Master Thesis Experiment Report V : Blood Clot

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Abstract

Adding a blood clot to the system

1 Context

Starting on the system previously build, we want to simulate a numerical model of Thrombolysis in a vascular system. Thrombolysis, or Thrombolytic Therapy is the processes of breaking up blood clots using medication or non-invasive procedures [1].

Following what was defined in previous reports, a clot is defined by a partial bounceback collision step. The partial bounceback (noted as PBB from now on) differtiates the standard BGK collision into two separate behaviors : part of the PDFs follow a standard BGK collision while the other part follows a standard point-based bounceback collision [2]. The proportion of the two PDFs is determined by a factor γ called the solid fraction. The solid fraction is a continous value varying from 0 (completely fluid voxel) to 1 (completely solid voxel). Formally speaking, PBB is defined by the following equation:

$$f_i^{out}(x,t) = (1-\gamma)f_i^c(x,t) + \gamma f_{\hat{i}}^{in}(x,t) \tag{1}$$

where $f_i^{out}(x,t)$ is the outgoing PDFs at site x and time t, γ the solid fraction, $f_i^c(x,t)$ the PDFs obtained with standard BBK collision, and $f_{\hat{i}}^{in}(x,t)$ the PDFs obtained from standard bounceback (with $\hat{i} = -i$).

The solid fraction γ is obtained using the viscosity ν and the permeability of a medium k [2]. Formally, we can obtain γ with :

$$\gamma = \frac{1}{1 + \frac{2k}{\nu \Delta t}} \tag{2}$$

where Δt is the simulation time stamp, which is equal to 1 in our case.

2 Problem

We will now implement the method in our system. We took the same U-tubing system from previously and added a clot in the vertical tube section on the right side of it. The system is shown in Figure 1. For the following tests, we will define an arbitrary non-evolving γ value for the whole clot. We will monitor the global population as well as the velocity profiles for the upper and lower tube sections of the lattice. We will perform three different tests with varying γ values : 0, 0.6 and 1.

In addition, we cleaned up the code from previous iterations and made a bland state to work upon.

3 Experiments

For the following 3 experiments, we set the system to iterate 30'000 times on the lattice described in Figure 1. The rest of the parameters as the same for every test.

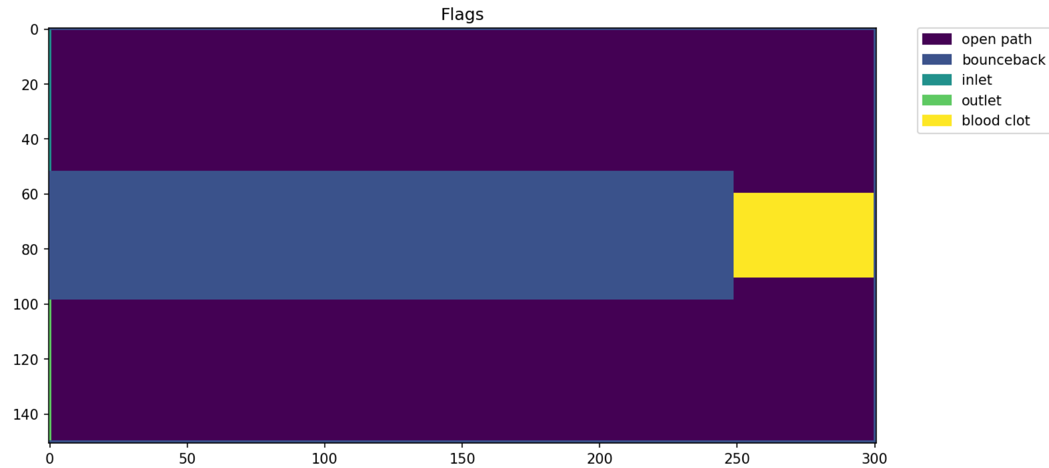


Figure 1: system with clot

3.1 Experiment 1

3.1.1 Description

The first test is made with a gamma value of : $\gamma = 0$. This means that we should get the behavior of completely fluid clot, which is theoretically the same as having no clot.

3.1.2 Results

The results are shown in Figure 2.

As expected, the fluid behaves as if there was no obstacle in the tubing. The steady increase in population is the same as previously seen with the Zu-he method, the velocity profile are the expected parabolas (the 2nd parabola from the lower section has less velocity than the first; this comes from the diminution of available energy in the fluid due to its viscosity). Figure 2c shows the velocities on the last iteration and serves as a visual interpretation of the behavior.

3.2 Experiment 2

3.2.1 Description

The first test is performed with a gamma value of : $\gamma = 0.6$. The chosen value here was arbitrary: we should expect some part of the fluid to pass through the clot.

3.2.2 Results

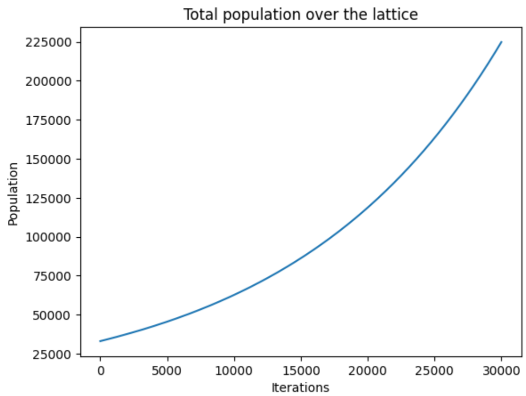
The results are shown in Figure 3.

Several things to note: the total population seem to increase more drastically that previously : this could be induced by the fact that less particles reach the outflow nodes and accumulate in the system. Moreover the maximum velocity of the tube section after the clot seem to be higher than the one without clot. Both of the issues will need some investigating.

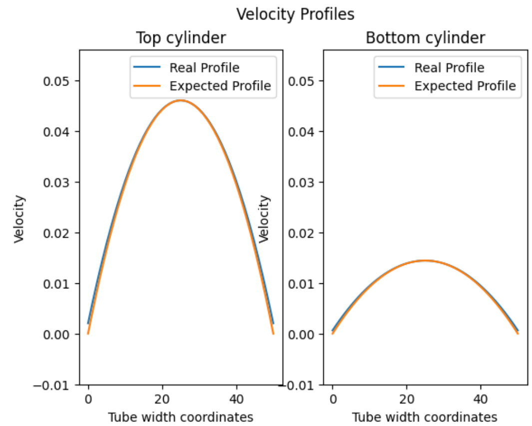
3.3 Experiment 3

3.3.1 Description

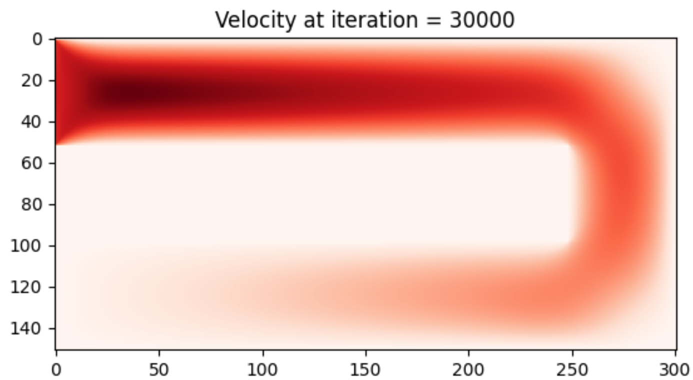
The first test is performed with a gamma value of : $\gamma = 1$. The clot here should be completely solid : meaning that no fluid should pass through and the velocity profile after the clot should be completely flat.



(a) Total PDFs evolution



(b) Velocity profiles



(c) Visual representation of the velocity at the last iteration

Figure 2: Testing of clot behavior with solid fraction $\gamma = 0$

3.3.2 Results

The results are shown in Figure 4. Note : we didn't include as visual representation of the velocity here it was not as relevant as the others (dur to fact that the accumulated velocity against the clot made the rest of the system seem at a standstill due to the color scaling of the *matplotlib Python* library.

As expected, their is no velocity after the clot and its profile is flat for the second tubing section. We can notice an even greater total PDFs increase which is induced by the same issue as described above.

4 Conclusion

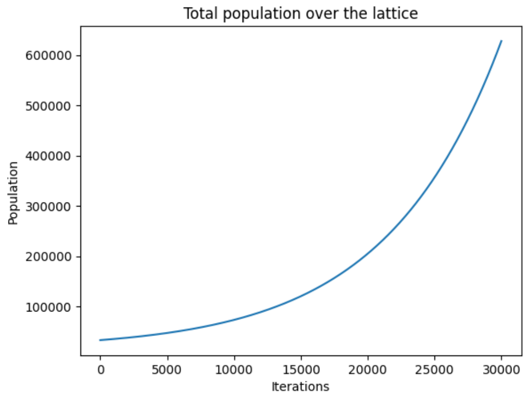
The implementation seems to work overall, we will further assess its relevancy before continuing.

5 References

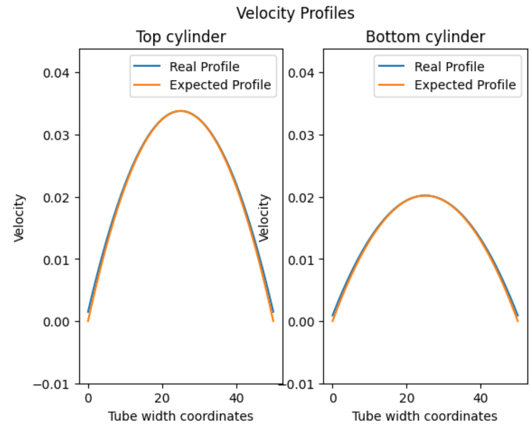
References

[1] O A Berkhemer et al. "A randomized trial of intra-arterial treatment for acute ischemic stroke". In: *New England Journal of Medicine* 372.1 (2015), pp. 11–20.

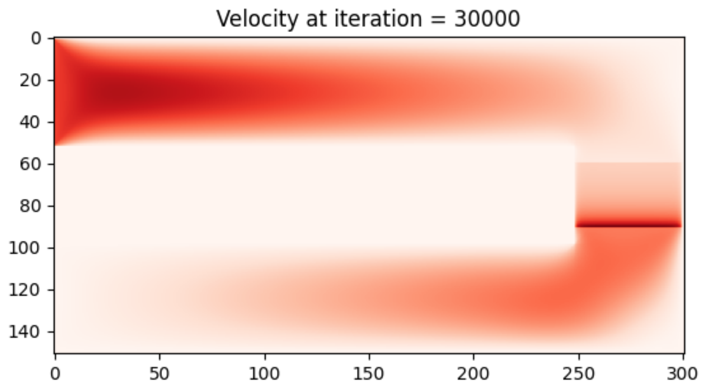
[2] Stuart D.C. Walsh, Holly Burwinkle, and Martin O. Saar. "A new partial-bounceback lattice-Boltzmann method for fluid flow through heterogeneous media". In: *Computers Geosciences* 35.6 (2009), pp. 1186–1193. ISSN: 0098-3004.



(a) Total PDFs evolution

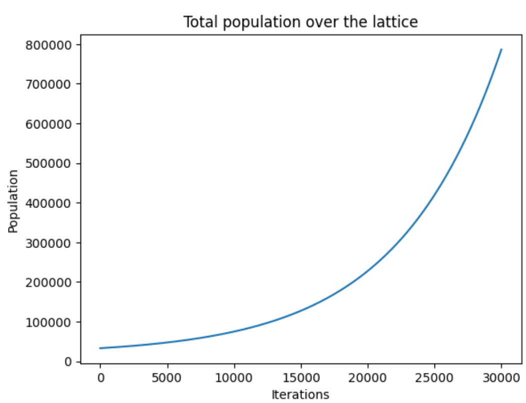


(b) Velocity profiles

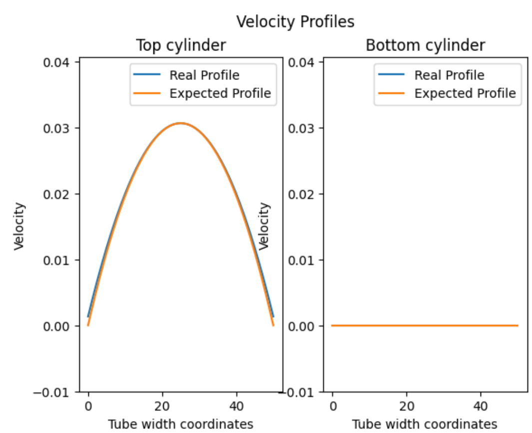


(c) Visual representation of the velocity at the last iteration

Figure 3: Testing of clot behavior with solid fraction $\gamma = 0.6$



(a) Total PDFs evolution



(b) Velocity profiles

Figure 4: Testing of clot behavior with solid fraction $\gamma = 1$