XLIII CILAMCE
21-25, November, 2022
FOZ DO IGUAÇU - PR - BRAZIL

Numerical Study of the Relationship Between Bit Stick-Out and Drill Bit Size in Deepwater Jetting Drilling

Natália C. S. Santos[1], Beatriz R. Barboza[2], Eduardo M. A. Pacheco1[1], João P. L. Santos[1], Delton L. Resende[3], Rafael Dias[3], Fábio Sawada[3]

[1]*Center of Technology, Federal University of Alagoas*
Av. Lourival Melo Mota, 57072-970, Alagoas/Maceió, Brazil
natalia.santos@ctec.ufal.br, eduardo.pacheco@ctec.ufal.br, joao.santos@ctec.ufal.br
[2]*Laboratory of Scientific Computing and Visualization, Federal University of Alagoas*
Av. Lourival Melo Mota, 57072-970, Alagoas/Maceió, Brazil
beatriz@lccv.ufal.br
[3]*Petrobras*
Av. Horácio Macedo, 21941-915, Rio de Janeiro/Rio de Janeiro, Brazil
deltonlustosa@petrobras.com.br, rafael_dias@petrobras.com.br, fabiosawada@petrobras.com.br

Abstract. Jetting is a common technique for conductor casing driving in cohesive soils. This installation method shows faster results with less cost. However, even nowadays, the jetting operation relies on the experience and expertise of the drilling team for a successful performance. Therefore, to have a clear picture of jet excavation, computational fluid dynamics (CFD) approaches have been applied as a safe and economical alternative compared to field tests. This paper presents a numerical simulation of jetting operation for conductor casing in cohesive soil. Since the main operation parameters are pump rate, the ratio of bit-to-conductor dimensions and bit stick-out, this work investigates the relationship between the bit stick-out and drillbits of different magnitude. For simulation of the soil-jet interaction, a two-phase Lattice-Boltzmann model (LBM) combined with the Volume of Fluid (VoF) method was used to track interface behaviour. The soil is represented as a viscous fluid and described by Herschell-Bulkley viscosity model. The model is calibrated for a well in the Brazilian Pre-Salt. Therefore, this study purposes a follow-up analysis of the jetting process on Brazilian wells to advance understanding of the interaction between its different parameters and their effect on the operation performance.

Keywords: Jetting, Bit stick-out, conductor casing

1 Introduction

The conductor casing is the first structure in well construction. As the conductor is responsible for the borehole stability, several methods were developed for its installation due to different soil characteristics. For cohesive soil, the lack of seafloor sediments, boulders or rubble zones provides an adequate setting for the jetting operation [1]. Whereas this process has become common in the deepwater environment, there are not many insights into the jetting of casing conducts in the marine soil and its mechanics.

This excavation technique is a faster alternative for the conductor installation, with lesser cost when performed correctly. In the first stages of the jetting process, the main components are the conductor casing, the drillbit and its bit stick-out, assemble showed in Fig. 1. Hence, the operational success relies on parameters dependable on this setting, such as pump rate, the ratio of bit-to-conductor dimensions and bit stick-out [2]. The pump rate is responsible for the formation removal by the jetting. Hence, it performs a key role during the whole operation. Zakeri et al. [3] appoint the pump rate as crucial for preventing fluids broaching. In a deep study, Akers [1] exhibits the relationship between the bit-to-conductor dimensions and the drilled area. This parameter is critical to in achieving the intended hydraulically washed area and mechanically removed area. Also, Gomes et al. [4]

presented the effects of the bit stick-out for pre-calibrated soils in Brazilian pre-salt, their study demonstrated a higher jetting performance for positive bit stick-outs, while maintaining other parameters constant.

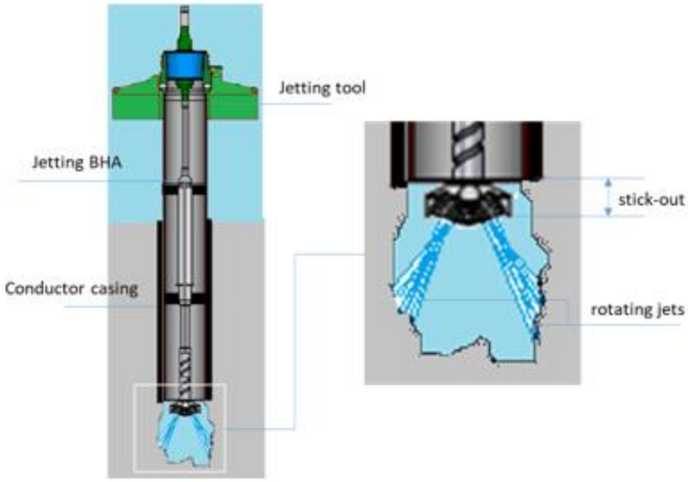

Figure 1. Schematics of the jetting structure components [4]

However, further research on those factors is hindered by the operation costs. Since jetting is an expensive process, the empirical approach to investigate it is unfeasible. Thus, the computational fluid dynamics (CFD) approach allows the examination of the jetting excavation considering the soil mechanics and its hydrodynamics phenomena. Wang and Li [5] investigated the hydrodynamic of jetting process by a numerical model with A Reynolds averaged k-e method. In addition, VoF method was applied to model the water and soil interactions, in which the soil was considered a viscoplastic material. In an analogous manner, Gomes et al. [6] analysed the effect of the ratio of drill bit size and conductor casing diameter through the Lattice Boltzmann method, also considering the soil behaviour as Herschel-Bulkley fluid for Brazilian soil data.

The fluid dynamics framework for modelling the marine soil has been applied to simplify the process analysis and non-Newtonian models rise as alternative from the geotechnical approach [7]. Thus, the Herschel-Bulkley model can be used to characterize cohesive soil through the link of soil and fluid parameters considered in the model shown in eq. (1). In CFD it is important to be attentive towards the numerical solution. Thus, eq. (1) presents a modified Herschel-Bulkley equation in which prevents instability as the viscosity is fixed for shear rates smaller than the fluid yield limit [8]. In the following expression, τ refers to shear stress, γ to the shear rate, μ_p is plastic viscosity and τ_y is the yield strength:

$$\begin{cases} \tau = \mu_p \gamma + \tau_p, for\ \tau > \tau_y, \\ \gamma = 0, for\ \tau \leq \tau_y \end{cases} \tag{1}$$

When modelling of two-phase flow, conservative methods include the solving of Navier-Stokes equations and molecular dynamics simulations [9]. Against this setting, fluid mechanics equations are difficult to solve and require great computational effort. Therefore, alternative methods such as the Lattice-Boltzmann appear as capable to simulate fluid dynamics whilst solving transport and thermodynamics phenomena [10].

The Lattice-Boltzmann method proposes a discretization in time, space and velocity of the Boltzmann Equation for modelling continuous fluid flows. Though a finite approach, the distribution function *f(x,v,t)*, the main variable of the Boltzmann equation, becomes a discrete-velocity distribution function or particle populations $f_i(x,t)$ [11]. Equation (2) presents the LBM equation, in which $\boldsymbol{e}_i$ refers to particle velocity towards a neighbouring point $x+\Delta \boldsymbol{e}_i$ at the next time step $t+\Delta t$, and Ω_i is the collision operator that models the collision by conserving mass and linear momentum and streaming to each lattice site b.

$$f_i(x + e_i, t + \Delta t) = f(x,t) + \Omega_i(f_1 \dots, f_b), i = 1, \dots, b \tag{2}$$

This propagation models the transference of proprieties through the stored particle distribution function, such as participle density found by the sum of f_i, as well as the physical phenomena described by the collision operator. Thus, under the premise that the fluid macroscopic behaviour reflects its microscopic interactions, the Lattice-

Boltzmann method relies on microscopic models and mesoscopic kinetic equations [12].

For LBM, the choosing of the lattice or velocity set structure and time-step are crucial for achieve the desired accuracy, stability and efficiency. The discrete velocity previously presented form with weighting coefficients velocity set which describe the number of dimensions is covered and the number of populations in each node. A common lattice choice for 3D flow modelling is de D3Q19 and D3, shown in Fig. 2. As for the time step, in a similar manner to other computational methods, the decrease of time step refines the process precision, however it increases the computational cost and the simulation time [13].

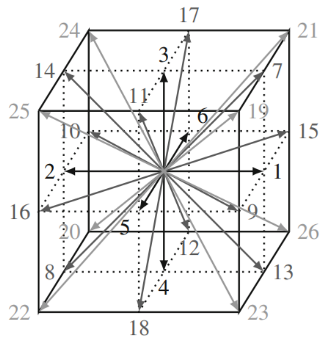

Figure 2. D3Q27 velocity set cube structure for each lattice

2 Methodology

This paper simulation was performed on the computational fluid dynamics simulator SIMULIA XFlow©, version 2019x (Dassault Systèmes). XFlow© uses the Lattice-Boltzmann Method (LBM) for the modelling of fluid flows, dealing with the Cartesian distribution of discrete points not requiring the generation of a computational mesh itself, making the simulation steps more efficient.

The initial step toward the simulation of the jetting system was the determination of the problem's domain. Considering the excessive computational cost for a large domain, the marine soil is presented by a 7x7 m² square area with 20m of height, in which the seawater occupies the other 2 meters and the insides of the conductor casing. The rectangular cuboid domain is shown in Fig. 3. For the boundary conditions, the domain's sides and base are closed while the top is open for material outflow. All solid walls have a free slip condition. The turbulence model adopted is based on wall-adapting local eddy.

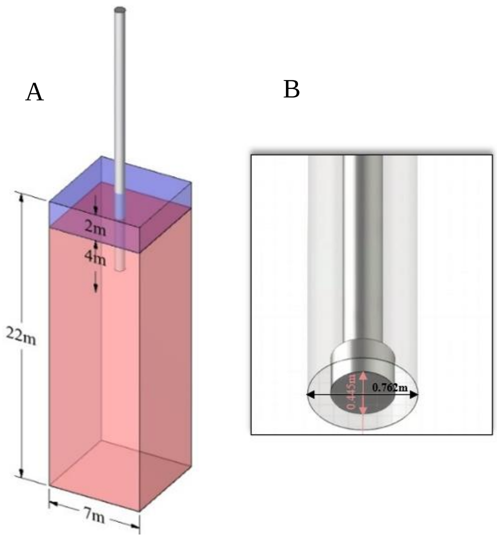

Figure 3. Numerical model dimensions for (A) domain and (B) inside the casing conductor

In the following steps, the geometry applied to the simulation was built in XFlow. As previously commented, for the jetting process there are frequently used dimensions for each element shown in Fig. 1. Thus, the geometry was designed following common configurations presented by Akers [1] between the casing conductor and bit diameter together with field reports. Table 1 exhibits the dimension for every component in the simulation. To reduce and simplify the structural configuration, the bit was considered as an enveloped surface following the results presented by Gomes et al. [4]. As for the bit stick-out dimensions, the chosen values were based by Kan et al. [2]. Their analysis showed that positive bit stick-out had a better performance than negative, thus the geometries used a 0 and 0.175m of bit stick-out for the current work.

Table 1. Magnitude of the jetting structure components

	Conductor Diameter	Drill string	Drillbit	Bit stick-out
Length (m)	20	20	0.3	0 0.175
Diameter (m)	0.762	0.241	0.445 0.660	-

In this work, the soil was modelled as a Hershel-Bulkley fluid, by applying the modified equation for numerical simulations previously shown in eq. (1). The rheological coefficients used were validated with field data from three Brazilian wells by Gomes et al. [4]. Table 2 presents the equation parameters as well as the physical properties of seawater under the given conditions.

Table 2. Rheological parameters of the Applied fluids

	Marine soil	Seawater
Specific mass (kg/m³)	1750	998.3
Viscosity (Pa.s)	-	0.001
Yielding viscosity (Pa.s)	8000	-
Yield stress (Pa)	40000	-
Power-law index	0.1	-
Consistency intex (Pa.s)	18831	-

The CFD modelling continued by adapting the solver environment for the studied process. In XFlow 2019x, the flow model was set as Multiphase since the fluids are immiscible. And the VoF applied for modelling each and their interaction. In the Volume of Fluid approach employed the fluid volume tracked at the interface lattice notes, here the pressure field solved continuously providing smoother results in interface when compared to particle-based tracking. The initial concentration of water is for x > 9 and for the volume inside the casing conductor, since its already plunged 4 m in time 0 s and the rest of domain filled with the soil, as shown in Fig. 4. As for the other jetting parameters such as pump rate and the bit rotation, the former defined as 12.6kg/s and the latter was unused because of its lower impact in modelling the of drilling process.

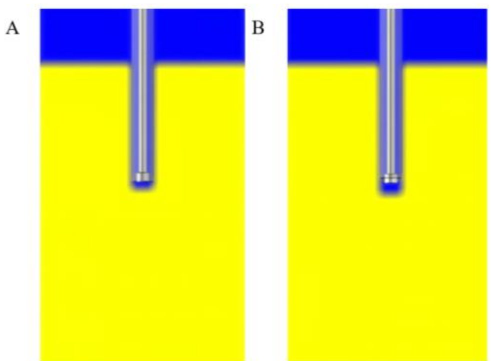

Figure 4. Volume fraction at t=0s for the 0.445m drillbit and (A) bit stick-out of 0m and (b) 0.175m

Albeit the LBM is a meshless method with a fixed organized lattice structure (D3Q27 for XFlow 2019x), there are a few criteria in the software that allows adapting this structure for the analysed situation. The lattice can be refined by the number of time-steps executed, by the wake region based on the high vorticity and at the fluid interface. Figure 5 shows how each region of the domain refined to agree with known phenomena of the jetting process. Also, two types of time steps available are verified: a fixed automatic with the Courant number set as 0.1 and an adaptive time-step performed by the program.

A B

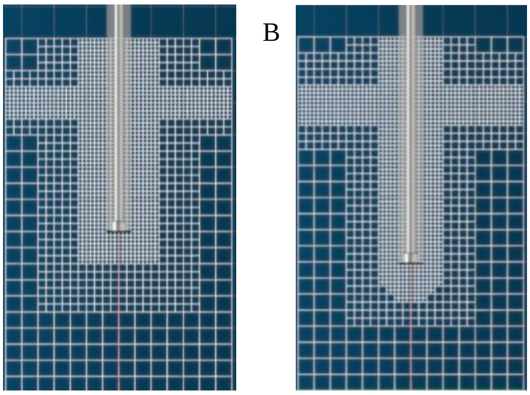

Figure 5. Grid refinement in the regions of interest in (A) t=0s and (B) t=30s

3 Results and discussion

As proposed for this paper, the numerical study is part of a follow-up analysis of the jetting process on Brazilian wells to highlight the effect of different operational parameters. Therefore, the first challenge imposed by this strategy was to associate different methods for modelling fluid flow.

For rheological proprieties, such as the parameters from Herschel-Bulkley, are not expected a large divergence in its values even if they are obtained by distinct numerical methods. The marine soil parameters used here are results of numerical simulations with the RANS method. Whereas the chosen software for the current paper uses the Lattice-Boltzmann method. There are many differences between the two, the RANS method requires mesh and the solving of Navier-Stokes equations, being a fluid mechanics-based method. Whereas the Lattice-Boltzmann method, as presented heretofore, is particle-based. Thus, a numerical divergence could be observed, but not to the extent of changing the physical behaviour of the operation.

However, this research found that the chosen time-step for simulating the fluid flows in the jetting of the casing conductor can drastically change the represented phenomena when using the LBM. At the first simulation, trials were performed to verify the boundary conditions, turbulence models and resulting phase fields. In this procedure, the two types of time step selected were not able to represent the jetting process accordingly. Figure 6 shows the results for the failed simulation (soil represented in red) set side by side with the adequate representation (soil in yellow).

A B

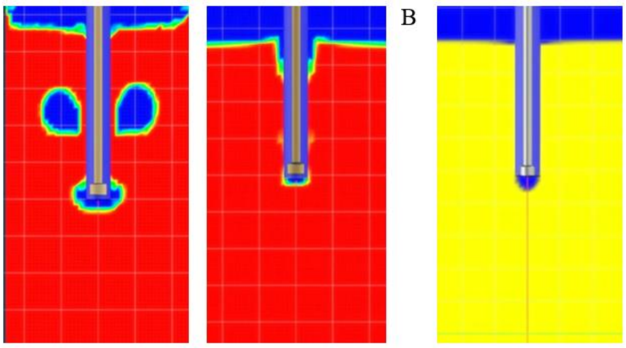

Figure 6. The volume of fluids in the numerical model for (A) inadequate and (B) successful simulations

The first type was the adaptive time-step, with a Courant number equal to 1. In the LBM community, there are many studies regarding the optimization of the method's time step, since it often presents as disadvantage. And adaptive time-steps that correct the Mach number are usually suggested. This is not a conservative approach and can lead to errors in mass or momentum conservation. Thus, as most work in CFD, it is relative to the simulated problem and its permitted approximations.

Other than the adaptative time step, the automatic time step suggested by the software also did not represent the jetting operation for Courant number between 1 and 0.1. The jetting operation was successfully simulated with time-steps with a Courant number of 0.1 or smaller. Consequently, demanding high CPU times. Despite the computational costs, the LBM showed stability and accuracy in performing fluid-fluid simulations.

Following up on the CFD modelling, the simulation results were analysed for investigation of the effect of the bit stick-out at the beginning of the soil excavation. The linear behaviour of the soil excavation was observed similarly to field data, as shown in Fig. 7. In addition, for the applied methodology, the jetting configuration with a bit stick-out of 0m showed a better-averaged performance than the 0.175m bit stick-out. Regardless of the similar achieved depth, the averaged velocity for the former was higher than the latter. Thus, this result might appoint the lesser effect of the bit stick-out between 0m and 0.175m for this configuration.

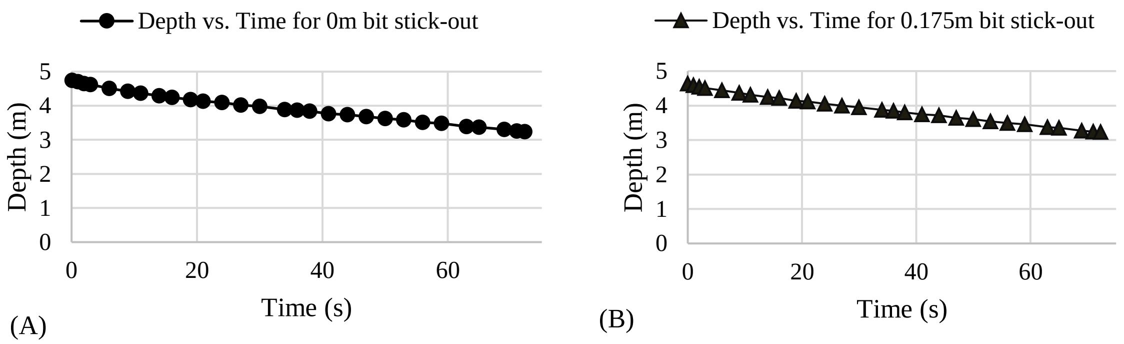

Figure 7. Achieved depth for the 0.445m-diameter drillbit and (A) bit stick-out of 0m and (B) 0.175m

Albeit the smaller calculated time, the positive bit stick-out was not favourable for the larger bit in the first stages of the jetting process. For the 0.660m-diameter drillbit in the 0.762m-diameter (30 in) casing conductor, the soil was mostly excavated mechanically rather than by the jets kinetic force. Also, as it is seen in Fig. 8, a portion of soil returned upwards by the annulus. This behaviour could interrupt the fluid flow inside the conductor casing. This performance could be a result of the conductor casing diameter in comparison to the drillbit or a combination of both small conductor-to-bit size and the positive bit-stick out. It must be emphasized that this analysis is regarding the first meters of the jetting of the conductor and made with specific soil parameters from a group of wells from the Brazilian pre-salt. Thus, soil geological differences, variations in flow rate and structures magnitude can affect the jetting performance.

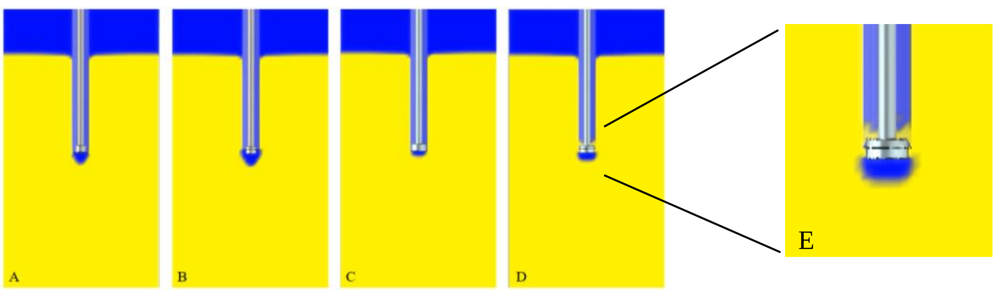

Figure 8. Volume fraction at t=27s for the four chosen configurations, (A) and (B) for 0.445m-diameter bit and (C) and (D) for 0.660m-diameter bit, (E) presents the obstructed section in (D)

4 Conclusions

The investigation of the jetting drilling is of utmost importance to mitigate potential risks and increase the success of this operation, thus a numerical study of the impingement of the conductor casing by the jetting operation is presented in this paper. The CFD modelling of the jetting drilling developed in a Lattice-Boltzmann-based software took a considerable computational cost to perform an adequate representation. Consequently, this study appointed refinement options and the influence of the authorized time-step in the modelling of fluid flows by the LBM. Furthermore, by a VoF approach, it was possible to analyse the multiphase interface between the jet and the excavated soil.

The results demonstrated that neutral and positive bit stick-out perform in a similar way for the first meters of the jet drilling in the calibrated soil from Brazilian pre-salt. And for both bits, the neutral bit stick-out performed better than the positive bit stick-out, different from the analysed references. This paper's result asserted the importance of the soil characterization previous the drilling. Moreover, it reaffirmed the effect of the design specification such as casing conductor and drillbit dimensions, as well as the bit stick-out, in jetting drilling. Also, it continues the discussion if there are features that impact the execution of the jet excavation in deepwater environments more than others. It is worth mentioning that this work is under development and the presented analysis is the preliminary result.

Acknowledgements. The authors would like to acknowledge Petrobras for the funding and participation in this study.

Authorship statement. The authors hereby confirm that they are the sole liable persons responsible for the authorship of this work, and that all material that has been herein included as part of the present paper is either the property (and authorship) of the authors, or has the permission of the owners to be included here.

References

[1] T. J. Akers, "Jetting of Structural Casing in Deepwater Environments: Job Design and Operational Practices". SPE Drilling & Completion, vol. 23, n. 01, pp. 29-40, 2008.

[2] C. Kan, J. Yang, R. Xie, Y. Wu, S. Guan, F. Xy, H. Wang, and F. Abimbola, "Field experimental investigation of bit stick-out for different soil strengths during deepwater conductor injection". Journal of Petroleum Science and Engineering, vol. 169, pp. 825-836, 2018.

[3] A. Zakeri, E. Liedtke, E. C. Clukey, and P. Jeanjean, "Long-term axial capacity of deepwater jetted piles". Géotechnique, vol. 64, n. 12, pp. 966-980, 2014.

[4] A. F. C. Gomes, B. R. Barboza, F. S. Cutrim, L. S. Cytrangulo, L. F. B. Nardi, M. C. Ito, P. R. S. Da Costa Junior, and R. Dias,. "Modelling of Conductor Jetting Operation Using a Moving-Grid CFD Model". Offshore Technology Conference (OTC), 2022.

[5] T. Wand and H. Li, "Numerical Simulation of Jet Excavation in Conductor Jetting Operations". Offshore Technology Conference (OTC), 2014.

[6] A. F. C. Gomes, B. R. Barboza, E. M. A. Pacheco, J. K. F. Tenório, J. P. L. Santos, F. S. Cutrim, and R. Dias, "Influence of the ratio of drill bit size and conductor casing diameter on jetting with Lattice Boltzmann method". *XLII Ibero-Latin-American Congress on Computational Methods in Engineering,* Rio de Janeiro, Brazil, 2021.

[7] H. Zhu and M. F. Randolph, "Numerical analysis of a cylinder moving through rate-dependent undrained soil". Ocean Engineering, vol. 38, pp. 943-953, 2011.

[8] M. S. C. Tenório, A. F. C. Gomes, B. R. Barboza, D. C. Galindo, J. L. G. Marinho, L. M. T. M. Oliveira, and J. P. L. Santos, "Fluid Dynamic Analysis of a Marine Soil in Jetting Excavation Employing Rheological Models: Influence of Drilling Fluid On Soil Deformation". Brazilian Journal of Petroleum and Gas, vol. 15, n. 3, pp. 81-94, 2021.

[9] M. R. Swift, W. R. Osborn and J.M. Yeomans, "Lattice Boltzmann Simulation of Nonideal Fluids". Physical Review Letters, vol. 75, n. 5, pp. 830-833, 1995.

[10] C. Xie, J. Zhang, V. Bertola, and M. Wang, "Lattice Boltzmann modeling for multiphase viscoplastic fluid flow". Journal of Non-Newtonian Fluid Mechanics, vol. 234, pp. 118-128, 2016.

[11] T. Krüger, H. Kusumaatmaja, A. Kuzmin, O. Shardt, G. Silva, and E. M. Viggen, "The Lattice Boltzmann Method: Principles and Practice". Springer International Publishing, 2017.

[12] S. Chen and G. D. Doolen, "Lattice Boltzmann Method for Fluid Flows". Annual Review of Fluid Mechanics, vol. 30, n; 1, pp. 329-362, 1998.

[13] T. Horstmann, H. Touil, L. Vienne, D.Ricot, and E. Lévêque, . "Consistent time-step optimization in the lattice Boltzmann method". HAL, 2021.