

SHEAR-ASSISTED HIGH-SOLIDS FILTRATION OF RED MUD USING HIGH PRESSURE DEWATERING ROLLS

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ABSTRACT

Every year, approximately 175 million tonnes of bauxite residue is produced globally from the Bayer alumina refining process. The residue, red mud, consists of ultra-fine particles and is extremely alkaline, posing an environmental hazard when stored as a liquid. Filtration to high solids content reduces the risk but is challenging for red mud, which forms compressible and impermeable filter cakes. Conventional filtration technologies are constrained by throughput and achievable moisture content, require regular cloth washing and replacement, and are typically batch operated. This work evaluates High Pressure Dewatering Rolls (HPDR), which is a continuous and cloth-less filter using a 30 μm screen, as an alternative mechanical dewatering technology for red mud.

An experimental program was undertaken to characterise the red mud residue sample and determine its filtration performance in the HPDR relative to a conventional filter. Particle sizing using light scattering confirmed an ultrafine particle suspension ($D[3,2] = 3.05 \mu\text{m}$). Filtration and sedimentation testing were used to determine compressibility and permeability functions across a broad solids concentration range, allowing prediction of solid-liquid performance. Shear yield stress measurements were used to quantify the susceptibility of red mud to mechanical shear. Red mud was filtered in the HPDR under controlled operating conditions, assessing achievable solids concentration, filtrate quality, and throughput as functions of roller speed, roll speed differential and hydraulic pressure.

The HPDR successfully filtered red mud with an initial solids concentration of 32.6 wt.% to very high cake solids of 71.2 wt% without the use of flocculants, significantly higher than conventional filtration at 1.2 MPa (60 wt%). Specific solids throughput was lower for the HPDR compared to the conventional filter due to the smaller cake formation pressure. Filtrate solids were relatively high for the HPDR since there was no flocculation but remained below 6 wt%. Lower roller speeds and speed differentials of 10 to 20% were found to enhance dewatering performance in the HPDR.

Overall, the results demonstrate that HPDR technology can achieve high cake solids for ultra-fine, compressible materials such as red mud, particularly where shear-induced dewatering mechanisms can be exploited. The findings provide practical guidance on material selection, operating windows, and key limitations relevant to the industrial deployment of HPDR as a complementary or alternative tailings dewatering solution.

KEYWORDS:

Filtration, tailings dewatering, red mud residue, shear, compressibility

1 Introduction

Bauxite residue, commonly known as red mud, is an ultrafine, highly alkaline by-product of alumina production via the Bayer process (Saveliev et al., 2024). The Bayer process accounts for approximately 95% of global alumina production (Wang et al., 2019), generating roughly 175 million tonnes of red mud annually (Archambo and Kawatra, 2021). Its high alkalinity, fine particle size, and large water content pose substantial environmental and operational challenges. Disposal in tailings ponds carries long-term risks such as soil and water contamination, structural instability, and high management costs, highlighting the need for improved dewatering strategies (Avery and Wilson, 2013, Wang et al., 2019, Archambo and Kawatra, 2021, Patil and Thorat, 2022, Saveliev et al., 2024).

Red mud particles are extremely fine, ranging from 0.1 to 200 μm , with an average size below 10 μm (Saveliev et al., 2024). This ultrafine nature results in slow filtration rates and high moisture content when processed using conventional dewatering technologies (Tao et al., 2025). Methods such as thickeners, vacuum drum filters, pressure filters, and belt presses are typically limited in throughput, achievable solids content, or operational continuity (Patil and Thorat, 2022). While flocculants can enhance dewatering performance, their effectiveness depends on careful selection, preparation, and optimisation, which can increase operational cost and handling requirements (Bonnier et al., 2025). Improving dewatering would enable dry stacking, reduce storage volume, enhance environmental safety, and allow greater water recovery for reuse in the Bayer process (Furnell et al., 2022). Existing tailings dewatering technologies each have limitations for red mud: gravity thickeners recover bulk water efficiently but yield low-solids concentrates; centrifuges and belt filters employ compression and shear but remain less effective for highly compressible, fine-grained suspensions; and pressure filters can achieve low moisture contents but are costly, rely on cloths that foul and require high maintenance. Moreover, conventional compression-only filters cannot exploit shear to enhance water removal, emphasizing the need for technologies that integrate compression, shear, and controlled drainage.

High Pressure Dewatering Rolls (HPDR) (Scales et al., 2017b, Scales et al., 2017a, Höfgen et al., 2019, Stickland et al., 2024, Hassan et al., 2025a, Hassan et al., 2026) represent an emerging continuous, cloth-less filtration technology that combines vacuum, mechanical compression and shear to improve water removal. By applying controlled shear in addition to compression, HPDR disrupts structured particle networks, promoting dewatering in ultrafine, compressible suspensions. This shear-assisted mechanism has the potential to achieve higher solids concentrations and more consistent filtration performance, particularly for red mud that resist consolidation under compression alone.

This study investigates the dewatering performance of red mud using HPDR under systematically varied operating conditions, including roller speed, roll speed differential and hydraulic pressure. The material is first characterised in terms of compressive yield stress, permeability, and shear sensitivity to provide insight into its filtration behaviour. HPDR performance is then compared with vacuum-only operation and conventional filter presses to assess the technology's potential as an industrially viable solution for high-solids tailings dewatering.

2 Materials

Neutralised red mud residue was received in bulk from a major Australian alumina producer. The material was obtained as thickener underflow and transported to the laboratory in sealed buckets. The slurry was stored at ambient temperature and homogenised in a single 205 L drum to ensure uniformity prior to testing. No flocculants or chemical modification were applied. The initial corrected solids concentration (adjusted for dissolved solids) was 32.6 ± 0.2 wt.%. The as-received material was used for material characterisation, as well as feed for HPDR and lab-scale filter press experiments.

3 Methods

3.1 Physical and Chemical Characterisation

Total solids were determined by oven drying at 105°C . Dissolved solids were measured following vacuum filtration through a $0.22\ \mu\text{m}$ PVDF membrane (Durapore, Merck) and oven drying the filtrate. Suspension and liquor densities were measured using a pycnometer and a DMA35 density meter (Anton Paar), respectively. Slurry pH and electrical conductivity were measured with a HQ40d multiparameter meter (Hach). Particle size distributions were obtained by laser diffraction (Mastersizer 3000, Malvern). All measurements were performed in triplicate.

3.2 Material Characterisation

The compressive yield stress, $P_y(\phi)$, and hindered settling function, $R(\phi)$, were determined to characterise suspension compressibility and permeability. $P_y(\phi)$ defines the equilibrium solids volume fraction achievable under an applied stress and reflects the strength of the particle network, as described by Buscall and White (1987). $R(\phi)$ is inversely proportional to Darcian permeability and describes resistance to fluid flow through the particle network.

Both properties were obtained using stepped pressure filtration (Green et al., 1998, de Kretser et al., 2001, Usher et al., 2001) and batch sedimentation (Lester et al., 2005). Stepped pressure filtration was performed in a piston-driven cell with a $0.22\ \mu\text{m}$ PVDF membrane (Durapore, Merck) between 20 and 1000 kPa. Equilibrium piston displacement was recorded at each pressure increment, and solids volume fractions at each pressure were calculated from the final cake concentration assuming conservation of solids mass. Batch sedimentation tests were performed on suspensions diluted below the gel point, recording interface height over time (Lester et al., 2005). Data from both methods were used to construct $P_y(\phi)$ and $R(\phi)$ curves according to Usher et al. (2013).

Shear yield stress, τ_y , was measured using the vane-in-a-large-cup method (Fisher et al., 2007) with a Haake VT500 rheometer. Suspensions were mixed for 2 minutes, gently tapped for 30 seconds to remove entrained air, allowed to rest for 2 minutes, and the vane was rotated at 0.2 rpm to record the peak stress.

3.3 High Pressure Dewatering Rolls

3.3.1 Overview

The High Pressure Dewatering Rolls (HPDR) is a continuous, cloth-less filtration device that dewateres suspensions using two semi-permeable rotating rolls fitted with 30 μm wedge wire screens. The rolls have a diameter of 215 mm and a length of 200 mm. One roller is fixed, and the other is mounted on a pivoting frame (floating roller) actuated by hydraulic cylinders. Feed suspension forms a cake on the roll surfaces, which are under vacuum. The cake is compressed in the nip between the rolls under high hydraulic pressure. Independent roll drives allow asynchronous rotation to introduce shear, while the adjustable filtration path length and high pressure enable high-solids cakes and mitigate permeability limitations (Hassan et al., 2025a).

HPDR tests were conducted in a partially submerged configuration that prevents slurry leakage at the scraper–roller interface while allowing pre-nip desaturation. Roller speed and gap were monitored in real time using calibrated encoders, and all process parameters—including hydraulic pressure, cake mass, and filtrate mass—were continuously logged via the PLC system. A schematic of the HPDR is shown in Figure 1.

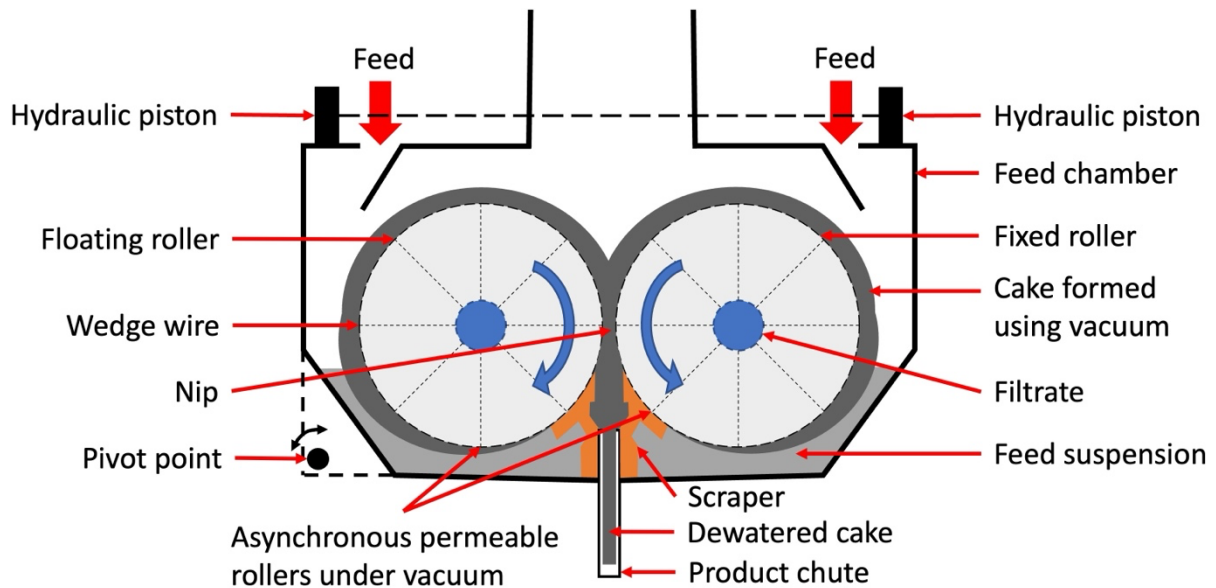


Figure 1: Schematic of the High Pressure Dewatering Rolls (Hassan et al., 2026).

3.3.2 Experimental Method

HPDR tests were conducted on red mud at an as-received feed solids concentration of 32.6 ± 0.2 wt.% and a hydraulic pressure of 68.8 ± 1.7 bar. Experiments were first performed with no roll speed differential (0%) at three constant roller speeds (0.2, 0.5, and 1 rpm), followed by speed differentials of 5%, 10%, 20%, and 40% at each roller speed. These operating conditions were selected to cover a range of roller speeds and shear rates, allowing assessment of both low-shear and high-shear effects on red mud dewatering performance.

For baseline comparison with vacuum-only filtration, the HPDR was operated with the floating roller opened to a fixed gap of 15 mm, preventing roller contact. In this configuration, only the fixed roller operated, applying no compression or shear, and filtration occurred solely by vacuum-assisted cake formation and consolidation on the wedge wire screen. Tests were conducted at roller speeds of 0.2, 0.5, and 1 rpm under the same feed conditions as the standard HPDR experiments.

A separate set of experiments investigated the effect of hydraulic pressure (12.0 – 92.9 bar) on cake solids concentration and solids throughput at a constant roller speed of 0.2 rpm and a roll speed differential of 5%.

3.3.3 Calculations

For each HPDR run, six samples of the cake were oven-dried for 24 h at 105 °C. Total solids were corrected for dissolved solids to report the average corrected cake solids concentration.

Cake solids throughput (Q_s , kg s⁻¹) was calculated using the cake mass:

$$Q_s = x \frac{dm_c}{dt} \quad 1$$

where x is the average corrected cake solids mass fraction (-) and dm_c/dt is the rate of cake mass collection (kg s⁻¹).

The roller speed differential (%) (Hassan et al., 2025a) and average shear rate ($\dot{\gamma}$, s⁻¹) (Höfgen et al., 2019) were calculated as:

$$\text{Roller speed differential (\%)} = \frac{\omega_1 - \omega_2}{\frac{\omega_1 + \omega_2}{2}} \times 100 \quad 2$$

$$\dot{\gamma} = \frac{\omega_1 r_1 - \omega_2 r_2}{g} \quad 3$$

where ω is the angular velocity of each roller, r is the roller radius, and g is the measured average roller gap.

3.4 Filter Press Benchmarking

Lab-scale filtration experiments were conducted using a fixed-cavity membrane filter press (Outotec) to benchmark the performance of the HPDR. Two chamber thicknesses, including the cavity, were tested: 34.4 mm and 22 mm. For each thickness, two fill times were applied while maintaining similar squeeze times. Fill and squeeze pressures were set at 600 kPa and 1200 kPa, respectively. Feed suspension had a solids concentration of 32.6 wt.%. Cake solids were oven-dried at 105 °C for 24 h, and corrected solids concentrations were reported. Solids throughput was calculated from the total cake mass, cake solids concentration, total cycle time

(including 348 s handling), and filter area (circular filter, 113.3 mm diameter; 0.0101 m²).

Numerical predictions were obtained using the flexible-membrane filter press model of Stickland et al. (2008), which incorporates the theoretical framework of Buscall and White (1987) and the constant-pressure piston-driven filtration model of Landman and White (1994). The model uses compressive yield stress ($P_y(\phi)$) and hindered settling function ($R(\phi)$) across the full solids concentration range from material characterisation. All inputs—including initial solids fraction (ϕ_0), cavity width ($2h_0$), membrane resistance ($R_m = 1.86 \times 10^{12} \text{ m}^{-1}$, determined from actual filter press tests), handling time ($t_H = 5.8 \text{ min}$), loading time ($t_L = 0$), and applied pressures (600 kPa fill, 1200 kPa squeeze)—were matched to the experimental conditions to predict solids volume fraction and solids throughput over filtration time.

The volumetric throughput per unit area, Q (m³ m⁻² s⁻¹), of a batch-operated filter press with loading, fill, membrane-squeeze, and unloading stages is expressed as (Stickland et al., 2018):

$$Q = \frac{V_f + h_0}{t_h + t_f + t_s} \quad 4$$

where V_f is the filtrate volume per unit area at the end of filling, h_0 is half the initial cavity width, t_h is the total handling time, t_f the fill time, and t_s the squeeze duration. The solids mass balance is:

$$\phi_0(V_f + h_0) = \phi_f h_0 = \phi_s h_s \quad 5$$

with ϕ_0 as the feed solids fraction, ϕ_f and ϕ_s the average cake solids fractions at the end of the fill and squeeze stages, and h_s the cavity half-width after squeezing. Combining Eqs. (4) and (5) gives the throughput as a function of cake solids:

$$Q = \frac{\phi_f}{\phi_0} \left(\frac{h_0}{t_h + t_f + t_s} \right) = \frac{\phi_s}{\phi_0} \left(\frac{h_s}{t_h + t_f + t_s} \right) \quad 6$$

This approach allows calculation of solids concentration and throughput for each stage of the batch cycle, accounting for variations in fill, squeeze, and handling times.

4 Results and Discussion

4.1 Material Properties

The as-received red mud had a corrected solids concentration of 32.6 wt.% with dissolved solids of 2.9 wt.%. The pH and electrical conductivity of the slurry were 10.1 and 31.8 mS/cm, respectively. The solids and liquor densities were 2982 kg/m³ and 1020 kg/m³, respectively.

The particle size distribution (PSD) was extremely fine. The Sauter mean diameter ($D[3,2]$) was $3.05\ \mu\text{m}$, and the volume mean diameter ($D[4,3]$) was $16.9\ \mu\text{m}$. The particle size percentiles were $d_{10} = 1.48\ \mu\text{m}$, $d_{50} = 3.98\ \mu\text{m}$, and $d_{90} = 34.5\ \mu\text{m}$. The ultrafine particle size is expected to contribute to high compressibility and low permeability, which are important factors affecting filtration and dewatering behaviour.

4.2 Material Characterisation

The dewatering-relevant properties of red mud were characterised using compressive yield stress, hindered settling function, shear yield stress, and the ratio of shear to compressive yield stress. These measurements provide insight into compressibility, permeability, and shear sensitivity, which directly influence filtration performance in systems such as HPDR and lab-scale filter presses.

Compressive yield stress, $P_y(x)$ (Figure 2a), increased with solids concentration. The gel point, where $P_y(x) = 0$, was 18.6 wt.%. At an applied equilibrium pressure of 1000 kPa, the solids concentration reached 59.1 wt.%, reflecting the strong resistance of red mud to consolidation. The wide solids concentration range from 18.6–59.1 wt.% across 0–1000 kPa indicates that the material is highly compressible, whereas suspensions that consolidate over a much narrower range are considered nearly incompressible. This high resistance to consolidation is consistent with the ultra-fine particle size ($D[3,2] = 3.05\ \mu\text{m}$) and high surface area, suggesting that mechanical compression alone is insufficient to achieve very high solids content, and there may be potential additional benefit from shear-assisted dewatering.

Hindered settling function, $R(x)$ (Figure 2b), reflects the relative permeability of the suspension, being inversely related to flow resistance. At high solids concentrations, $R(x)$ was on the order of $10^{12}\ \text{kg s}^{-1}\ \text{m}^{-3}$, indicating very low permeability. For comparison, calcium carbonate with a Sauter mean diameter of $12.2\ \mu\text{m}$ has $R(x)$ on the order of $10^{10}\ \text{kg s}^{-1}\ \text{m}^{-3}$ at high pressures (Hassan et al., 2025b), making it at least 100 times more permeable. These results show that water removal from red mud is strongly constrained by its compressible, tightly packed particle network, which resists consolidation and limits permeability under conventional filtration conditions.

Shear yield stress, τ_y (Figure 2c), is measurable just above the gel point (5.7 Pa at 22.3 wt.%) and increases rapidly to 774 Pa at 46.9 wt.%, indicating the formation of a strongly structured network that resists flow under shear. The high shear strength arises from its extremely fine particle size and large surface area, which promote strong interparticle interactions and increase resistance to yielding.

The ratio of shear to compressive yield stress, τ_y/P_y (Figure 2d), provides insight into the relative resistance of the suspension to shear versus compression. It is plotted against solids volume fraction normalised by the gel point, ϕ/ϕ_g , which represents how much the suspension has been compressed relative to its initial network at the gel point. Just above the gel point ($\phi/\phi_g \gtrsim 1$), the ratio is close to 1, indicating that shear and compressive strengths develop at similar rates. As solids concentration increases, τ_y/P_y decreases by two orders of magnitude, showing that compressive

resistance dominates while shear resistance is roughly 100 times lower. This low stress ratio highlights that red mud is particularly susceptible to shear-assisted dewatering: although compression alone is limited in achieving very high solids content, the application of shear can effectively disrupt the structured network and enhance water release.

Collectively, these characterisation results demonstrate that the material is ultrafine, highly compressible, low-permeability, and shear-sensitive, making it an ideal candidate for HPDR filtration.

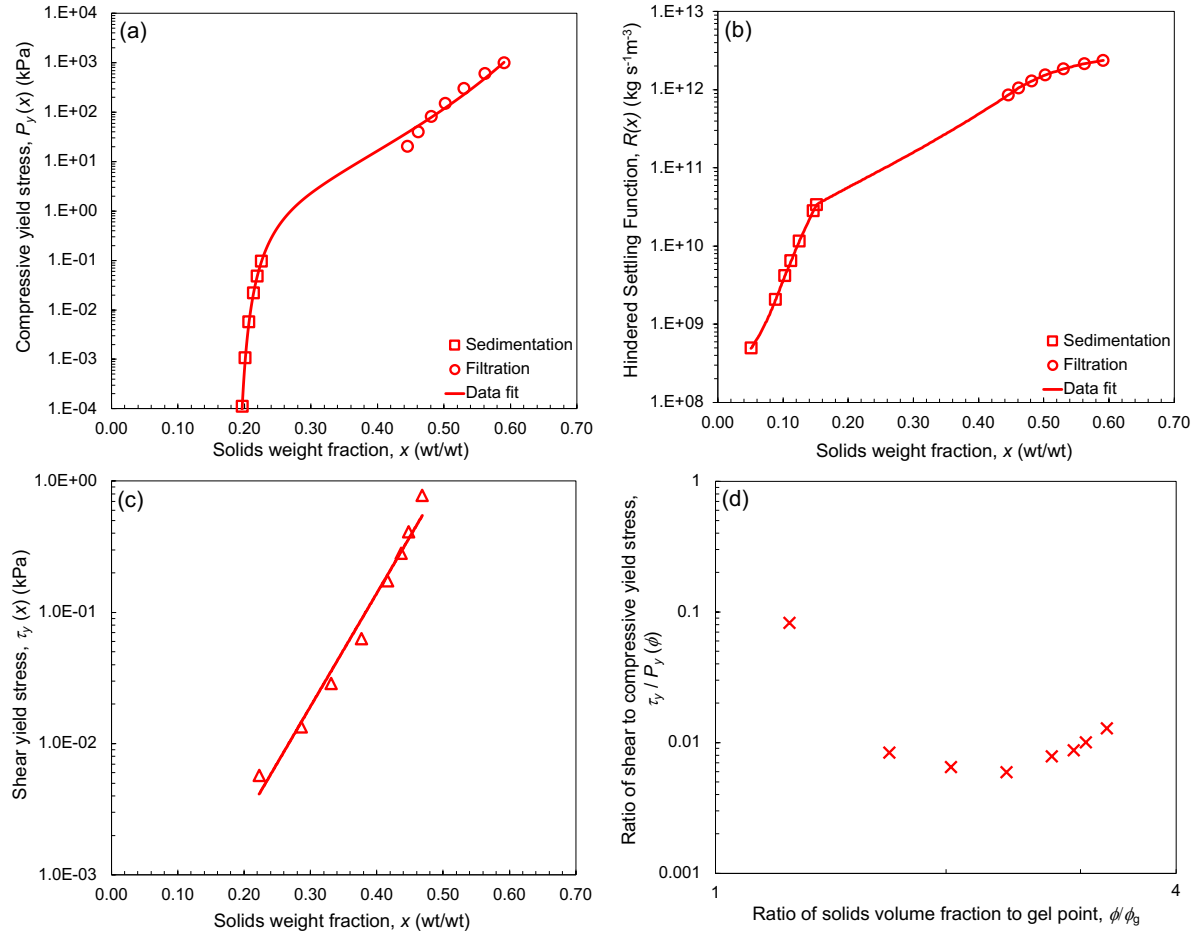


Figure 2: Material characterisation of red mud. (a) Compressive yield stress as a function of solids weight fraction, showing high resistance to consolidation; (b) Hindered settling function as a function of solids weight fraction, highlighting low permeability at high solids concentrations; (c) Shear yield stress as a function of solids weight fraction, highlighting rapid network formation and high flow resistance; (d) Ratio of shear to compressive yield stress as a function of solids volume fraction normalised by the gel point, illustrating shear sensitivity relative to compression and relevance for HPDR dewatering.

4.3 HPDR Results

4.3.1 Effect of Roller Speed and Applied Shear

Roller speed had a strong influence on red mud dewatering performance. The highest cake solids concentrations were achieved at 0.2 rpm, with progressively lower solids observed at 0.5 rpm and 1 rpm (Figure 3a). At lower roller speeds, the increased residence time allowed more effective vacuum-assisted drainage upstream of the nip, forming thicker pre-compacted cakes (Figure 3c). These thicker cakes were then compressed in the nip, resulting in higher final solids. Conversely, higher roller speeds reduced residence time, limiting upstream drainage and producing thinner cakes entering the compression zone. As expected, solids throughput increased with roller speed (Figure 3b), resulting from the faster roller movement overcoming the simultaneous decrease in cake thickness and solids concentration.

Under zero roll speed differential, cake solids concentration decreased from 66.7 wt.% at 0.2 rpm to 55.5 wt.% at 1 rpm, while solids throughput increased from 8.9 to 14.2 kg m⁻² h⁻¹. Over the same range, the average roller gap decreased from 0.71 mm to 0.24 mm, reflecting reduced cake thickness at higher speeds.

Introducing a roll speed differential altered this behaviour. Across all three roller speeds, the average roller gap remained comparable to the zero-differential case (Figure 3c), indicating that changes in cake solids were not driven by geometric effects alone. A 5% speed differential produced negligible improvement, while a 10% speed differential resulted in an increase in both cake solids concentration (Figure 4) and throughput. At 0.2 rpm, cake solids increased from 66.7 wt.% to 70.0 wt.%, and throughput increased from 8.9 to 10.7 kg m⁻² h⁻¹. Although the absolute increase in solids concentration was 3.3 wt.%, this change is significant given that the material is approaching its packing limit. Material characterisation data indicate that, under equilibrium compression at 1000 kPa, the red mud achieves a maximum solids concentration of only 59.1 wt.%, highlighting the substantially improved dewatering achieved by HPDR operation. Compared to other, less compressible or coarser materials we have tested, such as nickel tailings and calcium carbonate, red mud shows a much larger response to roll speed differential, reflecting its high shear sensitivity (Hassan et al., 2025a, Hassan et al., 2026).

With larger speed differentials of 20% and 40%, cake solids began to decrease, indicating that too much shear has a negative effect on dewatering performance.

Across all roller speeds and shear conditions, HPDR processing increased solids concentration substantially relative to the feed, achieving corrected cake solids of up to 70 wt.% without flocculants.

To further highlight the benefits of HPDR, the system was also operated in a vacuum-drum-only mode by opening the gap up to 15 mm, leaving only the fixed roller active (“0.5 HPDR” in Figure 3). In this configuration, there is no compression or shear. Cake solids reached 45.6 wt.% at 0.2 rpm, decreasing to 40.1 wt.% at 1 rpm, limited by the relatively low vacuum pull achieved in these runs (–21 to –32 kPa). These results likely underestimate actual vacuum-drum performance, which can achieve much stronger vacuum.

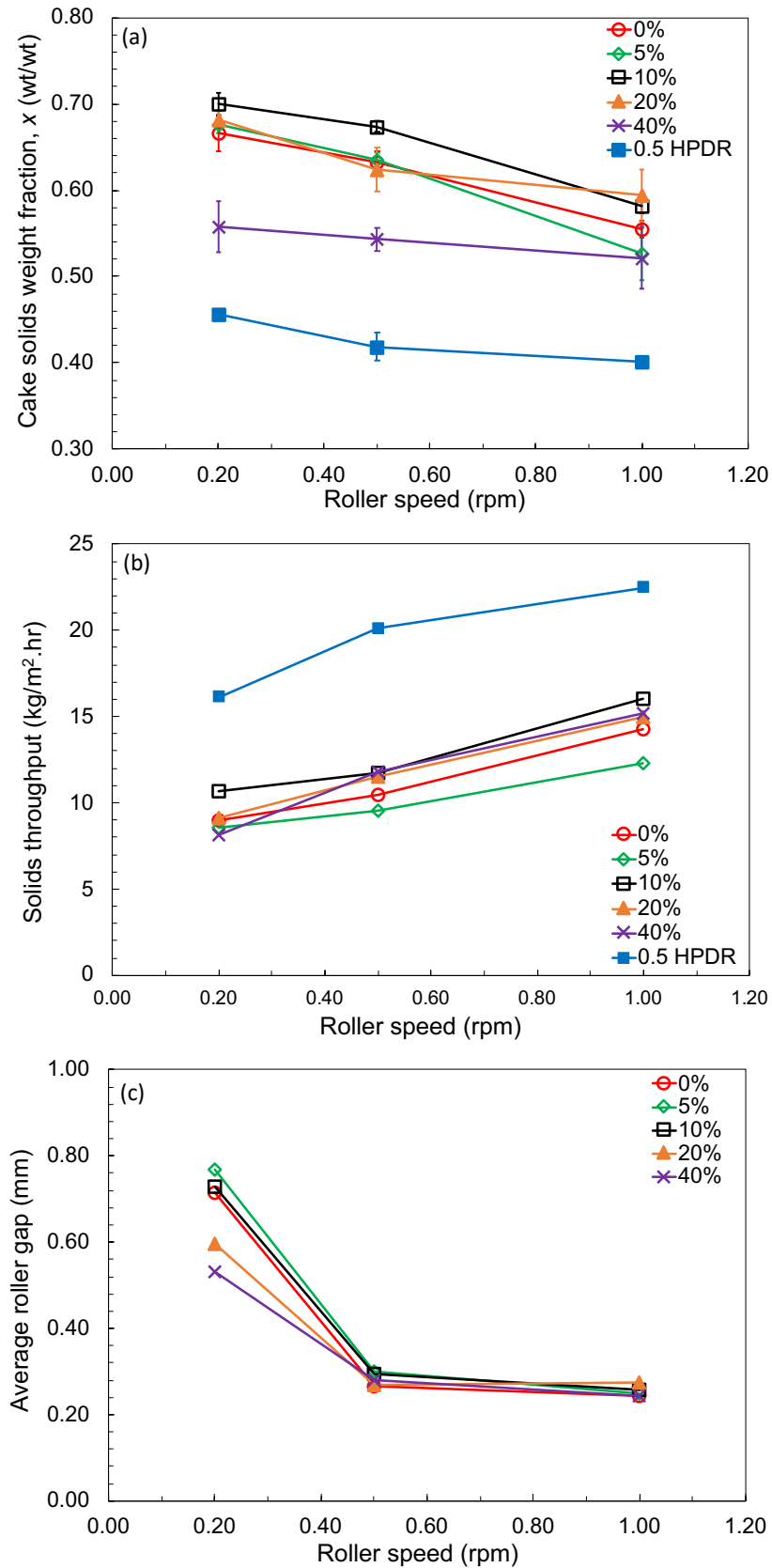


Figure 3: HPDR dewatering performance of red mud as a function of roller speed and applied shear under zero and varying roll speed differentials (0–40%). (a) Corrected cake solids concentration, (b) solids throughput, and (c) average roller gap. “0.5 HPDR” represents operation with only the fixed roller active, effectively functioning as a vacuum-drum filter.



Figure 4: Pictures of red mud filter cakes produced by HPDR at average roller speeds of 0.2, 0.5, and 1 rpm, with a constant roller speed differential of 10% and hydraulic pressure of 68.8 ± 1.7 bar. The corresponding cake solids concentrations were 70.0 ± 1.3 , 67.4 ± 0.6 , and 58.2 ± 0.8 wt.%, respectively, demonstrating reduced dewatering performance with increasing roller speed.

This comparison demonstrates that HPDR, with its combined compression and shear mechanisms, can achieve substantially higher cake solids of up to 70 wt.%. Vacuum-drum-only mode, however, achieved higher throughput per unit area — up to twice that of HPDR. The lower throughput in HPDR experiments was caused by material floating and slippage under high hydraulic pressures, while partial clogging at the narrow product discharge chute (~20 mm wide) limited material flow in all runs, including vacuum-drum-only tests.

For comparison, previous studies showed nickel tailings ($D[3,2] = 9.33 \mu\text{m}$) had a maximum throughput of $302 \text{ kg m}^{-2} \text{ h}^{-1}$, and calcium carbonate ($D[3,2] = 12.2 \mu\text{m}$) reached $445 \text{ kg m}^{-2} \text{ h}^{-1}$. Both materials have larger particle sizes and, based on our material characterisation, are substantially more permeable than red mud (Hassan et al., 2025a, Hassan et al., 2025b, Hassan et al., 2026).

4.3.2 Effect of Hydraulic Pressure

The hydraulic pressure was varied from 12.0 bar to 92.9 bar, while maintaining a constant average roller speed of 0.2 rpm and a roll speed differential of 5%. As hydraulic pressure increased, the cake solids concentration increased from 62.5 wt.% to 71.2 wt.% (Figure 6a). In contrast, both solids throughput (Figure 6b) and roller gap decreased (Figure 6c) with increasing hydraulic pressure. The higher pressure forced the rollers closer together, reducing the roller gap and producing thinner, more highly compressed cakes with higher solids concentration but lower throughput.

At lower hydraulic pressures, a larger roller gap was observed (1.2 mm at 12.0 bar), allowing a thicker cake to pass through the nip and resulting in higher solids throughput. Figure 5 shows the filter cake obtained at 92.9 bar, demonstrating the formation of thin, dense cake sheets with a solids concentration of 71.2 wt.%.

Operational factors such as material floating and partial restriction at the product discharge chute further limited solids throughput under high-pressure conditions.

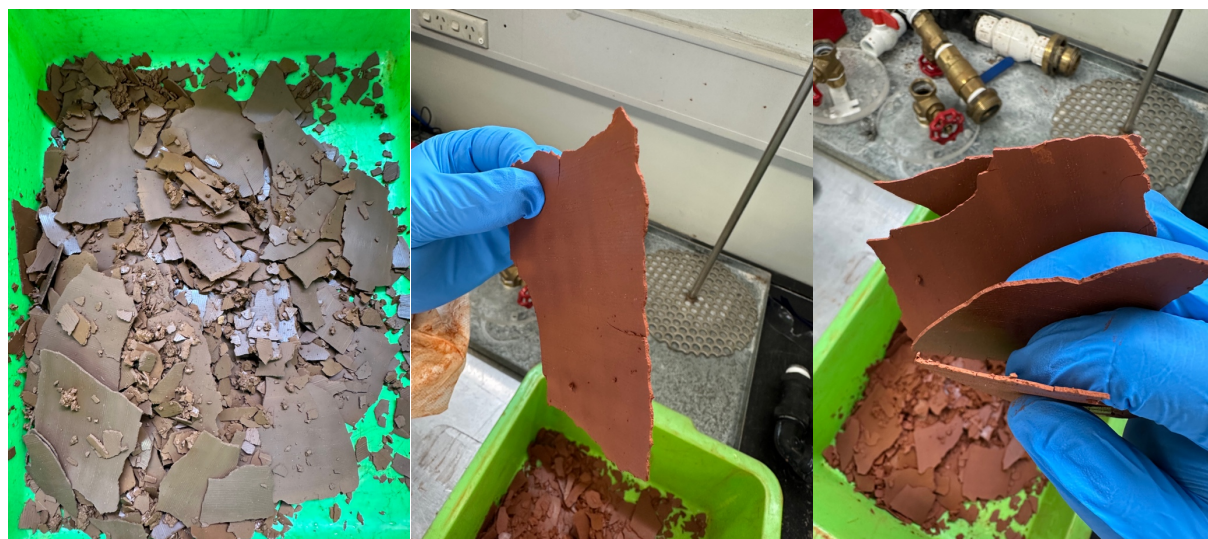


Figure 5: Pictures of red mud filter cake produced by HPDR at an average roller speed of 0.2 rpm, with a 5% roller speed differential and hydraulic pressure of 92.9 bar. The corresponding cake solids concentration was 71.2 ± 0.7 wt.%.

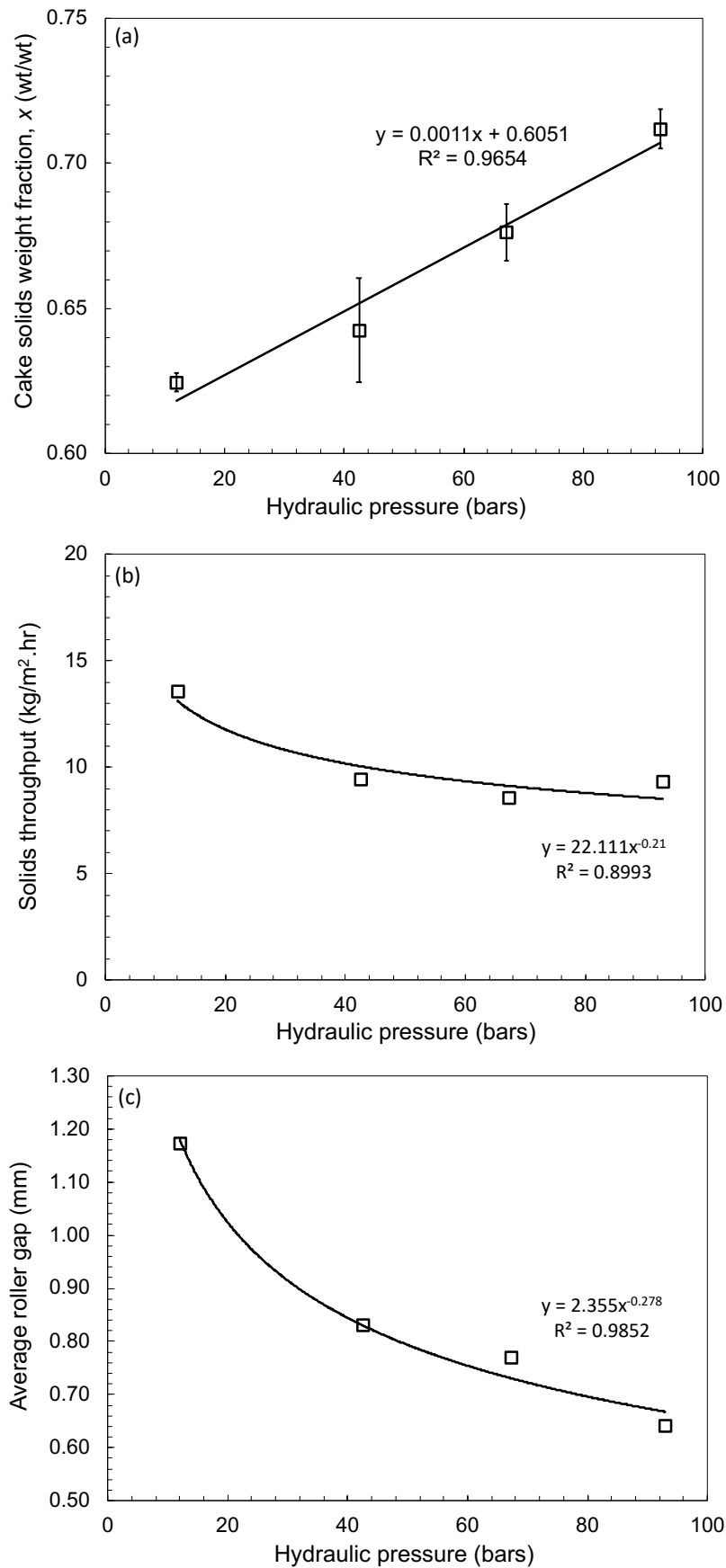


Figure 6: HPDR dewatering performance of red mud as a function of hydraulic pressure. (a) Corrected cake solids concentration, (b) solids throughput, and (c) average roller gap.

4.3.3 Filtrate Analysis

Filtrate solids concentration and PSD remained consistent across all HPDR runs, with an average filtrate solids concentration of 6.0 ± 0.5 wt.%, indicating effective solids capture despite the fine particle size of the red mud ($D[3,2] = 3.05 \mu\text{m}$) and the absence of flocculants. For comparison, vacuum-only operation produced a lower filtrate solids concentration of 3.6 ± 0.02 wt.% with a similar PSD, suggesting that compression in the nip increases the amount of particles of the same size passing through the screen.

Figure 7 compares the PSD of the feed and filtrate. The wedge wire screens have an aperture of $30 \mu\text{m}$; however, 88% of the feed particles were smaller than $30 \mu\text{m}$. 95% of the particles in the filtrate were below $30 \mu\text{m}$, confirming that most larger particles were effectively retained within the filter cake. The small fraction of particles larger than $30 \mu\text{m}$ detected in the filtrate likely passed due to particle shape and orientation relative to the wedge wire openings.

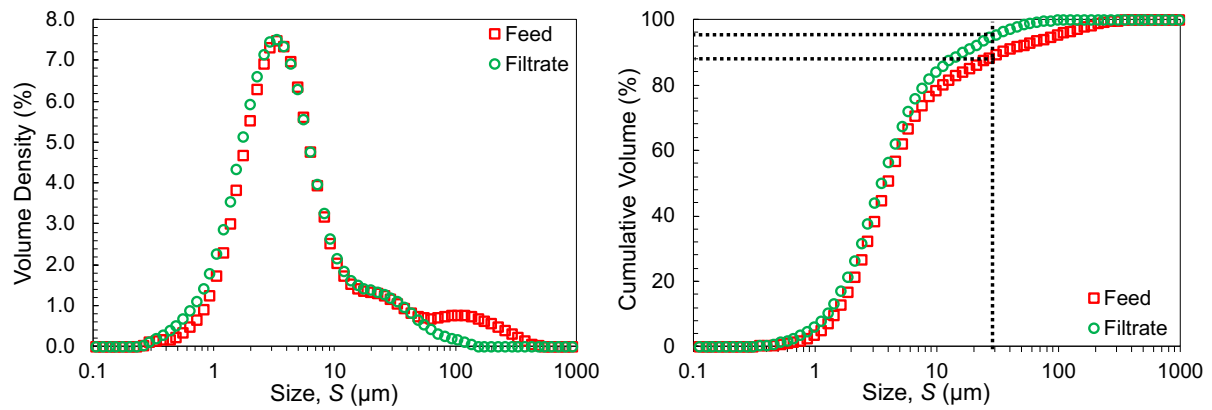


Figure 7: Particle size distribution of HPDR feed and filtrate, shown as volume density (left) and cumulative volume (right).

4.4 Comparison with Filter Press

Lab-scale filter press results show that the maximum cake solids concentration achieved was approximately 60 wt.%, regardless of chamber thickness or variations in fill and squeeze times (Table 1), indicating that under 1200 kPa compression, the red mud reaches its compressibility limit. Solids throughput was calculated using the handling time of 348 s and filter area of 0.0101 m^2 . Reducing fill time from 1415 s to 596 s while maintaining similar squeeze times increased throughput from $41.3 \text{ kg m}^{-2} \text{ h}^{-1}$ to $58.3 \text{ kg m}^{-2} \text{ h}^{-1}$. Due to the low permeability of red mud, smaller chamber thickness was also used: in Run 4, using a 22 mm chamber and shorter fill and squeeze times (302 s and 431 s, respectively) yielded a comparable throughput of $57.8 \text{ kg m}^{-2} \text{ h}^{-1}$ compared to Run 2.

Table 1: Lab-scale membrane filter press results for red mud. Feed concentration was 32.6 wt.%, fill pressure 600 kPa, and squeeze pressure 1200 kPa. The circular filtration area was 0.0101 m^2 (113.3 mm diameter) and handling time was 348 s. Chamber thickness, fill time, and squeeze time were varied.

Run	1	2	3	4
Chamber thickness (mm)	34.4	34.4	22.0	22.0
Fill time (s)	1415	596	624	302
Squeeze time (s)	743	670	400	431
Corrected cake solids concentration (wt.%)	60.07	59.94	59.90	60.04
Solids throughput (kg m ⁻² h ⁻¹)	41.34	58.26	49.92	57.79

Material characterisation indicated that red mud cakes could reach 59.1 wt.% at 1000 kPa. Extrapolating the full compressive yield stress ($P_y(\phi)$) and hindered settling ($R(\phi)$) curves across the complete solids range, the filter press model predicted a maximum cake solids concentration of 59.68 wt.% at 1200 kPa, in close agreement with the experimental lab-scale filter press measurements of approximately 60 wt.%.

Comparison between model predictions and experimental results demonstrates excellent agreement. Solids concentration differences were below 0.65 % across all runs, while solids throughput differences were less than 13.4 % (Table 2). Slight throughput discrepancies arise because the model assumes the filtration process is one-dimensional whereas the actual filter press has a single feed port in the side of the cavity and experiences multidimensional effects at long fill times (Stickland et al., 2006).

Table 2: Comparison between numerical model predictions and lab-scale fixed-cavity membrane filter press results. Model inputs (fill time, squeeze time, pressures, chamber thickness, feed solids concentration, and membrane resistance) matched experimental conditions.

	Run	1	2	3	4
Final cake solids (wt.%)	Actual	60.07	59.94	59.90	60.04
	Model	59.68	59.68	59.68	59.68
	Difference (%)	0.64	0.43	0.36	0.59
Solids throughput (kg m ⁻² h ⁻¹)	Actual	41.34	58.26	49.92	57.79
	Model	46.56	66.07	54.36	64.23
	Difference (%)	-12.63	-13.41	-8.89	-11.15

The conventional filter press is fundamentally limited to compression-driven dewatering and achieved a maximum of approximately 60 wt.% solids. To enable a direct performance comparison, HPDR throughput was evaluated at a comparable solids concentration. At 1 rpm with a 20 % roll speed differential, the HPDR produced a cake of 59.4 wt.% with a corresponding solids throughput of 15 kg m⁻² h⁻¹, which is lower than the 41–58 kg m⁻² h⁻¹ achieved by the filter press depending on chamber thickness and cycle time. The reduced throughput in the HPDR was primarily attributed to operational constraints, including cake slippage leading to material floating above the nip, partial vacuum loss caused by the scraper being positioned away from the nip region, and intermittent restriction at the product chute due to cake stickiness and adhesion. Improving vacuum capacity and extending the scraper closer to the nip point would help maintain vacuum integrity, promote more efficient initial dewatering, and enable a thicker, more uniform cake to build up upstream of the nip, increasing both solids throughput and final cake solids. Optimisation of the discharge geometry to minimise adhesion and build-up would be expected to further improve throughput.

5 Conclusions and Outlook

This study demonstrates the effectiveness of High Pressure Dewatering Rolls (HPDR) for shear-assisted, high-solids filtration of red mud. The material is ultrafine ($D[3,2] = 3.05 \mu\text{m}$), highly compressible, and has low permeability, which makes compression-only filtration insufficient to achieve very high solids content. The red mud is shear-sensitive, such that using HPDR, corrected cake solids of up to 71.2 wt.% were achieved at 92.9 bar hydraulic pressure without flocculants, substantially exceeding the 60 wt.% obtained with conventional fixed-cavity filter presses under 1200 kPa compressive pressure. Optimal dewatering occurred at low roller speeds (0.2 rpm) and moderate roll speed differentials (10–20%), whereas excessive shear reduced cake solids. Cake solids and throughput were strongly influenced by hydraulic pressure and roller speed: higher pressures produced denser cakes but lower throughput, while operational factors such as partial clogging and material slippage further limited performance. Filtrate solids remained low (6.0 wt.%), confirming effective particle retention governed primarily by cake filtration rather than the 30 μm wedge wire. Lab-scale filter press experiments and numerical modelling using measured compressive yield stress and hindered settling functions closely matched experimental solids concentrations and throughput, validating the predictive capability of the model. Overall, HPDR combines compression and shear to overcome the limitations of conventional filtration, providing a continuous, cloth-less method capable of producing high-solids tailings. These findings support the potential implementation of HPDR in continuous tailings dewatering operations, reducing water content, lowering environmental risk, and enabling dry stacking of red mud.

Acknowledgements

This project is funded by the Australian Research Council for the ARC Centre of Excellence for Enabling Eco-Efficient Beneficiation of Minerals, grant number CE200100009. The authors would like to thank Dr Mark Coghill and Nikk Vagias from Rio Tinto Bundoora Technical Development Centre for their assistance.

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