***tce* is published monthly by the Institution of Chemical Engineers**
Editorial: claudia@icheme.org
Subscriptions: jcressey@icheme.org
Advertising: nigel.stephens@mainlinemedia.co.uk
www.tcetoday.com

Settle down

In part 1 in a series on selection of liquid/solid separating equipment, **Henri Pierson** and **Barry Perlmutter** give practical tips, and shows how sediment behaviour can influence choice

THE range of liquid/solid separation equipment is very large and without an intimate knowledge it can be confusing and even illogical, the main reason being that there are only two basic principles of liquid/solid separation. This means that equipment which an independent expert would not necessarily chose first can still be made to work, albeit with poor efficiency. This implies that you should be extra careful with suppliers who offer only one type of equipment, as it may well be that although it can be made to work, it may not be the best choice!

For these reasons it is useful to carry out your own basic evaluation of possible or probable equipment, and above all establish which routes *not* to follow. This article aims to help you determine one, two or three types of equipment which have an above average chance of being right for the job, and eliminate those which are unsuitable. At that stage, you'll need to carry out pilot tests of actual machines to calculate pros and cons of each system, and of course talk to existing users.

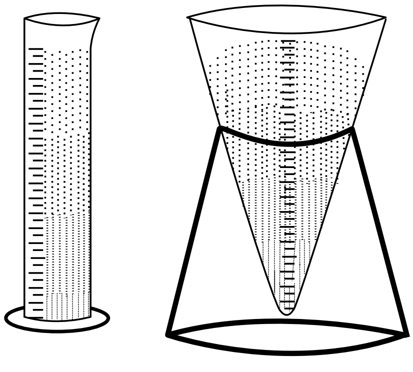
two basic principles

To separate liquids from solids, or solids from liquids there are only two mechanisms available:

- either the solids have a (if need be induced) tendency to go one way and the liquid the other way, (ie separation); or
- pass the suspension through a hole smaller than the solids you want to capture (ie filtration).

There are no more options than this, and yet there are more than 100 different types of equipment, which explains the potential confusion. On the plus side, however, it does mean that some basic laboratory tests can give an early indication of the most likely route to follow.

Figure 1: For basic tests, use a glass measuring cylinder (minimum 75 mm diameter) with graduations, or better still a glass measuring cone



laboratory tests

In theory, it's possible to determine the right equipment at the right size based on nothing more than an analysis of the solid and liquid. However, in reality, the chances of this happening are poor; there are simply too many variables in turning a mobile suspension into an immobile solid mass and a clear liquid.

Basic laboratory tests are therefore essential, and the initial equipment and tests are very simple. What is more difficult to obtain is a representative sample, for two reasons:

- Most process equipment is not fitted with a reliable sampling point. They often have a tendency to block, so check carefully that the sample is representative.
- Most suspensions alter with time. Either because of post crystallisation, sedimentation, coagulation or temperature changes. Attempts to reconstitute the sample by stirring normally breaks the particles and you almost never arrive at a truly representative sample.

If at all possible you should carry out the initial laboratory tests on site and as close to the source as possible – even if that means working under difficult conditions and without the normal laboratory facilities.

observation

Before rushing into tests immediately, pour some of the suspension into a glass beaker and observe what it does and what happens to it. And keep notes!

Does the suspension have a tendency to separate naturally, and if so, how? Does it form a scum layer? Are some solids settling rapidly, while the rest stays in suspension? Is there a tendency to foam? Do the solids look as if they are coagulating and give a more 'granular' or 'porridgy' appearance than at first? Do the particles form clusters, so that what one actually filters is not the particle itself but the loosely-held together structure of crystals? (This latter phenomenon often occurs with needle-shaped crystals.)

Try to get under the skin of the suspension and understand what its tendencies are and how you should treat it. For example, a suspension which forms fragile clusters should never be vigorously agitated or passed through a centrifugal pump prior to separation, whereas a suspension with a tendency of foaming can be very troublesome in vacuum filters or centrifugal ones.

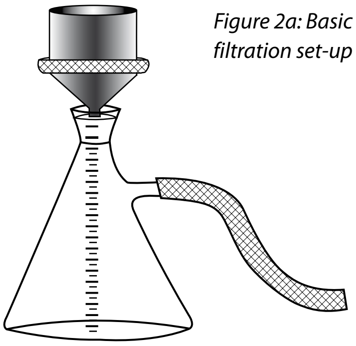


Figure 2a: Basic filtration set-up

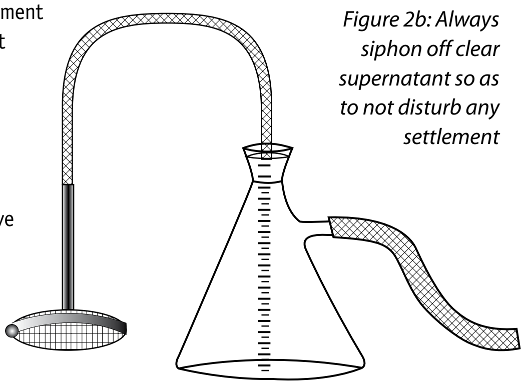
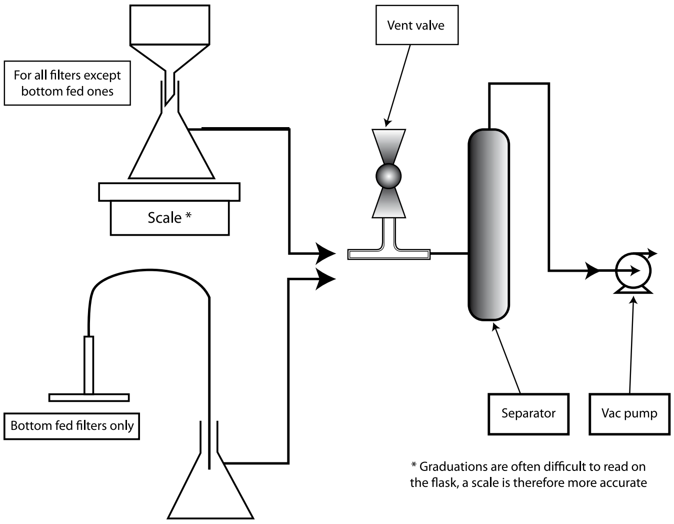


Figure 2b: Always siphon off clear supernatant so as to not disturb any settlement

settlement (sedimentation) tests

Once you have observed how the suspension behaves, you can carry out the first basic tests. For this, use a glass measuring cylinder (minimum 75 mm diameter) with graduations, or better still a glass measuring cone (see Figure 1). Gently shake the sample container to ensure that the suspension hasn't settled out, and pour some into the measuring unit. In small time increments, record the behaviour of any settling or floating of the solids. A note that says that "after two hours the suspension had a 20% sludge layer at the bottom" does not mean much – you need to know what the rate was. How long did it take for the suspension to separate somewhat? At which point was there some clear liquid at the top? When was there the first noticeable layer of solids? At what (time) rate did the sludge



* Graduations are often difficult to read on the flask, a scale is therefore more accurate

(Left) Figure 2c: Test kit arrangment

layer form? Does it seem to compact further with time or not?

By plotting such behaviour you should arrive at some preliminary conclusions. Of course if the liquid phase settles and the solids float to the top, the same applies.

At this stage, measurements can be in percentages of the whole, ie 100 ml sludge at the bottom of a 1 l cylinder = 10%. The observation record could be something like this:

Total time (min)	***Observation***
02	Suspension begins to look grainy
05	A thin clear supernatant layer forms
10	Supernatant now 10% – remainder looks thicker towards the bottom layer
15	Bottom layer becomes noticeably thicker
20	Supernatant very clear (15%). Interface still very cloudy
25	Bottom layer quite discrete, about 30%
30	Supernatant 20% and quite clear. Interface cloudy.
35	Bottom layer drops to 25% looks thick. Interface less cloudy.
40	Supernatant 30%, clear bottom layer under 25% interface clearish.
45	Reasonably clear supernatant for 60%, bottom layer to about 20% thick with about 6–7 % somewhat thinner sludge.
50	Sludge consolidates to a layer of about 23%. Very little interface. Supernatant quite clear.

Samples of the 'clear' supernatant as well as the sludge must be taken for later analysis for solid contents. Do not try to pour the supernatant off, you will disturb the settlement. Use a siphon. Take approximately the top 10% of the supernatant for evaluation and then siphon the remainder till you are left with the sludge layer.

If the settlement tests are reasonably successful, eg they produce sufficiently clear liquor and a reasonably dense sludge layer, there is a good chance that some form of separator may be appropriate. If this is the case, then you should repeat the test but this time with a 'long tube' – a glass tube of length 1.5–2 m, and 100 mm (or more) diameter, as used in pilot plants. Close the bottom with a proprietary stopper, fix a tape-measure along the wall of the tube, fill with suspension and take readings. The greater fall height gives much better accuracy than a simple cylinder and with a relatively high percentage of sediment, you can observe compaction, or conversely hindered settlement of the sludge layer.

sedimentation systems

With the results of the sedimentation tests, make a rough shortlist, like that shown in Figure 3a–c, where the time units indicate the total time for sedimentation to take place; here the best case therefore five minutes to arrive at a complete separation and in the worst case two hours.

Three types of feed concentration are shown – those producing approximately 0.5–5%, 15%, and 40% sludge volume.

In reality, non-assisted sedimentation systems, relying on natural gravity only, will produce results very similar to those of the laboratory tests. Scrapers in sedimentation systems can sometimes increase the solid content of the sludge somewhat, but don't expect miraculous differences.

Assisted systems, such as centrifugal decanters or centrifugal clarifiers will give better sludge compaction (especially in the case of decanters) and better clarity in the case of clarifiers.

Having made a rough selection as to which type(s) of equipment look most attractive it's time to talk to manufacturers. Some equipment types, especially if the manufacturers are well experienced, may be calculated and designed from bench tests, although a background-check on the manufacturers may be prudent. In addition, some equipment types, particularly centrifugal and hydro-cyclones are best subjected to stringent pilot tests to ensure that they work reliably. The turbulence which takes place inside these machines may give some unexpected results, good or bad!

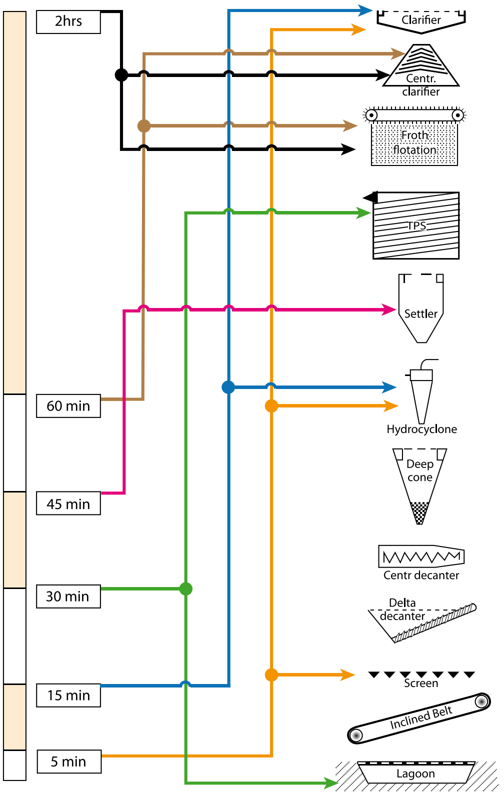
clarifiers

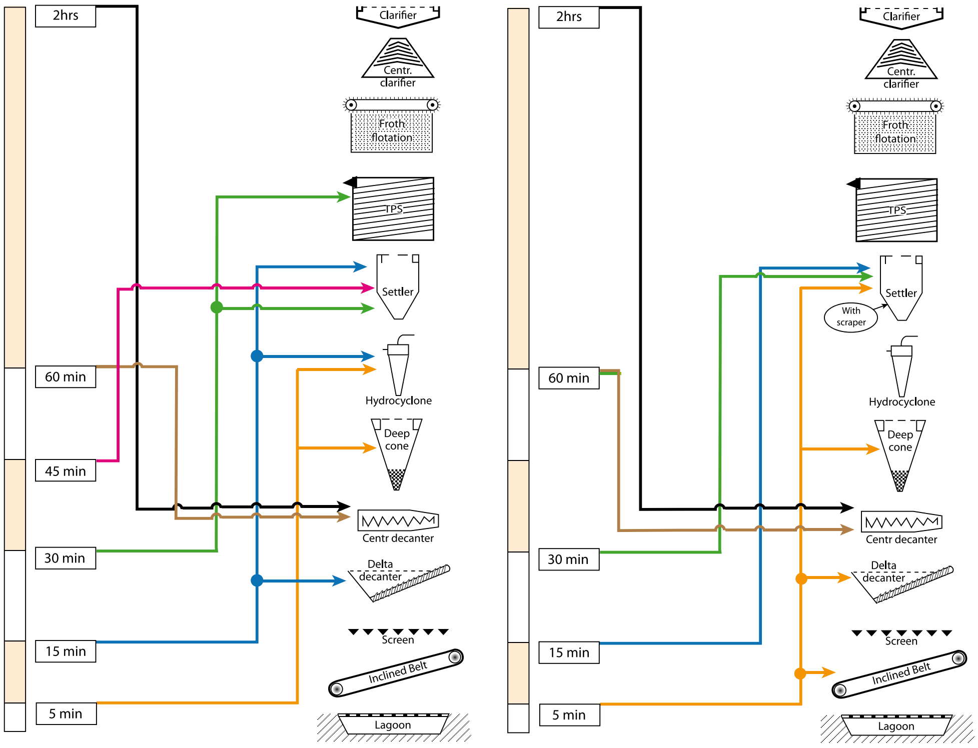
Clarifiers are used for suspensions with few solids. They are typically quite large, with relatively shallow sedimentation basins with a sloping bottom; the basin is built below ground in an all-concrete construction. Usually they are equipped with scrapers that can be designed to also assist in compacting the sludge layer. A great deal of know-how goes into them, and it's best to rely on practical experience of the supplier.

centrifugal clarifiers

A somewhat conical vertical machine, a centrifugal clarifier houses a large number of discs which spin at high speeds. The suspension accelerates on the spinning discs, throwing the solids to the outer wall, with the centrate leaving the machine from the top. Solids may slide down the wall to a discharge section or the machine may be constructed as two halves that can be separated momentarily, causing the solids to be thrown out by centrifugal force (nozzle-type decanter).

Figure 3a: Up to 5% sediment volume





(Left to right) figures 3b and 3c: Up to 15% and 40% sediment vol respectively

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froth flotation

Froth floatation is used for particles which either have a tendency to float or to stay suspended. Introduction of minute air bubbles gives the solids buoyancy, causing them to rise to the top. This can be due to the general gentle upwards flow of the bubbles, but preferably the bubbles impinge on the solids and take them upwards. Bubbles may be generated by diffusers or by electrolysis.

tilted plate separators (TPS)

Tilted plate separators are normally constructed as a cube into which a large number of thin plates (usually plastic) are fitted at a certain angle. Feed is introduced at the bottom, with overflow at the top. Since the spacing between the plates is quite small, particles only have to fall a small height before reaching the plate underneath where they slide down the slope to the sludge outlet.

settlers

Settlers are similar to clarifiers, but are used for suspensions with relatively high solids loading. They are typically not as large as clarifiers and often built above ground as all-metal constructions, with or without scrapers depending on the diameter, the type and percentage of solids. In sizes of up to about 5 m diameter you could fairly safely calculate the size, the shape and construction without needing a proprietary supplier. In this size range a scraper is rarely required as long as the sidewalls of the bottom cone are not much more than 30° from the vertical. The upflow velocity of the liquid phase should be equal to or less than the fall rate of the solids.

hydrocyclones

Hydrocyclones are substantially conical in construction. Suspension enters tangentially in the straight-sided tubular section above the cone. The entry velocity causes the body of fluid to accelerate to centrifugal conditions. The narrow bottom outlet is designed so that whereas the solids leave the machine as a wet 'rope', the clarified liquor reverses its direction and rises up into the 'vortex finder' which is the pipe reaching inside the machine to a (variable) height. Depending on the inlet velocity, outlet design, vortex finder and length of the machine, varying degrees of clarification are possible. The extreme simplicity of the machine belies its efficiency. Generally considered a machine for the separation of coarse and/or dense materials, it can also be used for light small particles. For maximum efficiency several smaller hydrocyclones are usually better than one big one.

deep cones

Deep cones are literally just that – deep cones without much of (if any) vertical walls. Since it is used for fast-settling (and thus heavy or large) particles, a centrally-mounted auger can sometimes be used to get the solids out of the cone.

centrifugal decanters

A centrifugal decanter is a roughly conical horizontal tube which rotates at fairly high speeds causing the entering suspension to take on more or less the same rotating speed and thus causing the solid particles to be thrown out against the outer wall. In practically all cases, a centrally-mounted screw, rotating at a different speed screws the solids towards the outlet which is normally almost horizontal creating a 'beach'. You can obtain quite dry solids, but at the cost of a cloudy centrate.

delta decanting settlement systems

This is a (typically) triangular settlement system with a screw taking the solids over the side. The solids have to be fairly coarse and granular for this to work reliably.

inclined belts

Typically, a grooved belt of quite wide dimensions and slightly curved at the sides runs at a reasonably high speed upwards taking fast-settling solids out of the suspension. Inclined belts are only suitable for large quantities with small percentages of heavy and/or coarse solids.

screens

Screens, of course, aren't sedimentation equipment, but belong to filters. However, if a suspension separates rapidly and the solid loading is not too excessive, there is a good chance that a screen might work. Screens are always stationary but may be mechanically activated, by vibrating or shaking them to induce the solids to go into one direction and out of the machine and/or to dislodge solids that otherwise would gradually clog the screen. Screens may carry extremely fine filter cloth, metal gauze, perforated sheets or bars. They are simple, inexpensive machines and well worth trying if they look at all hopeful. In general they scale up well from small test units, except the sieve bends, which are sensitive to hydraulic loadings and where advice from the makers must be sought.

construction tips for gravity sedimentation systems

Since all settlement systems may have blockages in their (sludge) outlets it's recommended that as a minimum, the whole sludge chamber has several strategically-placed (tangential) branches, fitted with suitable valves which can be connected to either high pressure compressed air or water to dislodge or re-pulp the sludge.

In settlement systems one must expect some 'floaters', ie lightweight material that has found its way into the system (matches, paper, plastics) as well as oil, but invariably is, eg incorporation of a scum baffle which allows for the periodic draining of this debris.

Having obtained preliminary results for sedimentation, the next stage is testing for filtration, which we will cover in a future issue of tce. **tce**

draining surface, connected to outlet ports. Filter cloth was fitted to the plates and the whole pack was closed either mechanically or hydraulically. Suspension would enter through the inlet ports, the filtrate would exit through the outlet ports of the plates, and solids would stay behind in the cavity till flow and pressure increase indicated that the press was full and had to be opened, the cake removed, the cloths cleaned and the press closed again for the next run. Modern presses use almost exclusively 'recessed plates'. These plates combine the drainage area as well as the 'upstand' at the edge to provide the cavity. Feed is through one or more large ports in the plates. They are more reliable and less prone to blocking than the plate and frame types. They are available in a very wide variety of sizes, configurations, and plate supports, and degrees of mechanisation exist.

- **leaf filter** Leaf filters consist of a pressure vessel inside which a number of filter leaves are mounted (similar to candle filters). The leaves are normally of metal and clothed with a fabric bag. The leaves may be vertically or horizontally mounted. For removal of the solids, different arrangements exist, ranging from opening the bottom of the vessel to mechanically spinning or vibrating the cake into a chute.

- **membrane presses** Not to be confused with membrane filters, the membrane press is basically a filter press but instead of having drainage grooves in the plates, the plates are fitted with an elastomer sheet (with has drainage grooves) which can be inflated. By inflating the sheet at the end of the filter cycle any residual moisture will be expelled and the cake itself will be squeezed, usually resulting in better cake moisture figures. Although most membrane presses have their plates vertically mounted, there exists a variation with horizontally-mounted plates. In this case the filter medium is in the form of an endless filter cloth/belt which is threaded through the plates and which, on opening of the plates, acts as a conveyor to carry the cakes out of the machine allowing them to drop into a chute.

- **nutsche filter** Circular or rectangular filters with a drainage bottom onto which a filter medium is fastened. If the drainage section is connected to a vacuum source the filters are often open top. If they are closed at the top, they can be pressurised and thus benefit from a higher driving force. The filters are fed from the top. Feed is introduced until an adequately thick cake is formed, thereafter the cake is drained as well as possible (and/or washed) and the cake is removed either manually or in case of mechanised nutsches by means of some scraper or scroll.

- **sheet filters** Basically identical to filter presses except that they have a very small cavity and no filter cloth but a sheet of, usually thick, filter medium. Solids impinge on the sheet and to a large extent lodge inside the sheet. They are, therefore, a combination of surface and depth filtration, and are obviously only suitable for extremely low solid contents.

- **tube press** These may be vertical or horizontal, and consist of a metal tube which has an inflatable membrane fitted. Inside this membrane is mounted a central filter core consisting of a drainage tube, suitably clothed with filter medium. The feed is introduced into the tube under pressure, filtrate exits from the central filter core. After filtration and/or washing the membrane is inflated to squeeze the cake solids to extremely low residual moisture values. To discharge the cake, the membrane is relaxed, the bottom section of the tube opened and the tube slightly or totally withdrawn, allowing the cake solids to drop off or to be scraped off.

continuous filters

- **brushed screen** Often circular screens with the flow entering at the inside. Rotating brushes remove all or most of the debris, which falls to a bottom receptacle from which it can be removed periodically.

- **compression belts** Two endless sieve-belts which are configured so that the two belts form a 'throat' at one end into which the suspension enters. After the throat the belts run gradually closer to one another until almost touching. This produces the squeezing action required to dewater the suspension. In order to obtain more squeezing effect, often extra pulleys are introduced so that the two belts form a zigzag pattern. Horizontal configurations are most common, although vertical ones exist. For them to work the suspension has to be quite thick and often requires coagulants.

- **curved screen** A substantially vertical screen, normally made of wedge wire. The screen has a curvature, and a feed box with overflow weir is fitted to the top. The suspension overflows onto the screen's curved surface and it is the hydraulic action of the oncoming suspension that pushes the collected solids down the screen into a solid-collecting receptacle. If properly calculated and installed, quite remarkable efficiencies can be obtained, although they are sensitive to hydraulic load changes.

- **disc filter** In essence a flat disc mounted on a hollow shaft. The disc is made of metal and has on either side an open cloth support structure which connects with the hollow shaft which carries the filtrate. A filter cloth is fastened to the disc and the hollow shaft connects to a vacuum source. The disc, usually 30% submerged, rotates slowly in a feed trough where it picks up the solids, which can later be scraped off just prior to re-entry into the feed trough. To facilitate manufacturing and maintenance, most disc filters do not have complete discs, but the 'disc' consists of roughly triangular elements which screw onto the hollow shaft. In general, disc filters are most suitable for fibrous suspensions.

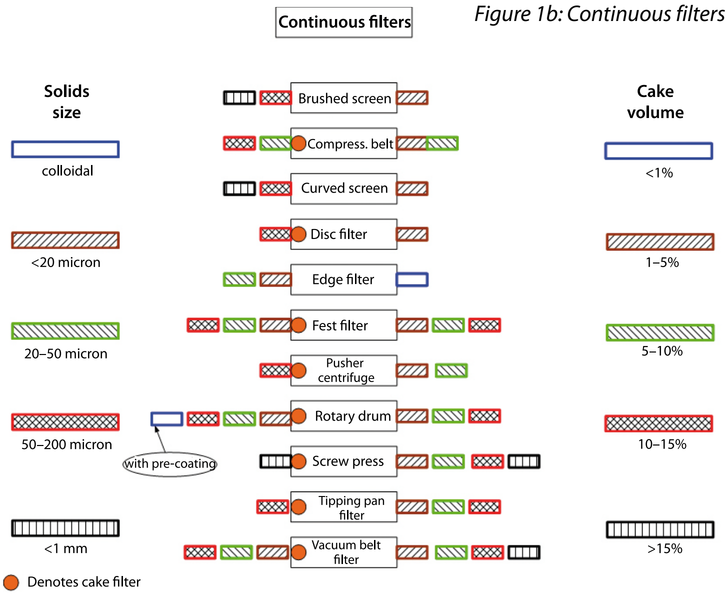

Figure 1b: Continuous filters

- **edge filter** The continuous edge filter consists of a filter cage which is mounted inside a pressure chamber. The cage is normally made of vertically-mounted wedge wire. The cage itself is mounted on a structure which resembles a female gear-ring except that the 'teeth' are not connected but are separate from each other. A small pinion-like wheel engages with the teeth in the outer ring. Depending on the design, the pinion is static and the filter cage rotates or *vice versa*. Filtration is from the outside inwards. When the pinion engages with a tooth, it acts like a gear pump and presses some of the collected filtrate outwards, dislodging the solids on the edge of the screen.

- **fest filter** Also known as a 'rotary pressure filter', it has a rotating core onto which are mounted 'pockets' fitted with drainage plates and filter medium. The pockets are connected to a rotating outlet valve which connects with a filtrate collection system. The core with pockets is mounted inside a pressure chamber. The inside of the pressure chamber has division strips which run longitudinally and are almost touching the pocket walls. In this way each or several rows of pockets can be separated from one another. Assuming clockwise operation, the feed is introduced at about 5 o'clock position. This may be followed with cake washing at, for example, 8 o'clock, cake drying with compressed (hot or cold) gas at 12 o'clock and finally at the 3 o'clock position the pockets meet a discharge scoop which scoops the cake from the pocket and into a discharge chute. Medium washing may follow. Depending on the size and design, quite high filtration pressures can be used.

- **pusher centrifuge** A horizontally-mounted filtering centrifuge with a filter cage made of metal bars, the smallest opening of which is about 100 µm. Inside the cage is a 'pusher' arrangement, basically a sturdy ring which lies very close to the filter medium. The ring is connected to a central shaft which rotates at the same speed as the filter cage but reciprocates (approximately 1–3 cm) causing the collected solids to be pushed out of the machine. Multi-stage machines exist. In these, the solids are pushed onto the second or third stage, which each time is of a larger diameter. The higher linear velocity as well as the tumbling action can be beneficial for dewatering and/or cake washing, although it may cause the crystals to fracture.

- **rotary drum filter** The original rotary drum filter consisted of a cylindrical drum, fitted with a drainage grid on the outside over which a filter cloth was stretched. The drum had perforations and was connected to a vacuum source. The drum itself was mounted on a horizontal shaft and submerged for about 30% in a feed trough. The vacuum caused the liquor phase to be sucked through the cloth, leaving the solids behind as a filter cake. The cake was scraped off just before re-entering the feed trough. This design, or variations on it, is particularly useful for pre-coat filtration, where the drum filter can be used to filter ultra-fine suspensions. In this case there is no cake as such but a fine layer of slimy solids. These are removed with a very small amount of pre-coat material by a knife which advances a pre-determined distance.

  Although the principle remains the same, the modern rotary drum filter has discrete filter segments mounted on the drum surface, with individual tubing leading to a rotating head valve, so that sections can be drained to separate outlets (filtrate and wash) and above all so that in the cake discharge position vacuum can be disconnected causing the cake to be much easier to remove.

  A further development of this is the rotary vacuum belt filter, which borrows its name from the filter cloth being in the form of an endless belt which can leave the drum to facilitate cake discharge and allow for cloth washing before joining the drum on re-entry into the feed trough.

- **screw press** An almost always conical filter cage with an auger inside which transports and squeezes the solids through the cage. They are only suitable for fibrous suspensions where squeezing with a very high line pressure is beneficial.

- **tipping pan filter** In its basic form, a filter tray consisting of a filtrate collection box connected to a vacuum source. A drainage grid is mounted inside the box, suitably clothed with a filter cloth. The whole arrangement can be tipped over 180°, causing the cake to drop out. This obviously is a batch filter but the same principle is used in the rotary tipping pan filter, where a very large horizontal wheel of several metres diameter is formed through triangular filter trays connected to a central drive and tipping mechanism. The wheel rotates the filter segments through the feed, dewatering, cake wash and final drying stages after which each individual tray is turned 180°, sometimes followed by cloth washing. The filtration mechanism and efficiency is very similar to that of a vacuum belt filter. Although very large filter areas can be offered, the circular shape is responsible for very large floor space occupation.

- **vacuum belt filter** Structurally, these filters resemble a conveyor belt, except that the essential belt is a filter medium which is subjected to a vacuum source. Feed is introduced at one end, where it is normally allowed to settle under gravity for a few seconds, causing the coarser fraction to form its own pre-coat. Thereafter the suspension is subjected to full vacuum application. Since the cake thickness can be controlled almost at will by increasing or reducing the speed of travel, one can filter at optimum cake thickness to obtain the required residual moisture and/or the required cake washing efficiency. The horizontal configuration makes this filter one of the most efficient cake washing filters, especially for counter current washings.

  Two mechanically different types exist. One supports the filter cloth on a rubber carrier (and drainage) belt, which in turn runs on a sealing belt which forms the seal between the rubber carrier belt and the vacuum box. The other types are inherently simpler as they do not rely on any carrier belts but support the filter cloths on the vacuum boxes. Open and gas-tight constructions are available.

pilot tests

Since it is more than likely that at some stage pilot tests will have to be carried out, we would emphasise the importance to over-budget both in terms of money, time, space and manpower. Due to the provisional nature of the installation things rarely (if ever) go according to plan. Temporary pipelines, flexible hoses, inadequate auxiliary services, poor working conditions, not to mention the difficulties of getting representative feed to the equipment, all span together to make life unpredictable. Pilot tests are valuable, often even essential, but allow plenty of everything for them. If not, the results will be meaningless and expensive misinformation. **tce**

further reading

Svarovsky, Solid-Liquid Separation, ISBN 0-408-03765-2, Butterworths

**For part 1, see "Settle down", p48–50, tce 816, June 2009. For part 2, see "The solution is clear" p53–55, tce 817/8, August 2009*

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