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Separation technologies for sludge dewatering

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Abstract

Particles in sludge feeds interact strongly one with another to prevent settling and offer a significant resistance to filtration and compression. This leads to the need for dewatering forces to be compressive ones applied directly to the networked solid phase; sometimes shear forces can be an assist dewatering. Designs of filtration equipment most suitable for sludge dewatering have evolved to meet the intrinsic characteristics of sludges, the most important of which are their compressibility and fine particle sizes, which lead to cakes with extraordinarily high solids contents close to the filter medium. Hence, the membrane plate press, the belt filter and the decanter centrifuge have become most widely accepted machines for sludge dewatering. Filter presses tend to yield a drier solids discharge, but the level of dryness depends on the sludge properties. The same feed properties dictate the need for chemical pre-treatment to ensure the highest rates of dewatering and best clarity of filtrate, and correct choice of filter cloth is also crucial in these respects.

Keywords: Sludge; Wastewater; Dewatering; Filtration; Pressure filters; Decanters; Centrifuges; Filter cloths; Cake compression; Compressibility

Commonplace requirements in many processing plants are to minimise the amount of wastewater generated or to reduce the concentration of contaminants in the wastewater, and there are often underlying problems related to dewatering and handling of the sludge. A number of methods are used to reduce the amounts of wastewater discharged and the concentrations of contaminants in the discharge. These include source reduction technologies that minimise the amount of wastewater generated in the plant, and treatment technologies that treat wastewater to reduce contamination levels. Contaminant level reduction is primarily either to make the water available for recycle or to reduce costs of treatment.

In-plant treatment of wastewater is often a key strategy as a precursor to recycling, and a wide range of treatment options is available. These include careful consideration of alternative uses for the wastewater before it is sent to the treatment plant, technologies to stabilise the wastes (for example, wet oxidation), and separation/concentration technologies (including screens, settlers, filters, centrifuges, and membrane (bio-)processes), as well as thermal processes (for example, evaporation). For dewatering, economic considerations determine that mechanical processes are preferred over thermal ones.

Wet oxidation is used to stabilise municipal and industrial wastewater sludges; at lower temperatures and pressures the sludge is conditioned to improve dewatering, but at higher temperatures and pressures biological sludge can be destroyed (as an alternative to incineration). The oxidation process is able to convert oxidisable constituents in the sludge, but still leaves a slurry that has to be dewatered. Hence, dewatering technologies are often key downstream operations in wet oxidation processes as well as in bioprocesses.

This paper will focus on the separation technologies most suitable for sludge dewatering. These are primarily pressure filters, rotary drum filters, and centrifuges.

1. Dewatering-related properties of wastewater sludges

No two wastewaters are alike although, in summary, the general effects on filtration of variations in their characteristics are:

- feed compositions are complex mixtures of organic and mineral particles, biosolids, and molecular and ionic substances;
- feed composition is significant in controlling cake resistance, rate of filtration, and cake moisture content;
- feeds invariably require flocculation to “reduce” their fines content, and the negative effect of the fines on filtration;
- due to their higher biosolids content secondary sludges tend to form wetter cakes and cake form rates are slower, when

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compared with filtration of primary sludges (under the same conditions of filtration);
- the filtering properties of many types of wastewater feeds are dependent of sludge age;
- formed filter cakes tend to vary from moderately to highly compressible.

During filtration, the compressible nature of a filter cake leads to the formation of a solids concentration variation through the cake that decreases from a maximum at the cake–cloth interface. The existence of compressibility in a cake suggests that further liquid can be removed from the cake by applying a compressive force to its surface—the so-called expression process. The solids volume fraction in the cake (ε_s) and the specific resistance of the cake (α) can be related to the solids compressive pressure (p_s) by

$$\varepsilon_s = \varepsilon_{s,0}\left(1+\frac{p_s}{p_a}\right)^{\beta} \quad \text{and} \quad \alpha = \alpha_0\left(1+\frac{p_s}{p_a}\right)^{n} \tag{1}$$

where the subscript '0' indicates the value of ε_s or α when the compression force is first transmitted through the solids network, p_a is a scaling factor, β and n are form constants that specify the degree of compressibility. When $n=0$ the cake is incompressible; when $n<1$ a cake has a low to moderate compressibility; $n>1$ suggests a highly compressible cake (such as sludges from oxidation processes); $n \gg 1$ represents an extremely compressible cake (typical of biological sludges). Wastewater sludge cakes usually fall into the latter two categories.

Fig. 1 is an example of how the solids volume fraction varies through the cake thickness for a typical polyelectrolyte conditioned sludge ($\varepsilon_{s,0}=0.9$, $p_a=5$ kPa, $p_s=100$ kPa, $\varepsilon_{s,feed}=0.077$, $\beta=0.5$, $n=5$, $\alpha_0=7\times10^{11}$ m$^{-2}\approx 5\times10^{8}$ m kg^{-1}), and it is also shown how the concentration changes during the expression process. The solids concentration profile shown in Fig. 1 is established from the onset of cake formation by filtration; the general shape of the profile remains throughout the subsequent expression process. An important point to note, and one which occurs only with extremely compressible cakes, is the steep gradient of the solids concentration profile close to the filter cloth – often referred to as "skin" formation – that causes a low permeability in this region and hence a high localised pressure loss, and high cake moisture contents result. Although "skin" formation is a property of the cake, it results from consolidation of the cake by constituents of the sludge packing more closely due to a wide size distribution or deformation of components in the feed. This results from a high compressive drag force acting on the solids during filtration, which can have the effect of "pushing" some of the feed components into the surface of the filter cloth; hence the cake can have a strong interaction with the filter medium which, in practical terms, will cause medium blinding.

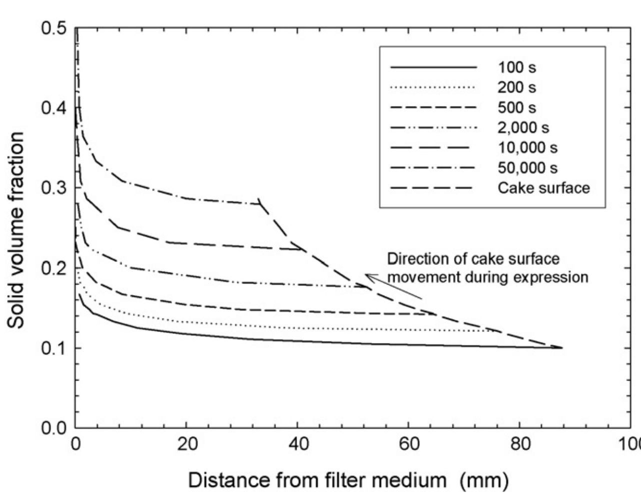

Fig. 1. Variation of solid volume fraction through the cake thickness during an expression process (data recalculated from Ref. [1]).

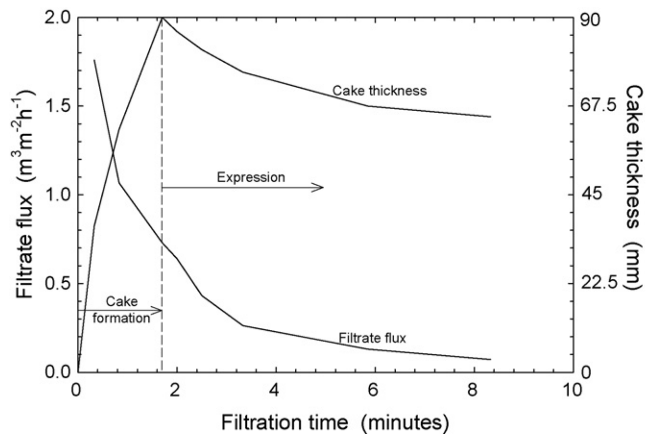

Fig. 2. Variation of filtrate flow rate and cake thickness during filtration and expression in a membrane filter—the cake properties are the same as for Fig. 1 (data recalculated from Ref. [1]).

Fig. 2 illustrates the variation of cake thickness (and hence its bulk volume and moisture content) and of the filtrate flux during filtration and subsequent expression. Immediately after the compressive pressure is applied during expression, the gradient of the filtrate flux rises slightly and the flux remains greater than would be the case if normal filtration had been continued.

The specific resistance of the sludge is related to the "size" of particles forming the cake through

$$\alpha \propto \frac{1}{x^2} \tag{2}$$

where x represents the particle size. Particles in sludges are often amorphous and do not have a clearly definable size, but in so far as a "size" can be attributed to them it is usually <10 μm. This points to sludge cakes having a high resistance and hence long filtration cycle times, which has implications for the magnitude of the force needed to affect dewatering and for the design of filter cloth chosen for the application.

The specific resistance of sludge cake is dependent on the age of the feed suspension; many suspensions, particularly those composed of fine particles or biosolids, tend to change in storage—an effect known as ageing. This effect is shown in Fig. 3 for filtration of an activated sludge, where the specific resistance has increased by almost an order of magnitude during 5 days storage; this is quite typical of activated sludges. For the data shown, the increase of specific resistance is largely attributable to the increase in specific surface as the floc struc-

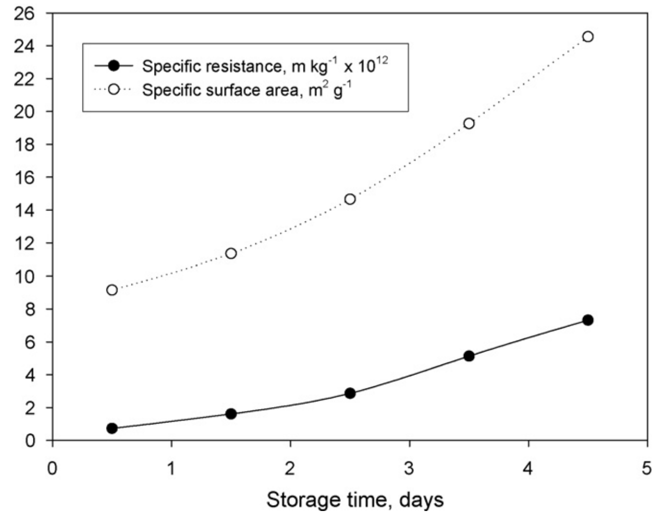

Fig. 3. The specific surface area and cake specific resistance for activated sludge from Aså Rensningsanlæg as a function of anaerobic storage time [5].

ture changed during the storage period. This has implications for sludge filterability testing, showing the importance of using "fresh" feed for the test work.

The compressible nature of wastewater sludges has significant impact on the design of filters that are appropriate for dewatering the sludge, which is summarised in Table 1. This explains why some types of filters have emerged as more appropriate for sludge dewatering than others; outline descriptions of filter and their uses are available elsewhere [2–4].

2. Filters

The characteristics noted in Table 1 lead to a preference for pressure filters for sludge dewatering; in the case of some industrial sludges the rotary drum filter can sometimes be considered an option. To make sludge feeds more amenable to mechanical dewatering the feed is more often than not pretreated by flocculants or coagulants, agglomerating the feed particles to increase their effective size.

3. Filter presses

Plate and frame filter presses, recessed plate presses, and membrane plate presses are all used to dewater sludges. Filter plates are supported on side beams (Fig. 4) or suspended from an overhead beam; filter plates of 1.5 m × 1.5 m are typical, but 2 m × 2 m plates are increasingly common—and larger plates are being developed. For wastewater applications, 80 chambers in a recessed plate press or 60 chambers in a membrane plate press is not uncommon.

Fig. 4. Sidebar filter press (Larox Hoesch GmbH).

Table 2
Recess plate filter press operating data for some municipal sludges [6]

Sludge type	Feed solids concentration (%)	Cake solids concentration (%)	Typical cycle time (h)
Raw primary + activated	3–8	45–50	2–2.5
Raw primary + activated + $FeCl_3$	5–8	40–45	3–4
Primary + activated + $FeCl_3$ digested	6–8	40	3
Tertiary + lime	8	55	1.5

The ability of membrane plate presses to utilize the compressible nature of the sludge makes them particularly useful for sludge dewatering applications. A typical filtration cycle for dewatering is: (i) slurry feeding; (ii) cake squeezing by inflating the membranes; (iii) air blow through the cake; (iv) core wash and/or blow. The cake squeeze is affected by diaphragms that are pressurised up to 16 bar in order to lower cake moisture content (or, increase the volume of liquid recovered from the feed). Cake moisture content reductions are dependent on its compressibility properties (Eq. (1)), but moisture contents of 25% more than can be achieved on a conventional filter press are not uncommon. Some operating data for recessed plate filter presses is given in Table 2.

Developments incorporated into modern filter presses to increase filter capacity, reduce cake discharge times, and reduce

Table 1
The effect of sludge cake properties on filter design and operation

Cake characteristic	Effect on filtration	Impact on filter design/operation
Compressibility	Filtrate rate does not increase in proportion to increases in pump pressure; pump pressure has only a limited effect on increasing cake solids	Force needs to be applied directly to the solids for better dewatering—hence mechanical compression or centrifugal force is needed to reduce cake moisture content
Skin formation	High pressure loss over cake formed close to filter medium; the filter cloth has a greater tendency to blind; high cake moisture contents	Filtration pressure should be low at start of filtration; cloth choice is critical to avoid blinding; frequent washing of cloth may be necessary
Fine particle "sizes"	Long cake formation times; cake dewatering by air or gas blowing may not be possible	High pressures may be necessary for cake formation; cloth choice most important

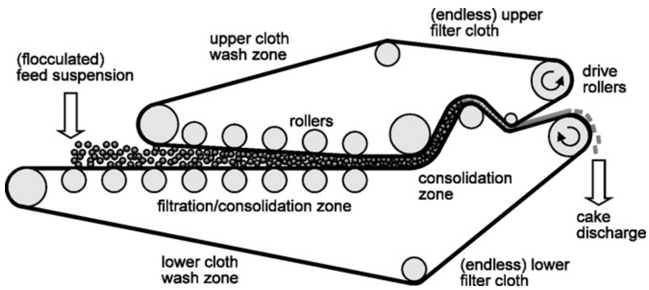

Fig. 5. Belt arrangement on a typical belt press filter.

labour intensity include: (i) automation and mechanisation of plate pack opening and plate shifting; (ii) use of long-travel hydraulic cylinders to move the pressure head to reduce press opening times (very large presses may have two moving pressure heads); (iii) cloth shaking or lifting mechanisms to promote cake discharge; (iv) cloth flushing or washing systems, which range from simple spray nozzles mounted above the plates to moving spray bars that are lowered and raised between plates singly or in groups, to remove adhering or penetrating particles (a limitation of most cloth washing systems is that only one side of the cloth is washed); (v) placement of the filter onto load cells to indicate if the filter fails to reach its tare weight (for filter control and/or throughput measurement); (vi) use of "bomb bay" doors to cover discharge chutes to prevent water entry into the dry cake handling facilities; (vii) light curtains and/or protective screens to prevent operator access.

Although membrane presses are significantly more expensive than conventional filter presses, the additional capital and operating costs are often justified by shorter cycle times (and hence greater sludge throughput) and the more easily handled cake that is produced.

4. Belt presses

Belt filters are characterised by two continuous, tensioned filter cloths. Flocculated sludge is fed to the lower cloth (belt); initial dewatering is under gravity as the belt carries the sludge into a consolidation zone where it is progressively squeezed under pressure by the upper and lower belts moving towards each other to form a closed "envelope". The cake is then squeezed under increasing pressure as the cloths move over a sequence of successively smaller diameter rollers. As the two belts pass over the rollers there is a relative movement of the belts, causing liquid to be removed by a combination of expression and shearing to produce a dry, crumbly cake (Fig. 5).

A key to successful operation of a belt press is that the feed must be flocculated, to avoid blinding of the filter belt and facilitate gravity drainage when it is initially fed to the belt. Conditioning is carried out by polyelectrolytes immediately before the drainage zone; some results for different sludge types are given in Table 3. Special care must be taken with belt washing, carried out on the belt return cycle with rinse water flow rates as high as 50–200% of that of the sludge. For good machine operation a feed sludge concentration >3–4% has been recommended [7].

Table 3
Belt press operating data for some municipal sludges [7]

Sludge type	Input solids concentration (%)	Cake solids concentration (%)	Polyelectrolyte dosage (kg te^{-1})
Raw primary	3–10	25–44	0.6–4.5
Raw activated	0.5–4	12–32	1.0–6.0
Raw primary + activated	3–6	20–35	0.6–5.0
Aerobically digested	1–8	12–30	0.8–5.0
Anaerobically digested	3–9	18–34	1.5–4.5
Thermally conditioned	4–8	38–50	–

5. Rotary drum filters

Vacuum filters have operational and process limitations that can be most important when choosing a filter for sludge dewatering. By definition, the driving force for dewatering is limited by the vacuum that can be applied; in practice, a vacuum of not more than 0.25 bar absolute (−0.75 bar g) can be applied. For this reason vacuum filters are not usually employed in systems where most of the particle sizes are smaller than about 5 μm; in turn, vacuum filters are rarely used to dewater municipal sludges but are more often suitable for some types of industrial ones. When vacuum filters are used, rotary drum filters are the preferred choice (Fig. 6) and their continuous operation and virtually no operator intervention during the normal operating cycle can be used to advantage.

6. Decanter centrifuges

High solids decanters (Fig. 7) are used to mechanically dewater environmental and biosolids sludges and are often a preferred choice of equipment due to

- the high forces of 2000–4000 g applied directly to the feed solids, enabling lower solids moisture contents (the "ultimate" cake dryness depends on the given sludge);
- its ability to handle higher solids content feeds;

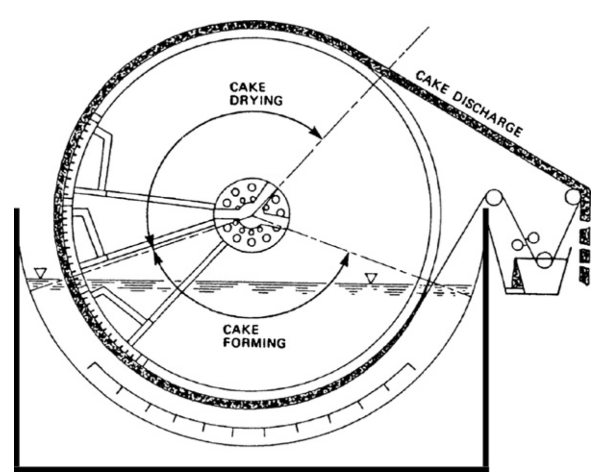

Fig. 6. Schematic representation of a rotary drum filter.

Table 4
Decanter centrifuge operating data for some municipal sludges [7]

Sludge type	Feed solids concentration (%)	Cake solids concentration (%)	Conditioner dosage (kg te^{-1})	Solids recovered (%)
Raw primary	5–8	25–36, 28–36	0.5–2.5, 0	90–95, 70–90
Raw activated	0.5–3	4–12	5.0–7.5	85–90
Raw primary + activated	4–5	18–25	1.5–3.5	90–95
Digested primary + activated	2–4, 4–7	15–18, 17–21	3.5–5.0, 2.0–4.0	90–95, 90–95
Thermally conditioned primary + activated	9–14, 13–15	35–40, 29–35	0, 0.5–2.0	75–85, 90–95

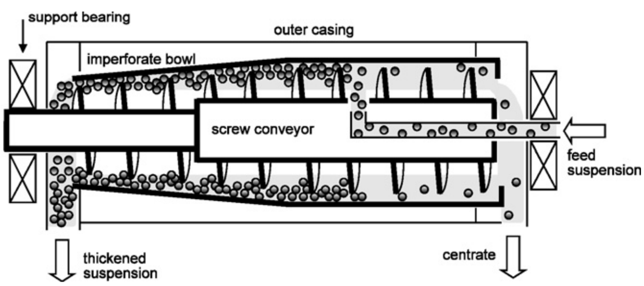

Fig. 7. Schematic representation showing the essential features of a decanter centrifuge.

- its continuous operation, with solids throughputs up to about 90 te h^{-1};
- the solids handling capabilities intrinsic through its design, with solids conveyed co-currently along the walls of the bowl by a helical screw.

The centrifuge can be over-torqued due to the flow properties of the thickened solids, or due to plugging by accumulation of unconveyed solids in the bowl. Wear problems on the screw can also be caused by more abrasive particles. To improve centrate clarity, flocculants or coagulants are frequently added to the feed to agglomerate finer particles. Examples of the expected performance of decanters dewatering different types of municipal sludges are given in Table 4.

Important innovations in decanter technologies are the CentriDry which combines centrifugal dewatering and thermal drying in the same machine [8], and the compound beach and adjustable gate centrifuges [9,10]. The compound beach profile has a steep conical beach followed by a 0° cylindrical beach, with an adjustable gate located near to the solids discharge end of the machine to meter the cake. In this way, only the driest cake layer adjacent to the bowl wall which is subjected to the maximum compressive solids pressure (see Eq. (1)) is skimmed for discharge while the wet cake layer near the cake surface is recycled back upstream. This is an attempt to increase solids capacity whilst not compromising cake dryness, as tends to happen in the conventional decanter centrifuge.

7. Filter media

Filter cloth choice is a key factor to successful filter performance, and necessary requirements are: (i) good resistance to blinding, as particles become embedded in the cloth filter capacity is reduced and cake moisture increased (this is particularly so in wastewater applications where the composition of the waste stream can vary widely in both its chemical composition and its solids content); (ii) good cake release from the cloth, which is essential to minimise operator intervention; (iii) good resistance to mechanical damage, by either components in the feed or by operation of the filter [11,12]. Woven textiles are the traditional cloths used for sludge dewatering, with a typical range shown in Table 5.

Table 5
Cloth types for sludge dewatering (mono- ≡ monofilament; multi- ≡ multifilament) [4]

Filter type	Filter cloth types	Filter media/filtration characteristics
Municipal sludge		
Filter press	Mono-polyester; mono-polyamide; staple polyamide; staple polypropylene; mono-polypropylene; mono-polyvinylidene chloride	Good resistance to blinding and mechanical damage; good cake discharge
Belt filter	Mono-polyester	High stability for good tracking; strong belt jointing; high mechanical resistance
Industrial sludge		
Filter press	Mono-polyester; mono-polyamide; staple polyamide; multi-warp/staple weft polypropylene	Good cake discharge; fine particle retention; high throughput

8. Filter media developments

Surface coatings applied to filter fabrics can enhance one or more of its filtration properties; microporous polymer coatings are a relatively new development used to provide a smoother and finer aperture size to the fabric surface, and to facilitate easier detachment of the cake and prolong the lifetime of the medium. A polyurethane coating on a woven polyester substrate is the basis for Madison's Primapor fabric for use on process filters such as rotary drums and filter presses.

The "second generation" treatment developed by Madison, Azurtex, has the coating pushed farther into the body of the fabric

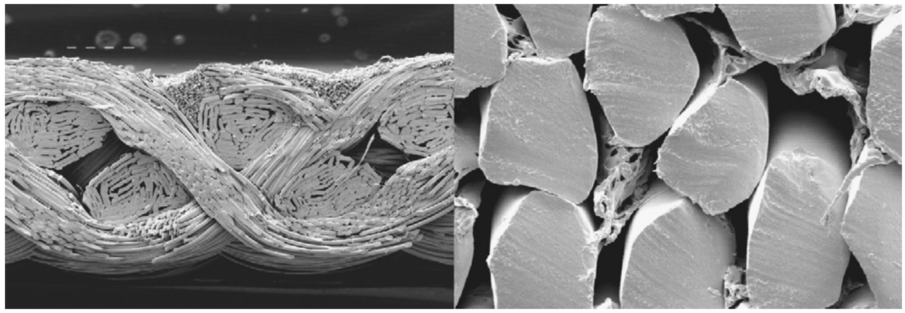

Fig. 8. Azurtex showing good coating of the fabric by the polymeric film but limited penetration of the polymer between individual yarns (Madison filter).

so that the surface finish is less prone to mechanical damage from external forces—shown in Fig. 8. Both treatments give better particle retention with improved cake release.

9. Conclusions

Designs of filtration equipment most suitable for sludge dewatering have evolved to meet the intrinsic characteristics of sludges, the most important of which are their compressibility and fine particle sizes, which lead to cakes with extraordinarily high solids contents close to the filter medium. The sludge feed tends to be networked, that is particles interact strongly one with another to prevent settling and offer a significant resistance to compression, which requires that the forces applied for dewatering be compressive ones applied directly to the networked solids phase. Hence, the membrane plate press, the belt filter and the decanter centrifuge have become most widely accepted machines for sludge dewatering. However, usually the same feed properties dictate the need for chemical pre-treatment to ensure the highest rates of dewatering and best clarity of filtrate, and correct choice of filter cloth is also crucial in these respects. The filter press tends to yield drier solids, but the choice of equipment depends not only on the cake dryness but also the process duty requirements and costs.

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