Testing of electrophoretic pumps in a brain tissue phantom

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EPSRC IRC
Targeted Delivery for Hard-to-Treat Cancers

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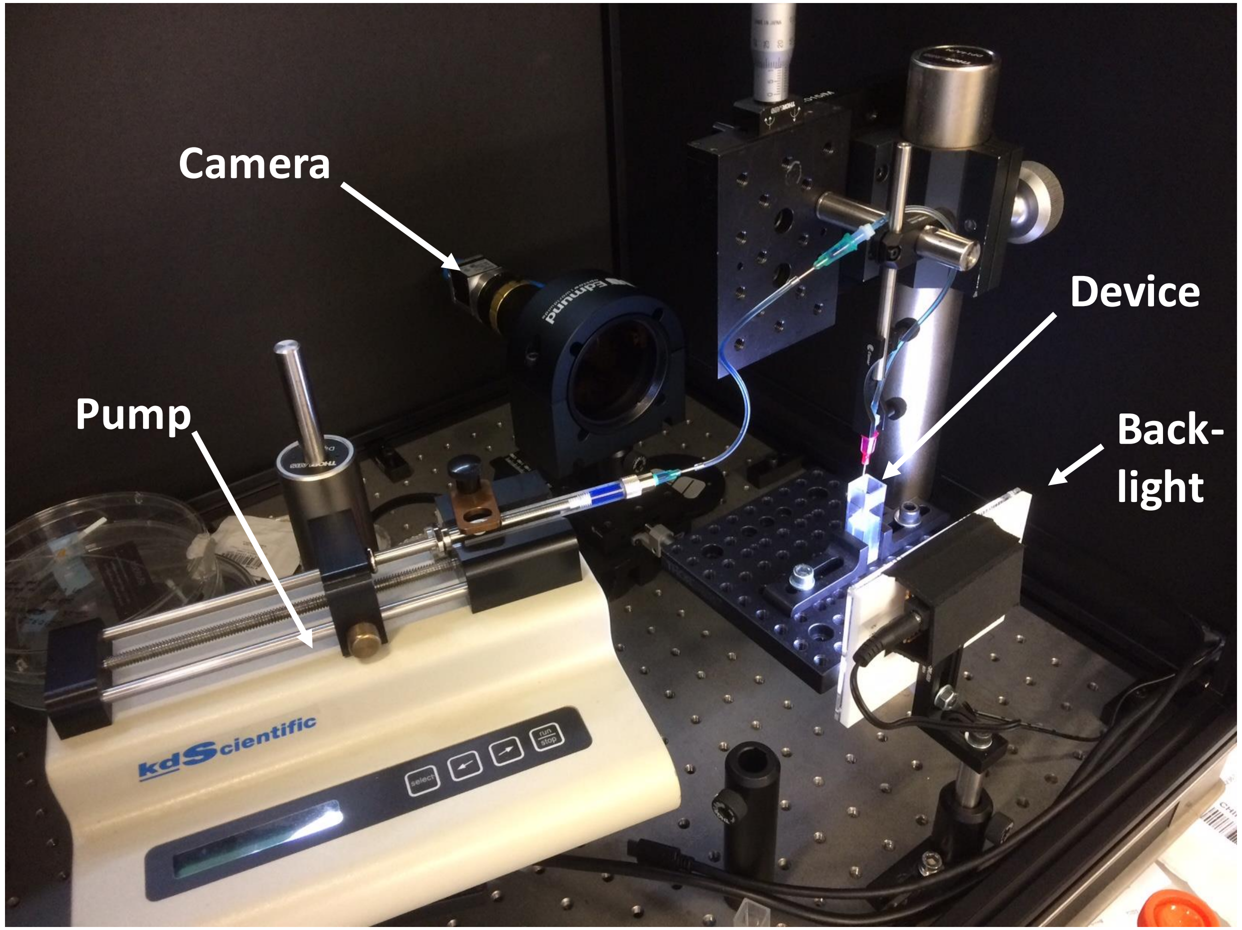
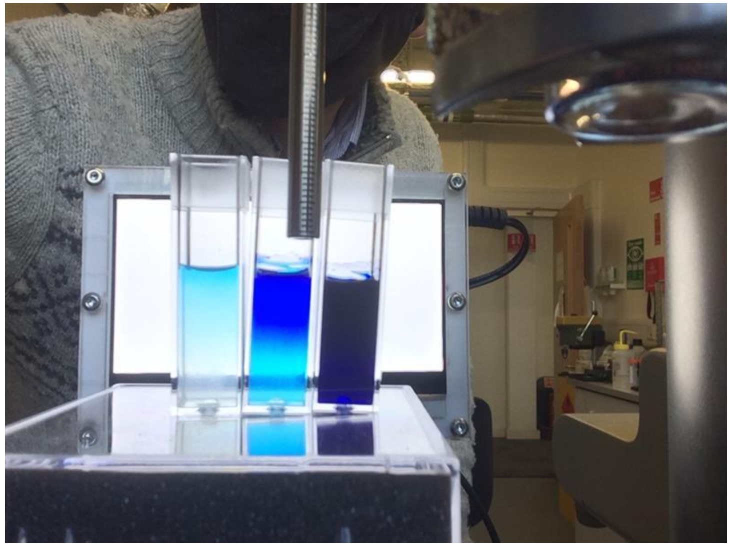
Overview of the testing rig





Absorbance images

- Absorbance A:

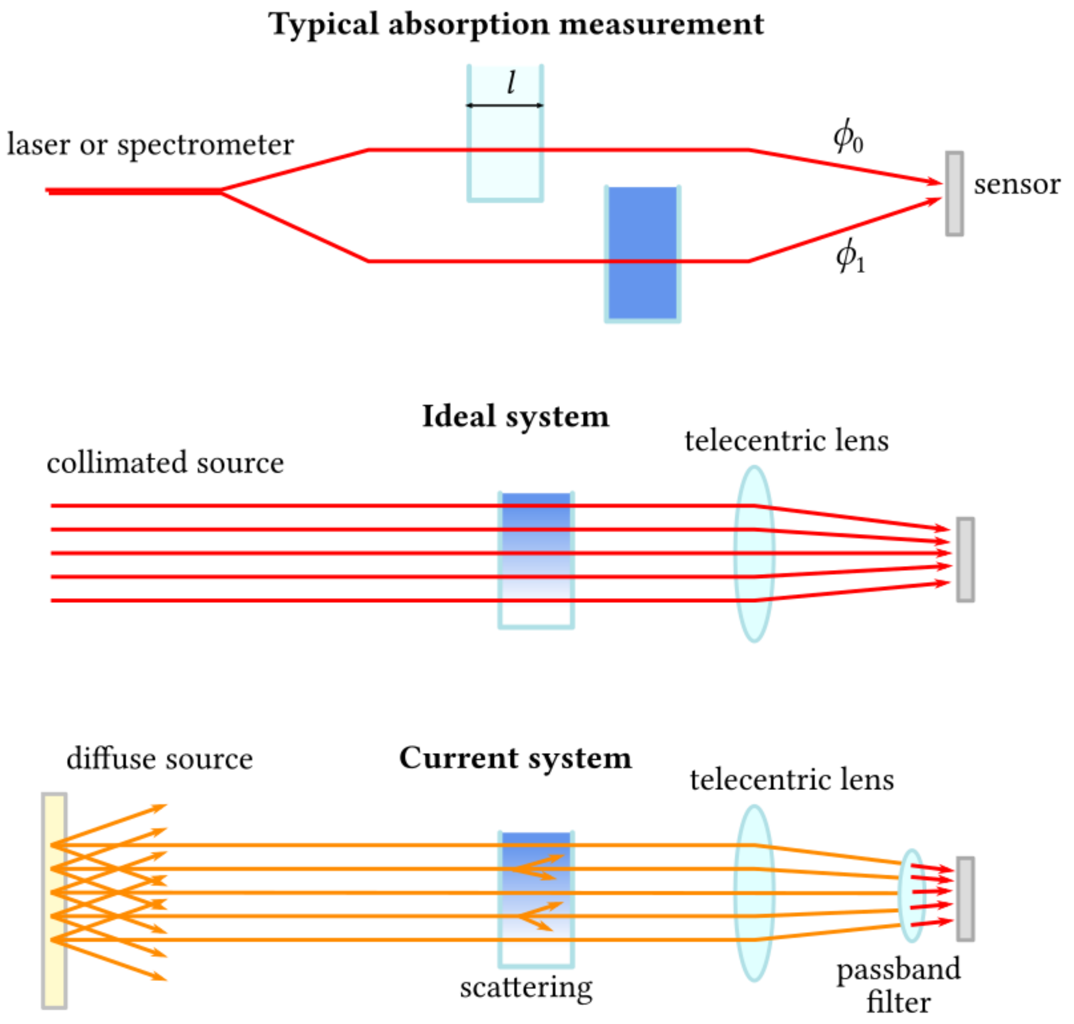
$$A = -\log_{10} \frac{\phi_1}{\phi_0}$$

- Beer-Lambert law:

$$A(\lambda) = \varepsilon(\lambda)\ell c$$

  - ε Molar extinction coefficient

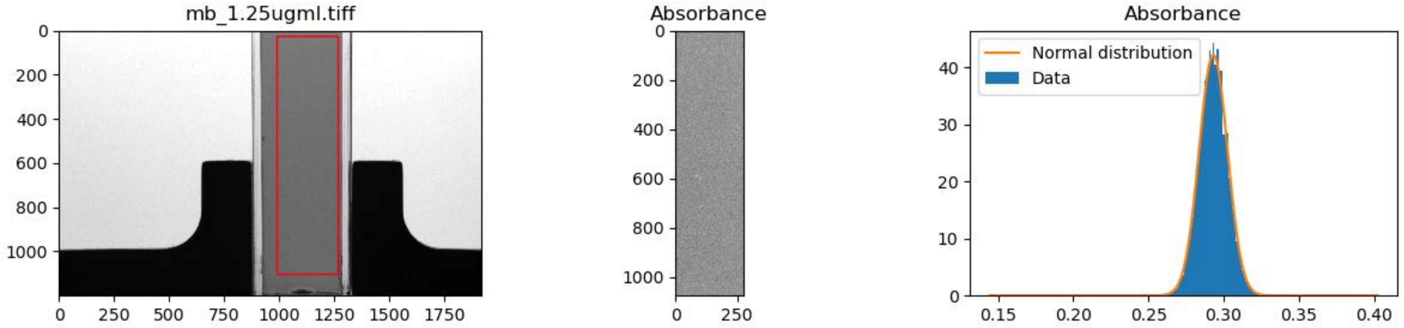
- Images: pixel-wise approach
  - First image of stack (t=0) as reference

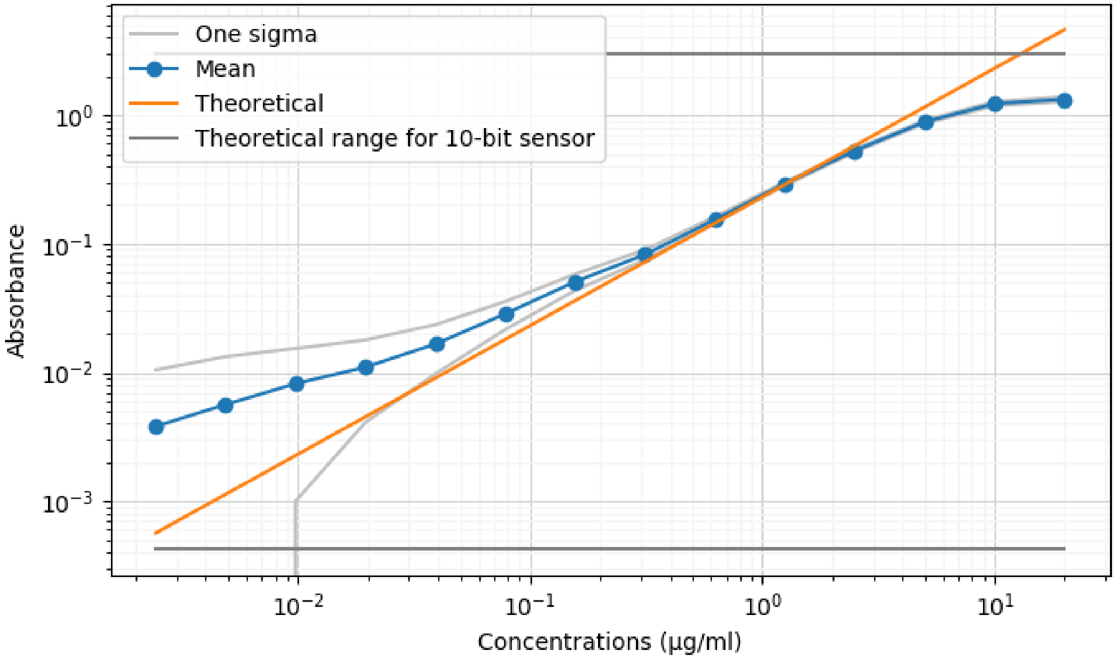


Dynamic range

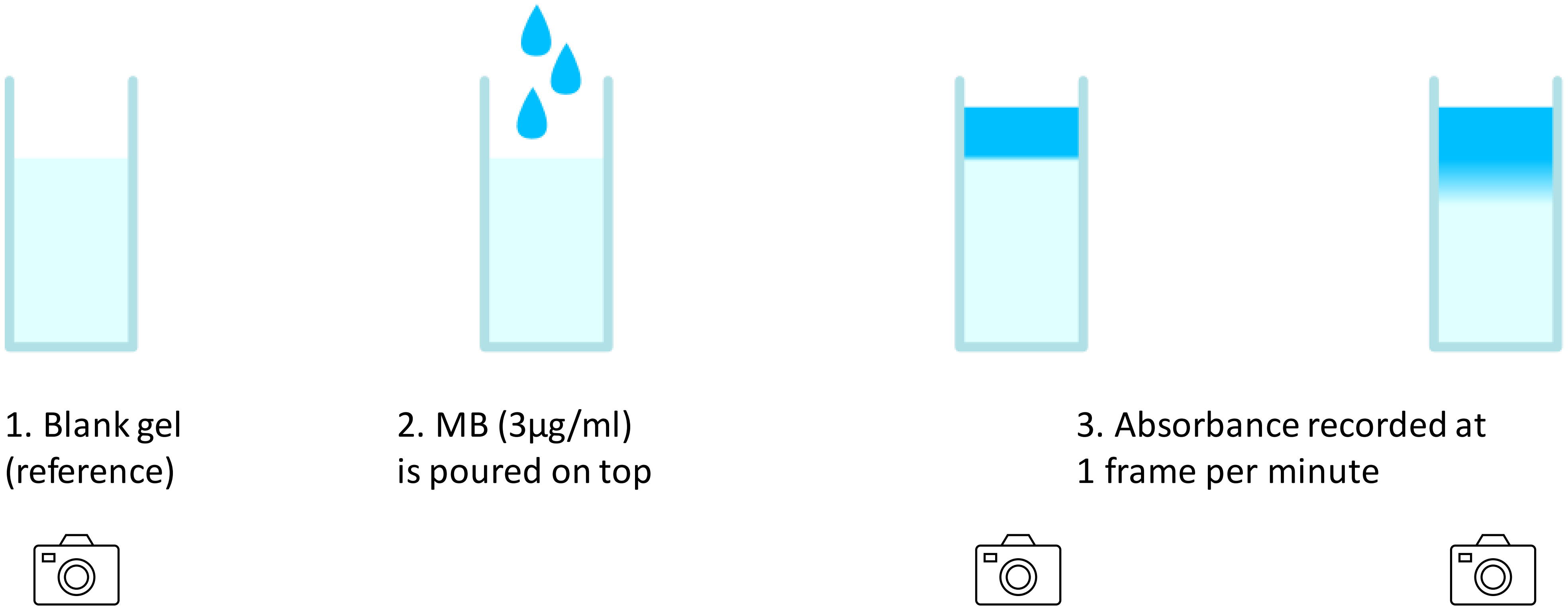
- Max and min concentrations depend on pixel depth.

- Other sources of limitation:
    - Sensor non-linearity
    - Sensor noise
    - Back-light non-uniformity
    - Scattering in the gel



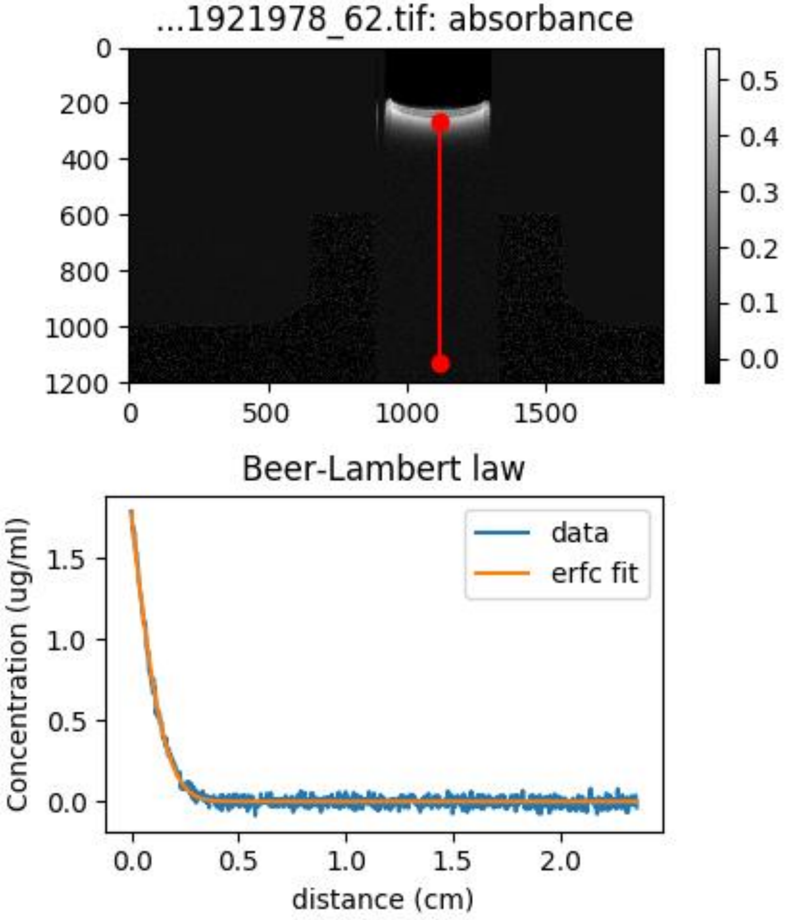


1D diffusion of methylene blue (MB)

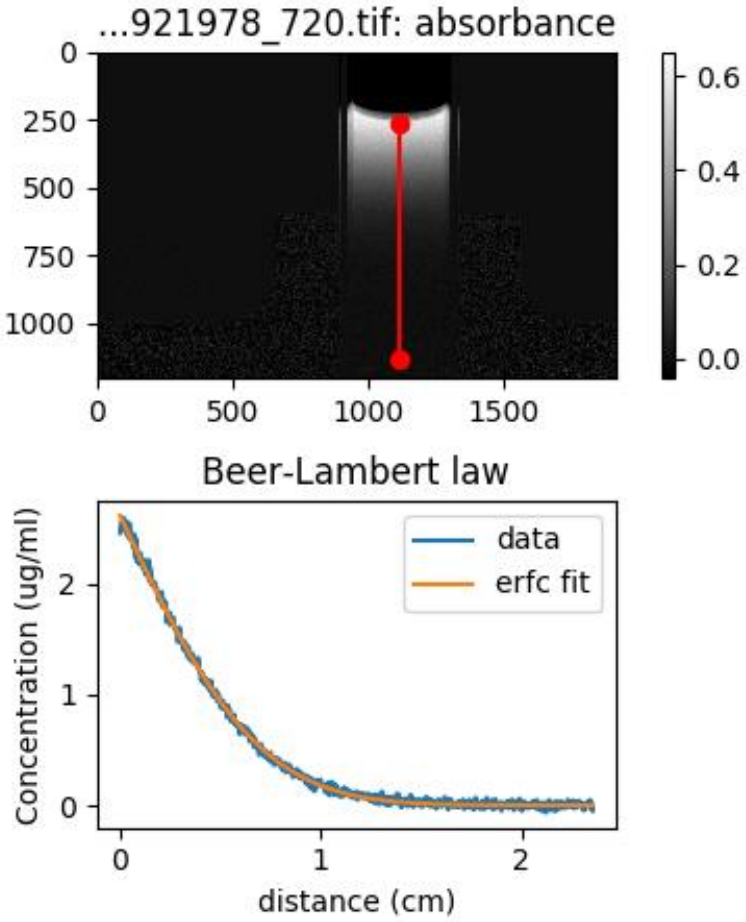


1D diffusion of methylene blue

After 1h

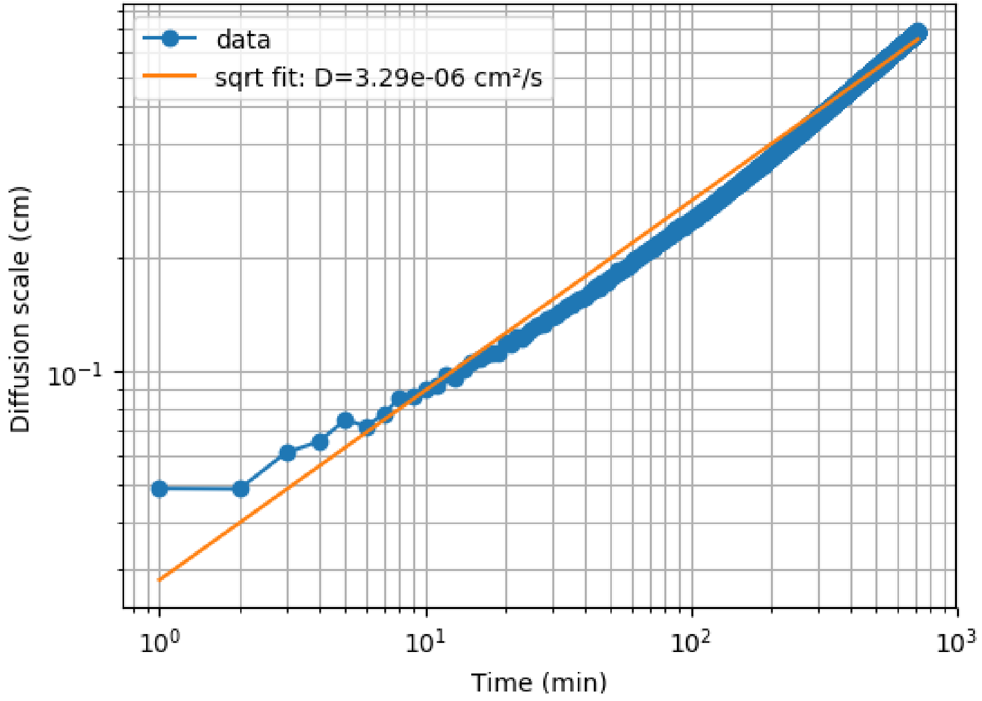


After 12 hours

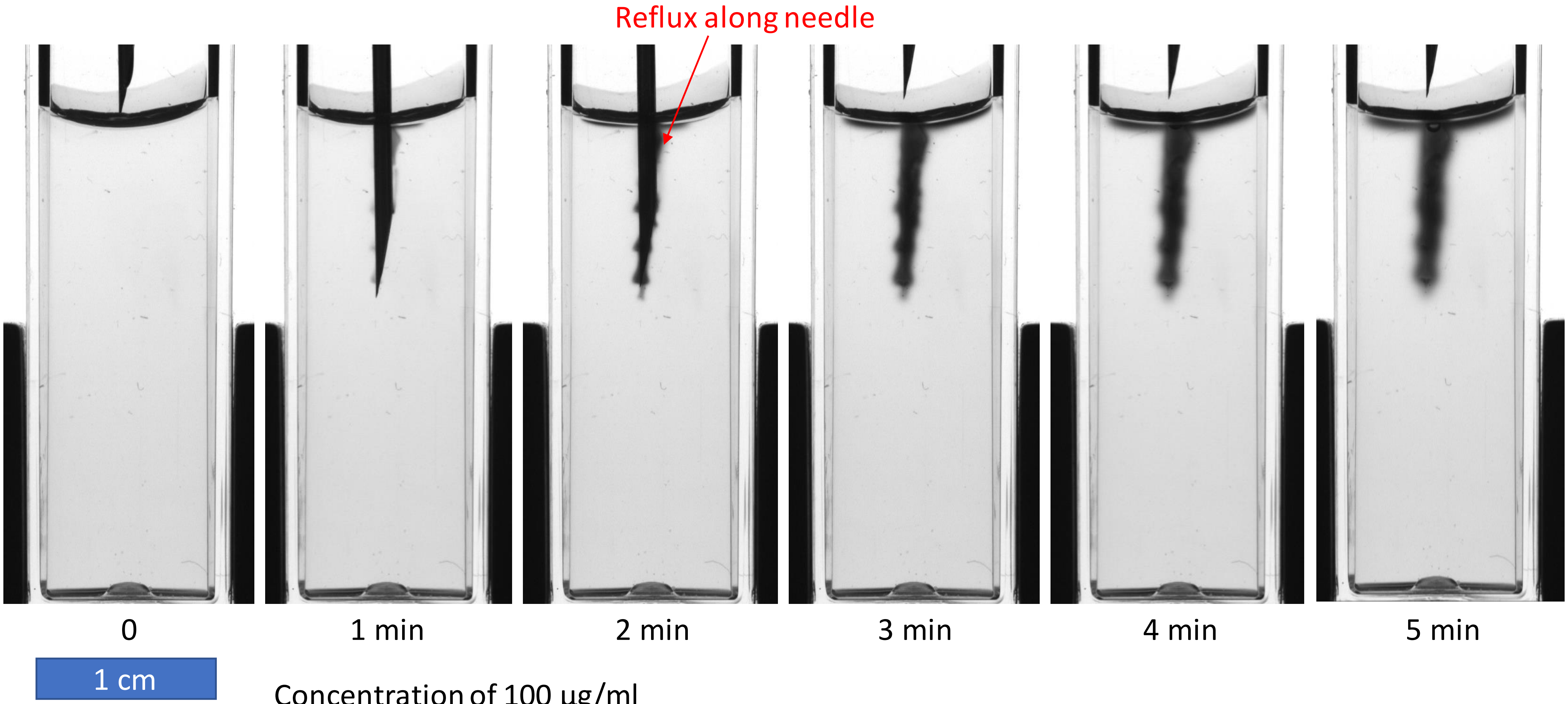


1d diffusion: results

- Apply function fit to the full stack of images
- Function parameters give diffusivity coefficient
- For water, D = 6.7x10^{-6} cm^2/s.



3D diffusion (sharp needle)

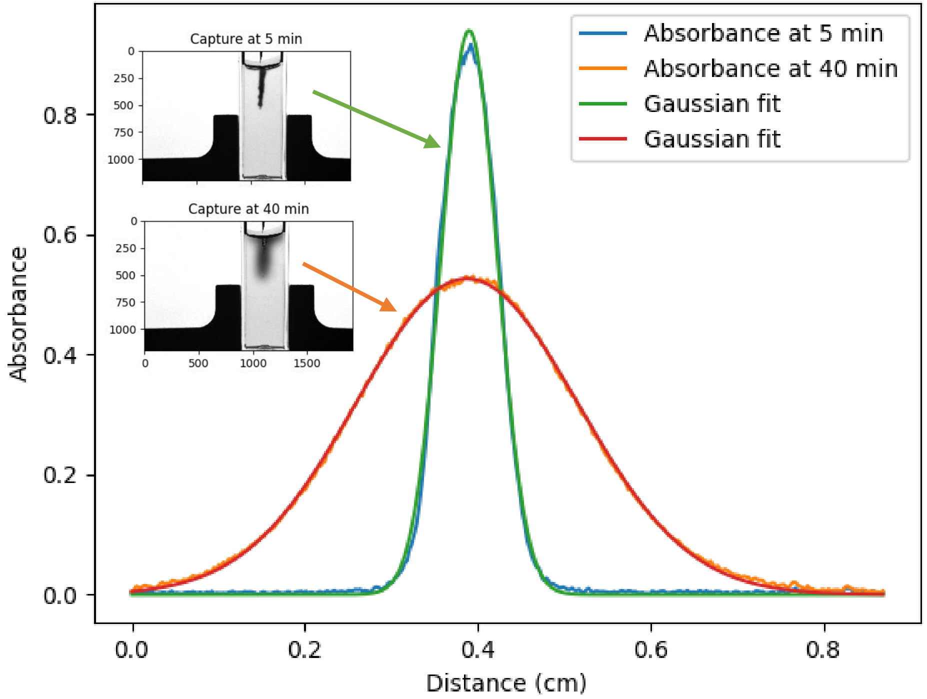


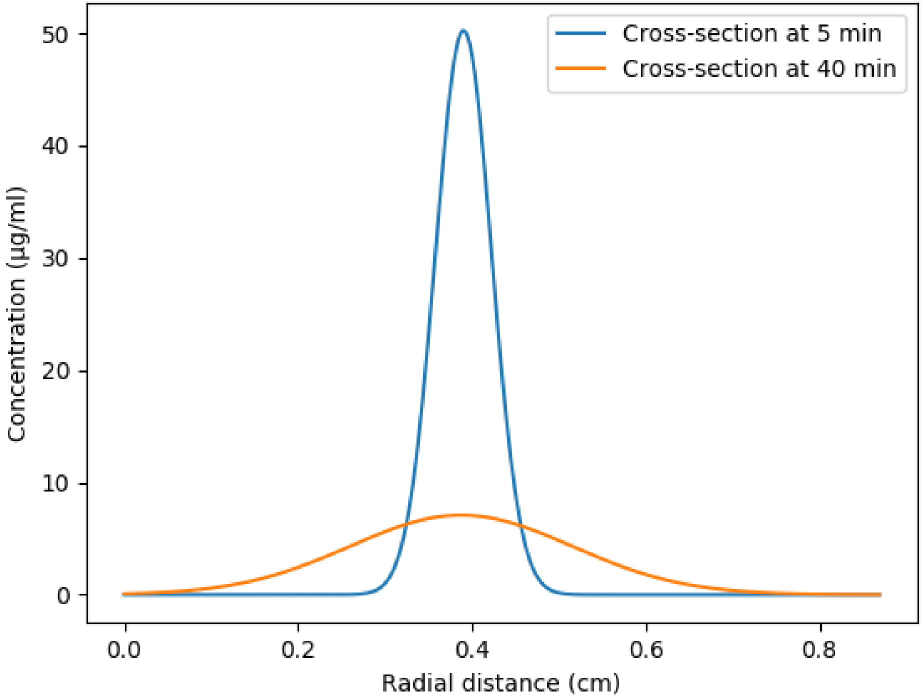
Concentration of 100 µg/ml

Analysis after needle removal

- Axial symmetry assumed
- Projected absorbance of a Gaussian is also a Gaussian

$$A(y) = \varepsilon c_0 \sigma \sqrt{2\pi} e^{-\frac{y^2}{2\sigma^2}} \Longleftrightarrow c(x,y) = c_0 e^{-\frac{x^2+y^2}{2\sigma^2}}$$





Analysis over time

- In Fourier space, diffusion is a Gaussian filter:

$$\hat{c}(\mathbf{k}, t) = \hat{c}(\mathbf{k}, t = 0)e^{-k^2 Dt}$$

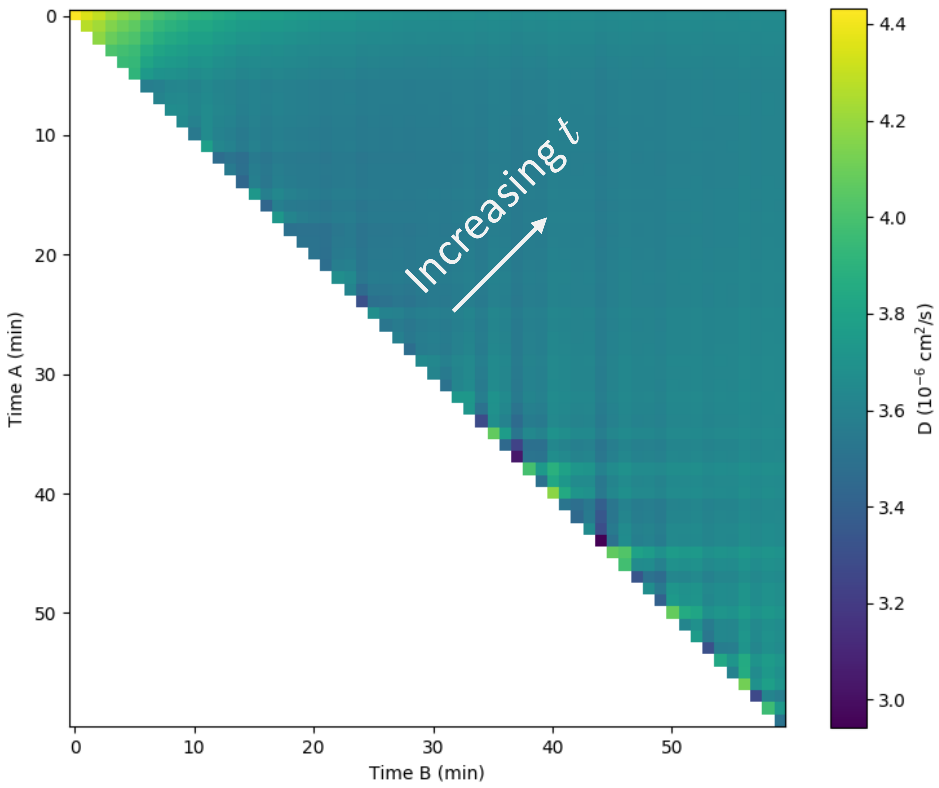
- The Fourier transform of a Gaussian is also a Gaussian, & vice versa:

$$c(x) = c_0 e^{-\frac{x^2}{2\sigma^2}} \;\Rightarrow\; \hat{c}(k) = c_0\sqrt{2\pi\sigma^2}e^{-\frac{\sigma^2}{2}k^2}$$

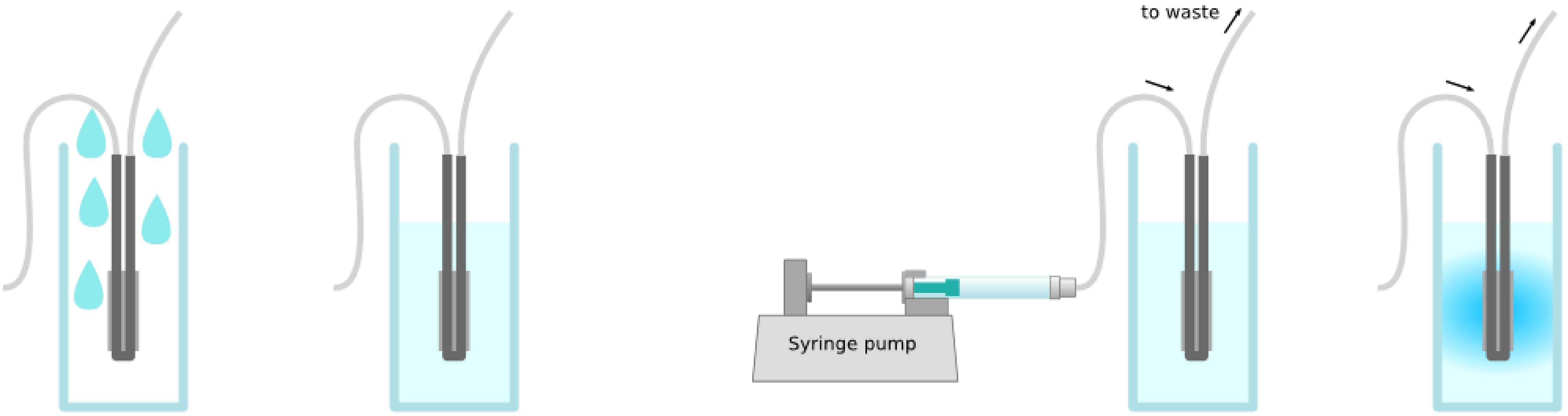
- So, the scale of a diffused Gaussian evolves as:

$$\sigma(t)^2 = \sigma(0)^2 + 2Dt$$

- We can measure the diffusivity D



Diffusion from devices (retrodialysis)

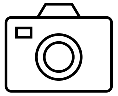


1. Hot gel is poured

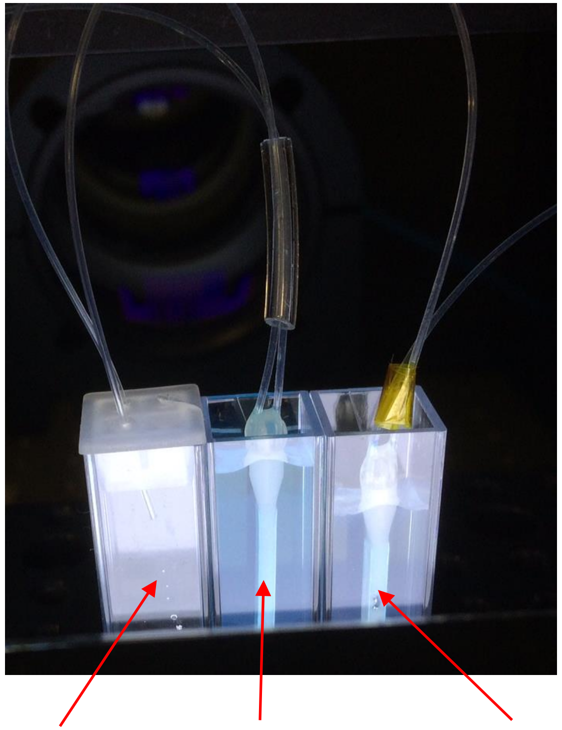
2. Wait 1 hour, then connect to syringe pump

3. Flush with 0.2 mL of MB

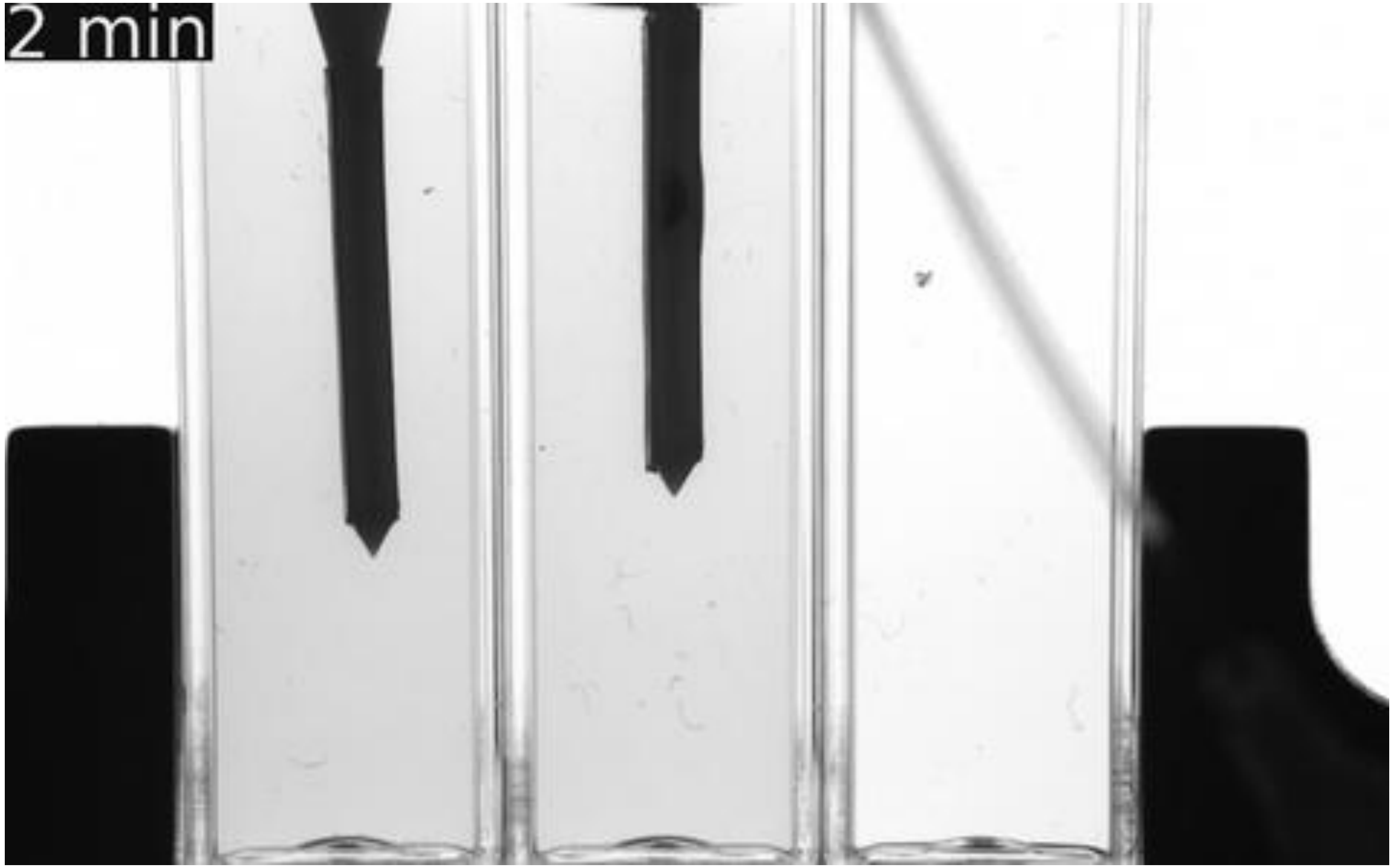
4. Start syringe pump, capture 1 frame/min



Diffusion from devices (retro-dialysis)



waste 1 µL/min No flow



No flow 1 µL/min waste

Concentration map

- De-noising
- Computed tomography assuming axial symmetry

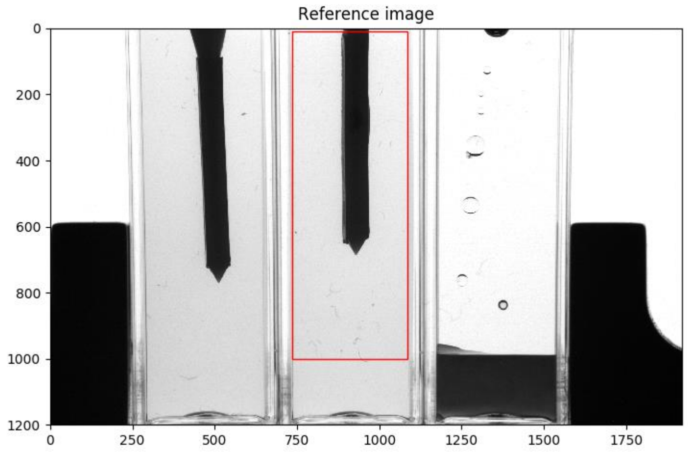
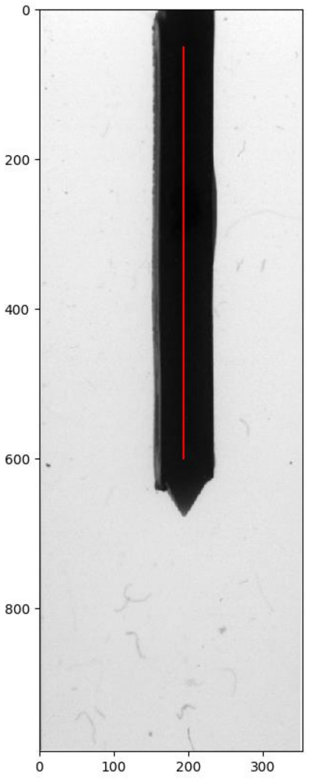
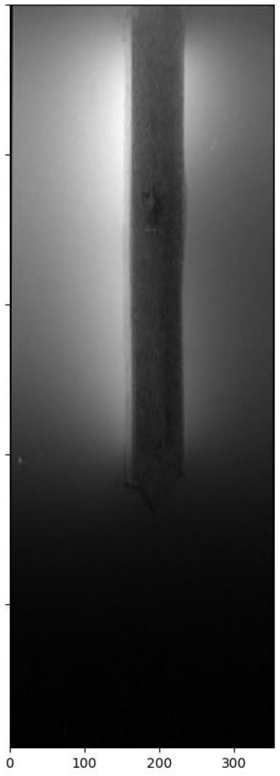


Image extraction

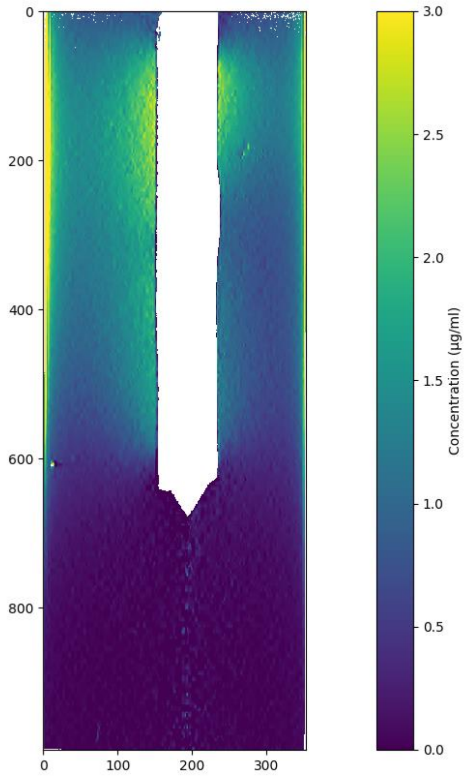


Symmetry axis



Absorbance

After 700 min

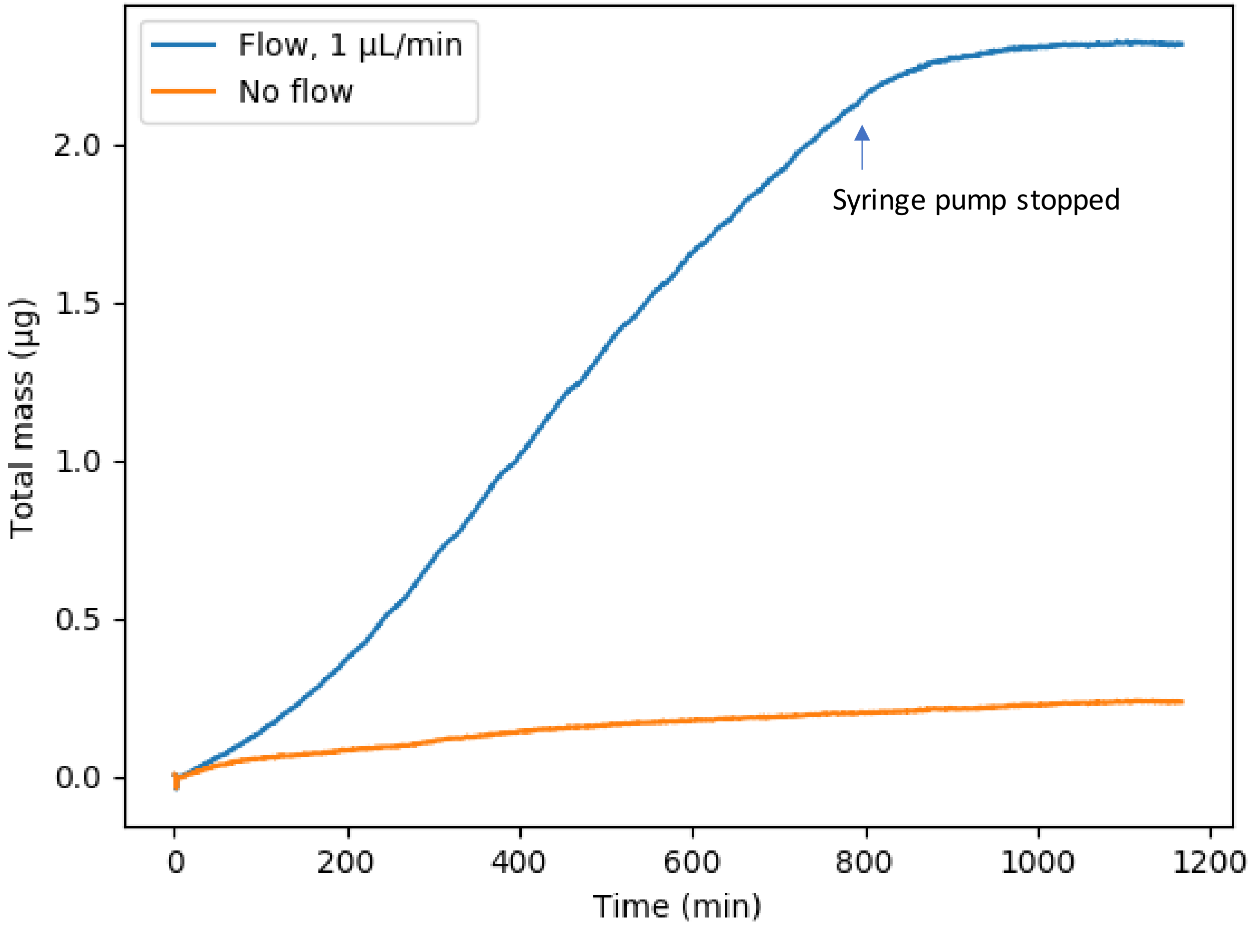


Concentration

Note: inlet at 10 µg/mL

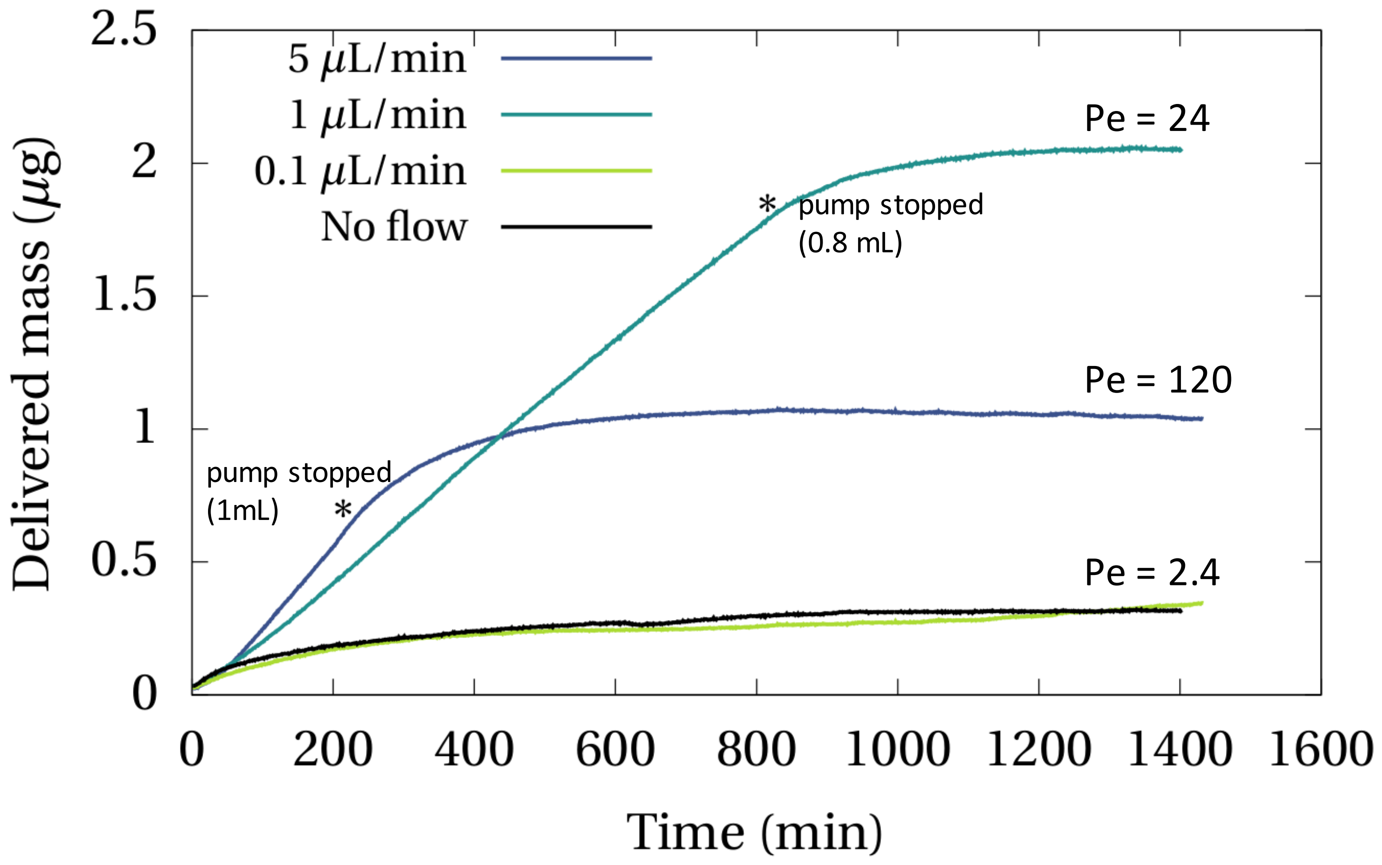
Integrated mass

Sum of absorbance pixels gives the mass of MB in the cuvette (minus probe shadow).

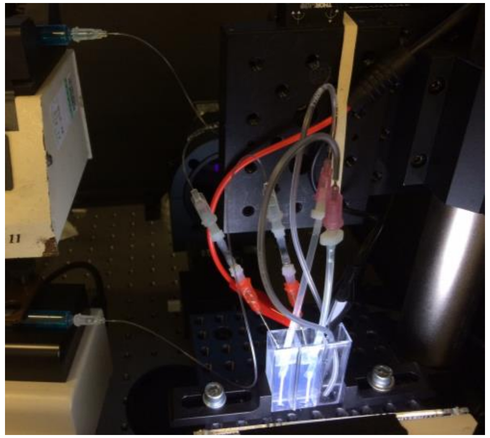


Influence of flow rate

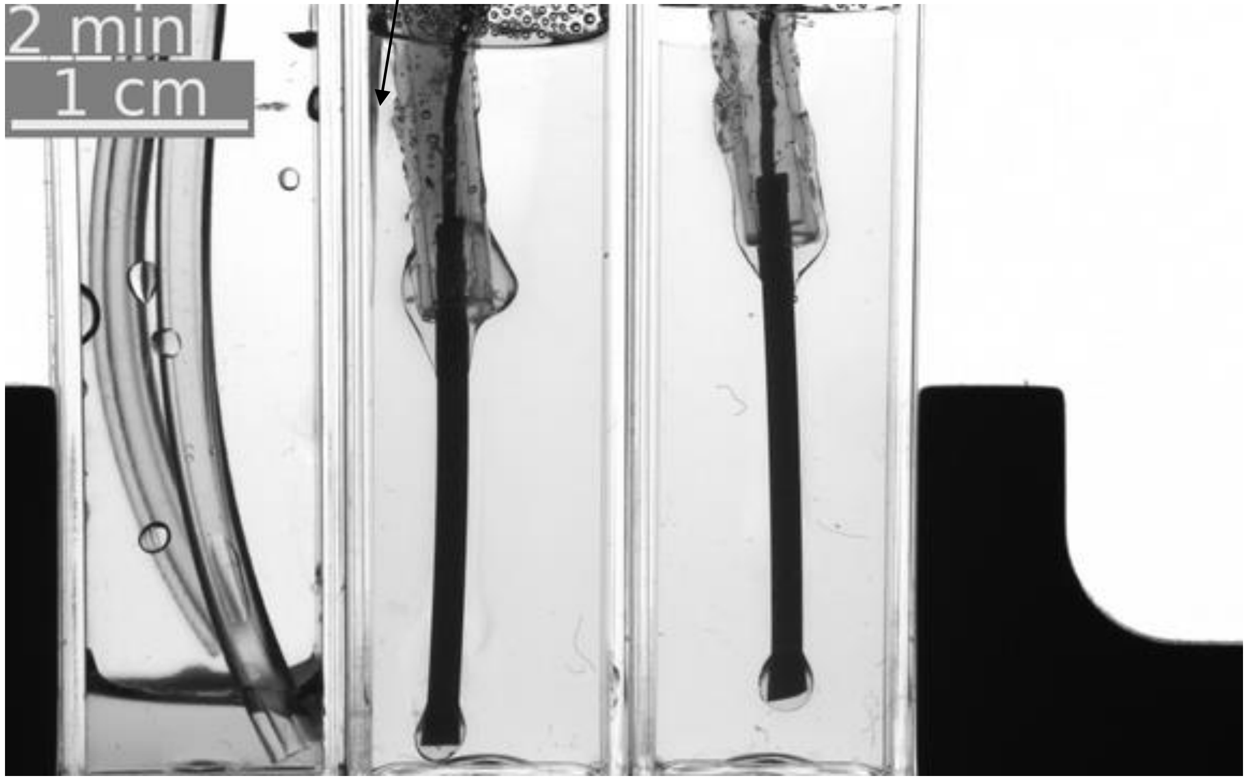
Péclet number in device:
Pe = Flow rate/
(diffusivity*Length)



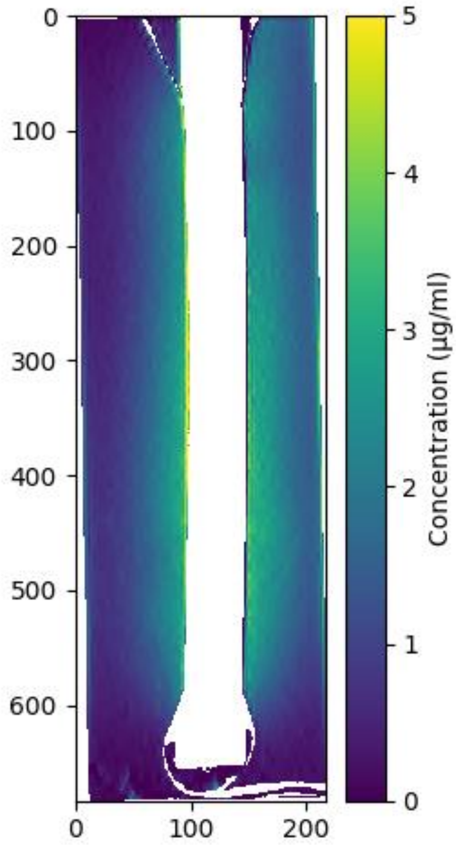
Electrophoretic operation



Platinum
counter-electrode



waste
10 µL/min
1 V DC
No flow (stopped due to leak)
No voltage



Conclusion

Test rig can be used to validate probes in retrodialysis operation

- Accurate concentration fields of MB
- Different flow rates
- Other important parameters: pressure, connectors.
- This will be used to validate models and simulations and feed design iterations.

Current work

- Electrophoretic operation
- DC and AC modes, electrodes considerations.
- Testing of conductive elastomers in gels.

Acknowledgements

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