

Applying CFD Modelling and FEA to Enhance Bauxite Residue Slurry Flow through Distribution Rings in Filter Presses

Thomas Grillot¹, Simon Gravel² and Nicolas-Alexandre Bouchard³

1. Research Professional

Cural laboratory, UQAC, Saguenay, Canada

2. Research Scientist

Aluminium, Rio Tinto, Saguenay, Canada

3. Principal Adviser Processing & Technology

Development & Technology, Rio Tinto, Saguenay, Canada

Corresponding author: simon.gravel3@riotinto.com

<https://doi.org/10.71659/icsoba2024-br004>

Abstract

In November 2019, Vaudreuil commissioned its bauxite residue filtration plant (BRFP), to treat thickened bauxite residue using four (4) filter presses. Each filter press is capable of holding 0.25 m³ of material per filtration chamber. These chambers are assembled by joining two plates covered with filter cloths and two pairs of distribution rings. The bauxite residue slurry enters the chambers with high velocity causing significant stresses on all filter components due to the combined high density and abrasive properties of the slurry. This leads to short and long-term components failures. The main issue is the excessive wear and increased maintenance costs related to the frequent replacement of filter cloths and distribution rings. This paper provides an overview of the potential of modern numerical methods like computational fluid dynamics (CFD) in helping to determine fluid velocity and more importantly flow patterns inside the chambers. CFD coupled with finite element analysis (FEA) to assess the structural integrity of the distribution rings and plates, valuable insights can be gained for geometric adjustments to reduce filter cloths wear, extend their life cycle and improve the overall performance of the filter presses. As a result, reliability of the BRFP can be enhanced.

Keywords: Hydrogen Reduction, Al₂O₃ leaching, Fe separation.

1. Context and Current Situation

The Rio Tinto Vaudreuil Bauxite Residue Filtration Plant (BRFP), located in the Saguenay Lac St-Jean region, in Quebec, Canada, installed four (4) Diemme GHT.2500.F18 filter presses with membrane squeezing for the treatment of bauxite residue [1]. This filtration process allows for a significant reduction in drying time for the residue compared to the previous method of mud farming. It also increases the longevity of the disposal area by maximizing its surface area and reduce the plant's environmental impact [2, 3, 4].

The bauxite residue undergoes an initial washing step in a counter-current washing circuit before entering dedicated deep thickeners and the slurry is pumped to the BRFP for the final filtration step. Each filter press consists of a stack of alternating recessed and membrane plates, as shown in Figure 1, covered with high-performance filter cloths to form the filtration chambers of 0.25 m³ in volume. The bauxite residue slurry is introduced into these chambers through distribution rings with an average flowrate of 2.5 m³/h where hydraulic pressure from the feeding pump forces the filtrate through the cloths, forming the filter cake. To minimize residual moisture in the filter cake, an additional high-pressure step with membrane squeezing is applied to achieve a final moisture content between 25 % and 30 %. Once filtration is complete, the plate stack opens, and the filter cake is discharged from the filters and transported to the disposal area by a series of conveyors [4].

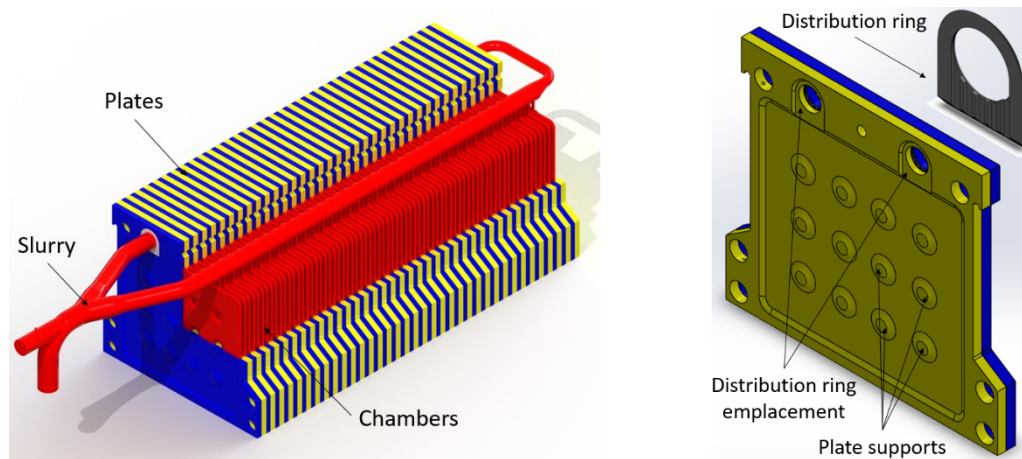


Figure 1. Model of a filter press. Left: the plate stack with slurry, Right: two plates and distribution ring.

Since the commissioning and ramp-up of the BRFP, the filtration chambers filling step has always been a challenge mainly due to the properties of the bauxite residue slurry. Considering the enormous strain that the filter presses are under during the filtration process and the inability to physically monitor the flow and behaviour of the slurry inside the filtration chambers, modern numerical methods like Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) are excellent tools for troubleshooting and assessing improvements. This paper presents how CFD and FEA improved the performance of the filter presses by studying the effect of fluid dynamics through various distribution ring designs and understanding their structural integrity under normal operating pressure.

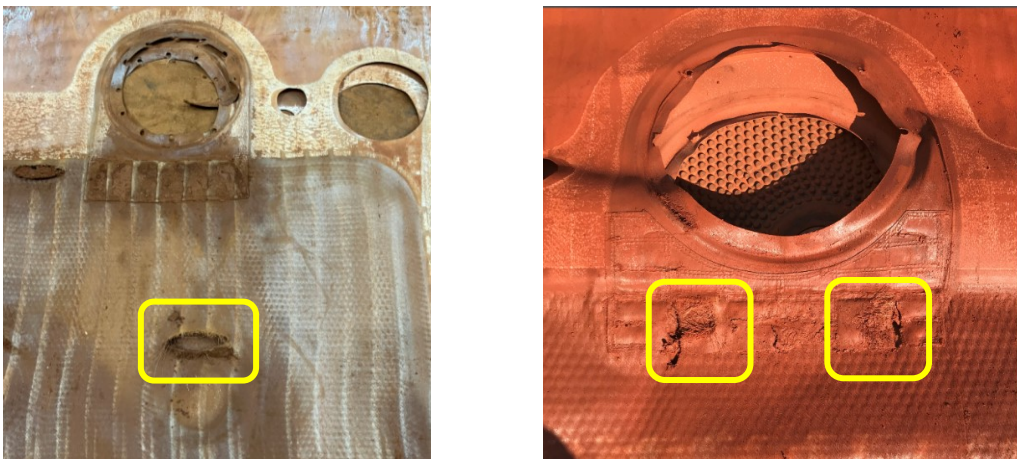
2. State of the Art

A homogeneous distribution of the slurry within the chambers of the filter press is essential to maximize filtration capacity and ensure the quality and uniformity of the filter cake. Techniques like mechanical smoothing or jet distribution systems can help achieve this goal. Prior to filling, mechanical smoothing of the mud could improve filtration capacity by 15 % and reduce the water content of the filter cake by 10 % [5]. Minimizing void spaces in the filter cake is crucial for increasing solids content and reducing the volume of generated waste. Approaches such as assisted compaction or optimization of mud rheology can help achieve this. The utilization of a rheology modifier to optimize mud rheology has been showed to reduce voids in the filter cake by 20 % and increase solid content by 5 % [6]. Shortening the filling and unloading time of filter press chambers can enhance the overall productivity of the system. Automation of operations and optimization of filling parameters play a significant role in achieving productivity increase. This has resulted in a 25 % reduction in cycle time and a 10 % increase in production [7].

A recent study using a numerical model to optimize the filling of filter press chambers [8] indicates that increasing the feed concentration improves filtration capacity but may reduce cake uniformity, with only a 6 % increase in solid concentration in the cake. Additionally, chamber geometry and plate arrangement influence mud flow under different patterns referred to as “spider” or “umbrella.” Despite these advancements and recent studies, issues with filter cloth tear still occurred. This paper provides an in-depth analysis of the process to further increase filter press productivity.

3. Challenges and Modelling Plan

Extending the life of filter cloths is an ongoing challenge for operational purposes. The maintenance required to change the cloths can disrupt production and decrease the overall filtration plant availability. The main reason for cloth replacement is wear and tear (Figure 2), which can lead to slurry seeping into the plates, contaminating the filtrate and necessitating further cleaning and maintenance. One of the main causes of cloth tears is the localised high velocity of the slurry entering the chambers, along with the abrasive nature of the material. To minimize cloth damage, standard practices include reinforcing the cloth in areas where tears are most common, such as beneath the distribution rings. However, these mechanical reinforcements, despite their higher cost, are often insufficient to significantly extend the useful life of the filter cloths. Another challenge is the inability to physically measure the flow pattern inside the filtration chambers. The first objective of this study is to understand the hydrodynamic movements of the slurry during the filling phase using CFD modelling. The second objective is to develop and assess potential solutions to extend the life cycle of the filter cloths while maintaining high filtration performance and minimizing operational maintenance and interventions. These solutions will also be examined using FEA to account for the intense forces present within the filter press.



**Figure 2. Example of cloth wear and tear.
Left: over the first plate support, Right: under the distribution rings.**

A first study was conducted based on a turbulent biphasic model to simulate the filling of the bauxite residue slurry across the entire length of chambers to understand the flow behaviour and estimate the velocities at the inlet of each chamber through the distribution rings. A second study with Fluid-Structure Interaction (FSI) focused on a single chamber to identify critical stress zones, where the fluid velocity impact is at its highest (Figure 3). This approach was chosen due to the variety of flow patterns and observed failures of filter cloths at the plant in upper quadrants.

The hydrodynamic behaviour of the slurry using a range of distribution ring designs were evaluated and compared to the base case distribution rings. The objective was to evaluate these designs, quantify the stress from fluid impact on cloths and plates, and ensure their structural integrity without deformation. Multiple biphasic air-bauxite residue simulations were conducted with varying distribution ring geometries, to reduce the fluid entry velocity into the chamber, thereby prolonging the lifespan of the filter cloth. These configurations have undergone structural analysis to ensure resistance to deformation during filter press closure, and to avoid any flow blockage caused by excessive compression of the distribution rings.

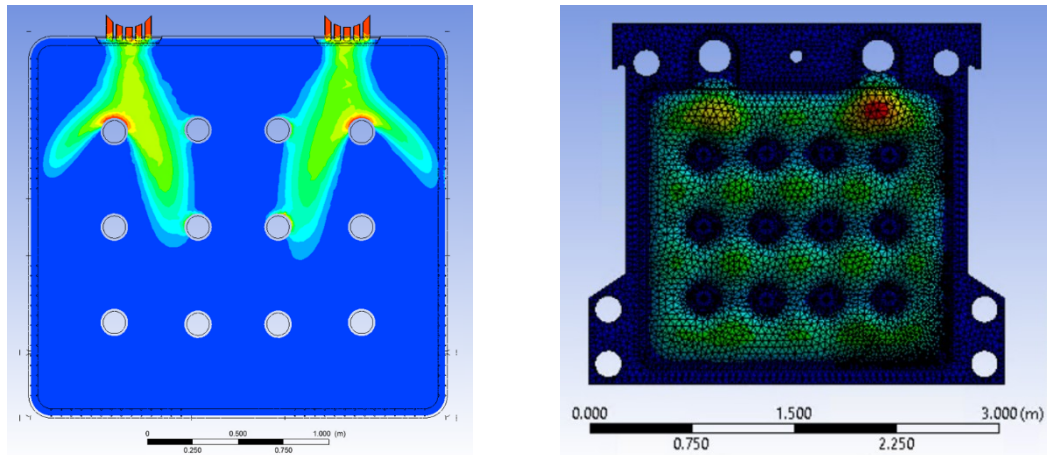


Figure 3. Fluid Structure Interaction.
Left: mud volume fraction, Right: structure deformation.

4. Work Description

For the hydrodynamic study, the CFD simulation software Ansys-CFX was used. This software employs the finite volume method to solve the multiphase Navier-Stokes equations, while incorporating a k-epsilon turbulence model. The speed and robustness of this software were two important factors in the selection of this calculation tool, given the critical nature of the problem and the need of the filtration plant for a quick response.

To set up the CFD model and focus exclusively on the hydrodynamic aspects, only the region where the fluid is in motion is considered in the modelling, as represented by the red volume in Figure 4. According to the previous simulation, the filling of the filter press is not uniform: some chambers fill more quickly than others, leading to significant flow rate variations through the distribution rings. The inlet flow rate used in the filling simulation is the maximum flow rate and as such represents the worst-case scenario where damages are likely to occur.

Therefore, several calculation assumptions were established to successfully conduct this study:

- The feed flow rate remains constant over time, with a value of $9.1 \text{ m}^3/\text{h}$ of bauxite residue slurry.
- The simulation focusses on the first 30 seconds of filling, where the velocity is at its peak.
- Gravity can be disregarded since gravitational forces are negligible compared to kinetic forces. Additionally, no filtration occurs during the first 30 seconds of filling.
- The filtrate outlets are assumed to be at atmospheric pressure.
- The density of the bauxite residue slurry is 1460 kg/m^3 , while the density of air is 1.2 kg/m^3 .

The ANSYS Static Structure module offers a suite of powerful tools dedicated to analyzing the mechanical behavior of structures subjected to static loads and supports. This rigorous approach allows for evaluating the strength of the distribution rings during the operation of the filter press. Unlike hydrodynamic studies, the chosen geometry here comprises the two distribution rings where the stresses will be applied. Subsequently, defining the constitutive mechanical properties of the material (Young's modulus, Poisson's ratio, yield strength, etc.) enables a realistic modelling of their behavior under stress. Finally, prescribing the static loads, such as pressure on each side and two fixed supports, represents the actual strains applied to the structure during the filter press closure, as seen in Figure 4.

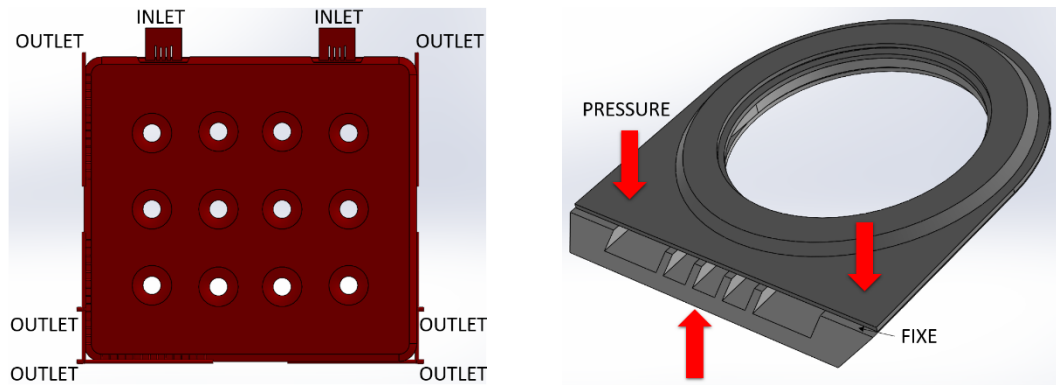


Figure 4. Simulation configuration of the plate and distribution ring.
Left: CFX, Right: Static Structure.

5. Results and Discussion

The base case distribution rings hydrodynamic model was initially analyzed to understand the flow behavior and locate high-stress zones. Figure 5 shows the geometry, with particular attention given to the plate support under the distribution rings. The hypothesis is that this zone is subject to high slurry velocity where the facing cloths are squeezed together, enhancing the risk of cloth damage. Two analysis methods are proposed: a qualitative one, where streamlines combined with velocity fields are presented across the chambers for each geometry, and a second quantitative one where a series of twelve virtual sensors were strategically positioned in the upper part of the chamber underneath the distribution rings, as shown in Figure 5. This provides a general comparison among all geometries.

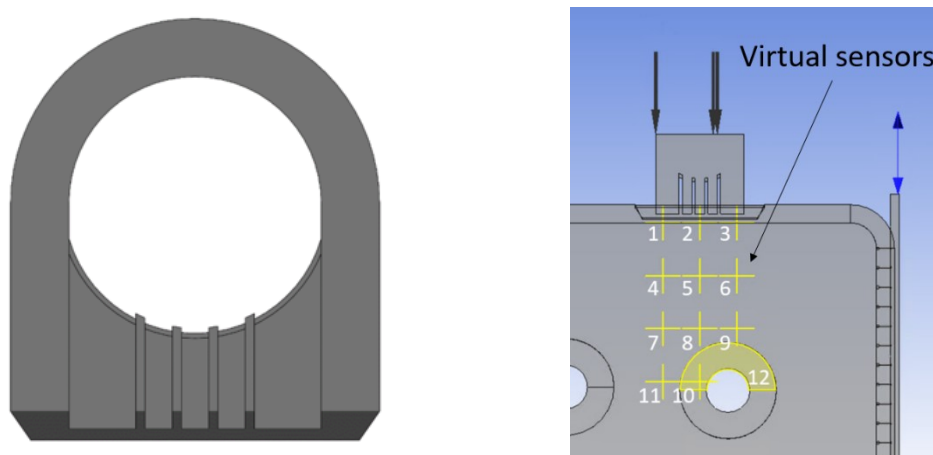


Figure 5. Base case. Left: distribution ring, Right: virtual sensors positions.

CFD modeling results are displayed in Figure 6, where the red zone indicates a high slurry velocity, while the blue zone indicates low velocity areas. A zone of maximum velocity is observed between the grooves due to the small fluid passage area. Since the fluid is incompressible, the principle of mass conservation states that the smaller the passage area, the higher the velocity will be. Furthermore, it is noted that the fluid flows directly onto the first plate support, confirming the aforementioned hypothesis and creating a zone of high stress and constraint. The CFD modeling suggests a velocity of around 0.225 m/s, supporting this observation. This high velocity may likely lead to a significant abrasion phenomenon at this location on the filter cloth, explaining the premature wear observed in the plant.

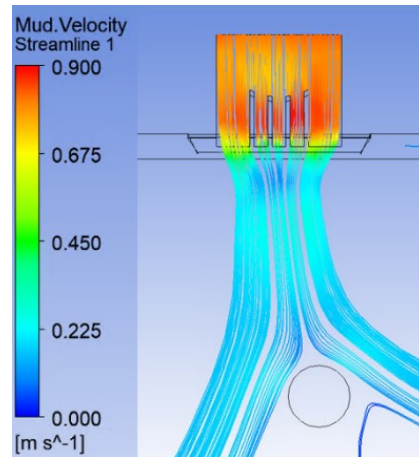
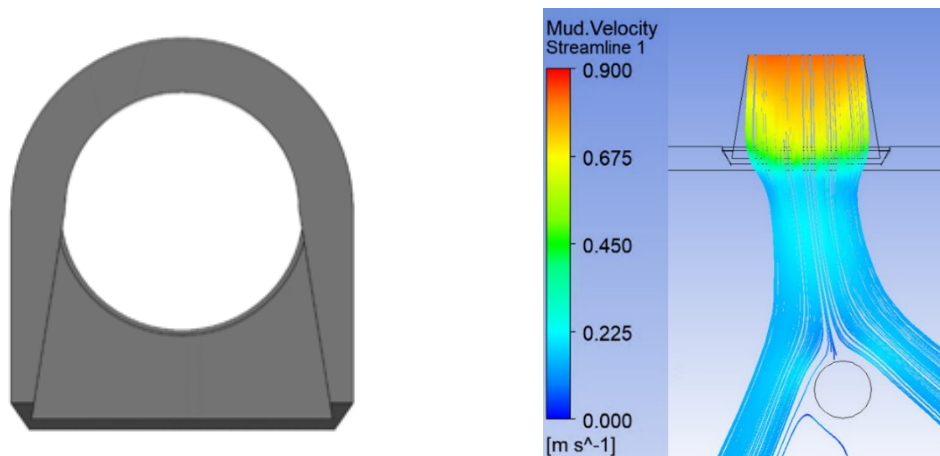


Figure 6. Streamlines for the base case distribution rings.

One of the strengths of numerical modeling is the speed and lower cost at which solutions can be tested. There is no need for plant shutdowns or attempts to try out new distribution ring geometries that could potentially solve the above problems. In total, over a dozen geometries were tested, but only the standout geometries are presented in this paper.

As mentioned earlier, since the fluid is incompressible, the only way to decrease the fluid velocity while maintaining mass conservation is to increase the flow path area. Since the diameter of the central hole cannot be modified, to remain compatible with the filter press feed piping, one solution is to remove all the crossflow supports and increase the spacing of the fluid path section at the base of the feed rings. This provides a flared shape starting with a gap of 125 mm and ending with a gap of 317 mm, as shown in Figure 7. The lower dimension cannot be increased further to ensure that the distribution rings remain sufficiently sturdy and can properly fit each of their respective plates. The results of the CFD simulations presented in Figure 7 suggest a decrease in the velocity of the slurry, indicated by the absence of bright red color in the streamlines, which should lead to a reduction in filter cloth wear. While the streamline representation is purely visual, virtual sensors positioned along the flow path offer more explicit results.



**Figure 7. Flared shape distribution rings.
Left: geometry, Right: CFD-generated streamlines.**

Table 1 shows the percentage of flow velocity with the new distribution ring geometry (flared shape) compared to the base case. Generally, an average decrease of about 20 % in velocity is observed, confirming the observations made in the Figure 7. The primary objective of modifying

the distribution ring geometry is to dissipate the kinetic energy of the feed flow, which has been achieved. However, it should be noted that despite a general decrease in velocity, it is relatively higher at the center of the flow, namely at points 2, 5, and 8 as shown in the table below. Combined with the previous observations, the new flared-shape geometry does not sufficiently diffuse the flow, and the center of the distribution rings directs the flow onto the first plate support, which could still cause cloth wear and tear.

Table 1. Velocity percentage compared to the base geometry at different virtual sensors for the flared shape distribution rings.

Virtual sensors	1	2	3	4	5	6	7	8	9	10	11	12	Avg.
Base case (m/s)	0.54	0.30	0.38	0.27	0.26	0.22	0.20	0.16	0.16	0.20	0.19	0.15	0.25
Flared shape (m/s)	0.34	0.36	0.26	0.16	0.21	0.18	0.14	0.15	0.12	0.17	0.15	0.13	0.20
Velocity percentage (%)	63	119	69	60	80	84	71	91	78	84	80	85	80.4

However, in terms of structural resistance, the flared shape geometry reveals a significant problem due to the pressure when the filter press is closing. A structural analysis using the ANSYS Static Structure module was conducted, showing significant deformation at the base of the distribution ring, as shown in Figure 8. This deformation reaches a maximum of 56 mm, which would result in the closure of the fluid path, blocking the entry of slurry into the filtration chamber and rendering it completely inoperable.

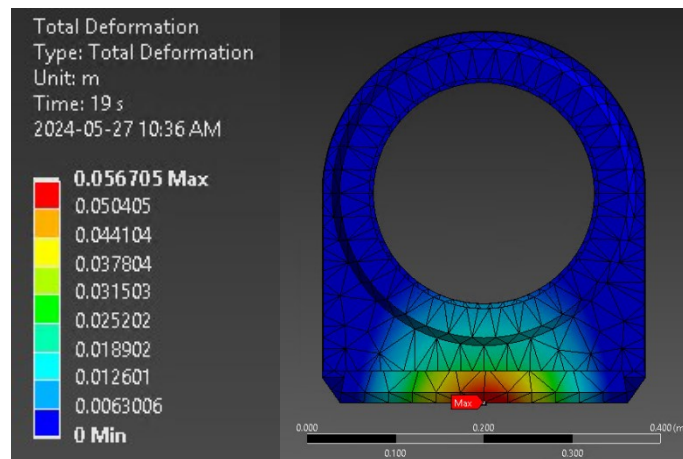


Figure 8. Modelling of the flared shape distribution rings deformation.

To address these issues, it has been proposed to reinstall a crossflow support at the center of the fluid path section, as shown in Figure 8. Instead of having a support shape parallel to the flow like the base case design, a pyramid-like shape could divert the flow while ensuring sufficient support under the filter press closing pressure. Figure 9 illustrates the impact of the new geometry on the flow, provided by CFD modeling. The first noticeable change is the deviation of the slurry, with the flow diverted away from the first plate support, which was previously the most exposed part to abrasion, thereby sparing the cloths from damage.

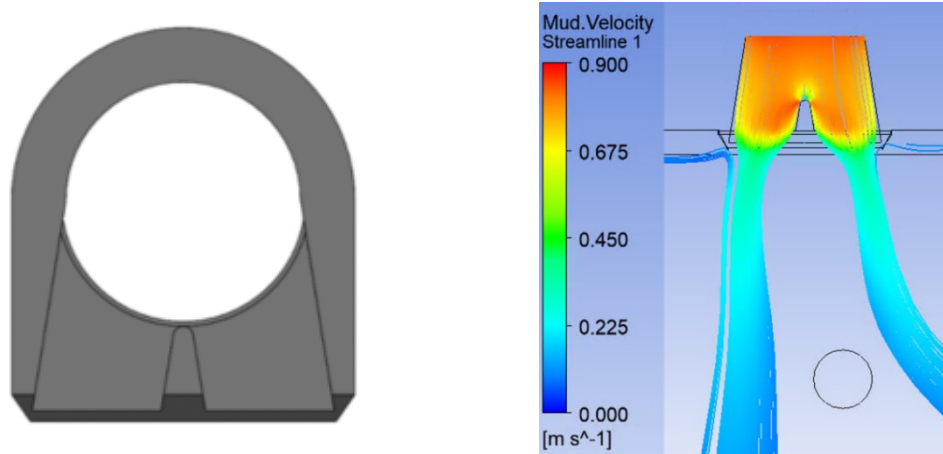


Figure 9. Pyramidal support distribution rings. Left: geometry, Right: CFD model streamlines.

As detailed in Table 2, the average of all the virtual sensors shows the same value as the previous design, indicating again an overall velocity reduction of 20 %. However, the distribution varies significantly due to the pyramid shape of the support. Specifically, velocities at the center, (sensors 2, 5, 8, and 10), are lower than in the previous case, suggesting that less severe abrasion will occur on the first plate support. The flow diversion to the sides leads to higher velocities at sensors 3, 4, 7, 9 and 11. Nevertheless, this should result in a lower impact on the filter cloth as the fluid avoids the critical zone where they are pinched together, opening the path through the chamber and dissipating the kinetic energy.

Table 2. Velocity percentage compared to the base case geometry at different virtual sensors for the pyramidal support distribution rings.

Virtual sensors	1	2	3	4	5	6	7	8	9	10	11	12	Avg.
Base case (m/s)	0.54	0.30	0.38	0.27	0.26	0.22	0.20	0.16	0.16	0.20	0.19	0.15	0.25
Pyramidal shape (m/s)	0.36	0.18	0.42	0.28	0.18	0.17	0.20	0.09	0.15	0.12	0.17	0.10	0.20
Velocity percentage (%)	66	59	110	105	71	79	100	59	94	59	92	69	80.3

In addition to reducing wear on the filter cloths by deflecting and slowing down the feed flow, the pyramidal reinforcement significantly enhances the structural integrity of the distribution rings. Figure 10 shows the deformation patterns on the distribution rings when exposed to filter press closing pressure. Unlike the previous study, the red color indicating strong deformation at the center is much less prominent, and the two facing rings no longer collapse. Therefore, the reinforcement minimises the deformation of the rings and primarily prevents any blockage of the slurry in the passage section when the filter press is closed.

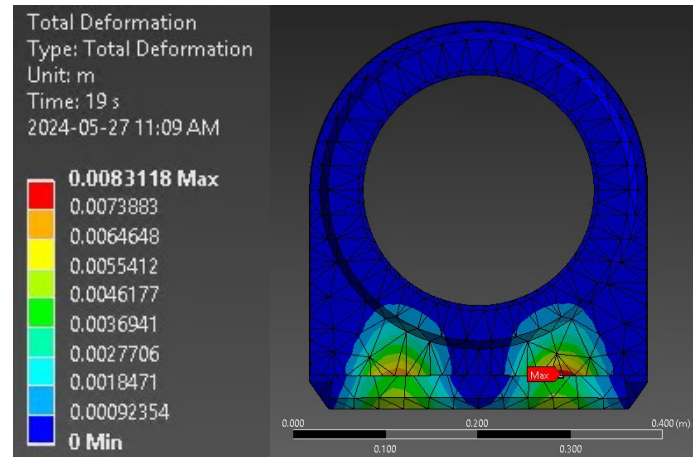


Figure 10. Total deformation for the pyramidal support distribution rings.

6. Conclusions and Options for Future Studies

Modern numerical methods, such as CFD and FEA, can assist in the optimization of the design of filter presses for the treatment of bauxite residue. This study demonstrates how these tools can successfully identify critical areas of stress and wear, thereby enabling the development of innovative solutions to enhance the overall performance of filter presses.

The CFD analysis provided detailed visualization of the slurry flows inside the filtration chambers, revealing the direct impact of the high entry velocity of the flow on the wear of the filter cloths. The initial design of the distribution rings directed a high-velocity jet directly onto the cloth, leading to significant abrasion and premature wear. This paper demonstrates that various designs can be easily tested using CFD to evaluate flow patterns and measure the reduction in slurry velocity in critical zones. The FEA complemented the study by evaluating the structural strength of the distribution rings under pressure and demonstrated that crossflow support is essential to prevent blockage of the slurry passage.

In conclusion, the use of modern numerical methods like CFD and FEA opens new perspectives to optimize filter presses for the treatment of mining residues. These tools allow for in-depth analysis of the complex phenomena occurring within the filtration chambers. This work can serve as a starting point for significant progress in the field, helping to reveal and measure phenomena that are typically invisible and difficult to assess with current technologies. It can pave the way for the uses of numerical simulation to model slurry as a biphasic suspension, enhancing the understanding of solid-liquid separation inside the filtration chambers. This approach can help identify the flow of the liquid phase in the cake and locate constraint zones to pinpoint areas for improvement. The continued application of these numerical methods in this field will help minimize the environmental impact of the mining industry and enhance the value of mining residues for potential applications.

7. References

1. Francesco Kaswalder, and Andrea Pezzi, Case Study – Installation and startup of a system for red mud filtration with filter presses, *TRAVAUX 51, Proceedings of the 40th International ICSOBA Conference*, 10–14 October 2022, Athens, Greece.
2. Steve Healy et al., Sustainable bauxite residue management guidance, *International Aluminium Institute*, 2022, 34–42, <https://international-aluminium.org/resource/sustainable-bauxite-mining-guidelines-second-edition-2022-2/> (Accessed on 27 August 2024).
3. Evans Ken, The history, challenges, and new developments in the management and use of bauxite residue, *Journal of Sustainable Metallurgy*, Vol. 2, No. 4, 2016, 316–331.

4. Simon Gravel et al., Conversion to filtered tailings: commissioning and ramp-up of Rio Tinto's bauxite residue filtration plant, *Proceedings of Alumina 2024, the 12th International Alumina Quality Workshop*, 22–24 April 2024, Dubai, UAE.
5. Prem Ranjan and Manjeet Prem, A filtration layer of slow sand filter, *International Journal of Current Microbiology and Applied Sciences*, Vol. 7, No. 7, 2018, 637–645.
6. Zhengyuan Pan et al., Simulation of performance of fibrous filter media composed of cellulose and synthetic fibers, *Cellulose*, Vol. 26, 2019, 7051–7065.
7. Biao Xie et al., Improving filtration and pulse-jet cleaning performance of metal web filter media by coating with polytetrafluoroethylene microporous membrane, *Process Safety and Environmental Protection*, Vol. 136, 2020, 105–114.
8. Liang Zhang et al., Numerical investigation of a chamber filter press on flow characteristics and influence of parameters under variable working conditions, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, Vol. 46, No. 1, 2024, 5180–5200.