A suitable width-size of a channel flow for obtaining the velocity profiles by using the Lattice Boltzmann method

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Abstract. The Poiseuille flow has been widely analyzed from analytical and experimental point of view with different approaches. Although the Lattice Boltzmann method (LBM) has proven to be a suitable tool for mimicking the fluid flow behavior not only for complex but also for simple geometries such as lid driven cavity and channel flow, the required computational size or characteristic length to obtain an acceptable approximation of the described physical phenomena has to be defined. The aim of this study is to evaluate the impact of considering different width-sizes of a channel flow when the velocity profiles are obtained. Channel flow with several width-sizes are evaluated while keeping the Re and aspect ratio as constant.

1. Introduction

The increasing applications of computational resources and the ability to describe different transport phenomena using computational tools originate an additional analysis related to the required domain size to obtain a better approximation of the different studied transport phenomena. In order to obtain a model or description closer to the reality, it is required to establish the best suitable domain size according to the physical/morphological characteristics involved in the phenomena. Using domain size greater than needed would produce a waste of computational resources, while if the domain size is smaller than the required, the approximation to the reality would not be the adequate.

Fluid flows in simple geometries such as Lid driven cavity and Poiseuille flow have been widely developed and analysed during the last years from experimental and computational point of view [1][2]. An initial step of a computational study is to determine the domain size to be considered to mimic the fluid behaviour according to the morphological characteristics of the medium. Describing the fluid flow behaviour trough parallel plates in a two-dimensional case can be seen as simple as a rectangular domain. However, the size domain has to be chosen according to the used methodology when the fluid behaviour is obtained.

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In the current study, a detailed analysis of the wide-size channel to describe the velocity profiles is carried out. The fluid flow behaviour through the parallel plates is recovered from the Lattice Boltzmann method (LBM), which has proven to be a powerful tool to solve several transport phenomena under different and complex conditions [3][4]. The aim is to propose a suitable channel width-size relation to obtain the best approximation of the fluid flow behaviour through the parallel plates. The study is performed considering a laminar regime, i.e., Re=5.

2. Methodology
The computational domain is digitally generated in coding taking into account the aspect ratio as shown in Figure 1. The length of the channel is represented by L while the width of the channel is given by H. To determine the value of H, only the active nodes are considered. The aspect ratio for all the simulations is established as L/H=10.

Once the first domain is generated, i.e., H=1, the inlet velocity profile is computed aiming a Re=5. Since the new domain increases the width-size, the inlet velocity profile is newly computed to match the Re value. The analysis is carried out considering a variation from H=1 \(\text{lu}\) to H=15 \(\text{lu}\) in order to determine the suitable width-size. The velocity profiles are measured at different in-flow positions until the 10% of the total length (L), and then compared with the theoretical solution. Inlet velocity profile values are given in Table 1.

| Re | \(H(\text{lu})\) | \(u_o (\text{lu/ts})\) | \(H(\text{lu})\) | \(u_o (\text{lu/ts})\) |
|----|----------------|----------------|----------------|----------------|
| 5  | 1              | 0.833333       | 8              | 0.104167       |
|    | 2              | 0.416667       | 9              | 0.092593       |
|    | 3              | 0.277778       | 10             | 0.083333       |
|    | 4              | 0.208333       | 11             | 0.075758       |
|    | 5              | 0.166667       | 12             | 0.069444       |
|    | 6              | 0.138889       | 13             | 0.064103       |
|    | 7              | 0.119048       | 14             | 0.059524       |
|    | 15             | 0.055556       |                |                |

3. Results and discussions
As mentioned, the fluid flow is obtained using the LBM. The velocity profiles for each position are presented once a steady state solution is achieved. Due to the number of lattice elements is increasing for each computational domain, the number of time steps is also increasing but not in a linear trend as presented in Figure 2. It is important to notice that a channel with 1 and 2 lattice elements are not presented since the results are not adequate since the solution do not converge.
Numerically, the solution of the momentum and conservation equation converge if the width of the channel greater than 3 lattice elements. However, the approximation of the simulated flow to the analytical solutions must be checked. Figure 3 shows the fluid flow behaviour for selected width-sizes.

From Figure 3, it is observed, based on the velocity field at the entrance, that the fluid behaviour for the two first examples is not as expected, i.e., the behaviour must correspond to expected when a shear stress is acting [5]. However, for the two last samples the fluid flow behaviour is nicely recovered. It seems that in channel flows with a greater width-sizes the velocity fields are computed with a better approximation. To determine the minimum acceptable width-size for obtaining a desirable deviation...
error when computing the field velocity, the velocity obtained with the LBM is compared with the theoretical expected velocity.

![Figure 4. Deviation error of the computed velocity at mid-height as a function of the width-size of the channel](image)

Figure 4 shows that the width-size domain has to be increased to obtain lower deviation error. However, it implies a bigger computational domain, and therefore; more computational resources are required.

4. Conclusions

In this study, a suitable width-size of a channel flow to compute the velocity field is determined. According to the obtained results, having a width-size of the channel greater than six lattice elements produces a deviation error smaller than 5%. If the width-size is increased, the deviation error decreases considerably reaching values near to zero but the computational resources are also increased. The computational time for computing the velocity field for $H=15\, lu$ is 1.95 times the required when $H=6\, lu$. For width-sizes smaller or equal than two, the mathematical solution does not converge.

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5. References

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