Master Thesis Experiment Report VII : Looping System

Jérémie Guy

November 24, 2024

Abstract

Changing the system into a loop

1 Context

After adding an acceleration field instead of a constant imposing of velocity given by Zou-He, we want to make the system cyclic.

2 Description

We changed the system so that the fluid goes into a closed loop as illustrated in Figure 1. The acceleration field (illustrated by the yellow box) adds at every iteration a constant force $F = [Fx, Fy]$ to the PDFs. All walls of the system are bounceback nodes as is the central obstacle.

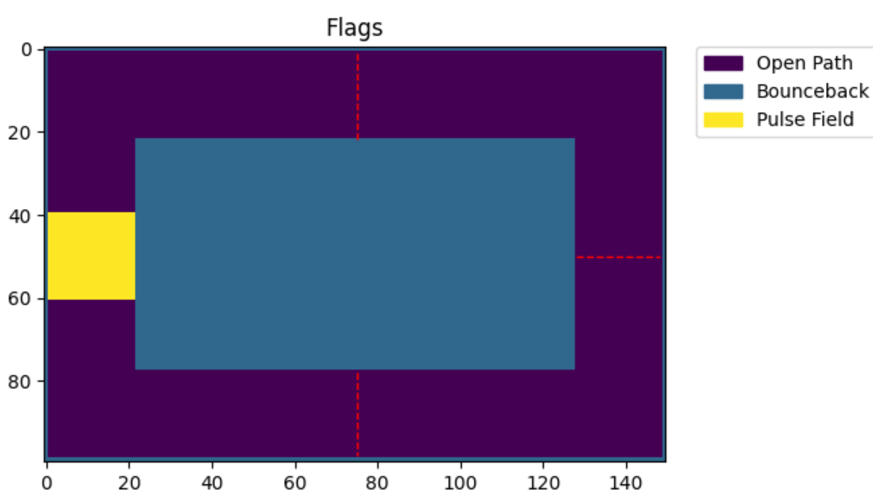

Figure 1: Looping system. Note : the red dotted lines are the sites were we will measure the velocity profiles

3 Experiments

3.1 Experiment 1

3.1.1 Description

We implemented the new geometry on a small 150x100 system, with each tube diameter being 21. F is set as $F = [0, 0.0001]$, which implies that only a vertical acceleration is applied to the PDFs. We set the viscosity as $\nu = 0.01$ and the initial density as $\rho = 2.5$ and let the simulation run for 50'000 iterations.

3.1.2 Results

The results are illustrated in Figure 2. As shown in Figure 1 the three velocity profiles have been taken in order from : the top horizontal tube, the right vertical tube and the bottom horizontal tube.

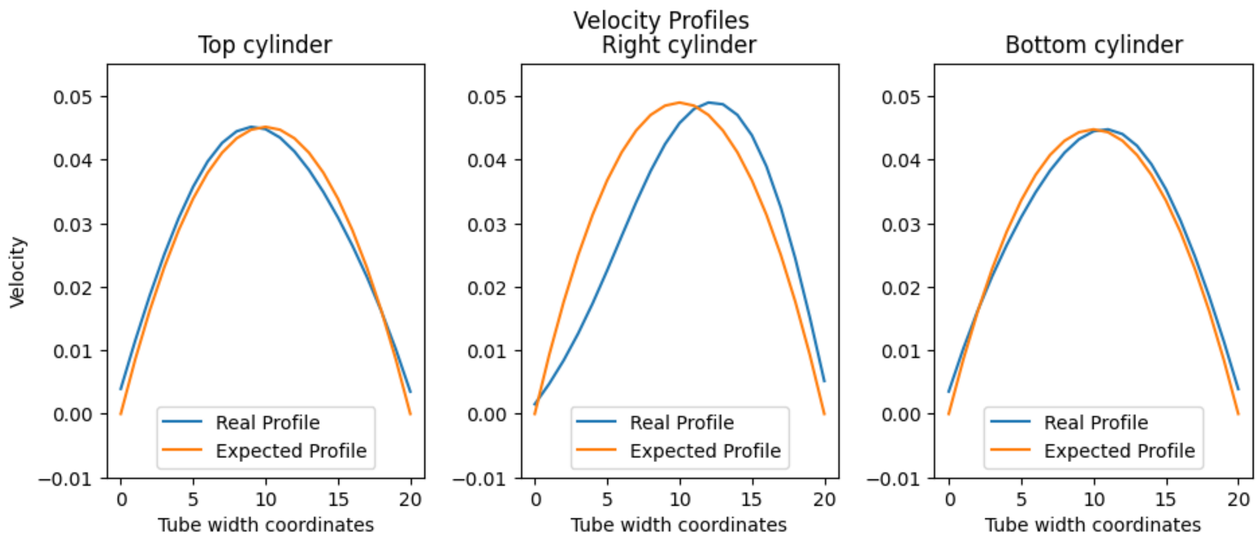

Figure 2: Velocity profiles of the top, right and bottom cylinder

As expected, the three profiles converge to Poiseuille's form. The right cylinder is however slightly shifted and has a bit more velocity as compared with the two others : this could be a side effect of the geometry taken with the chosen dimension of 150x100. We will test this theory in the next experiment.

3.2 Experiment 2

3.2.1 Description

We tested the same method using this time a bigger square system of dimension 200x200 as illustrated in Figure 3. The simulation runs for 30'000 iterations with the exact same parameters as before. The velocity profiles are measures in the same places as the previous system as Figure 3 shows.

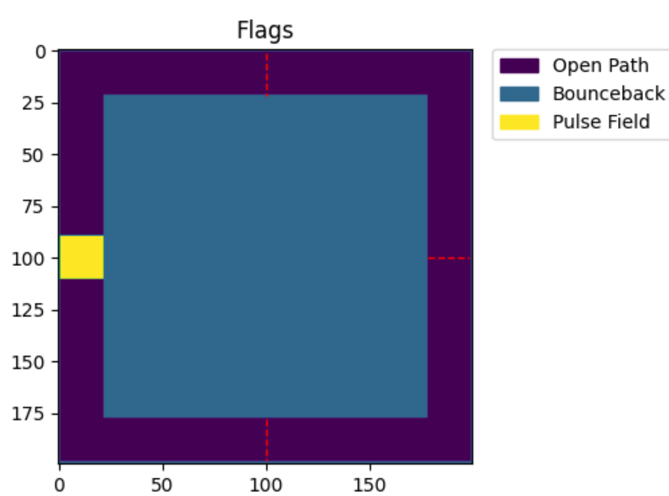

Figure 3: Square system

3.2.2 Results

Figure 4 shows the results. As we expected, all the velocity profiles now converge to a correct Poiseuille flow. This implies that for the fluid to flow correctly, some precautions on the size and shape of the system have to be taken.

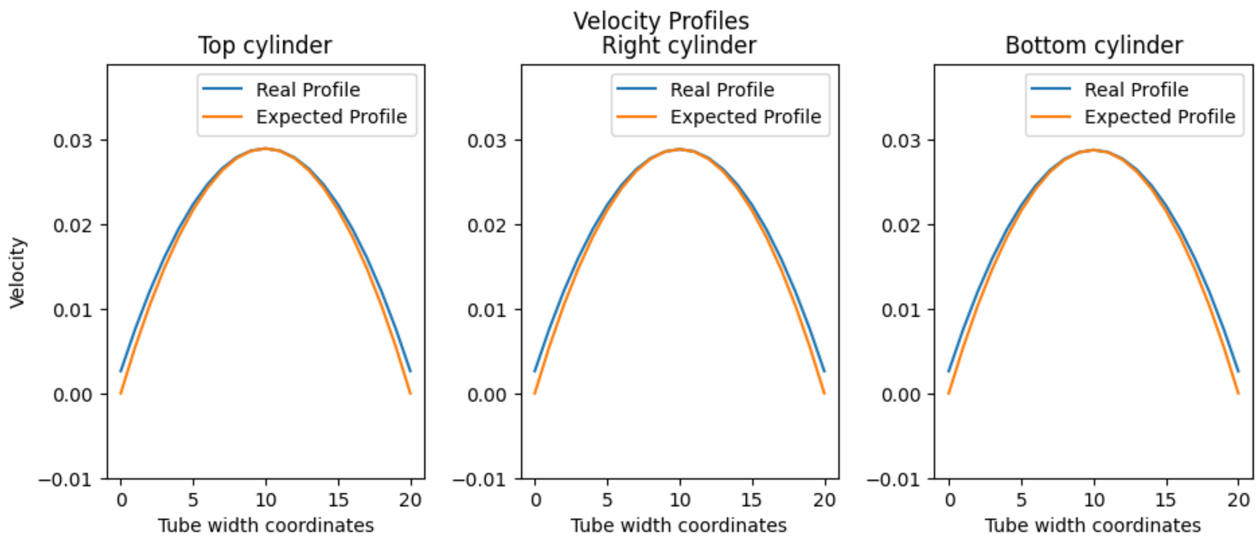

Figure 4: Velocity profiles of the top, right and bottom cylinder

3.3 Experiment 3

3.3.1 Description

For the next experiment, we added a clot in the upper tube of the system as illustrated in Figure 5. The representation on the figure is the same as before, with this time only two velocity profiles measured. The parameters are the same as the previous experiment expect the acceleration force: we changed F to $F = [0, -0.0001]$ so that the fluid flows upwards and reaches the clot faster to make the system converge faster. We let the simulation run for 30'000 iterations.

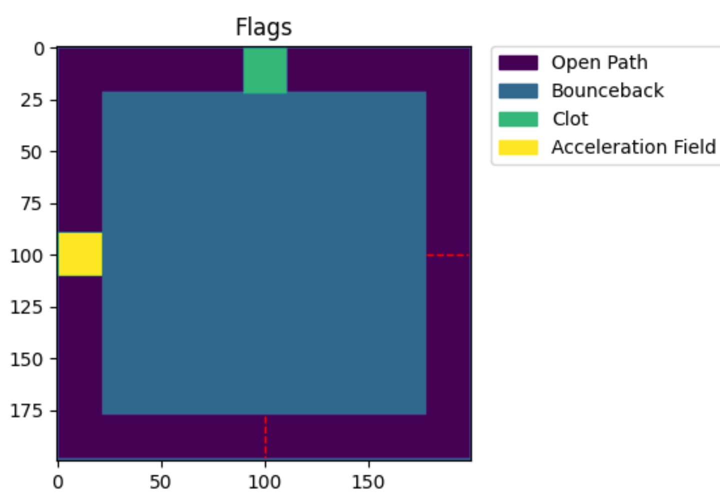

Figure 5: Square System with a clot in the upper tube section

3.3.2 Results

The velocity profiles are illustrated in Figure 6. The system converged at approx. 15'000 iterations and the results displayed are from the last iteration. We can see that both profiles have the expected Poiseuille's parabola. Next the graphics shown in Figure 7 are in order : the full system's velocity norm, the mean of each vertical slice of the velocity on the section determined by the red dotted lines, the mean of each vertical slice of the density on the same section and finally the flow obtained by multiplying the velocity and density $flow(x) = u(x) * \rho(x)$. The blue dotted lines represent the clot.

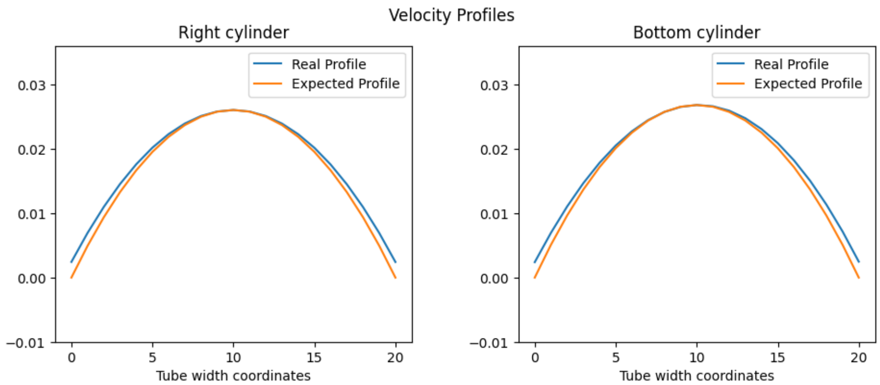

Figure 6: Velocity Profiles for a square system, with a clot

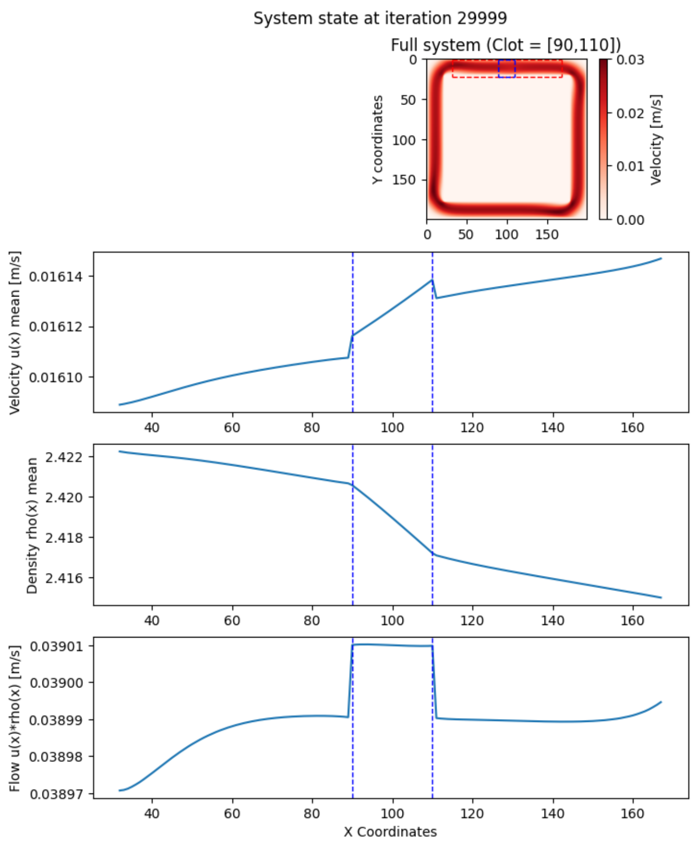

Figure 7: Clot velocity, density and flow for a square system with clot

On Figure 7 we can see that inside the clot the velocity is slightly increasing while the density is slightly decreasing, making the flow constant with a precision of $1e-4$: those are the expected results which follow, at the very least visually, Darcy's law on porous media. We can notice a decrease of the flow on the extremities of the surveilled tube section : this is a direct consequence of the geometry. The fluid does not have enough space to fully become linear inside each of the straight tube sections. To assess if the theory is correct, we will run the same experiment on a rectangular system.

3.4 Experiment 4

3.4.1 Description

As mentioned above, we will change the system into a rectangle of dimension 260x200, as illustrated in Figure 8. The system being bigger, it converges slower so we increased the iterations to 50'000.

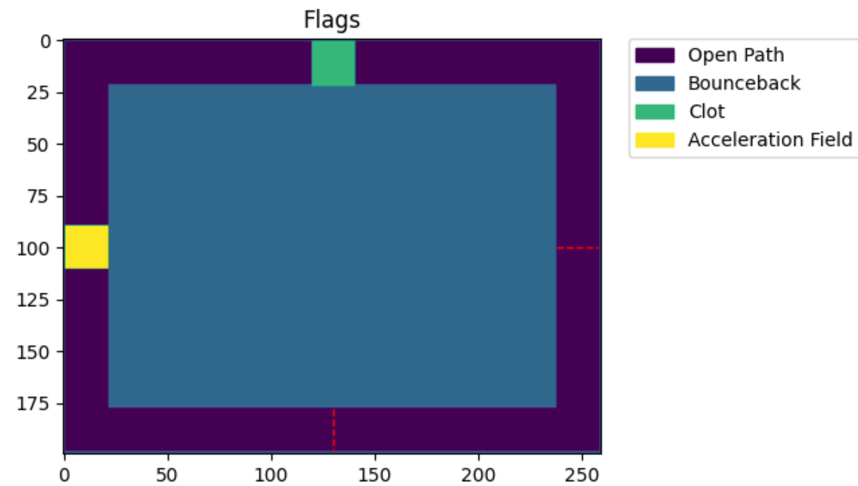

Figure 8: Rectangular system with a clot in the upper tube section

3.4.2 Results

We can see in Figure 9 that the velocity profiles are once again following Poiseuille's flow curve. On the clot velocity, density and flow illustrated in Figure 10, we can see that the dropping effect mentioned above is less significant and further away from the clot : this certifies that the previous drops are a side effect of the topology.

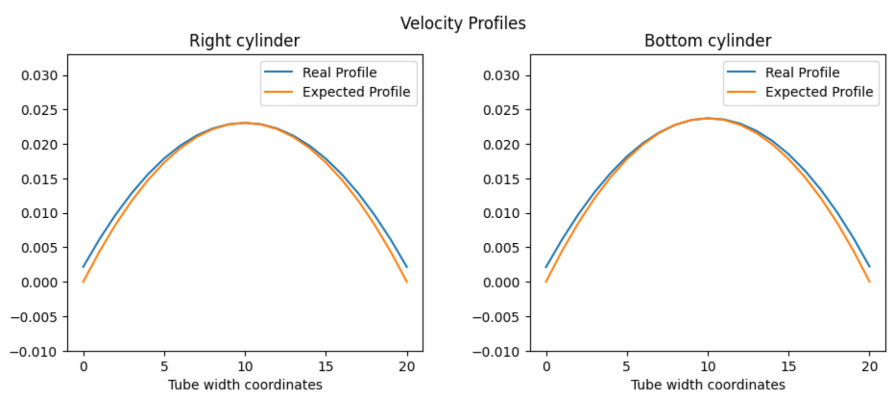

Figure 9: Velocity Profile for a rectangular system, with a clot

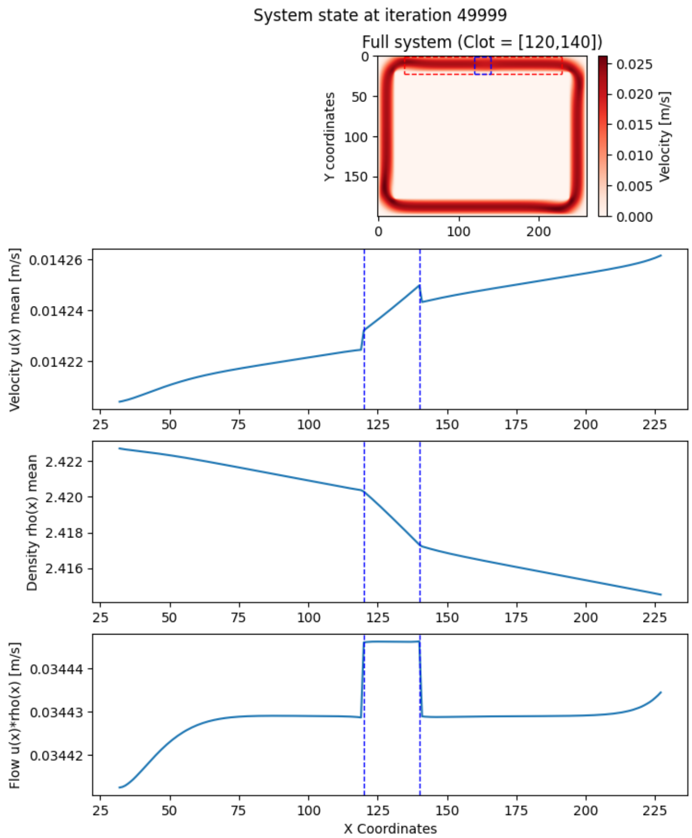

Figure 10: Clot velocity, density and flow for a rectangular system with clot

3.5 Experiment 5

3.5.1 Description

The next step we implemented is adding a branch to the system: before the clot, we want to add another unobstructed tube to asses the behavior of the fluid with a branching system partially blocked by a porous media. Figure 11 shows the topology of the system.

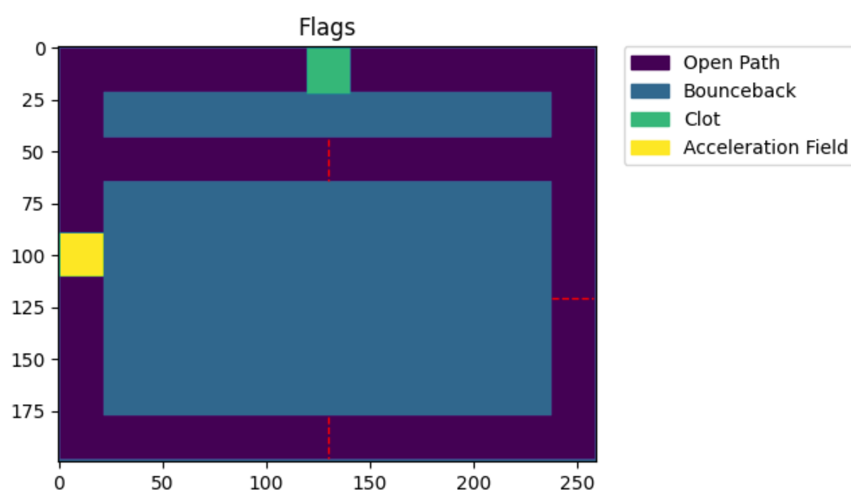

Figure 11: Rectangular branching system with a clot in the upper tube section

To assess the behavior, we run the simulation with the same parameters as described before and let it run over 70'000 iterations.

3.5.2 Results

As the system is less linear, the convergence occurred around 40'000 iterations. The velocity profiles displayed in Figure 12 each follow Poiseuille's parabola. The maximum velocity measured in the branch is smaller than the two other ones : as the fluid divides into two sections, we can expect the total momentum to be also divided, which then implies a reduced velocity.

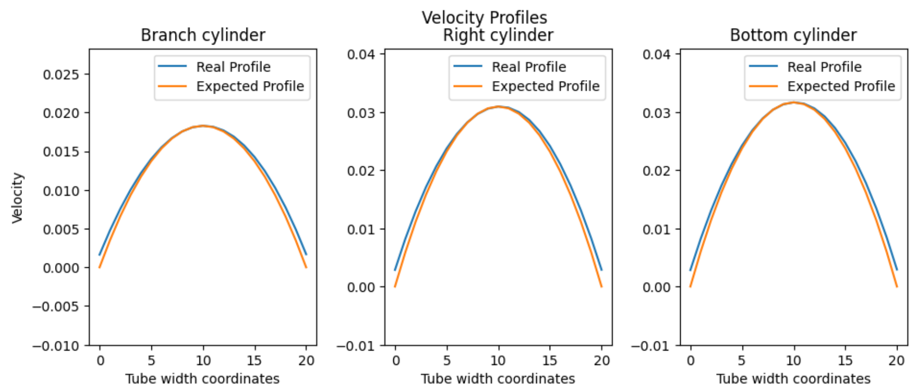

Figure 12: Velocity Profile for a rectangular branching system, with a clot

The results shown in Figure 13 show once again the expected results : a slight increase in velocity inside the porous media coupled with a slight decrease in density which results in a constant (with a precision of $1e-4$) flow.

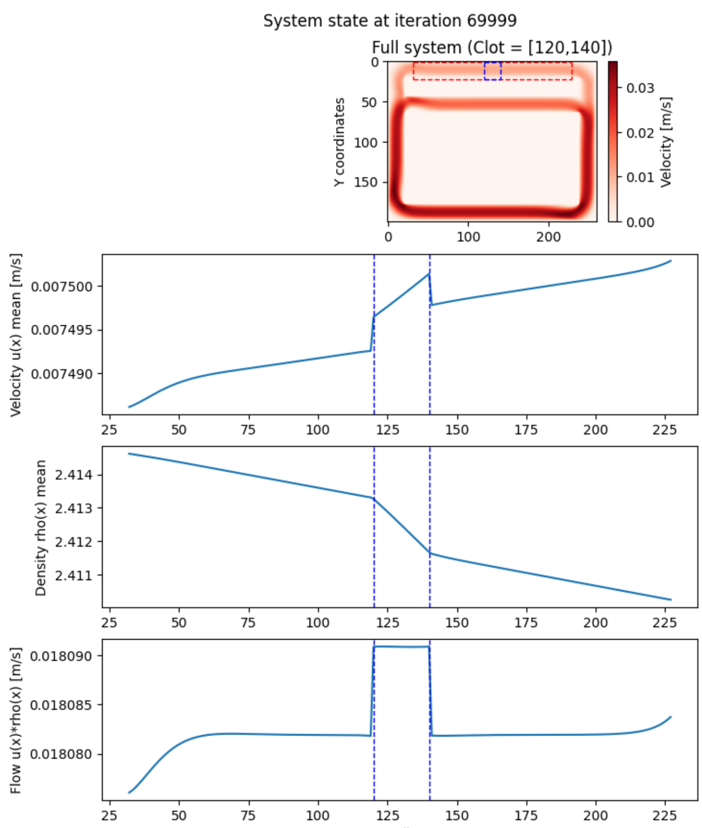

Figure 13: Clot velocity, density and flow for a rectangular branching system with clot

3.6 Experiment 6

3.6.1 Description

The simulation above displayed satisfactory results. However, two slight mistakes have been made in the implementation: first, the force field was applied wrongly: instead of applying like classical mechanical physics using $u(x,t) = u(x,t-1) + a * t$ where $u(x,t)$ is the velocity at position x and time t, and a the acceleration, we need to instead equilibrate the PDFS of fout. Secondly, the accelerating force was applied to the whole system instead of just the acceleration field (described as a yellow box in the figures above).

We corrected both of the errors : now the accelerating field is only applied by adding PDFs to fout in a specific area. Moreover, we did a complete clean up of the code, removing some testing parameters such as having an initialization to 0 for ρ, fin and fout for the bounceback nodes, and came back to a simple code which encapsulates more the core of lattice Boltzmann.

To test the result of the modifications we run the simulation through 55'000 iterations with the exact same parameters as stated in the previous experiments. The only difference is that we tested three different K values: $K = [0.001, 0.001]$, $K = [0.01, 0.01]$ and $K = [0, 0]$ (which translates to no clot). Note : we also made K have an effect in both directions, as we expect the fluid inside the porous media to flow in every direction and will thus find resistance in all of them, not only in the x direction as we did previously.

The system used for this experiment illustrated in Figure 14 is the same as the previous experiment, although with a slight correction on the clot's coordinates for it to fit better inside the tube.

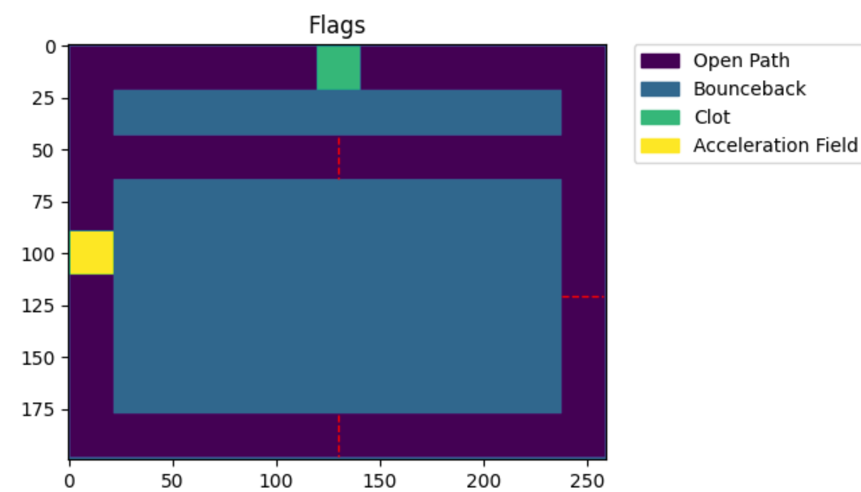

Figure 14: Rectangular branching system with a clot in the upper tube section

The velocity profiles, u and ρ will be measured in the same way and same places as before.

3.6.2 $K = [0.001, 0.001]$

Figure 16 shows the velocity profiles obtained for $K = [0.001, 0.001]$. The Profiles are as we expected, following Poiseuille's parabola. The flow illustrated in Figure 16 shows even more satisfactory results : the slight deviation we had on the edge of the measured area completely disappeared, resulting in a nice and steady flow (with a precision of $1e-6$, which is better than before).

3.6.3 $K = [0.01, 0.01]$

The velocity profiles shown in Figure 17 confirm that the fluid flows normally and in the expected way. Figure 18 shows also a correct flow. As we can observe, the flow has decreased compared to the

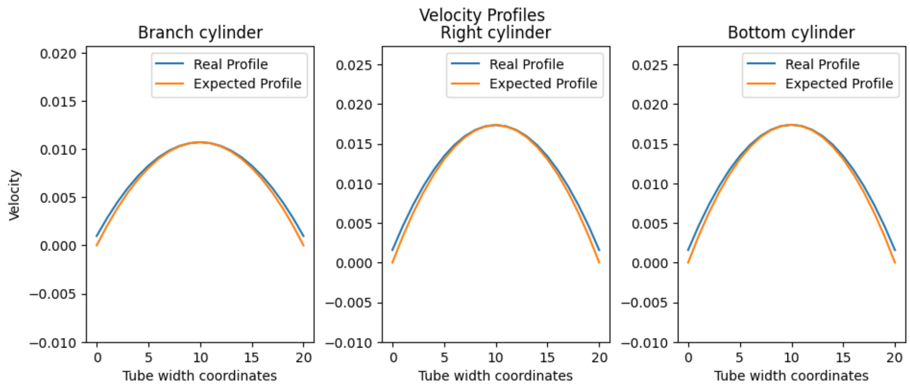

Figure 15: Velocity Profile for a rectangular branching system, with a clot, K = [0.001,0.001]

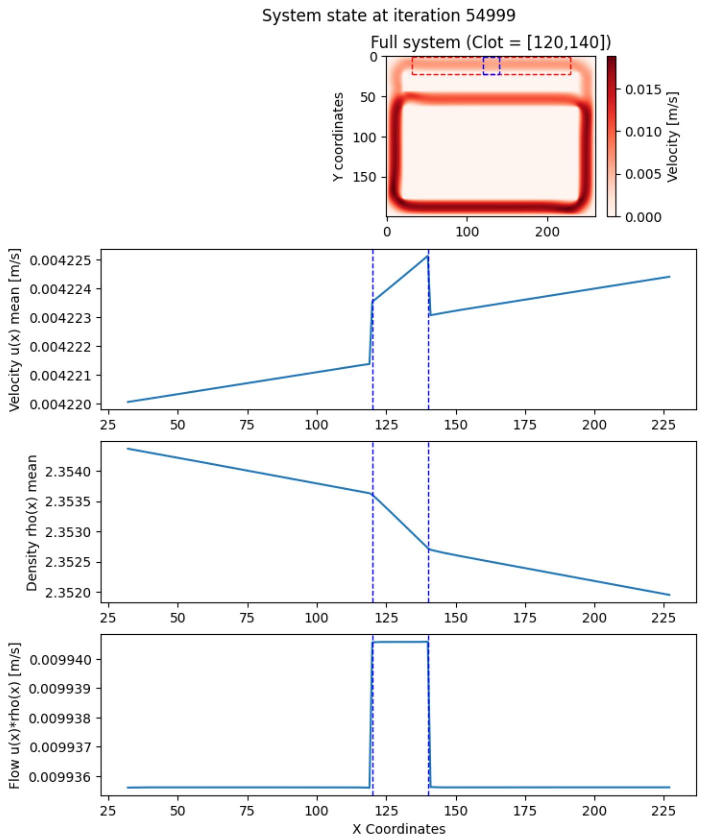

Figure 16: Clot velocity, density and flow for a rectangular branching system with clot, K = [0.001,0.001]

previous test as this time the resistance of the clot is higher which results in less momentum for the PDFs and thus less flow. This confirms that the system functions correctly.

3.6.4 $K = [0, 0]$

Figure 19 shows that the velocity profiles are pretty much as we expected. We can notice that the maximum velocity measured inside the lower branch of the bifurcation is equal to 2/3 of the total velocity : this is once again a direct consequence of the geometry. As when the system divides, the majority of the PDFS go into the first branch they encounter(lower top tube) and the rest goes into the second. To have exactly half the total velocity, we would need to have the both branches starting

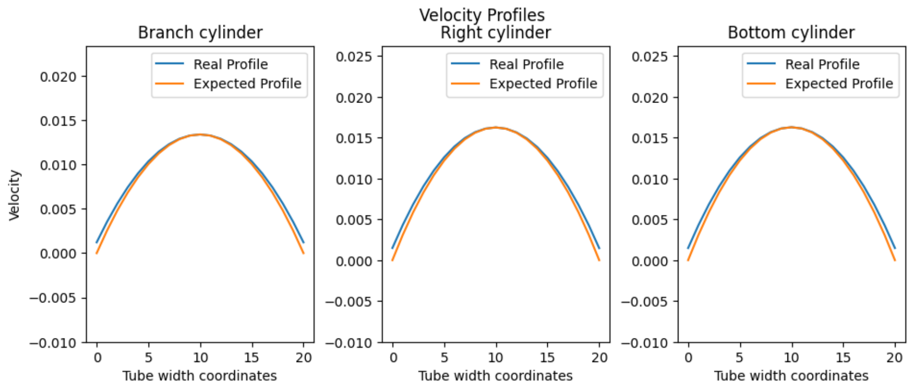

Figure 17: Velocity Profile for a rectangular branching system, with a clot, K = [0.01,0.01]

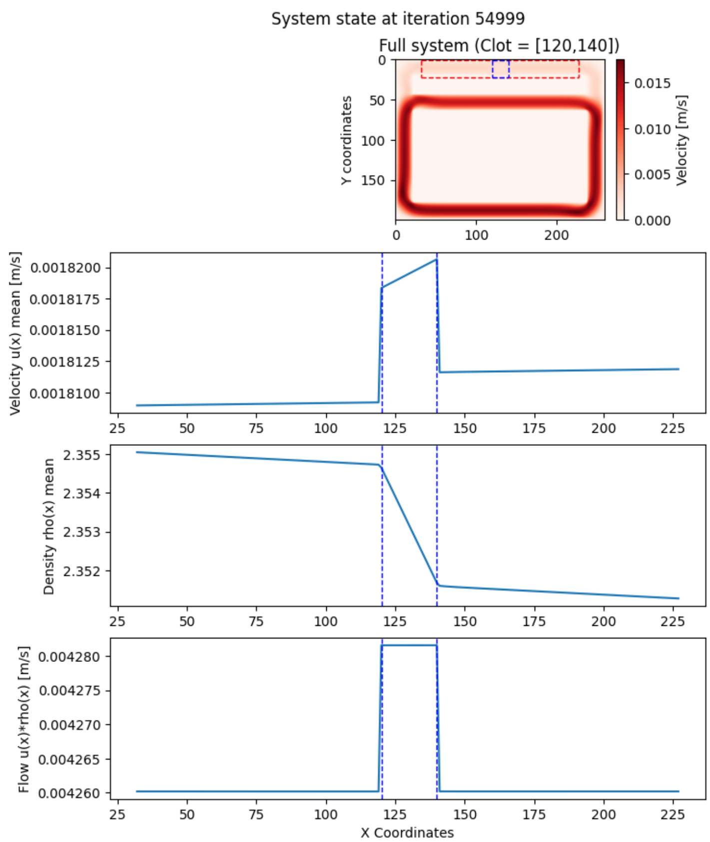

Figure 18: Clot velocity, density and flow for a rectangular branching system with clot, K = [0.01,0.01]

at the intersection. The flow shown in Figure 20 is satisfactory, it's constant to a $1e-8$ magnitude which indicates a very steady flow.

3.6.5 Conclusion

Given the obtained results, we can conclude that the system behaves correctly. We will now proceed to the simulation of the dissolution of the clot.

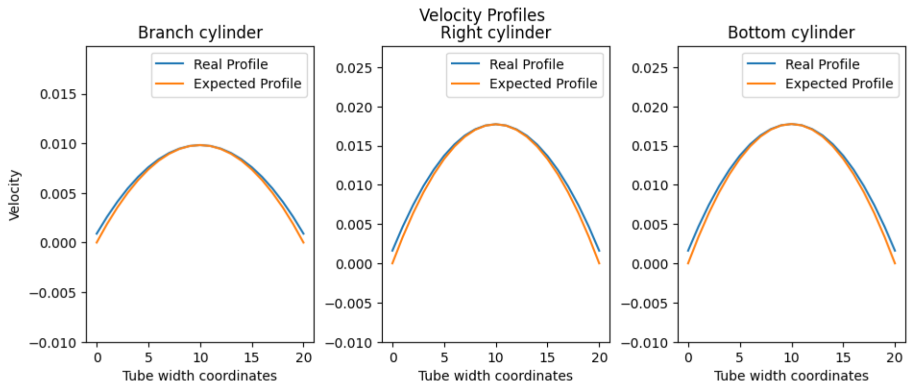

Figure 19: Velocity Profile for a rectangular branching system, with a clot, K = [0,0]

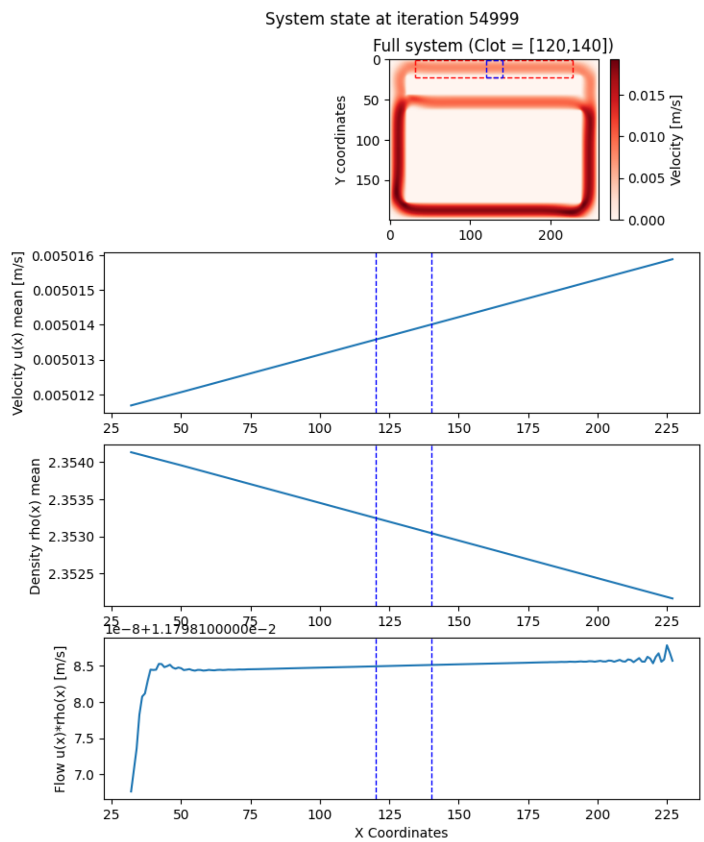

Figure 20: Clot velocity, density and flow for a rectangular branching system with clot, K = [0,0]

3.7 Experiment 7

3.7.1 Description

As an additional test, we changed how the macrovariables are computed. Previously, we computed the macroviarables as well as the equilibrium only on the open path of the system. We tried calculating them again on the whole system this time (including bounceback nodes) with the same parameters as before with $K = [0.001, 0.001]$ and $K = [0.01, 0.01]$. We let the code run for 100'000 iterations to be sure of the convergence.

3.7.2 $K = [0.001, 0.001]$

The velocity profiles illustrated in Figure 21 are satisfactory once again. The flow shown in the last graph of Figure 21 is slightly less constant than before. However, it still is at a magnitude of $1e-5$, which can be considered as constant. Additionally, when visualizing the flow (omitted here), we can see the fluid behaving like we expected it immediately (instead of waiting convergence) : instead of the system being full of ripples, the system starts at a standstill and slowly converges. We will need some discussion to assess how correct both approaches are and will chose one for the next part.

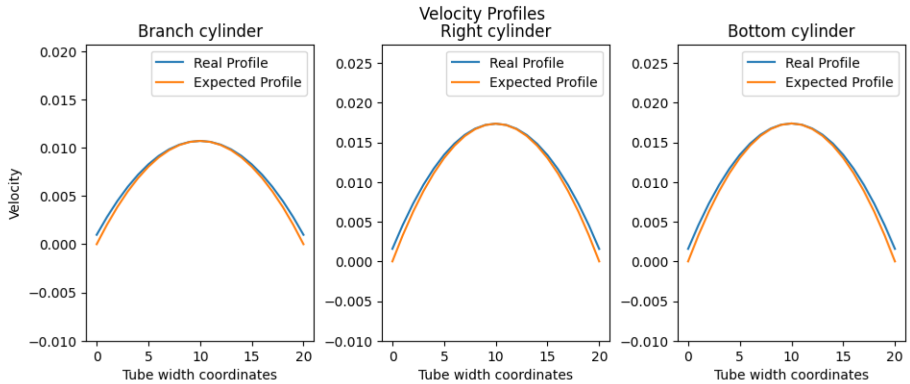

Figure 21: Velocity Profile for a rectangular branching system, with a clot, K = [0.001,0.001]

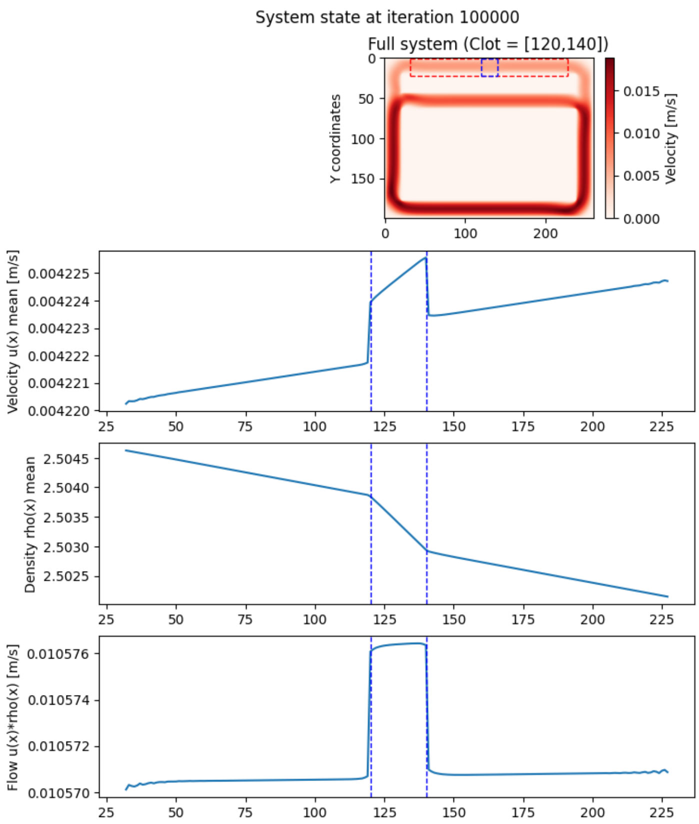

Figure 22: Clot velocity, density and flow for a rectangular branching system with clot, K = [0.001,0.001]

3.7.3 $K = [0.01, 0.01]$

We tested as well $K = [0.01, 0.01]$ just as a precaution mean. Figure 23 and 24 show the once again satisfactory results.

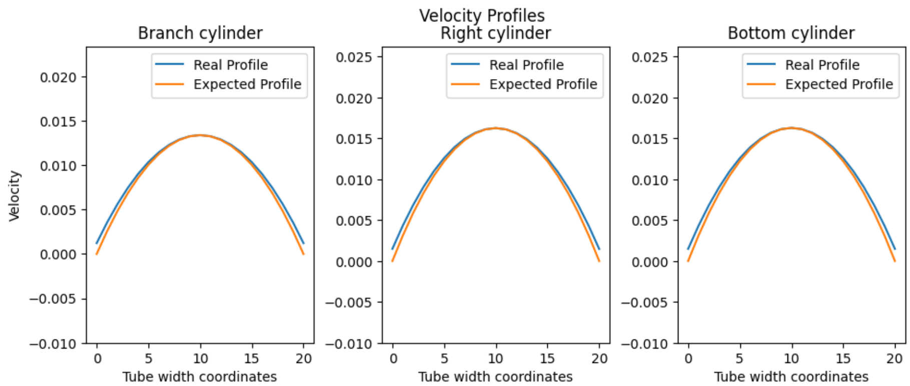

Figure 23: Velocity Profile for a rectangular branching system, with a clot, K = [0.01,0.01]

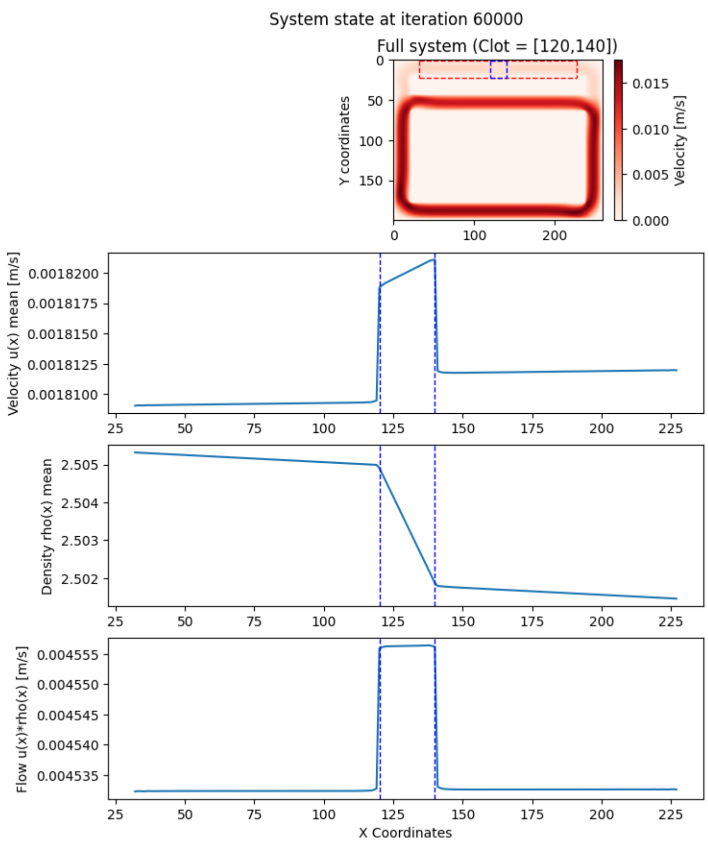

Figure 24: Clot velocity, density and flow for a rectangular branching system with clot, K = [0.01,0.01]

4 References