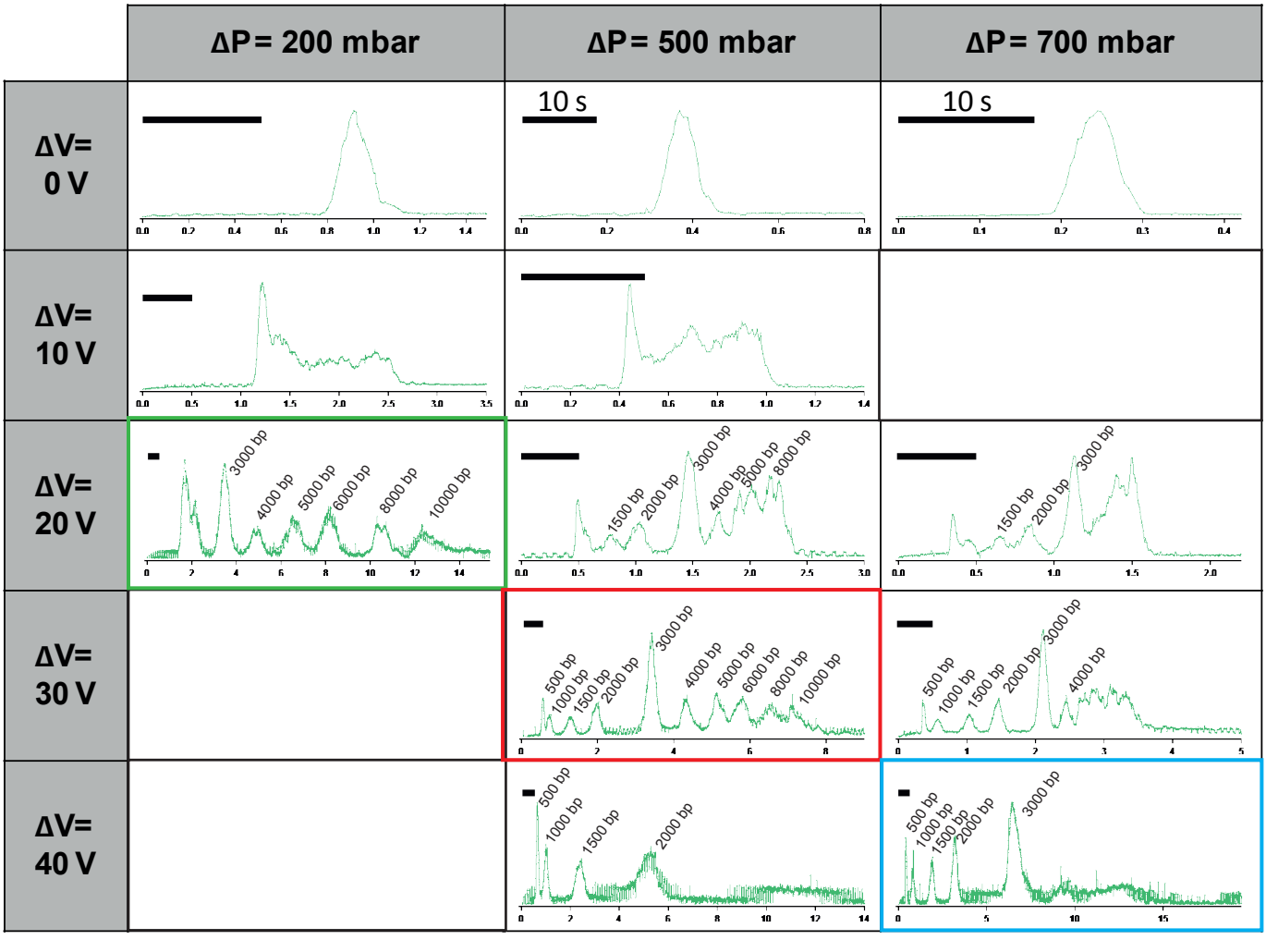

Kilobases Mass (ng)
10.0 42
8.0 42
6.0 50
5.0 42
4.0 33
3.0 125
2.0 48
1.5 36
1.0 42
0.5 42


Base Pairs Mass (ng)
1,517 45
1,200 35
1,000 95
900 27
800 24
700 21
600 18
500/517 97
400 38
300 29
200 25
100 48

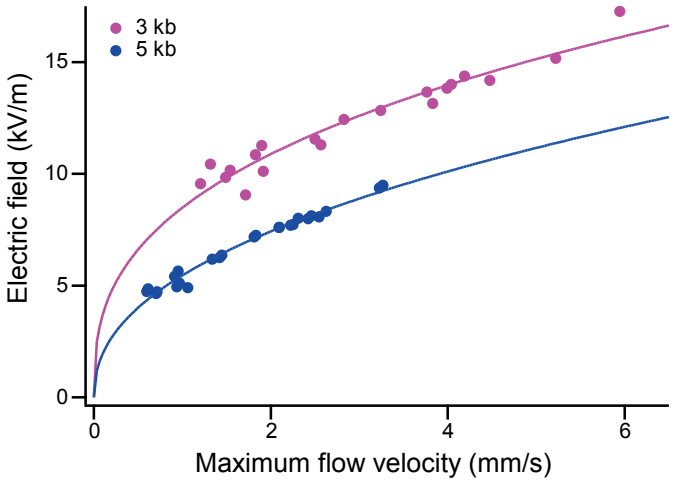
B


RFU
Capillary D= 50 µm, L=60 cm, separation length 12 cm, PVP 2%
2 bars, 0.6 kV
2 bars, 0.8 kV
2 bars, 1.0 kV
Intensity (RFU)
Time (min)

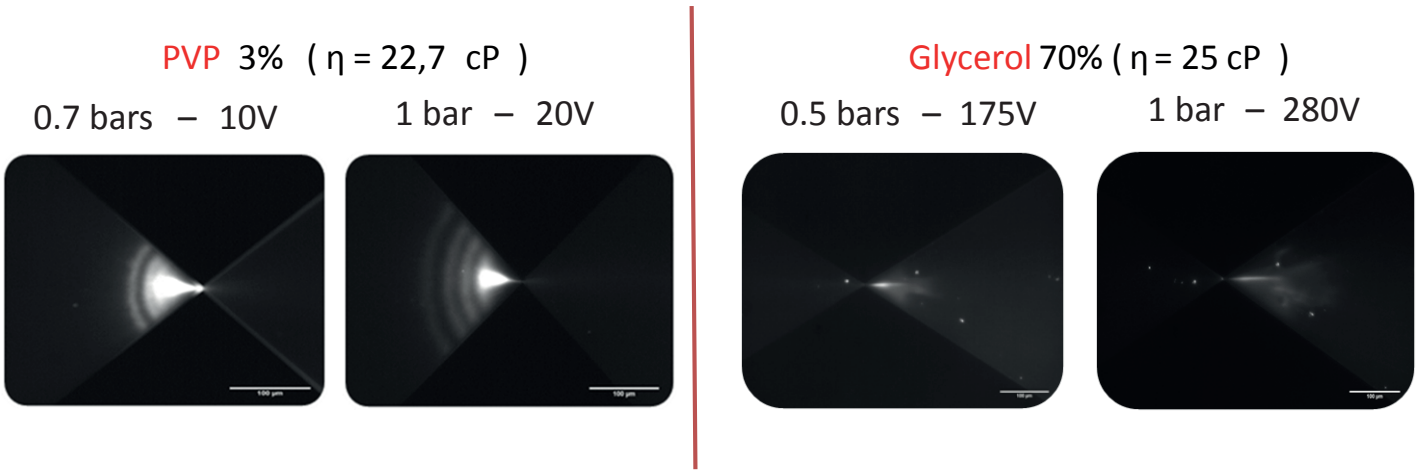
C


ΔP= 200 mbar
ΔP= 500 mbar
ΔP= 700 mbar
ΔV= 0 V
ΔV= 10 V
ΔV= 20 V
ΔV= 30 V
ΔV= 40 V
10 s
10 s
3000 bp
4000 bp
5000 bp
6000 bp
8000 bp
10000 bp
1500 bp
2000 bp
500 bp
1000 bp

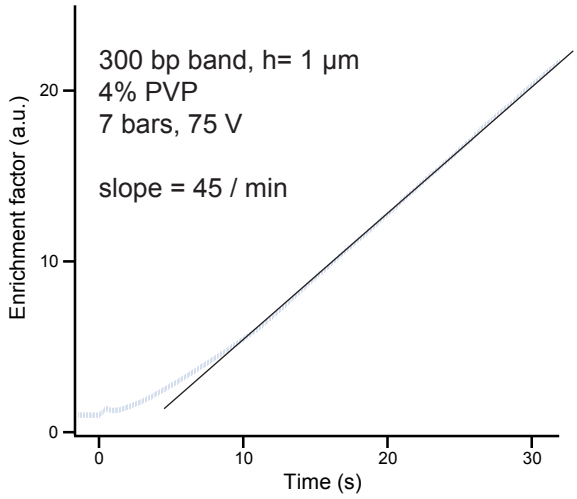
A


3 kb
5 kb
Electric field (kV/m)
Maximum flow velocity (mm/s)
0
5
10
15
0
2
4
6

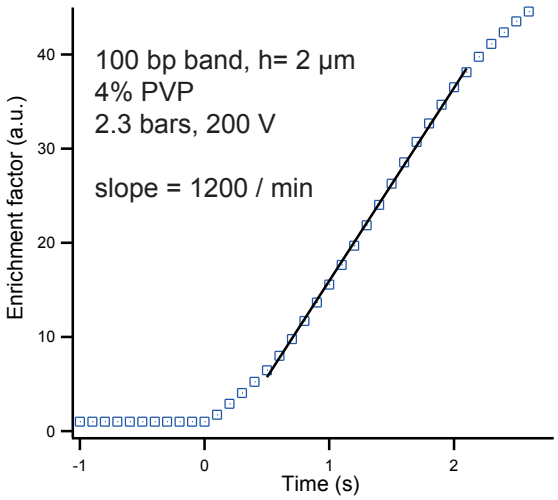
B


PVP 3% (η = 22,7 cP)
0.7 bars – 10V
1 bar – 20V
Glycerol 70% (η = 25 cP)
0.5 bars – 175V
1 bar – 280V

C


300 bp band, h= 1 µm
4% PVP
7 bars, 75 V
slope = 45 / min
Enrichment factor (a.u.)
Time (s)
0
10
20
0
10
20
30

D


100 bp band, h= 2 µm
4% PVP
2.3 bars, 200 V
slope = 1200 / min
Enrichment factor (a.u.)
Time (s)
0
10
20
30
40
-1
0
1
2