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What happens inside a filter press during tailings filtration

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Abstract

Due to the increasing importance of filtering and stacking tailings, the number of filter presses being used is rapidly increasing. However, to ensure that this process step does not affect the overall throughput of the plant, a deep understanding of the filtration sub-steps and optimisation is necessary. Monitoring cake water content during filtration allows visualisation of different filtration behaviours and facilitates enhancement. This study investigated the filtration characteristics of coarse-grained feldspar using a laboratory filter press and a filter plate-integrated sensor, and compared them to fine-grained kaolin data. Furthermore, copper tailings particles were tested. It became apparent that larger particles experience a significant reduction in dewatering kinetics once the transition from cake build-up to cake consolidation occurs. This behaviour was also pronounced when examining copper tailings. Building on that, a theoretical approach for increasing throughput by timely switching to the subsequent process sub-step is presented.

Keywords: *filtration, digitalisation, sensor, filter press, filter plate*

1 Introduction

Filter presses are used in many industries because they can achieve low residual moisture levels and allow for post-treatment of the cake through diaphragm squeezing (often referred to as membrane squeezing), washing or air blowing (Ripperger et al. 2013). A main benefit is the double-digit pressure differences that can be achieved with the feed pumps. Therefore, they are suitable for dewatering compressible, difficult-to-filter particle systems characterised by a significant proportion of particles under 10 µm (Ripperger et al. 2013; Wakeman 2007). In tailings processing it is not only clay-sized particles that pose a challenge for the selection of filtration equipment but also the presence of specific clay minerals which make filtration difficult (Grosso et al. 2021). These factors, among others, have led to the widespread use of filter presses in this application to enable safer residue storage and enhanced water recovery (Davies 2011). However, the large mass flows and the requirement for presses to operate in batch mode mean that several machines usually need to be installed in parallel (Jewell & Fourie 2015) and the throughput of the filtration process plays a pivotal role.

The optimisation of the filtration process in filter presses, often associated with a deeper understanding of the process itself (Anlauf 2019), is an important topic, as evidenced by a variety of studies (Kaswalder et al. 2018; Weigert 2001; Fränkle 2024a) and a current study management guideline (BHP Rio Tinto Tailings Management Consortium 2024).

Figure 1 schematically shows the characteristics describing the filter press process, based on the three sub-processes relevant in tailings filtration: filtration, diaphragm squeezing and cake air blow (Metso:Outotec 2021). A distinction must be made between equilibria and kinetics. The equilibrium describes what can be achieved. Simply put, each filtration pressure results in a specific cake water content due to a correlating compaction state. The quantitative value of each of these equilibria depends significantly on the particles (e.g. tailings) and the filter cloth (e.g. interaction of the particles with the cloth and blinding of the cloth), as well as the feed pressure created by the pump.

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It is important to note that the particles themselves already contain a large amount of information, such as particle size distribution (PSD), mineralogy, distribution of mineralogy over the PSD, shape, density, porosity of the particles themselves and physio-chemical properties. How quickly the system approaches the equilibria values is described by the kinetics. For example, there are two underlying mechanisms during filtration: cake build-up (how quickly the two filter cakes in a chamber grow together from the opposite filter cloths) and cake consolidation (by further feeding into the filled chamber) (Anlauf 2019). Both sub-steps can have their own kinetics, which is of utmost importance for the throughput of the plant. A very decisive additional influencing factor for the kinetics is the cake height, which is half of the depth of the filter chamber. Analogous explanations can be given for diaphragm squeezing and air blow. Each sub-process has its own equilibria and kinetics.

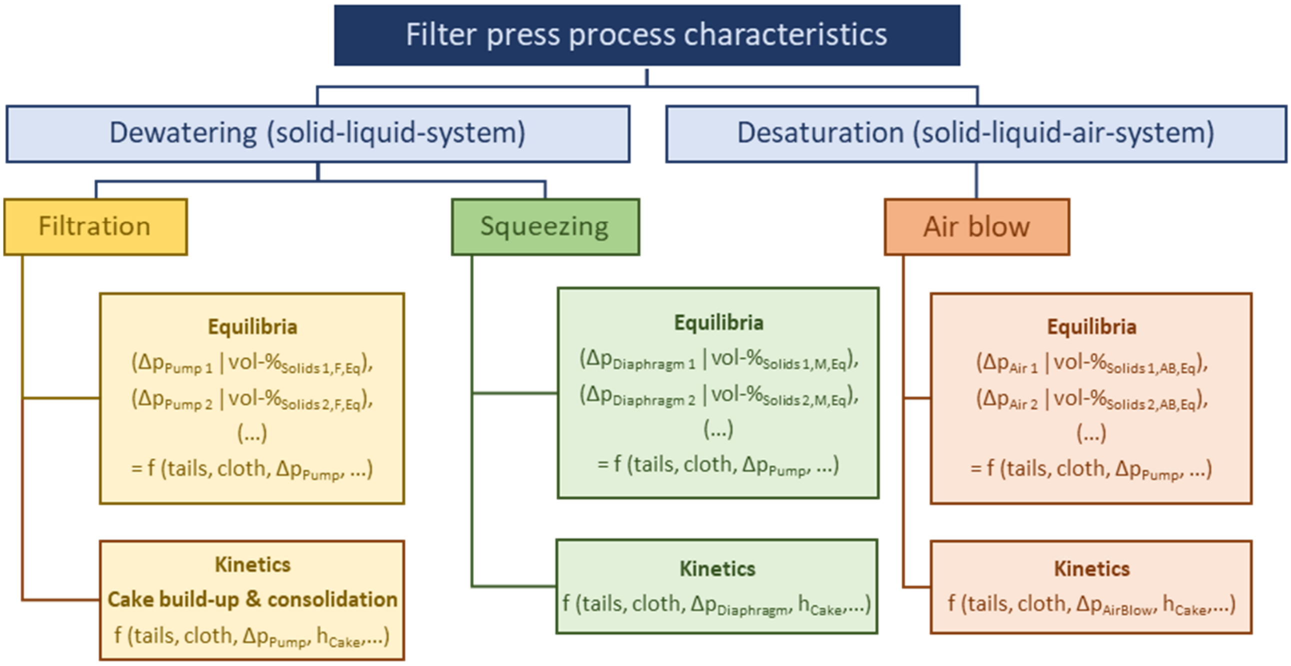

Figure 1 Schematic illustration of different equilibria and kinetics of filter press filtration sub-processes, and their characteristics and dependencies

One major issue concerning filtration in filter presses is that it's a 3D problem. The scale-up of standard laboratory filtration experiments determining generic parameters like height-specific filtration resistances (VDI 2010) is supposed to be done using a pilot scale (Pezzi et al. 2016). Another challenge is that solid-liquid separation occurs with the plate pack closed. Monitoring the process itself based on quantification of the cake properties is difficult: instead, mass balancing is applied; for example, by weighing or automated sampling of cake fragments prior to the conveyor (Chaponnel 2024). Digitalisation related to filter presses is mostly supportive, like tracking of fabric filtration cycles or turbidity measurement in the filtrate to detect broken cloths (Chaponnel 2024).

Direct visualisation of filtration is only possible for a few years. The key to this is integration of a suitable sensor into the filter plates as by the intelligent filter press of ANDRITZ, using the LENSER i-Plate technology (ANDRITZ 2020; LENSER Filtration 2024). A recent iron ore case study in Brazil demonstrates the benefit (Gerards & Panholzer 2025). A broader transfer of the technology to tailings filtration is upcoming (Jenkins 2024).

Investigations with such sensor technology have so far been carried out on kaolin (Dursch 2021; Fränkle et al. 2024c). This material has also been used for fundamental studies in the field of tailings dewatering, where it has been shown that different mass fractions produce significant effects (Luo et al. 2024). There is a necessity to extend the investigations with a coarser, nearly homogeneous particle system to approach a second boundary case of the filtration process in a simplified form. Furthermore, since tailings represent a very broad PSD for various minerals, further investigations with copper tailings are conducted within this study to deepen filtration process understanding for this application.

2 Methodology

For the experiments in this research, test filtrations were carried out in a laboratory press. First a feldspar particle system was examined. Its filtration properties were compared with kaolin data from a previous study showing compressible behaviour (Fränkle et al. 2024c). Additionally, filtrations with copper tailings were conducted.

2.1 Filter press test set-up

An LCM 320 (Aquachem GmbH, Senden, Germany) laboratory filter press with a manual hydraulic closing was used to carry out the experiments, and was also used in the previous kaolin study (Fränkle et al. 2024c). Its maximum filtration pressure is 15 bar. Figure 2 shows the press in the opened position. The suspension is fed into the press by an air-operated diaphragm pump Tapflo T20 (Tapflo AB, Kungälv, Sweden). The filter press is equipped with a head, an end and a thermoplastic elastomer (TPE) membrane filter plate. The two cylindric chambers have a depth of 32 mm each. While having a filtration area of 0.183 m², the total chamber volume of the plate pack is 3.0 dm³. The three plates are equipped with four gasketed and calendered Q46 Multi (Aquachem GmbH, Senden, Germany). They have a thickness of 0.9 mm and an air permeability of 2 l m^{-2} s^{-1}.

(a) (b) (c)

Figure 2 Filter press set-up. (a) End plate designed as LENSER i-Plate including sensor; (b) Feed shoe, gasketed filter cloth and membrane filter element; (c) Kaolin filter cake with drainage structure and sensor imprint

2.2 Properties of the suspensions and particles systems

A feldspar suspension containing 25 vol-% solids type AKFlux 700 (Amberger Kaolinwerke Eduard Kick GmbH & Co. KG, Hirschau, Germany) in tap water was used. In addition, a 30 vol-% solids copper tailings slurry with tap water was filtered. These tailings were also used in previous studies with a different filter press and objectives (Fränkle 2024a; Fränkle et al. 2024b). Solid volume content was increased to 30 vol-% for the copper tailings to reduce segregation by sedimentation.

Table 1 lists the mineralogical compositions and excerpts from the PSDs are in Table 2. These are taken either from the respective data sheet or the mentioned studies. The applied measurement methodology is also specified, if known. The kaolin and feldspar consist mainly of kaolinite and feldspar, respectively. The copper tailings are significantly more heterogeneous in their composition. The main components are quartz and feldspar.

Table 1 Mineralogical composition of kaolin KICK 2, feldspar AK700 and the copper tailings (Amberger Kaolinwerke 2023; Amberger Kaolinwerke 2024; Fränkle 2024a)

Mineral	Kaolin (%)	Feldspar (%)	Copper tailings (%)
Method	–	–	XRD
Kaolinite	75	–	–
Illite & montmorillonite	–	2	–
Illite	–	–	4
Mica	3	–	8
Feldspar	16	80	34
Gypsum	–	–	3
Pyroxene	–	–	4
Clay (general)	–	7	–
Quartz	4	13	48

The kaolin has a D_{50} of 7 µm and a proportion of 19% below 2 µm. It is therefore relatively fine and has a relatively narrow PSD compared to the feldspar with a D_{50} of 50 µm. Furthermore, the feldspar is coarser than the copper tailings, having a D_{50} of 27 µm. The significant proportion of particles below 2 µm in the tailings is noteworthy.

Table 2 Excerpts of particle size distributions of kaolin KICK 2, feldspar AK700, and the copper tailings (Amberger Kaolinwerke 2023; Amberger Kaolinwerke 2024; Fränkle 2024a)

Size (µm)	Kaolin (%)	Feldspar (%)	Copper tailings (%)
Method	**Zellcheming V/27.6/90**	**DIN 66165**	**Laser diffraction**
< 2	19	–	8
< 40	–	38	59
< 45	99.5	–	62
< 63	–	67	70
< 100	–	95	82
< 200	–	99	96
D50	7	50	27

2.3 LENSER i-Plate and i-Plate cake water content sensor

The end plate of the filter press is designed to be a LENSER i-Plate. A moisture sensor is inserted into the plate which can measure filter cake water content, conductivity, and temperature of the suspension and the filter cake directly in the chamber. It is positioned below the filter cloth, having a similar level as the top of the drainage structure, as can be seen in Figure 3.

Figure 3 Plate-integrated cake water content sensor (LENSER Filtration 2024)

The technical specifications of the i-Plate and the i-Plate sensor are listed in Table 3 (LENSER Filtration 2024). General information, measurement ranges, signal transmission and electrical installation are described. There are three standard possibilities to adapt the i-Plate to the process: using a separate datalogger, implementation in the process control system or integration in the ANDRITZ Metris system.

Table 3 LENSER i-Plate and i-Plate moisture sensor specifications (LENSER Filtration 2024)

Property	Specification
Cake water content	0 to 100%
Temperature	0 to 70°C
Electrical conductivity	0 to 5 mS cm^{-1}
Material	Stainless steel/special ceramic material
Sensor size	110 × 60 mm
Filter plate size	320 × 320 mm to 2.5 × 2.5 m
Max. filtration pressure	Depending on filter plate specification
Max. cake wash pressure	8 bar

3 Results and discussion

Building on a presentation and discussion of the results of the feldspar filtration and a comparison with kaolin data, this chapter examines the filtration behaviour of copper tailings. Subsequently, an optimisation approach to increase the throughput of tailings filter presses is presented.

3.1 Filtration characteristics of coarse-grained feldspar and fine-grained kaolin

Figure 4 shows a filtration of the feldspar slurry at 5 bar feeding pressure. The progression of the cake water content of the suspension and the cake, measured with the moisture sensor in the end plate, is depicted. Upon activation of the pump, the recording was started. As soon as the fill level in the chamber increases and the level rises in front of the sensor, there is a sharp increase in the water content. This peak represents the approximate suspension concentration. Once the chambers are filled, cake formation begins on the filter cloths. This results in a significant decrease in the water content. The rapid dewatering can be attributed to the good filterability of the relatively coarse feldspar particle system. As soon as the two filter cakes in one chamber merge, the cake water content curve bends significantly. It becomes almost flat, which means that the dewatering kinetics decreased significantly. The strong variation in the kinetics of the consolidation phase compared to the cake build-up sub-step is due to the low compressibility of this feldspar particle system. Continuous feeding with suspension results in only minimal further consolidation. The cake formation responsible for most of the dewatering in this filtration was completed in less than a minute. An additional eight minutes of consolidation using the feed pump achieved only an approximately 1% further reduction. The filtration was stopped after approximately 10.5 minutes. Opening of the press and removing the cake resulted in a sharp decrease of the water content in front of the sensor.

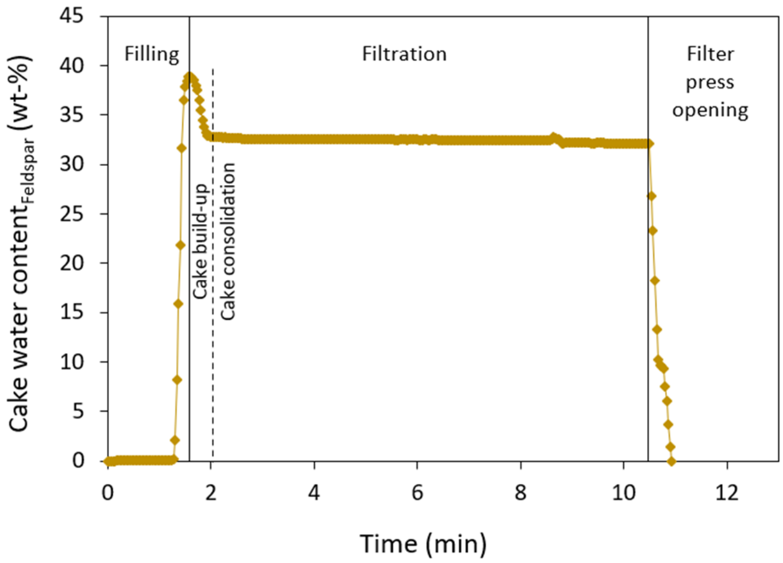

Figure 4 Cake water content curve for a filtration of the feldspar at 5 bar in the laboratory filter press

The significant values during the filtration sub-steps, namely the measured peak water content and the equilibrium value at the end of the filtration, are listed in Table 4. In addition to the feldspar, kaolin data are shown (Fränkle et al. 2024c). Due to the rapid changes during filling and at the beginning of the filtration, the peak values are lower than the mass percentage of water in the suspension.

Table 4 Range of the water content for feldspar and kaolin based on the properties of the suspension and the equilibrium value at the end of the filtration

Test	Peak water content	Cake water content
Feldspar/5.0 bar filtration	38.9 wt-%	32.1 wt-%
Kaolin/5.0 bar filtration (Fränkle et al. 2024c)	43.2 wt-%	28.9 wt-%

A comparison of the filtration behaviour between the feldspar particles, relatively coarse for filter presses, and the relatively fine kaolin particles is shown in Figure 5. The data represent the excerpt from the peak of the water content curve to seven minutes of filtration. To compare the curves, both systems are plotted on their own axis in the range of the peak water content and the respective equilibrium at the end of the filtration, i.e. the final cake water content. It is evident that neither filtration, especially the kaolin, has reached the equilibrium within the depicted time. After seven minutes the kaolin filter cake still has a higher residual moisture in relation to the equilibrium. The two curve progressions show a significant difference. The relatively fine kaolin exhibits a continuously slowing dewatering. In contrast, the coarser feldspar has two almost linear regions and a sharp bend at their transition. In the first region, cake build-up occurs on both filter cloths. Due to the good filterability, the kinetics of dewatering are very fast. Once the cakes from both cloths, i.e. sides of the chamber, have grown together, the consolidation sub-step begins. This involves compaction and the associated dewatering through further addition of suspension with the pump. The kinetics of this phase are very low for the slightly compressible feldspar system. Due to pronounced compressibility, a distinction between the two sub-steps is not possible for kaolin. Additionally, it can be concluded that feldspar, compared to kaolin, has a correspondingly lower height-specific filter cake resistance.

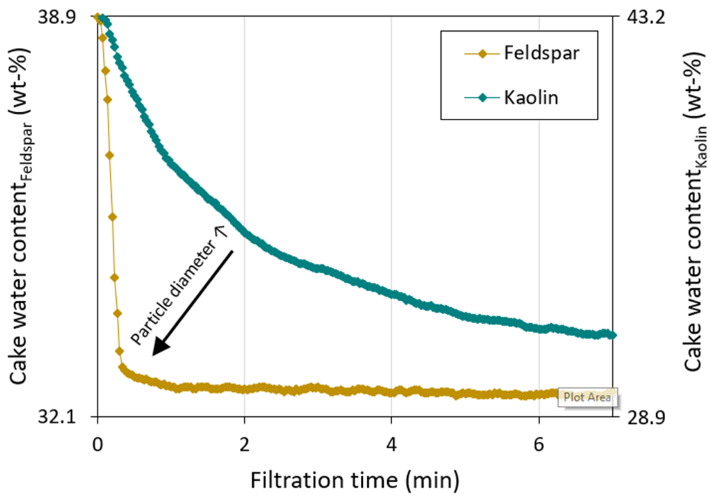

Figure 5 **Excerpt of a feldspar filtration cycle (filtration sub-step) and comparison to kaolin filtration data (Fränkle et al. 2024c). The coarser the particles the more clearly the cake build-up can be distinguished from the cake consolidation phase by a change in the kinetics**

3.2 Copper tailings filtration

Figure 6 shows filter cakes of the copper tailings resulting from different filtration parameters in the laboratory filter press. In Figure 6a a soft and sticky cake filtered at 2.5 bar is shown. In contrast, the cake in Figure 6b was brittle as it was filtered at 7.5 bar, with an additional membrane squeeze at 10 bar and an air blow at 5 bar for 180 seconds. This shows that the selection of process sub-steps and the setting of the respective parameters are of enormous relevance.

(a) (b)

Figure 6 **Copper tailings laboratory filtration. (a) Open filter press with sticky cake (filtration only at 2.5 bar filtration pressure); (b) Brittle cake after filtration (7.5 bar), diaphragm squeezing (10 bar) and air blowing (180 seconds at 5 bar)**

An exemplary copper tailings filtration at 5 bar feed pressure and 10 bar TPE membrane squeeze pressure is shown in Figure 7. The online monitoring data of the water content, as well as the feed pressure and the squeeze pressure, are displayed. After approximately two minutes of filling, the fill level rose above the sensor position, noticeable by the peak. Then the cake build-up began, causing the water content to decrease almost linearly, and a counterpressure had to be overcome by the pump. A kink in the cake water content curve was noticeable after a short time. The cakes growing from both filter cloths had then merged. This marked the transition to cake consolidation, accompanied by significantly lower dewatering kinetics. The behaviour was quite similar to the feldspar filtration. This means that despite the significant fine fraction, these tailings exhibited the filtration characteristics of a relatively coarse material. In the five minutes of the consolidation sub-step, the cake water content decreased to a limited extent to approximately 22 wt-%. At the same time, the pressure of the diaphragm pump continued to rise slowly. After approximately nine minutes the membrane squeeze was activated, clearly visible by the increase in squeeze pressure. This resulted in further dewatering, which was rapid at the beginning and then tapered off shortly after reaching the maximum squeeze pressure. After that, it was already close to its equilibrium at approximately 19 wt-%.

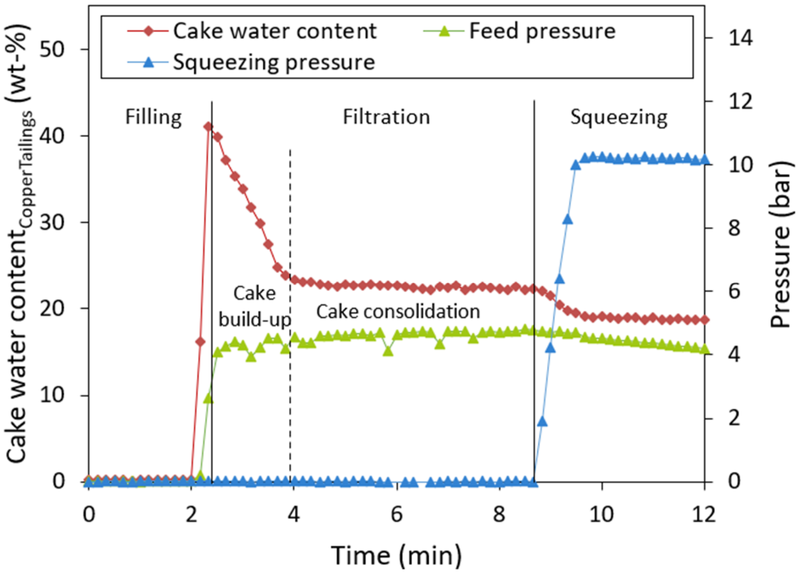

Figure 7 Online monitoring data of copper tailings filtration in a laboratory filter press at 5 bar filtration and 10 bar thermoplastic elastomer diaphragm squeezing

3.3 Throughput optimisation approach

Knowledge about the behaviour of a particle system during filtration in a filter press can be used to optimise throughput. This is especially possible with a clear distinction between cake build-up and consolidation kinetics in relatively coarse particle systems.

Based on an excerpt of the filtration data of the copper tailings, shown in Figure 8, an appropriate procedure is demonstrated. For this, the area of the consolidation sub-steps and the diaphragm squeezes are relevant. As mentioned above, the slightly compressible behaviour of the tailings particles resulted in very slow dewatering kinetics during continuous pumping into the already cake-filled chambers. Highlighted in red, the start of the consolidation phase in this study is simplified defined as the first time the difference in cake water content at the next measurement point (10 seconds) is less than 1 wt-%. Then the water content of the copper tailings filter cake decreased by only approximately 1.6 wt-% (23.9 to 22.3 wt-%) within four minutes and 50 seconds. In contrast, the subsequent membrane squeezing achieved an additional reduction of 1.6 wt-% (22.1 to 20.5 wt-%) within 20 seconds (highlighted in green), even though the membrane pressure was still being inflated and not fully applied. It can be stated that the kinetics of squeezing dewatering are significantly faster.

Based on the monitoring data from Figure 7 showing 12 minutes of filtration cycle time and an assumed additional technical downtime of two minutes, the total time of the process would be 14 minutes. A reduction of 4.5 minutes would save approximately 32.1%. Since the cakes are already growing together during the transition to consolidation, the chambers are sufficiently filled to use the membrane without the risk of overstretching.

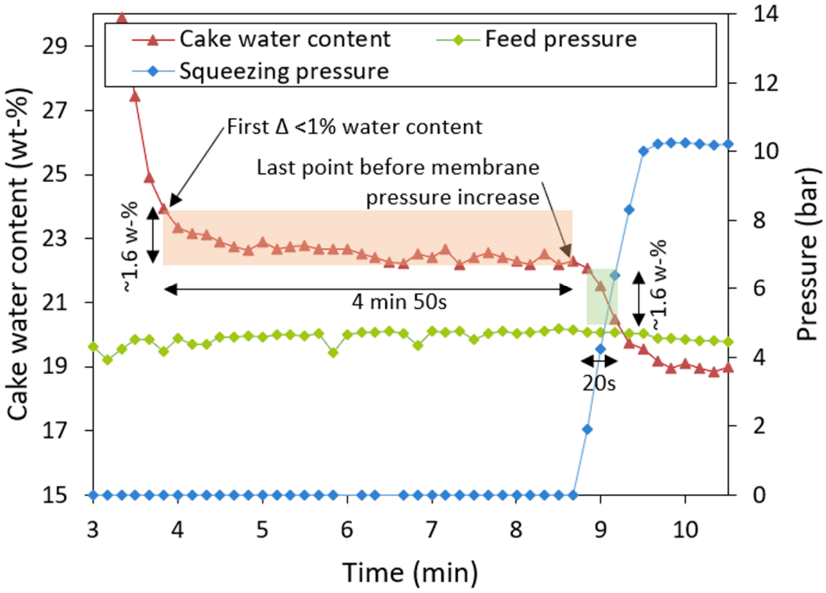

Figure 8 Excerpt of copper tailings online monitoring filtration data with highlighted areas for process optimisation

A fundamental question in the filtration process and its optimisation are the relevant target variables, such as cake water content and process time. One aspect concerning dewatering is whether the achievable equilibrium value for common process parameters using filtration only is above or below the target water content. This significantly determines whether a cake requires post-treatment with diaphragm squeeze, air blow or a combination of both. When additional target variables such as process time are considered, complex questions arise and have several possible solutions. For example, an air blow also has fast kinetics for the tailings investigated (Fränkle et al. 2024b).

4 Conclusion

Online monitoring of the cake water content using a plate-integrated sensor like in the LENSER i-Plate deepens the understanding of the filtration process in filter presses and enables optimisation. The comparison of the relatively coarse feldspar to relatively fine kaolin filtration data showed that there can be significant differences in the dewatering characteristics. Coarser and slightly compressible particle systems show a clear transition between the cake build-up and the consolidation sub-step during the filtration phase. The kinetics of dewatering are significantly higher during the growth of the two filter cakes in the chamber. Due to the low compressibility, only very low kinetics dewatering occurs during consolidation. Finer and compressible particle systems show a different filtration behaviour in filter presses. Here there is a gradual transition between cake build-up and consolidation.

The examined copper tailings, despite a more heterogeneous mineralogical composition, also show low compressibility, like the feldspar. Therefore, a distinction between the cake build-up and consolidation sub-steps is also possible. This can be used to optimise throughput as the kinetics of the subsequent diaphragm squeeze are significantly faster than those of cake consolidation. A theoretical consideration has shown that switching to the squeeze upon recognising the beginning of consolidation would significantly reduce process time. Based on the data of this set-up and the assumptions used, the reduction would be approximately 32.1%.

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