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Fine material filtration using conventional pressure and steam pressure: a relationship between filter cake height to crack formation and residual moisture content

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ABSTRACT
Crack formation is an undesired phenomenon encountered frequently during the filtration process, especially in fine particulate filter cakes. This phenomenon causes disadvantages related to the dewatering efficiency and washing efficiency. The filter cake height has not only an effect on crack formation but also meaning in the economic and operational of filtration. In this research, Limestone and Coal are the chosen fine powder materials to survey the effect of this factor during conventional pressure filtration (CPF) and steam pressure filtration (SPF). The permeability ratio is suggested to quantify cracking while the saturation and the residual moisture content indicate the water remaining. Test results show lower dewatering efficiency as well as an increasing trend of probability and degree of cracks when the filter cake becomes thicker. By visual observation, macro- and micro-cracking are described for shrinkage behavior on filter cake. The delamination was also mentioned and observed after filtration. Steam pressure filtration (SPF) is introduced as one of the methods to reduce the degree, even prevent the formation of cracks as well as improve the dewatering efficiency.

KEYWORDS
Conventional pressure filtration; steam pressure filtration; shrinkage cracking; delamination plane; permeability ratio

1. Introduction

Crack formation is a disadvantageous phenomenon occurring when filtering fine material. This phenomenon leads to high gas and washing water consumption during hyperbaric filtration. The filter cake has a higher residual moisture content and lower purity (Barua 2014; Pham and Peuker 2021). In order to meet the requirement of the customer as well as be suitable for the standard, the product after filtration has to dry by further expensive methods (such as thermal drying) or re-process (Wiedemann and Stahl 1996; Redeker, Steiner, and Esser 1983).

According to Pham and Peuker, two kinds of cracking can be described in Figure 1 (Pham and Peuker 2021; Pham 2021). Micro-cracking has a small size (which cannot be visible) and does not or less affect the dewatering as well as the washing process. Meanwhile, macro-cracking is large and recognizable to the naked eye. The occurrence of this type of crack has a tremendous negative effect on further dewatering and the need to avoid the appearance. Furthermore, one of the phenomena, that affect the integrity of filter cake can be mentioned is the delamination plane. This phenomenon divides the filter cake into two or more sections, as illustrated in Figure 2. The crack is formed horizontally of the filter cake. The delamination plane of the filter cake led to the degree of shrinkage of the filter cake is not uniform in the upper part and lower parts. The result leads to the collapse of the structure filter cake during filtration. Heretofore, shrinkage cracking is considered to be a random phenomenon and has been tolerated in industrial filtration. Some research efforts to minimize the formation of cracks such as using the roller, specially designed spindles incorporating flattening elements and pressure belts (Anlauf, Stahl, and Krebber 1985; Anlauf 2003; Anlauf and Stahl 1986). Those methods prevent the occurrence without completely addressing this negative phenomenon. Recent research focuses on finding out the mechanism of shrinkage cracking (Barua 2014; Wiedemann and Stahl 1996; Anlauf, Stahl, and Krebber 1985; Anlauf 2019) as well as the effect of factors on the crack formation (like filter cake height, temperature, etc.) (Barua 2014; Pham and Peuker 2021). Based on the obtained knowledge, the measures to prevent crack formation applied in production can be listed: the addition of feed suspension (Anlauf, Stahl, and Krebber 1985; Anlauf 2019); the formation of pre-coat by filter aid (Rushton and Holdich 2015); pre -compaction is also an appropriate action to avoid the crack (Illies et al. 2016; Illies et al. 2016). According to Barua, the height of the filter cake affects the crack formation as well as the efficiency of dewatering (Barua 2014).

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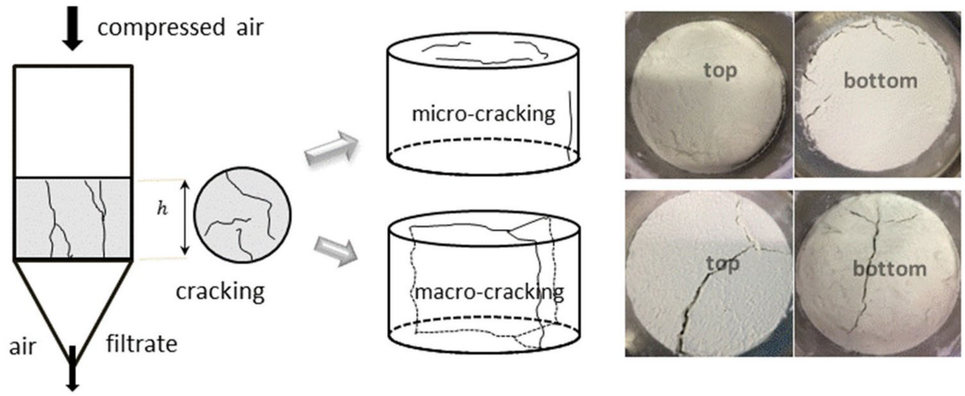

Figure 1. Diagram and images for micro-cracking and macro-cracking on filter cake during the mechanical displacement phase (Pham and Peuker 2021).

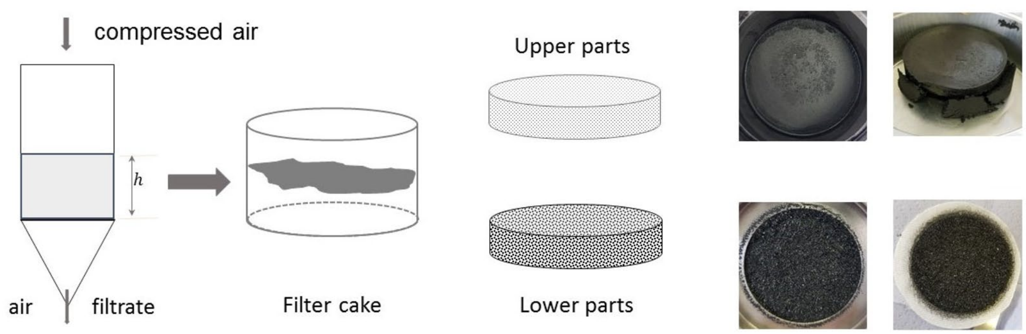

Figure 2. Diagram and images for cracking horizontally due to sedimentation.

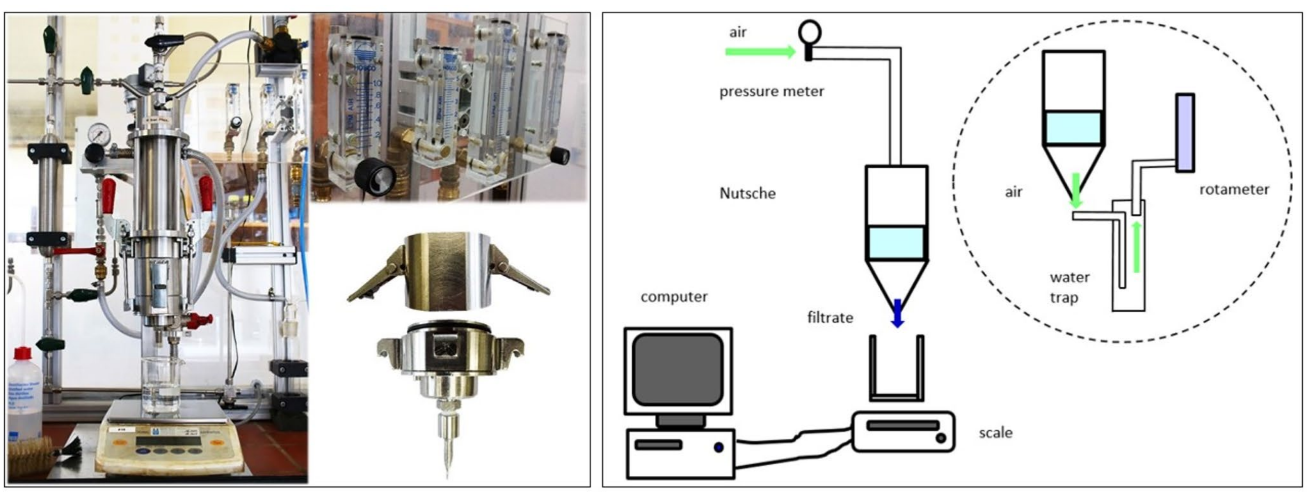

Figure 3. Images and schematic diagram for the Nutsche apparatus (according to VDI 2762-2) (Pham and Peuker 2021; Pham and Peuker 2021; Esser and Peuker 2020).

The article contributes more knowledge related to the relationship between cake height and crack formation when using conventional pressure filtration (CPF) and steam pressure filtration (SPF). The result shows that filter cake height cracking can be avoided but also ensures the capacity of the filter. Furthermore, a suitable filtration manner for filtering fine material is suggested (Peuker and Stahl 2001).

2. Method and material

2.1. Experimental equipment

The CPF rig is built according to VDI 2762-2 guidelines (VDI 2010). The equipment is a stainless steel Nutsche with an area (A) of 19.64 cm^2, as shown in Figure 3. The filter medium has support from a perforated medium sheet with a large open cross-section area. There is a cake formation unit connected Nutsche long tube and filter medium support unit. The device possesses a quick connection for the lid and is equipped with a valve to regulate the pressure and pressure gauge. The lid has a sight glass to look inside and attached light. The quantity of filtrate is measured by using a scale connected to a computer (VDI 2010).

The SPF rig (Figure 4) was built based on the standard Nutsche with the same size which has been described above (VDI 2010). The evaporator provides the steam. This steam and the entrained water from the evaporator are separated before coming to Nutsche. Styrofoam covers the tube, the cake formation unit and almost all pipes to avoid heat transfer into the ambient environment. An oil heater heats Nutsche and cake formation unit to approximately 160 °C. There is a thermocouple that is installed to control and maintain temperature stability. Another thermocouple contacts the cake formation unit to measure the filter medium's temperature and the filtrate's temperature (Pham and Peuker 2021; Esser and Peuker 2020; Esser and Peuker 2020; Peuker and Stahl 2001).

2.2. Experimental procedure

The slurry includes the solid powder material that is remixed and dispersed in the distilled water at room temperature (approximately 20 °C). The amount of water depends on the mass of the solid and the fixed volumetric concentration value for tests. After that, the slurry is poured into the Nutsche. In the investigation of crack formation during filtration, two stages of filtration were conducted (the third stage of drying was not mentioned further during this research). The first stage is the cake formation. The compressed air is applied to push the filtrate flow out. The filter cake is built on the filter cloth (SK 006). This step will be finished when the saturation of the filter cake reaches 1. It is observed through the light glass until no water surfaces on the filter cake. The electronic scale recorded the filtrate mass over time. This result is used to calculate the specific resistance cake and liquid permeability before the air breakthrough the filter medium, as can be indicated in Figure 5 (VDI 2010). The second stage is the mechanical displacement phase. Depending on the kind of filtration, the compressed air or the saturated steam is applied. For CPF, compressed air is applied to push water flow out from pores. When there was no water flow out of the filter tube, the air flowmeters were connected to Nutsche to measure the air volume flow rate. Depending on the value of output air volume flow, one of four air flowmeters HOSCO with the different ranges 0.1–1; 0.5–5; 4–50 and 10 – 100 LPM air was used. For SPF, the steam outlet and magnetic valve (which can be seen in Figure 4) are opened to allow the steam to enter the Nutsche. After the instant time (1 or 2 seconds),

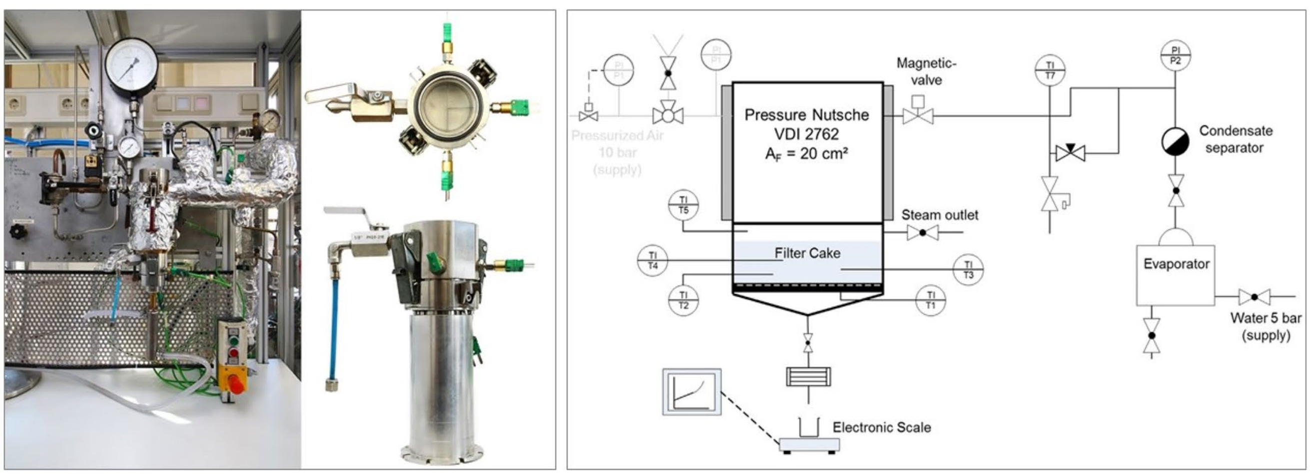

Figure 4. Images and diagram of steam pressure filtration according to VDI 2762/2 (Peuker and Stahl 2001; VDI 2010; Esser and Peuker 2020; Esser and Peuker 2020).

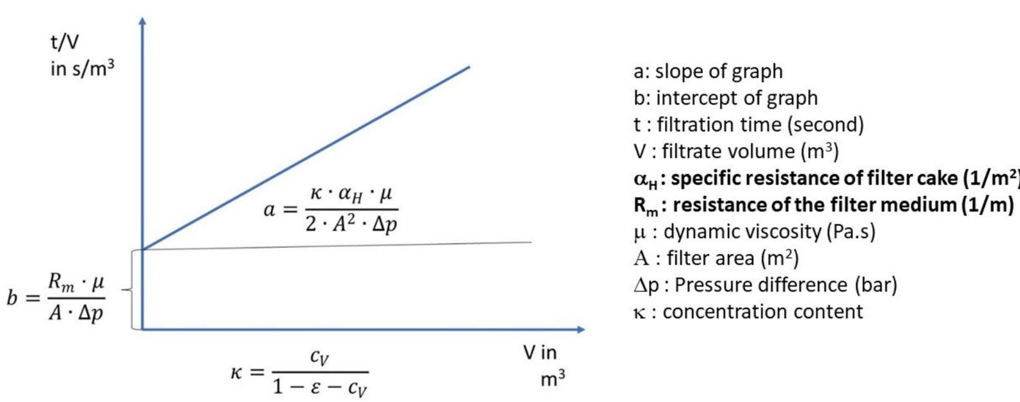

Figure 5. Calculation specific resistance of filter cake and resistance of the filter medium base on the graph of t/V vs V (VDI 2010).

the steam outlet is closed, and steam starts to displace water from the pores. Tests were conducted until the steam breakthrough of the filter cake, which was observed by the temperature of the filter cloth thermocouple (TC1). The condenser unit, afterward, is connected to collect the amount of steam breakthrough under the liquid form. The balance scale is used for measuring the amount of condensation water over time. After recording the mass of condensed steam, the steam flux is stopped by closing the magnetic valve. The Nutsche is then vented slowly in order to prevent the filter cake from breaking (Pham and Peuker 2021; Esser and Peuker 2020; Esser and Peuker 2020).

The filter cake then is taken photos to observe the shrinkage cracking. Finally, it was quickly removed out of the cake formation unit to dry at 50 °C until the constant weight. The pressure difference is changed during the survey of filter cake height, as can be seen in Table 1. The saturation, which is the relation between the pore volume occupied by liquid and the total pore volume of the filter cake, is calculated. The amount of water remaining in the filter cake is also mentioned in some cases by the residual moisture content in mass %.

Cake cracking means that the gas flow rate necessary for sustaining the dewatering pressure difference rises considerably due to the increase of free-flow area in the filter cake (Anlauf, Stahl, and Krebber 1985). Accordingly, the permeability for gas will grow up (when the crack occurs) compared with the permeability of the liquid inside the filter cake. The permeability ratio is applied to quantify the number of cracks and the degree of cracks as can be calculated by the ratio of liquid permeability in the cake formation phase and air permeability after filtration (Barua 2014; Pham and Peuker 2021; Pham 2021).

In the case of conventional pressure filtration, the permeability ratio is applied following Pham and Peuker (Pham and Peuker 2021; Pham 2021) (Equation (1)), which considers to the relative gas permeability. In the case of conventional pressure filtration, it can be written again for steam pressure filtration (Equation (2)). The detailed elements of two the equations are chosen and calculated according to (Pham 2021; Wyckoff et al., 1933; Wakeman and Tarleton, 1999; Wakeman, 1985).

$$Permeability\,ratio\;\beta^*_{CPF} = \frac{relative\,gas\,permeability}{liquid\,permeability} = \frac{K_G}{K_L} \quad (1)$$

$$Permeability\,ratio\;\beta^*_{SPF} = \frac{steam\,permeability}{liquid\,permeability} = \frac{K_{ST}}{K_L} \quad (2)$$

Table 1. The various pressure differences at all tests.

Pressure difference conditions	Pressure difference in the cake formation phase	Pressure difference in the deliquoring phase
1-1 bar	1	1
1-3 bar	1	3
3-3 bar	3	3

2.3. Material

In order to have a link to the purpose of mineral processing, fine-grained coal (after processing) and limestone are used. The coal belongs to the Cua-Ong Coal Washing Company (CCWP), currently being filtered by hyperbaric disk filter technology. The filtration results there are not as expected. The residual moisture contents are 20-22% and 15-16% after filtration and thermal drying, respectively. The result is pretty high compared to the technical standard and the customer demand (usually 8%, maximal 12%). This type of sample is low-quality coal with an ash content of around 35%, and the density (dry state) is measured at 1497 kg/m^3. The median particle size $x_{50,3}$ is 11.78 µm. The particle size distribution of materials has a span $(x_{90}-x_{10})/x_{50}$ of 10. The below 10 µm particle size accounts for 45% and 90% of particles are below 0.125 mm. Meanwhile, limestones are provided accessible by commercial companies (Germany). Two kinds of limestone (KS12 and KS100) are the same density of 2710 kg/m^3 with the median particle size $x_{50,3}$ of 2.46 µm and 20.68 µm, respectively were used. The particle size distribution of materials has a span $(x_{90}-x_{10})/x_{50}$ of 2.98 for KS12 and 3.88 for KS100. The proportion of particles below 10 µm of KS12 and KS100 is significantly different, with 94.51% and 33.39%, respectively. The particle size distribution of materials was analyzed using the method of laser diffraction. The principle of this method is measuring the angular variation in the intensity of light scattered as a laser beam passes through a dispersed particulate sample (mechanical dispersion). This method is a widely used particle sizing technique for materials ranging from hundreds of nanometers up to several millimeters in size. Ultrasonic was used in order to avoid the form of flocs Figure 6 shows the characteristics of powder materials with the mass distribution.

By the Scanning electron microscope (SEM) technique, the images of the irregular shape of big coal particles and the flake–shape of fine and ultra-fine particles. While images for both coarse and fine limestone demonstrate irregular–shapes (Figure 7). Because the amount of very fine particles in all material samples is significant, more crack formation as well as the low efficiency of dewatering are the challenges.

3. Results and discussion

3.1. Test using conventional pressure filtration

In investigating the crack formation and studying its effect on filter cake moisture, filter cake height is a parameter not to be missed. This parameter is essential for scale-up and is directly related to the filter equipment's performance. Choosing the right filter cake height has a technical meaning and brings higher economic efficiency and higher productivity.

The varied mass of powder material in each test depends on the surveyed height of the filter cake. The gas pressure difference for these tests are "1-1" bar; "1-3" bar and "3-3" bar. The volume fraction of the initial suspensions was fixed (0.1 and 0.3 of cv). Because of the limitation of the filter volume, the filter cake's maximal height is 34 mm. The result is shown in Figures 8 and 11.

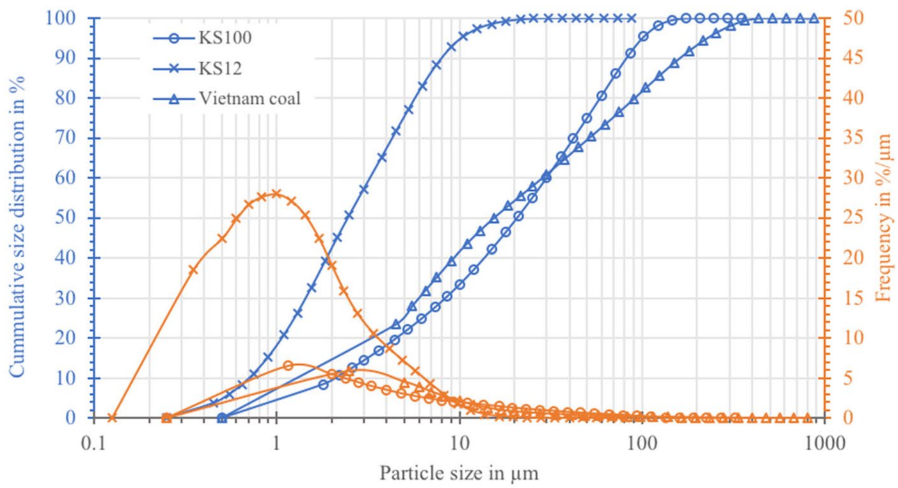

Figure 6. The particle size distribution of KS12, KS100 and coal.

Generally, there is an increasing trend of permeability ratio when the filter cake becomes thicker. However, depending on the material's characteristics and the volume fraction of suspension, the degree of a rising trend is different. As can be seen, the fine material (coal and KS12), has a significant increase in permeability ratio, while the value for coarser material KS100 changes slightly. Thick filter cakes that are formed from the dilute suspension (cv 0.1) have a significant value of permeability ratio in comparison to the remaining experimental cases. This means the probability and degree of cracking in this status are also high. While the permeability ratio for KS100 is around 1, the highest permeability ratio of KS12 filter cake reaches 62 at 30 mm filter cake height in the 3 bar of pressure difference at the deliquoring phase. Coal demonstrates the big difference between the dilute status and concentrate status of the initial suspension. For a solid volume concentration of 0.1, the permeability ratio's value reaches approximately 80 at 22 mm of filter cake thickness. When the feed slurry becomes more dense (cv 0.3), the permeability ratio of maximal 27 at 23 mm. The reason for this issue is related to the homogeneous degree of filter cake. For lower cv, almost coarse particles focus at the bottom of the filter cake while the fine particles form on the top. The high tensile stress of the particle system on the upper part of the filter cake led to the crack occurring. This phenomenon is explained in another research by Pham about the effect of solid volume concentration of suspension on crack formation (Pham and Peuker 2021; Pham 2021). In order to stabilize the structure of the filter cake, when the height of the filter cake increases, the pressure applied (during deliquoring phase) should rise to reduce the degree of crack formation.

As can be seen in Figure 8, the permeability ratio generally increases slightly at the low filter cake height before significantly rising at one special point (temporarily named "critical" point) of filter cake height. The "critical" point is 11 mm of filter cake height with surveyed materials. The similar value of the critical point is random. It can be changed in case of other materials, different slurry concentrations, filtration pressure, etc. The meaning critical point indicated that this is a suitable filter cake height for these test conditions in order to get a low permeability ratio (no cracking on the filter cake). For almost the filter cake height below that point, the crack does not occur and the filter cake is deliquored well.

The phenomenon of the increasing degree of cracking when the filter cake becomes thicker can be explained by the wall effect (Barua 2014), the filter cake's weak positions (Pham and Peuker 2021; Pham 2021), the agglomeration of particles (Barua 2014; Pham and Peuker 2021) and the sedimentation (Pham and Peuker 2021; Pham 2021; Anlauf, Stahl, and Krebber 1985). The first reason can be explained that the more significant losses because of wall friction during filtration are the main reason. The thin filter cake has a small contact area with the containment wall. Therefore the compressed force can be applied to the whole filter cake without any significant effect at any particular location. However, with a high filter cake, the wall friction is more significant due to the large contact area. The compressive force is different at locations on the filter cake. The particle density is intense in the middle of the filter cake and reduces gradually to the edge, mainly when contacting the containment wall. This results in a lower packing density on the edge of the filter cake (Gray 1968). The weaker points appear at the interface of particles and containment walls. The different distributions of density and stress lead to cracks forming around the filter cake edge. This explanation is valid for the lab-filter Nutsche and is less or no significance meaningful on a pilot scale or in practice. The second reason is due to the thick filter cake, the ability of stress to transition from the top to the bottom of the filter cake under compressed air is low. Due to lost stress, the particles in the lower part have loose connections. The elastic strain is recovered. Un-uniform packing density and filter cakes are easily divided into two parts horizontally (horizontal cracks) or cracks at the bottom. One more assumption is the occurrence of agglomeration in high filter cake thickness. The increase in the filter cake height means the mass of powder material increases in the fixed space. It could be a condition to increase the chance of encountering and agglomeration of fine-grained particles in the material. The agglomerated particles have loose connections. They are

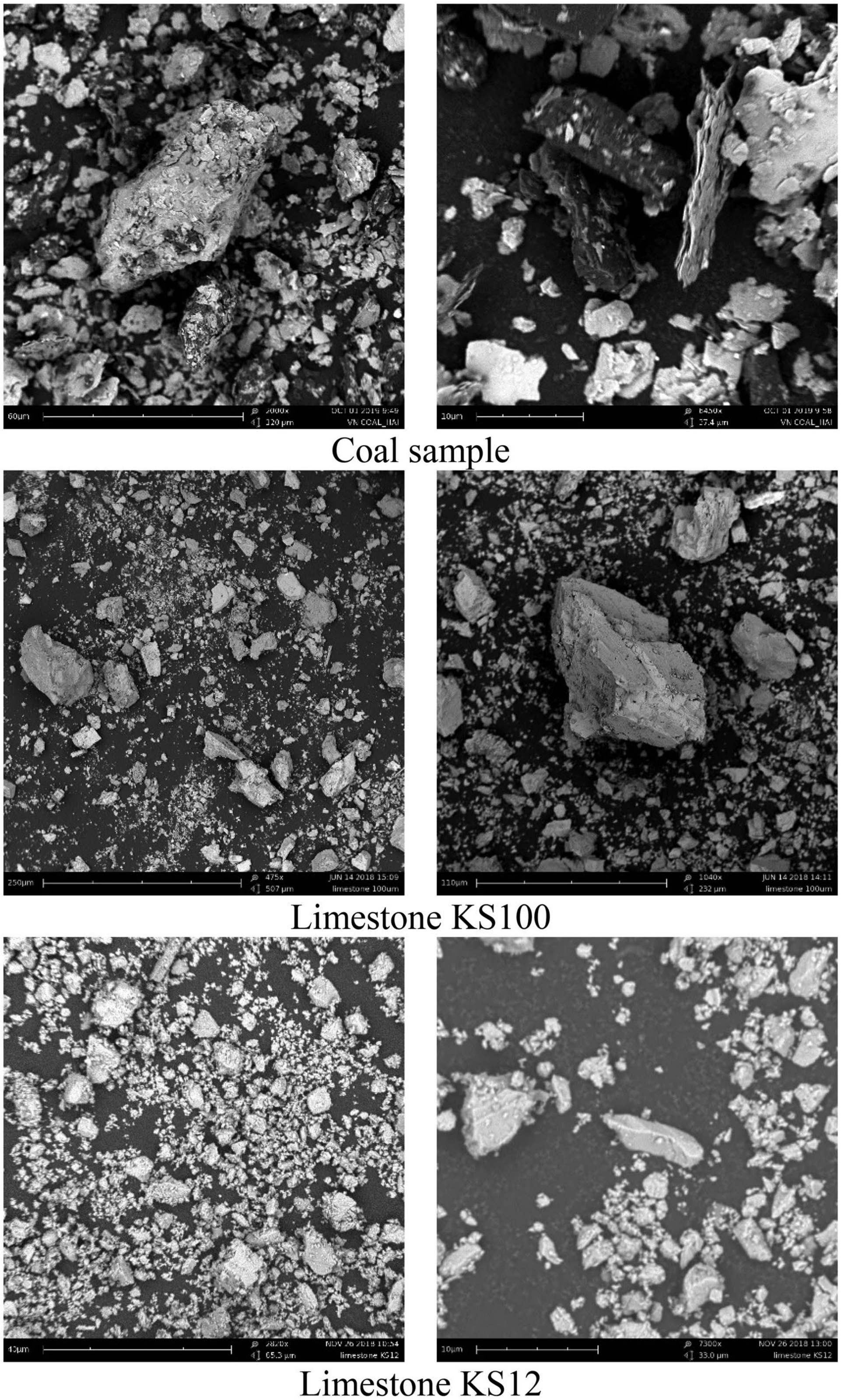

Figure 7. SEM images for coal, KS100 and KS12 particles.

parts inside the structure of the filter cake. They are easy to collapse forming weak points that cause the occurrence of cracking. The final assumption that can be mentioned is the effect of sedimentation. The increase in filter cake height is due to the corresponding increase in the amount of powder material mixed with distilled water. The cake formation time increases. Coarse particles have enough time to settle on the filter cloth, while fine particles take longer. Stratification may occur during the cake formation phase. The fine particles focus on the upper part of the filter cake leading to high tensile stress inside the filter cake that causes the cracking phenomenon.

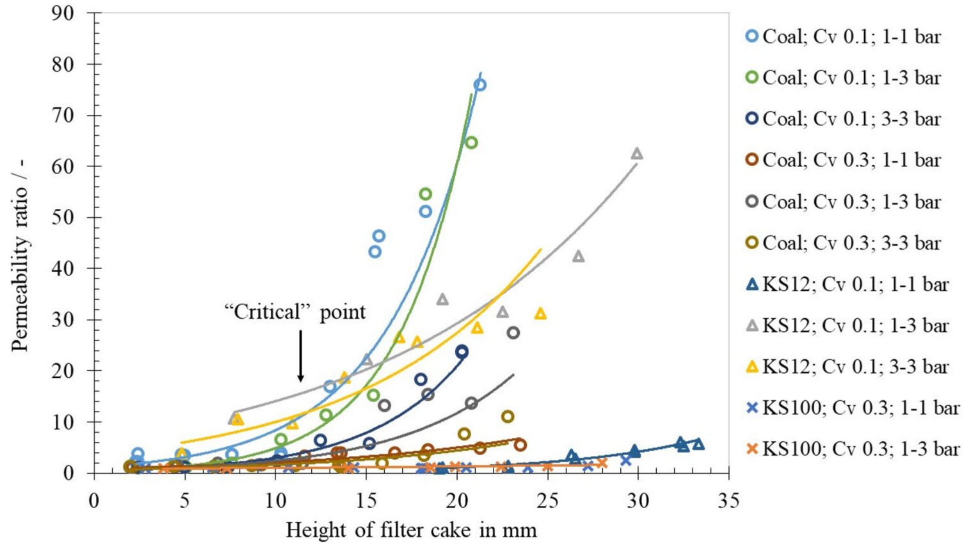

Figure 8. Permeability ratio (β^*_{CPF}) of filter cake in the variety of filter cake height.

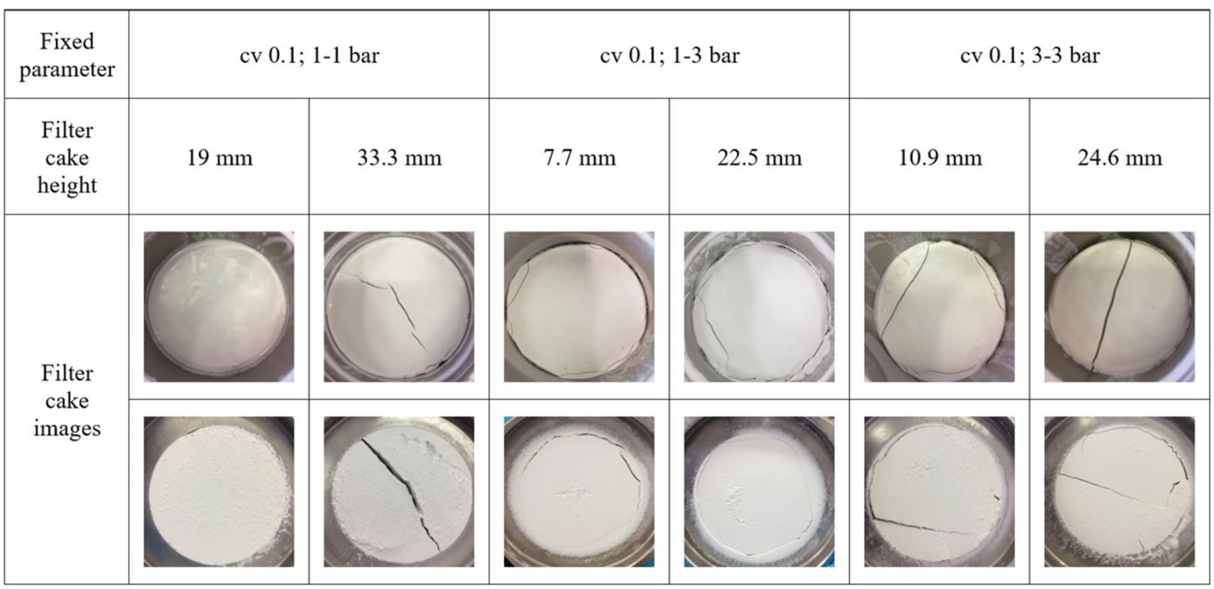

Figure 9. Images of KS12 filter cake in the variety of filter cake height.

The images of the KS12 (Figure 9) filter cakes reinforce the results of the permeability ratio (degree of crack formation). The higher the height of the filter cake, the greater the probability and extent of cracking. By visual observation, macro-cracking occurs in almost all cases in the filter cake. The shape of these cracks is quite diverse. Some cracks cut across the filter cake and spread to the bottom of the filter cake. In other cases, the cracks appear around the filter cake's circumference, close to the particles' interface to the containment wall. There are some cracks shaped like branches. The image for the coal filter cake does not indicate due to the difficulty of observation visually. However, the delamination plane can be since the filter cake is separated into two parts or the crack formation at the filter cake horizontally (Figure 10).

The saturation and residual moisture content characterize the amount of water remaining in the filter cake after filtration. Those values were calculated when the air/steam break through the filter cake. While saturation demonstrates the water remaining on the pore during dewatering, the residual moisture content is the amount of water by mass in filter cake (frequently used for production and commercial activities in practical). The result for both two output parameters demonstrates the increasing trend when the filter cake height increases (Figure 11) KS100 is a material that is easy to filter with the lowest amount of water remaining. The saturation even achieves 0.2, equivalent to the 8% residual moisture content at 4 mm filter cake thickness. These values increase slightly from 0.2 to 0.4 of saturation(from 8% to 11% of residual moisture content). The height of the filter cake does not affect the amount of water remaining inside the filter cake in this case. As can be mentioned in Figure 8, the crack did not occur although at the highest filter cake height. One of the prospects for increased productivity of

Figure 10. The specific case indicate the cracks that divide the filter cake into two sections horizontal.

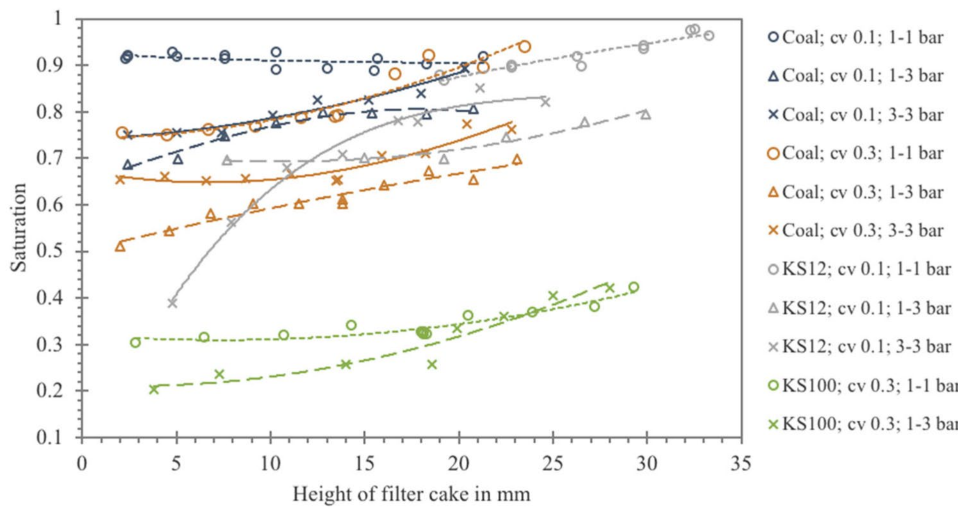

Figure 11. Saturation of filter cake after deliquoring in variety of the surveyed filter cake height; limestone KS12, KS100 and coal.

filtration in the case of this material can be expected. Meanwhile, the crack occurs more in the case of KS12, which comes together is the low efficiency in dewatering. The saturation reaches approximately 1 in some thick filter cakes. The residual moisture content is generally over 20%. The result cannot be improved for this kind of ultrafine material, although the applied pressure is “1-3” bar and “3-3” bar. The measures in getting a good result of filtration should be the combination of high applied pressure, thin filter cake and steam pressure filtration. For coal, there is a big difference between dilute and concentrated initial suspension. The issue was mentioned in another publication related to the heterogeneous and homogeneous filter cake (Pham and Peuker 2021; Pham 2021). Accordingly, the status of homogeneous filter cake was achieved at a higher slurry concentration. There, the dewatering efficiency is improved and the shrinkage cracking is prevented. Like the result of KS100 and KS12, the best result in dewatering belongs to the lowest filter cake height. The 0.5 of saturation (13% of residual moisture content) in the case of coal is pretty low but is not satisfied with the customer requirement and the technical standard. The reason can be realized related to the delamination phenomenon of filter cake and the high amount of fine particles. The recommendation for coal dewatering is steam pressure filtration, which is discussed in the next part.

Overall, the significant probability and degree of shrinkage cracking occur in the case of great filter cake height. The permeability ratio increases rapidly after the “critical point" of the filter cake deep. For lower filter cake than this "critical point," the material is well-dewatered without cracks. The values of the permeability ratio, saturation, residual moisture content, porosity, and specific resistance have no change. The mechanism of forming cracks depends on the characteristics of powder particles, equipment and operational filtration parameters. In some cases, its mechanism is caused by the systematic effect, which derives from the lab-scale equipment. This issue will be improved further on the pilot scale and industrial scale.

3.2. Steam pressure filtration

The tests using steam pressure filtration with limestone KS12 and coal are conducted. The purpose of preventing crack formation and improving the dewatering efficiency is expected to be solved by using the advantages of the steam filtration mechanism (including the high-temperature effect). The result in Figure 12 also shows the different permeability ratios in two kinds of filtration. The permeability ratio using SPF is lower than that using CPF. At the height of filter cake less than 10-13 mm, the permeability ratio is almost constant

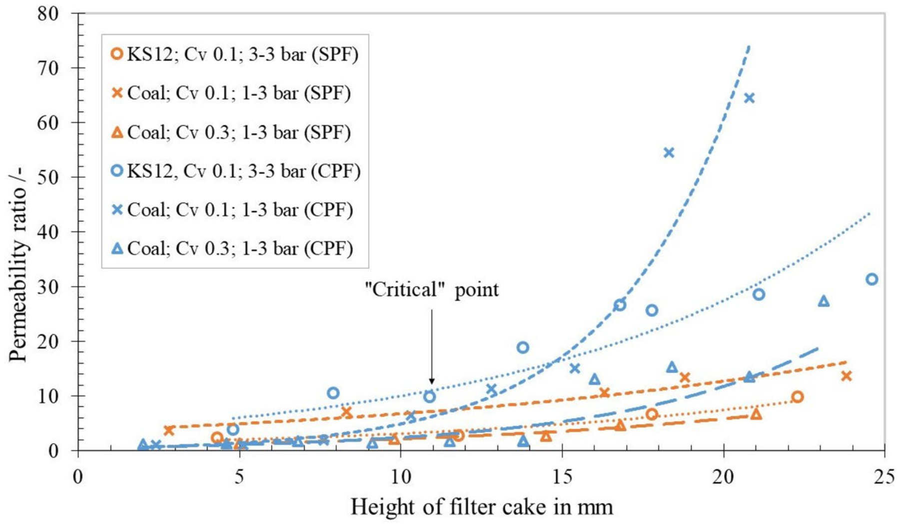

Figure 12. Permeability ratio of filter cake using conventional pressure filtration (β^*_{CPF}) and steam pressure filtration (β^*_{SPF}) in the variety filter cake height.

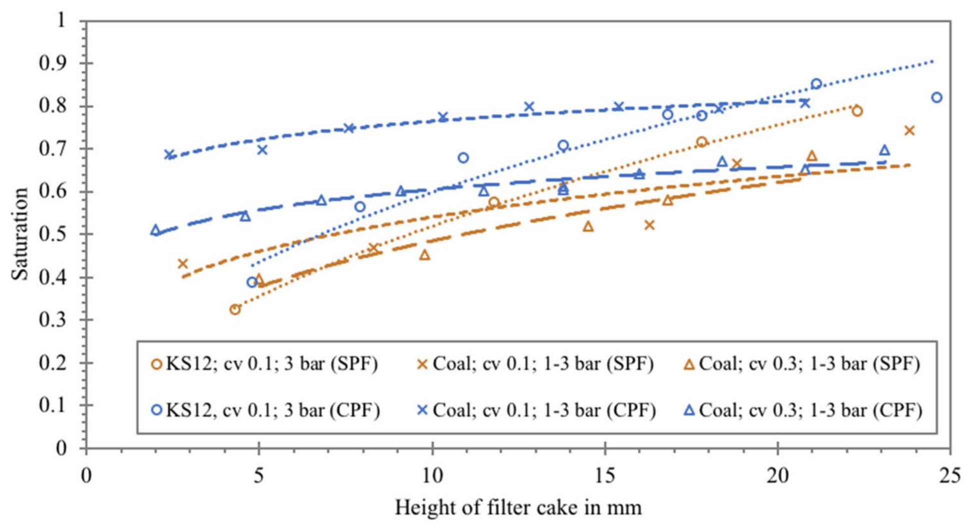

Figure 13. The saturation over the permeability ratio on filter cake in the variety of surveyed filter cake heights using SPF and CPF.

and has a similar magnitude as traditional filtration. While a significant increase trend of value is observed in CPF, the trend of permeability ratio rises slightly in SPF. The highest permeability ratio is around 10 in SPF at 20 mm coal filter cake height. This value in the case of CPF is six times higher, reaching 60. Similarly, for KS12, the probability and cracking are enhanced by using SPF with a permeability ratio three times lower than that of CPF. The probability and the degree of crack still increase as the filter cake height increases (although the lower degree). Crack formation causes are mainly due to the wall effect, the break of agglomerated fine particles in particle network as well as the compression pressure loss. These mechanisms of cracking are not overcome when using steam pressure filtration. However, the more prolonged mechanical displacement phase in the case of the filter cake becomes thicker (Peuker and Stahl 2001; Gerl and Stahl 1996). The result is the heated-up filter cake because of conduction and convection heat before the steam breakthrough. The appearance of the drying effect inside the filter cake contributes to further dewatering efficiency. This issue brings the prospect of higher productivity filtration.

As can be seen in Figure 13 the results are quite positive when saturation of filter cake shows a better degree than traditional filtration. Although the rising trend still occurs when the filter cake becomes thicker, the degree change is not considerable. The minimum saturation of KS12 using SPF is 0.3, equivalent to 13.45% of residual moisture content. The result for coal is 0.4 and 11.62%, respectively. One note that should be mentioned is that the amount of water remaining is measured and calculated at the mechanical displacement phase's endpoint where no gas flows through the filter cake. The residual moisture content will be reduced more (especially in steam pressure filtration) if the drying phase is applied. Some test results in the next part will show this good dewatering efficiency.

Table 2. Some result of filtration tests including drying phase; KS12, KS100 and coal; 150 seconds of drying time.

	KS100			KS12		VN coal				
Volume fraction	0.1	0.3	0.4	0.1	0.3	0.1		0.3		0.4
Pressure difference (cake formation -deliquoring-drying) in bar		3-3-3		3-3-3		1-3-3	3-3-3	1-3-3	3-3-3	3-3-3
Mass of solid in grams		50		50				30		
Residual moisture content in %	10.83	9.05	6.73	16.74	16.12	14.83	14.88	10.51	13.78	12.65

3.3. Pretest in the combination of three-phase of steam pressure filtration

In steam pressure filtration, the remaining water in the filter cake at high temperature, under the air flowing through it, continues to evaporate and reduce moisture (Peuker and Stahl 2001; Gerl 1999). Test results for coal and limestone show the reduction of residual moisture content with a fixed drying phase time of 150 seconds (Table 2). In the comment of Gerl and Stahl (Gerl and Stahl 1996), the dewatering can be further reduced, even attaining the value of 0. The higher the amount of absorbed heat, the greater the evaporation of water. Finally, further water loss inside the filter cake and the dewatering efficiency obtained better.

4. Conclusion and outlook

The evaluating parameter of the probability and degree of filter cake cracking is the permeability ratio. This indicator is characterized by the ratio of the gas permeability to the liquid permeability. The amount of liquid in the filter cake is represented by residual moisture content and saturation.

There are two main types of cracks: macro cracking and shrinkage micro cracking. Macro cracks are large cracks that can form from the top of the filter cake, spread to the bottom and contact with other cracks. This type of crack dramatically affects the efficiency of dewatering as well as subsequent processes. The second type is the shrinkage, micro-cracking. These are cracks that form on the surface, bottom or edge of the filter cake, which have little effect on the dewatering efficiency. Another phenomenon is the cracked horizontally of the filter cake (also called the delamination plane) due to the strong sedimentation and de-mixing of the coarse particles. The relationship between the delamination and permeability ratio is not yet clear and needs to be investigated further. When the filter cake becomes thicker, the probability and degree of cracking also increase. The amount of water remaining in the filter cake also increases. There is a "critical point" where the cracking occurs to a significant degree when filter cake height continues increasing. For filter cake height below that point, the filtration results are almost unchanged with a low degree of cracking as well as high dewatering efficiency.

Steam pressure filtration indicated the advantage of avoiding the crack and reducing the amount of residual moisture content. In essence, steam pressure filtration is a perfect combination of mechanical and thermal dewater processes in one equipment. This issue offers practical advantages in terms of production costs and initial investment costs compared to having separate filters and dryers. However, the steam filter application is still very limited in practice, leading to the requirement of more in-depth studies with each specific material and the up-scale ability.

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