Practical : Microfluidics and diffusion

Micro and Nano fluidics

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Abstract

The objectives of this practical are to analyze diffusion figures of two miscible liquids (respectively water and water coupling with a dye) in a microfluidic channel (width of 400 um). We first made some theoretical studies on how the diffusion should act within the fluids with respect to Fick's diffusion. First we perform the experiment, and we snap some images with a USB microscope of the diffusion once it is steady. In order to perform image analysis, we use the software ImageJ/Fiji. At different length of the channel, we determine the diffusion length by looking at the mean intensity.Finally, the diffusion coefficient can be computed thanks to Fick's law. It depends on different factors such as the hydraulic resistance of the channel, the density of the water, the hydrostatic pressure drop. After our measurements, we can conclude that the diffusion is indeed occurring in the microchannel and that it respects the expected behaviour of linear diffusion.

Keywords: Microfluidics, Diffusion, Channel, Flow, Dye, Capillary, Chip, Navier-Stokes, Reynolds, Syringe, Valve, Hydraulic Resistance, Pressure drop

1 Introduction

Microfluidics is a fantastic tool to perform many experiments of dynamic fluids at a micro or nanoscale (in case of nanofluidics). It has many uses in microbiology and microtechnology as we can build lab on chips. The main advantages of microfluidics for our experiments are [1]:

- handle small amounts (low costs)
- small detection times
- higher sensitivity

Many applications are coming from these studies such as MEMS (Micro-Electro-Mechanical-Sytems), Bio-Chip, Proteomics/Genomics ...

During these 8 hours of practical at LiPhy, our goal was to do first the fabrication of a PDMS microfluidics chips, first in the clean room and then in a lab. The second challenge was to use our chip to study diffusion in our microchannels chip. The first part will not be discussed in the report. We will focus on the study of the diffusion of the liquid in our chip.

To sum-up briefly what we did, we studied the diffusion of two liquids (one was clear water and one was dyed water) in a T-shaped microchannel. Based on theoretical aspect, we expect to see a specific behaviour of the diffusion of the dye liquid and then determine the diffusion coefficient D of the dye.

2 Materials and Methods

2.1 Materials

First, we have the T-shaped microfluidic PDMS chip that has been made on the first session. As agreed with the lecturer no details will be given on that processes. The Microfluidic chip looks like the one in Fig 1.

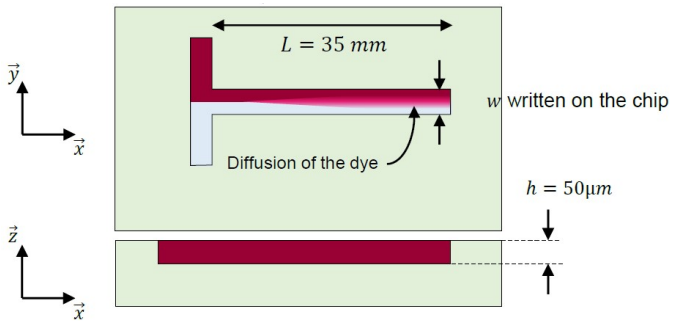


Figure 1: T-shaped microfluidic channel with two inputs and one output. The length L is 35 mm and for our case, h = 50 mm and w = 400 um. Adapted from [2]

Then, the fluidic set-up that is going to be used is made of two 1000 mL measuring cylinders, an adjustable bracket, three large capillaries, three small capillaries that have a length Lc = 35 cm and the diameter is 500 um. We will also need four large plastic syringes. Finally, to connect all these we will use plastic connectors and a three way valve as depicted in Fig 2.

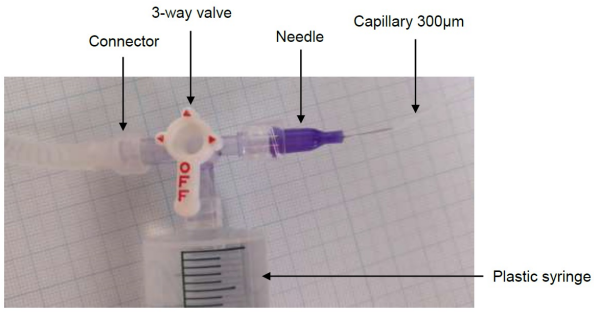


Figure 2: We can clearly see : the connector to connect the large tubes to the valve, the three way-valve that will allow to close one or more channel (depending on what do we want), the needle to adapt to the capillary that will be inserted in the chip. Adapted from [2]

2.2 Methods

Now that we have seen all the needed materials, we will study how to do the set-up for our measurements and then how can we get good data for our further analysis.

2.2.1 The set-up

First thing first, we want to have a flow between the input liquids and the output. Therefore, we will need a pressure difference to get that, a pressure drop. It will then be a Poiseulle flow that will respect the Navier Stokes equation with many hypotheses such as steady flow, laminar flow (Re>1), 2D flow. That pressure difference will be obtained by having a height difference between the two measuring cylinders. This is caused by the hydrostatic pressure. Therefore, by filling the two cylinders with clear water at an approximately same volume, we put the input one on the adjustable bracket higher than the test tube.

Then, on the first input for clear water, we connect a large tube ,that is dipping in the input cylinder, with the three way valve. We connect on the valve to the syringe and by pulling it we fill the tube with water. We force water into the capillaries and air out of them. [2]. We have to be aware that we do not want any air in the tube to not miss our measurements. After that, we do the same with the other input but we will use two valves and two syringes, the first one will be filled with clear water and the second one with 10 mL of dye. We use this technique in order to fill the input tube with water (again we have to avoid the air bubbles).

Once this is done we connect the valves with the needles and the capillaries and once the capillaries are filled with liquid we insert them with care inside the chip.At this moment, we open the valves, so the liquid can go through. We are waiting until we observe a drop of liquid at the output. Once this is observed, we connect the output capillary that will directly link to the output cylinder. (Before that we did the same setup at the output will the syringe and the tube full of water). There is a scheme of the set-up on Fig 3 and the actual one on Fig 11.

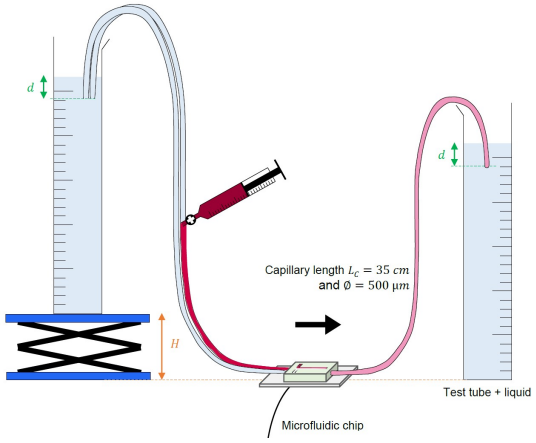


Figure 3: This is the set-up as described with the tubes, the syringe, the cylinders, and the chip. Adapted from [2]

2.2.2 Image recording

To do the image recording, we have a camera / microscope that is really useful as we only need to plug it on our laptop and open the software Plugable Digital Viewer [3] that is free. Then, by adjusting the focus we can take several snapshots of the chip to analyse them later.

3 Results and Discussion

3.1 Theoretical expectations

The final goal of this practical is to determine the diffusion property of the experiment; the diffusion coefficient. To obtain this result, many steps are needed. First and foremost, we recall what is the Fick's law with the diffusing species concentration C:

$$\frac{\partial C}{\partial t} = D \cdot \frac{\partial^2 C}{\partial x^2} \tag{1}$$

If we do a dimensional equation with Ld the diffusion distance, and T the time we obtain the following equation :

$$\frac{C}{T} = D\frac{C}{Ld^2} \tag{2}$$

so at the end we will obtain :

$$Ld = \sqrt{D \cdot T} \tag{3}$$

By analyzing the images we will obtain Ld but how can we obtain T ? We have X the distance that is travelled by the fluid in a certain amount a time. What is the relation between this distance and the time. We also know the speed of the fluid that is V. Therefore :

$$\Delta t = \frac{\Delta x}{V} = \frac{\Delta X \cdot S}{Q} \tag{4}$$

Q is the flow rate per surface [m3/s] and S is the surface [m2]. Then, an analogy with the Ohm's law, we obtain that:

$$Q = \frac{\Delta P}{Rh} = \frac{\rho \cdot g \cdot \Delta z}{Rh} \tag{5}$$

Indeed here is the analogy with the electrical circuit. Fig 4 and the zoom on Rh on Fig 5.

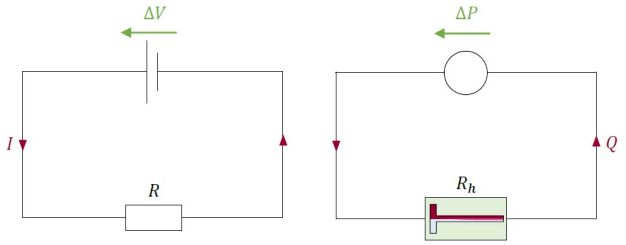


Figure 4: Analogy of the pressure circuit with the electrical one. Adapted from [2]

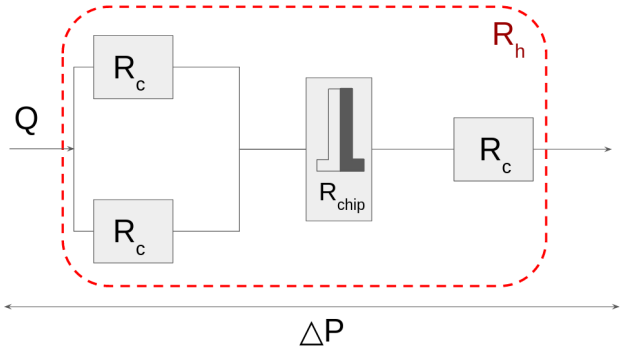


Figure 5: Zoom on the hydraulic resistance.

Rh is the hydraulic resistance that we can be obtained by doing the sum of the input capillaries resistances, the resistance of the chip and the ouput capillary resistance. Rc is the resistance of the capillary and Rchip is the resistance of the chip.

$$Rh = \frac{3 \cdot Rc}{2} + Rchip \tag{6}$$

We calculate Rc and Rchip with the following formulas, Fig 6.

Here are the numerical values :

$$Rcap = 228 \cdot 10^9 Pa.s/m^3 \tag{7}$$

$$Rchip = 9.12 \cdot 10^9 kPa.s/m^3 \tag{8}$$

$$Rh = 9.46 \cdot 10^9 kPa.s/m^3 \tag{9}$$

Therefore, we have the final equation:

$$\Delta t = \frac{\Delta X \cdot h \cdot w \cdot Rh}{\rho \cdot g \cdot \Delta z} \tag{10}$$

Now we have to do the image analysis to measure X and Ld.

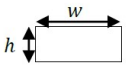
CHANNEL SHAPE		EXPRESSION OF R_h
Round		$R_h = \frac{8\,\mu\,L_C}{\pi a^4}$
Rectangle		$R_h = \frac{12\,\mu\,L_C}{wh^3(1-0.63\,h/w)}$

Figure 6: The formulas to calculate Rc and Rchip. Adapted from [2]

3.2 Image analysis

For the image analysis, we use the software **ImageJ/FiJi** [4]. More images can be found in the appendix. However, the basic principle of the measurement is to process the image with the right contrast / brightness. Then we measure the Ld at a certain DX.

3.2.1 Protocol

First, we take the raw image that we obtained with the USB microscope. Then we rotate it so the angle of the channel is zero. We scale the image (nb of pixels / mm). Then we transform it in a 16 bit image and we raise the contrast to observe in a better way the boundary of the fluid diffusion. We obtain an image like the one in Fig 7.

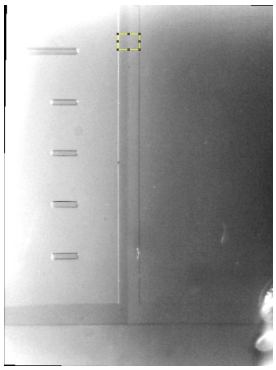


Figure 7: The microfluidic channel seen under the microscope and after the contrast processing.

Then we select at the desired Dx a square countaining the channel and we can do the mean intensity of it. This is shown on Fig 8.

Finally, we obtain the intensity regarded with the distance to the channel. To know what is the boundary of the diffusion we select the distance where we have the strongest derivative (the steepest change). This is in Fig 9.

3.2.2 Plot and Regression

In Excel, we make a tab with the value of dX and the value of the corresponding Ld. Then we calcule dt for each

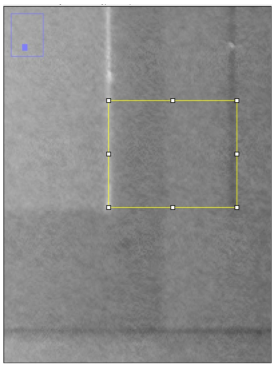


Figure 8: Selection of a square to plot the value of the section pixels.

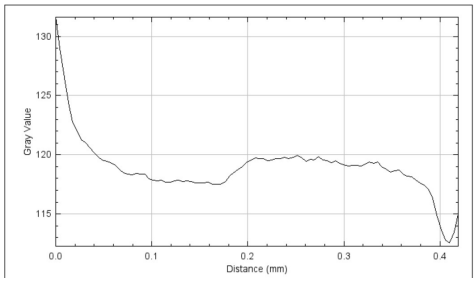


Figure 9: The section pixels intensity compared with the width of the microchannel.

dt and we plot Ldsquare = f(dt). Finally, we apply the linear regression on it. The final result is the curve in Fig 10.

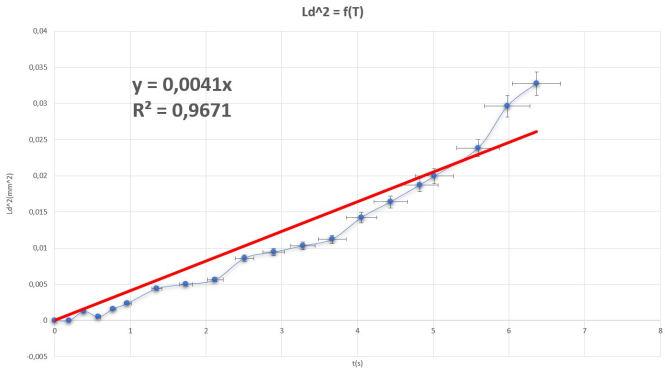


Figure 10: The plot with its regression.

3.3 Discussion

We can observe on the graph that the diffusion process has indeed a linear behaviour. The linear regression gave:

$$Ld^2 = 0,0041 \cdot \Delta t \tag{11}$$

$$D = 0,0041 \frac{mm^2}{s} \tag{12}$$

$$R^2 = 0,9671 \tag{13}$$

The R2 is quite high that is enjoyable. However, we can wonder what are the uncertainties that have a strong impact on our measurements.

- From the chip : the width of the microchannel (in the fabrication process), to neglect some resistances (the ones from the valves), the hydrostatic pressure value.
- From the image analysis: to determine the diffusion boundary (which point should we select, which rule do we apply when there is the swap), the contrast, the scale.

To illustrate that, we did not proceed to an uncertainty propagation, but we consider that there should be a difference of at least 5 percent. This trend is therefore illustrated with error bars in Fig 10.

Concerning the value of the diffusion coefficient. We found that the self-diffusion of neat water is [5] :

$$D = 2,299 \cdot 10^{-}9m^2 \cdot s^{-}1 \tag{14}$$

. Our D is relatively close to this value considering the uncertainty and the linear regression.

4 Conclusion

To conclude, we built a set-up so that there is a pressure drop between the two cylinders. This pressure drop will induce a flow in the chip, a Poiseuille flow (pressure gradient). The fluid inside the channel follows the Navier Stokes equation with a laminar behaviour and also a steady one. We inject in the chip two fluids : water with a dye and water without a dye. According to Fick's equation we manage with image analysis to determine the diffusion coefficient of the dye.
To sum-up, it is a nice experiment, but it is a little hard to put in place and there are many aspects that one cannot control, so we have uncertainties that have at the end with the propagation a big influence on our measurements.

References

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[2] Cramail, Caroline: *Microfluidics and diffusion practical booklet.* 2022.
[3] Plugable: *Plugable digital viewer free software, windows.* https://plugable.com/pages/microscope-drivers, 2022.
[4] ImageJ: *Image processing and analysis in java.* https://imagej.nih.gov/ij/download.html, 2022.
[5] Wikipedia: *Molecular diffusion.* https://en.wikipedia.org/wiki/Molecular$_diffusion$, 2022.

A Some more images

Figure 11: The set-up as it actually looks in the lab. Adapted from [2]

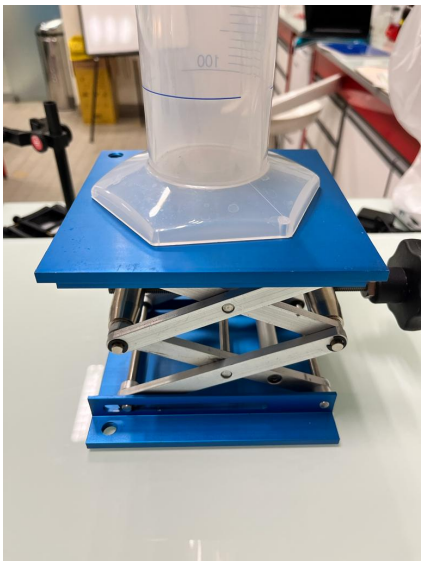

Figure 12: The adjustable bracket where we put one of the cylinder to have the height difference, the pressure drop.