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Editorial: claudia@icheme.org
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Advertising: nigel.stephens@mainlinemedia.co.uk
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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.

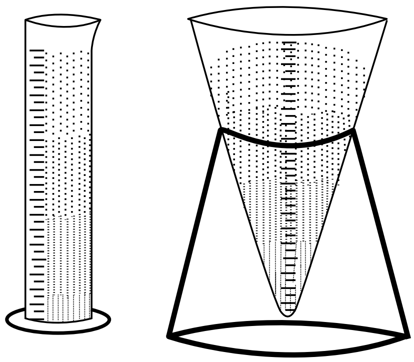


Figure 1: For basic tests, use a glass measuring cylinder (minimum 75 mm diameter) with graduations, or better still a glass measuring cone

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.

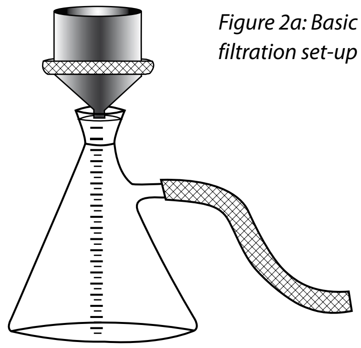


Figure 2a: Basic filtration set-up

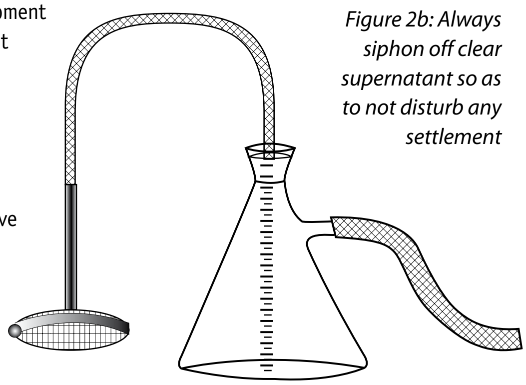


Figure 2b: Always siphon off clear supernatant so as to not disturb any settlement

observation

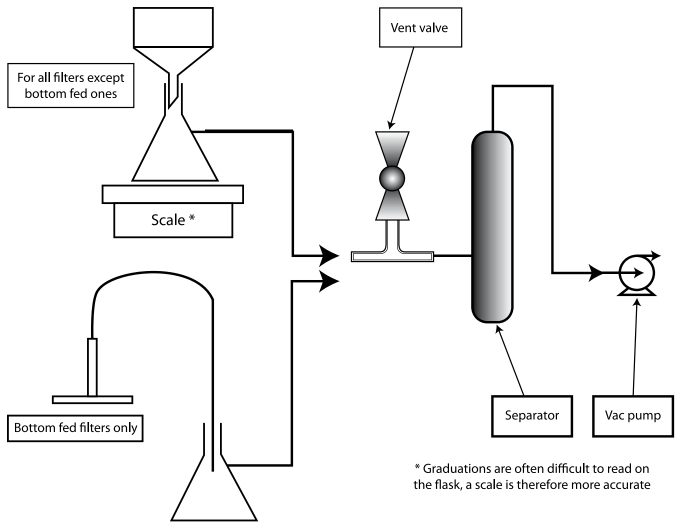
Before rushing into tests immediately, pour some of the suspension into a glass beaker and observe what it does and what happens to it. And keep notes!

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.

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



(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!

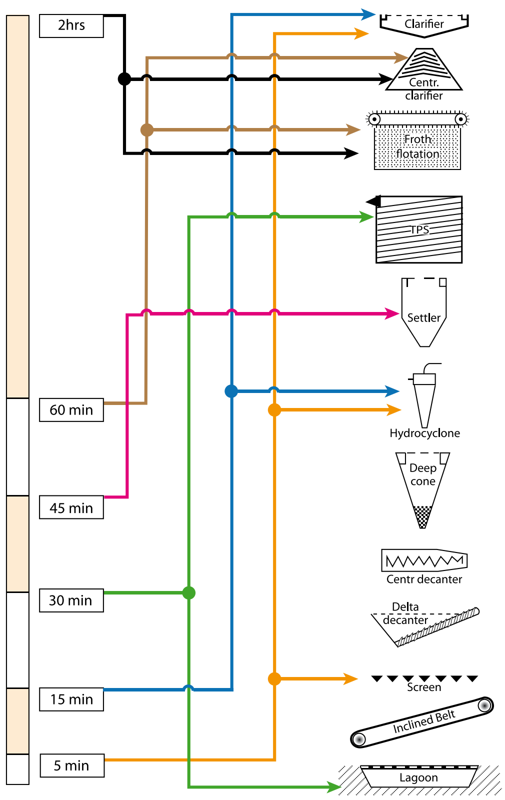
clarifiers

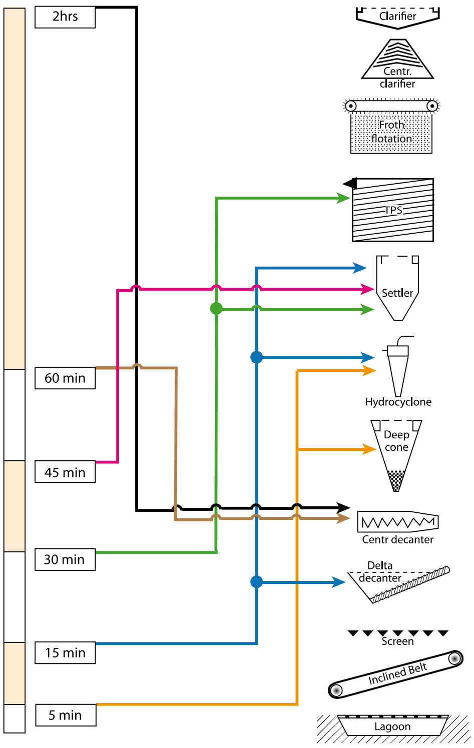
Clarifiers are used for suspensions with few solids. They are typically quite large, with relatively shallow sedimentation basins with a sloping bottom; the basin is built below ground in an all-concrete construction. Usually they are equipped with scrapers that can be designed to also assist in compacting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

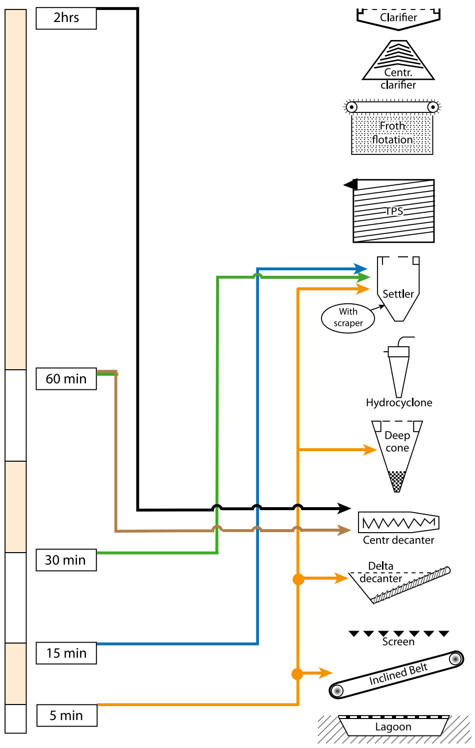
centrifugal clarifiers

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

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**

Henri Pierson is director at BHS Filtration; Barry Perlmutter (barry.perlmutter@bhs-filtration.com) is president and md of BHS Filtration

The solution is clear

In part 2* of their series on selection of liquid/solid separating equipment, **Henri Pierson** and **Barry Perlmutter** discuss the finer points of filtration

WHEN testing for filtration, for basic filter tests you need two pieces of equipment (see Figure 1) – a filter funnel (also known as Büchner) with flask and a hose (with 'bleed' or 'vent' valve) to the vacuum pump, (Figure 1a), and a dipping leaf, to be connected to the filter flask and vacuum pump (Figure 1b).

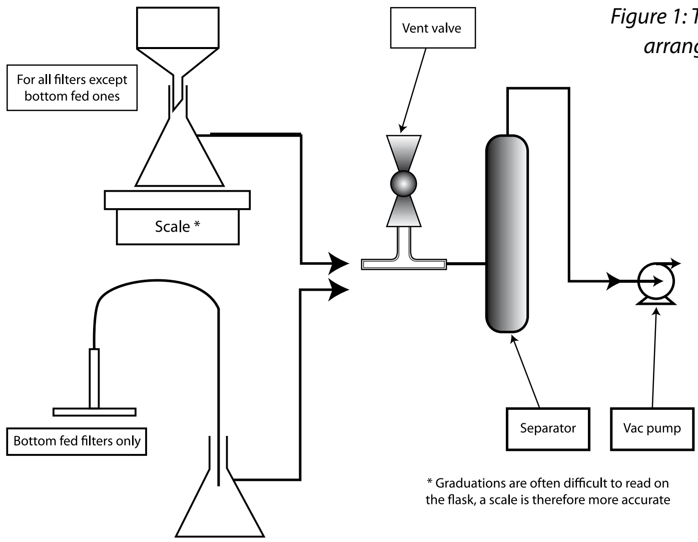


Figure 1: Test kit arrangment

filter funnel (Büchner) tests

Although in theory you could use a ceramic filter funnel, in practice the results are meaningless for equipment evaluation. The filter funnel has to have a drainage grid that is representative of the average grid in a production filter and it has to be clothed with a filter cloth which in practice can be used in a commercial filter.

Typically, the filter should have a diameter no less than 100 mm. Smaller diameters will still give a reasonable filtration performance, but the edge effect can be so great that the measured cake moisture may be very misleading. Which type of cloth to use for the first tests is to some extent a 'chicken-and-egg' question. Until you have some idea what filter(s) could be useful, you do not really know which cloth will suit. In general a supple, woven multifilament polypropylene cloth of medium weight and a fairly small pore size (say 30 µm) is not a bad starting point. The behaviour of multifilament cloths will vary somewhat from the more commonly-used calendared cloths, but these have a tendency to leak solids in filter funnels, due to their thickness and weave characteristics.

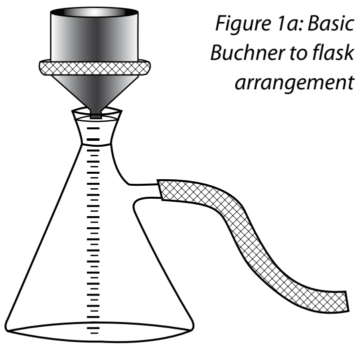


Figure 1a: Basic Buchner to flask arrangement

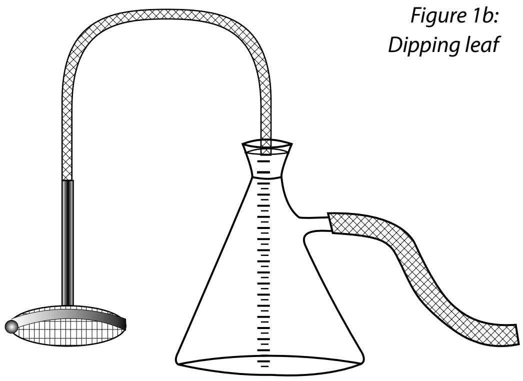


Figure 1b: Dipping leaf

The amount of suspension to be fed to the test filter is mainly dependent on the amount of solids in the suspension and, of course, the filtration characteristics of the suspension.

As a rule it's probably best to run the first test with a volume which should produce a cake of about 5 mm.

Fit the filter together, check that the bleed valve is open (with the vacuum pump swirched off at this stage), pour a measured quantity into the filter, switch on the vacuum pump, start the stopwatch and gradually close the vacuum bleed valve to build up vacuum.

Register as much of the behaviour as possible. Table 1 illustrates typical records for behaviours.

To remove the cake, dismantle the filter funnel, take the cake and cloth out and peel the cloth away from the cake. Record whether or not the cloth peels away cleanly, or if the cake sticks and has to be scraped off. Weigh, measure the cake thickness, and keep in a sealed bag for later analysis of percentage dry solids.

If the filtrate is not clear enough, re-do the test with a tighter cloth or, if the filtration rate is pretty fast, increase the suspension volume, which will probably give a better overall filtrate clarity.

If the filtrate and cake characteristics are reasonable, repeat the test with increased feed volumes until efficiency drops off. If the filtration time is unreasonable, reduce feed volumes. Having found a provisional optimum, repeat with varying levels of vacuum and record any differences.

dipping leaf tests

This test is a bit more awkward, and it will help to have an assistant. It also needs a much larger quantity of sample – a bucketfull! Assemble the filter and, whilst the assistant keeps the suspension gently

Feed volume cc	Time total	Vac level Mm Hg	Filtrate vol cc total	Notes
500 cc	0'10"	150	50	cloudy filtrate
	0'40"	350	200	clear
	1'20"	550	400	clear, first pinholes in cake
	1'45"	550	450	clear; cake cracks
	2'15"	500	450	clear; good discharge

Table 1: Typical behaviours to note

Figure 2a: The filter cake often acts as a filter medium

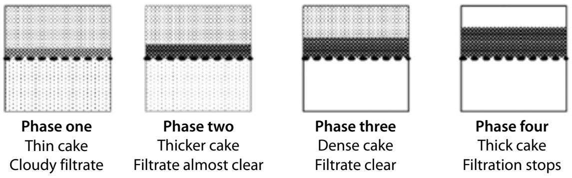
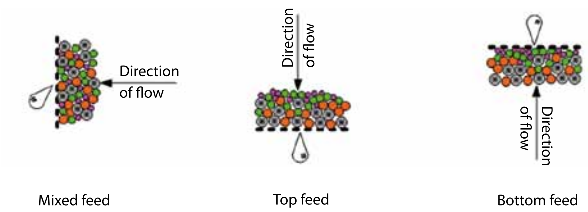


Figure 2b: Three ways to introduce the feed to the system



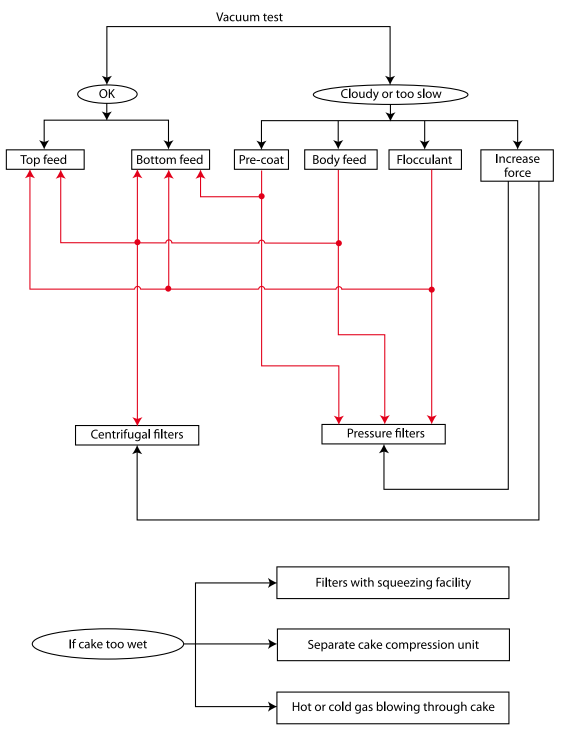
agitated, insert the leaf (entering the suspension at an angle and only then levelling it to horizontal) and keep it there until what looks like a reasonable quantity of filtrate has been sucked into the flask. Angle the leaf again and remove it gradually from the bucket. Turn the leaf with filter area uppermost and give it sufficient time under vacuum to allow a cake to form which appears to be acceptable. Measure all times and results as with the filter funnel.

If the cakes have to be washed, the time required for this operation must be added to the filtration (and possibly cake drying) time to form one total filtration time.

preliminary interpretation of basic principles

If neither system is capable of filtering the suspension in a reasonable time, investigate separation aids (see below) and/or test a pressure filter or a centrifugal filter. Again, they can be hired from filter manufacturers. However, pressure and centrifugal filters follow the same basic principles. A suspension which filters badly under vacuum will also be difficult with increased pressure or with centrifugation.

Figure 3: Preliminary selection process



You should always aim at producing in the lab the same cake thickness that you'd want to obtain in practice. Only in the case of extremely low solid suspensions which could give filtration times of days or even weeks could you extrapolate from thinner cakes. In all other cases it's unreliable to produce a cake of say 4 mm and try to calculate what would be required to produce one of 30 mm. The chances of getting that wrong are high, whereas a bit more time in the lab will give the exact figures.

In an ideal world these tests would show, say, that settlement and a dipping leaf do not work, but the filter funnel does.

However, it may be that all three work to some extent. In that case, keep an open mind and don't necessarily look for one solution but leave options open for two subsequent steps. For example:

- If settlement rapidly produces a perfectly clear supernatant but the sludge layer is far too wet, a simple settler followed by a filter to turn the sludge into firm filter cake may be an efficient solution.
- If filtration gives good throughput and good cakes, but the initial filtrate is too cloudy, the solution here may be to install a small polishing filter in the first filtrate line or allow for recycling of the first runnings.
- If the suspension filters very well, but the percentage solid in the feed is extremely low (resulting in absurdly large filters), one or two hydrocyclones may come to the rescue, providing a thick underflow for the filter and an acceptable supernatant, which can mix with the filtrate or be polished separately.

separation aids

If the tests show that not one of the systems is very promising you can consider separation aids such as flocculants or, only in the case of filters, the use of some inert crystalline material either as body feed or as a sacrificial filter medium. Obviously this pre-supposes that the introduction of this extra agent is acceptable to the process.

flocculants

In essence, flocculants are 'glue' which when added to the suspension causes the particles to bind together and form larger clusters, often incorporating extreme fine solids as well. The larger size and mass makes initial filtration and settlement easier.

While this is an important improvement, be aware that this can result in a very much wetter sludge in a settling system or a wetter cake in a filter: flocculated materials rarely result in the low moisture levels from non-flocculated suspension. Experimenting with varying concentrations and types of flocculants is therefore recommended.

inert filter aids

These range from proprietary products like diatomaceous earth or expanded silica to random selected crystalline materials. In general they are only useful in filtration processes, although in specific cases they can assist settling, if the suspended solids have a tendency to impinge on the filter aid.

They may be added to the feed in order to 'bulk' up the cake solids and thus provide a more open cake structure which allows for continuing drainage, or they may be used to form a fairly thick filter bed on top of the filter cloth, to ensure that all fines get trapped. In practice a combination of the two approaches is most common. In all cases remember that this filter aid becomes part of the solids and that normally there is no practical way to separate them.

interpretation of results

filter systems

All filters rely on only one principle: "find an aperture smaller than the particle which you must catch and apply enough force to get the liquid through it." This fact has led to some glib statements, such as: if you halve the percentage solids, you can double the flow rate; to get more throughput, use a slightly more open filter cloth; with more pressure you will increase the capacity; and cake dryness is a function of final pressure etc. While they may sometimes be true, most of the time they are not, and an understanding of the mechanics is essential.

For the purpose of this article membrane filters as used in reverse osmosis, and laminar flow filters are not considered filters in the more classical sense of the word and are thus not included.

cake filters and non-cake filters

There is no definitive agreement on the terms 'cake filter' and 'non-cake filter', but it is suggested that it is a useful distinction. Processes which require the cake to be solid and as dry as is practicable use cake filters. Those which can tolerate a wet cake or even sludge use non-cake filters. However, all filters produce 'cakes'.

filter cake

A major part of the filtration takes place with the filter cake acting as the filter medium. This applies equally to batch filters as continuous filters (see Figure 2a):

Phase 1 – suspension flows through the clean filter medium, some solids stay behind.

Phase 2 – suspension continues to flow but now through the partially-coated medium and thus at either reduced rate or higher pressure differential, more solids stick.

Phase 3 – suspension now meets a medium with very much reduced apertures and has to flow through the cake solids. Most solids will now be caught, filtrate is cleaner, flow reduces further and cake starts to consolidate.

Phase 4 – solids have built up on the medium until there is so much resistance that filtration has virtually stopped. In the case of batch filters this means stopping the filter, discharging the cake, cleaning the medium (if possible) and restarting, whereas in continuous filters the cake is continuously discharged and the medium cleaned.

From this it follows that suspensions with low percentage solids will stay for a long time in phase 1 and those with more solids will soon reach phase 2. However, they all will have to go through 2, 3 and 4. In those phases it is almost irrelevant what the original pore size of the filter medium was, because it is now covered in cake solids which will always pack to a tighter aperture than the original medium. In addition, the filter cake presents a tortuous path which in itself assists separation due to impingement and even sedimentation. As such, it's often desirable to stay as long as possible in phases 2 and 3 as this can make it possible to filter to extreme filtrate clarity although the filter medium is not particularly tight.

That condition can only exist if in phase 1 the filter medium did not become totally blocked (blinded) by the solids. This can easily happen with low solids suspensions and especially if the first phase is carried out at too much pressure, causing the solids to be 'shot' into the filter medium at high velocity. Almost always, this also causes cake discharge problems.

In those cases you should reduce, if at all possible, the pressure and flow during phase 1 and only increase them when phase 2 has been reached.

Equally important is the way in which the cake is formed, which is mainly a function of the way in which the feed is introduced to the filter. Three basic systems exist (see Figure 2b).

- *Mixed flow filtration* – The feed as a homogeneous mixture enters the filter and meets the filter element. There is no tendency for cake stratification or for preferential liquid flow. This condition applies to most pressure and centrifugal filters.
- *Top feed filtration* – The feed flows onto a horizontal filter area (usually, by gravity) where it can be given some time to settle out and thereby form a stratified cake.
- *Bottom feed filtration* – The liquid phase of the feed gets sucked through the filter medium, leaving the solids to impinge on the medium.

The mixed flow is the most common system and has the theoretical advantage that all particles are deposited in their natural ratio and thus the smaller ones will be able to find apertures between the larger ones. In theory that should produce optimum filter cakes with a minimum of residual moisture. In practice it often leads to premature densification of the cake and thus to reduced efficiency. This effect can be offset to a large extent by keeping the initial feed pressure as low as possible and only increasing the pressure gradually.

With top feed it is possible to allow for settlement during the first phase causing the largest particles to settle out and thus building an open matrix for the remainder to pass through. In practice this translates into better overall filtration rates, better cake discharge and often somewhat drier cakes.

With bottom feed, exactly the opposite takes place. No matter how much you try to keep the suspension agitated there is a tendency for the fines to be sucked onto the filter medium in preference to the coarser (heavier) material, potentially producing wetter cakes with some discharge problems. In extreme cases it can lead to the filter acting like a thickener sucking the liquid phase out of proportion, with the solids staying in the feed trough.

preliminary selection of filters

Providing the lab tests produce filter cakes of the required thickness, you can calculate the basic theoretical filter area requirements simply by dividing the production capacity requirements by the obtained capacity in the lab tests. Figure 3 shows a preliminary selection process.

If the vacuum test obtains the right quality of filtrate and cake,

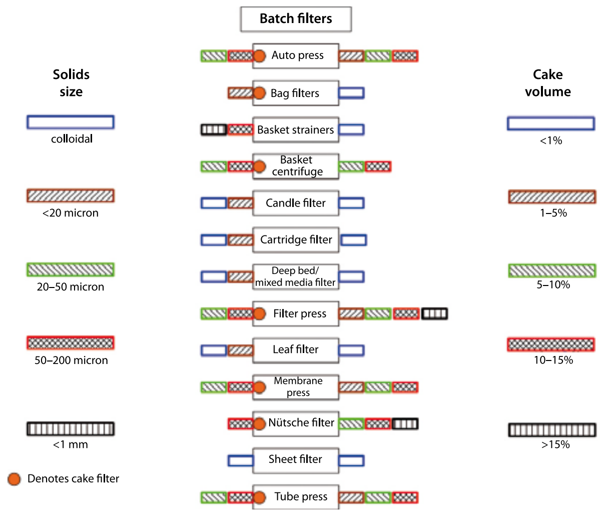


Figure 3a: Batch filters

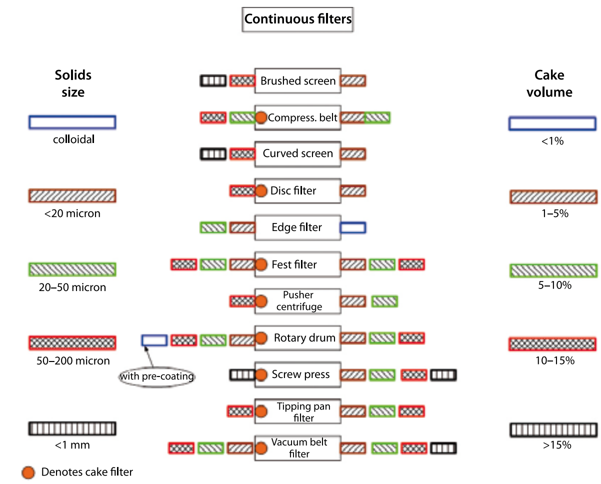


Figure 3b: Continuous filters

then for both batch and continuous vacuum filters you have the choice between bottom-fed and top-fed machines.

If the vacuum tests are encouraging but the rate of filtration is rather slow or the filtrate too cloudy, you can consider pre-coat filtration (which is only possible with bottom-fed vacuum filters), or alternatively use flocculants or body feed which can be used in either type.

If vacuum is not satisfactory you will have to resort to higher filtration forces, ie centrifugal filtration with the option of body feed, or pressure filtration with the options of body feed, flocculants or pre-coating.

If basically everything is acceptable but the cake is too wet, consider machines with inherent cake compression or gas-blowing facility, or alternatively feed the cake into a separate squeezing unit which is often easier and cheaper. **tce**

**For part 1, see "Settle down", p48–50, tce 816, June 2009*

Henri Pierson is director at BHS Filtration; Barry Perlmutter (barry.perlmutter@bhs-filtration.com) is president and md of BHS Filtration

Tools for the job

In part 3* of their series on selection of liquid/solid separating equipment, **Henri Pierson** and **Barry Perlmutter** look at preliminary selection of filters

THE selection of filters shown in figures 1a and 1b should not be taken as being exhaustive. They only represent the most popular types and it should be borne in mind that for each type there are at least several variations, which can be quite distinct from each other. A summary of the different types of filtration equipment follows.

batch filters

• **auto press** A horizontal pressure filter in horizontal, tubular construction; it has a membrane in the form of a tube which lies against the inner wall of the outer tube. The outer tube with membrane can slide over a plate pack consisting of a series of circular filter plates connected to a filtrate drainage outlet. The plates are kept apart by compressible spacers. Prior to filtration the inflatable tube is pressurised so that the circular filter plates have a side wall – ie the flexible tube – and thus have a cavity for cake solids. The thickness of the final cakes is determined by the degree to which the spacers are being compressed, to suit the suspension characteristics. Feed is pumped into the cavities, filtrate flows away, cake washing may follow. Air drying of the cake may follow and at the end of the cycle the pressure on the spacers and the inflatable tube is relaxed, the metal outer tube is withdrawn and the cakes are discharged automatically. Auto presses result in good cake washing and dry cakes.

• **bag filter** A bag with a connection for a high pressure inlet held captive in a metal cage. Filtrate runs through the bag and the solids stay inside.

• **basket strainer** Similar to the bag filter, except that the strainer may be the filter medium in which case the solids have to be dug out.

• **basket centrifuge** A metal basket rotating at centrifugal speeds. A cloth bag is fitted inside the basket. The drive mechanism runs the basket up to high speeds and feed is poured into the basket. Filtrate runs through the basket and is collected in an outer mantle. When sufficient solids have collected inside the bag, the machine is stopped and the solids removed or it is slowed down to allow a mechanical scraper to remove the bulk of the solids (a 'heel' stays behind). In a horizontal version, the Peeler Centrifuge, the bulk of the cake can be removed without slowing the machine.

• **candle filter** A vertical pressure vessel with a horizontal plate fitted to the top of the cylindrical portion. The plate has a number of holes from which candles hang. The candles may be of a filtering material (eg sintered metal) or, more commonly, of a support structure which enables the fitting of a 'hose' or 'sock' made of filter medium.

The top section of the filter (above the horizontal plate) forms a small chamber and is fitted with an outlet branch.

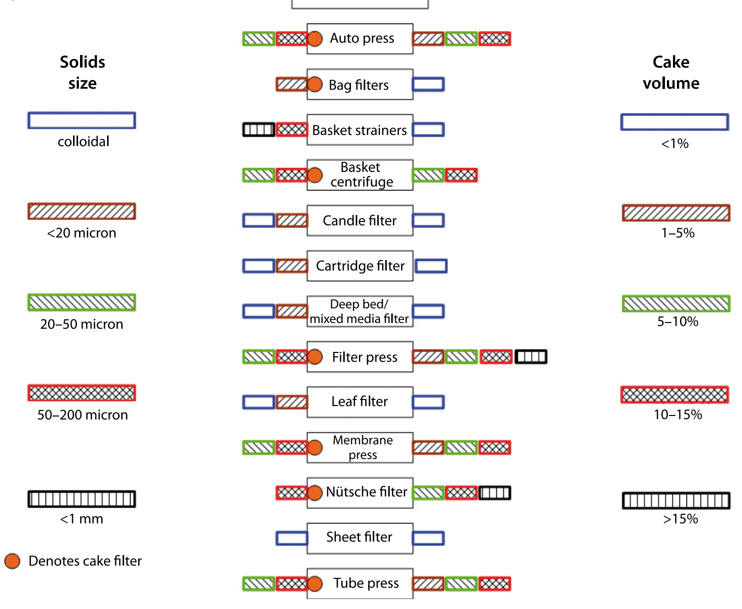
During operation the suspension is pumped into the main vessel with filtrate exiting into the top half from where it flows out of the outlet branch. When sufficient solids have deposited onto the candles, the feed is stopped; usually compressed air is blown through the vessel to drive off residual suspension. The removable bottom part of the filter is opened and the cake solids are blown off the candles. In case a sludge discharge is acceptable, the bottom half stays closed but through a reverse flow wash the cake solids are washed off the candles and the sludge exits through a bottom outlet. To ensure fine filtration and/or to ensure reasonable cake discharge, the filters often work with pre-coats of some inert material as well as having body-feed added to the suspension.

• **cartridge filters** Pressure vessels inside which are fitted a number of filter cartridges. Almost without exception the flow is from the outside inwards. Cartridges are available in cleanable or (much more common) disposable form. A very wide variety of materials, textures, pore size and physical sizes are available.

• **deep bed/mixed media** Mainly used in sewage works or water treatment installations, these are large circular or rectangular tanks with a drainage floor in the bottom. On top of the drainage floor lays a bed of inert filter material or a mixed bed of inert, or inert and organic filter medium. Flow through the bed is by gravity, the filtration being effected more by the tortuous path than by the apertures of the bed. For cleaning of the bed a backwashing system is used.

• **filter press** The original filter presses were of the 'plate and frame' construction. This consisted of a relatively large number of filter plates being interspaced by filter frames. The frames and plates had lugs on either side which allowed for the whole pack to be suspended on side bars. The frames had the same outer dimension as the plates but were hollow in the middle, thus forming a cavity. The frame thickness determined the cake thickness. A feed entrance port was in the wall of the frames. The plates had a grooved

Figure 1a: Batch filters



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

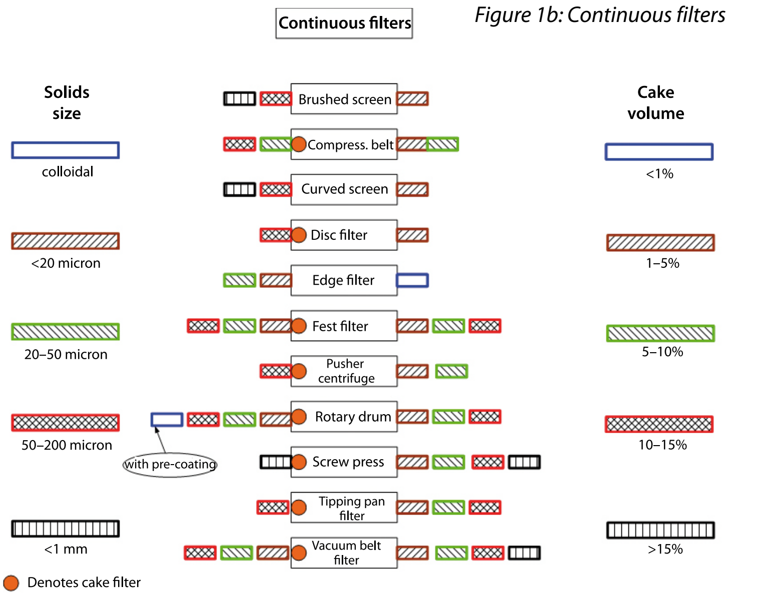
• **brushed screen** Often circular screens with the flow entering at the inside. Rotating brushes remove all or most of the debris, which falls to a bottom receptacle from which it can be removed periodically.

• **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*

Henri Pierson is director at BHS Filtration; Barry Perlmutter (barry.perlmutter@bhs-filtration.com) is president and md of BHS Filtration