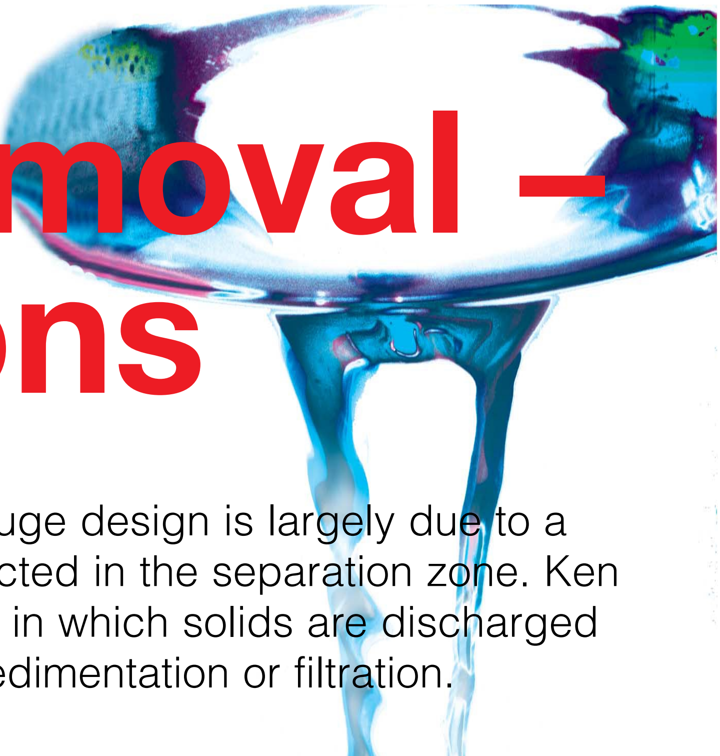
Centrifuge focus: solids removal – the options



Complexity and variety in centrifuge design is largely due to a need to dispose of solids collected in the separation zone. Ken Sutherland reviews some ways in which solids are discharged from centrifuges, after either sedimentation or filtration.

A recent news story in *Filtration + Separation* ['APD centrifuge makes its debut', *Filtration + Separation* April, 2005 (42/03)] made mention of a novel means of discharging separated solids from a centrifuge, and it seemed timely to summarise the various ways in which such discharge can be effected. As with process filters, most of the complexity and variety in centrifuge design results from the need to dispose of solids that have collected in the separation zone of a centrifuge, preferably without having to slow the machine down from its operating speed (or, at least, not bring it to a complete stop).

Centrifuges achieve separation by means of the greatly accelerated gravitational force achieved by rapid rotation. This can either replace normal gravity in the sedimentation of suspensions, or provide the driving force in the filtration of suspensions through a filter medium of some kind. The term centrifuge covers a wide range of equipment, with uses throughout industry, and which represents a major part of the mechanical separations business. No attempt will be made here to describe the full range of centrifugal separation equipment, but only the way in which they separate solids from suspension in a liquid, and then discharge it (or allow it to be discharged) for subsequent treatment or disposal. Further information can be found in W W-F Leung's general 1998 guide, *Industrial Centrifugation Technology* and the more specific *Decanter Centrifuge Handbook* (A Records & K Sutherland, 2002).

Figure 1: Following five years of research and development, Celeros Inc of Michigan, USA, has introduced a Model APD centrifuge.

Sedimentation centrifuges

The separation achieved in a centrifugal device is similar in principle to that achieved in a gravity sedimentation process, such as a circular clarifier, but with the much higher driving force resulting from the rotation of the liquid. In the case of sedimentation, where the driving force results from the difference in density between the solid particles and the suspending liquid (or between two immiscible liquids), the separation is achieved with a force of from 1000 to 20,000 times that of gravity.

The simplest device using centrifugal force to achieve separation is not normally thought of as a centrifuge: it is the **hydrocyclone**, in which the centrifugal separation is produced by the motion of the slurry, a motion induced by the tangential introduction of the feed material, rather than by means of an imposed mechanically driven rotation. The solid separation occurs in the passage of the suspension along the barrel of the hydrocyclone, to form a thickened slurry at the outer wall, which then leaves the hydrocyclone as a continuous stream from its discharge nozzle. The thickness of the product slurry is determined by the shape of the hydrocyclone and the relative feed and offtake rates.

The intriguing thing, in the present context, is that sedimenting centrifuges were invented for liquid/liquid separation (cream from milk, soapstock from alkali) and not to handle solids at all. Those solid contaminants that did enter the centrifuge were a considerable nuisance, requiring a complete shut down so that the bowl could be cleaned.

Other than this inertial motion, all centrifuges are given their rotation by some kind of motor drive, at constant speed, or at speeds that vary from one part of the operating cycle to another. The types of centrifuge used for sedimentation include:

- beaker centrifuge
- tubular bowl
- chamber bowl

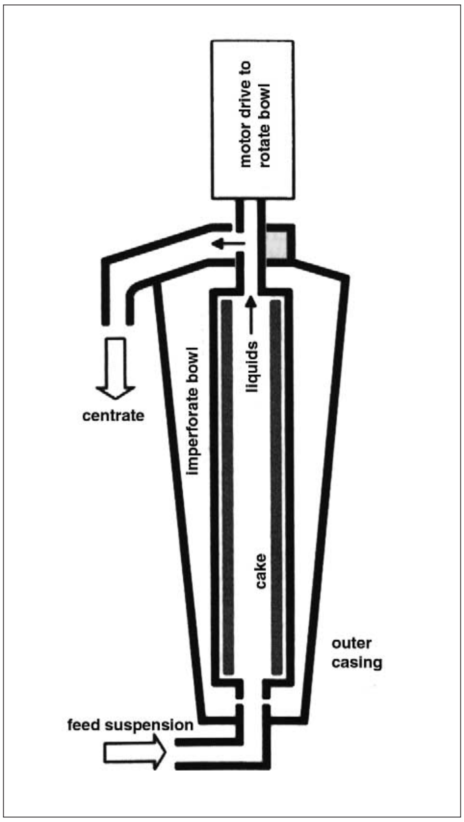


Figure 2: Operating principles and general forms of the tubular bowl centrifuge.

- imperforate basket
- disc stack separator
- decanter.

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However, it soon became apparent that these machines had wider applications, which would involve the presence of solid impurities, leading eventually to uses for separating solids from liquids. The above list of machine types is in order of increasing complexity of design – a complexity increase, mainly, according to the increasing concentration of solids in the feed, and to the wish to be able to discharge these solids on a continuous basis.

The simplest of these designs, used mainly for laboratory analytical and test work, has a set of open vessels, held in a frame that allows them to hang vertically to be filled, and then swing outwards as the frame starts to rotate up to operating speeds. Typified by the **beaker centrifuge**, but also including the very high speed **ultra centrifuge**, these have to be brought back to rest, before the separated solids are removed manually from each individual vessel in turn.

The **tubular bowl centrifuge** (see *figure 2*) has been used for longer than most other designs of centrifuge, and is one of the simplest in design terms. It is formed from a tube, of length several times its diameter, rotating between bearings at each end. A mixture of liquids (such as oil and water) is fed at one end, the separated liquids leaving at the other, while any solids in the feed will separate to the wall of the bowl and stay there. These solids can only be removed by stopping the machine, dismantling it and scraping or flushing the solids out manually. Until, that is, the recent appearance of the Celeros APD centrifuge (*see figure 1 on page 16*) in which a piston moves through the bowl, of a machine intended to separate solids, so as to push all of the collected solids out of one end of the bowl. This can be done under fully enclosed conditions, so that the centrifuge can be used for sanitary processing.

The **chamber bowl centrifuge** (*see figure 3, below*) is, effectively, a number of tubular bowls arranged co-axially. It has a main bowl containing cylindrical inserts that divide the volume of the bowl into a series of annular chambers, which operate in series. Feed enters at the centre of the bowl and the suspension passes through each chamber in turn, at increasing distances from the axis. The solids settle onto the outer wall of each chamber and the clarified liquid emerges as an overflow from the largest diameter chamber. As there is an increasing centrifugal force acting on the slurry as it passes from one chamber to the next, there is a classification of the suspended solids, with coarse particles sedimented from the suspension in the innermost chamber, and increasingly fine particles deposited in subsequent chambers. The removal of sedimented solids again requires the stopping of rotation and manual cleaning – but the cylindrical dividers can usually be removed as a set, and replaced by a clean set, while the full ones are cleaned.

The tubular and chamber bowl designs are used where the dirt content of the liquid is low (so that stoppages for cleaning are infrequent). If the solid content of the suspension is higher, then the **imperforate basket centrifuge** (*see figure 4/5 below*) may be used to separate the solids, and produce a reasonably clean liquid (separation efficiencies are not all that high with this type of centrifuge). This consists of a simple drum-shaped basket or bowl, usually rotating about a vertical axis. The solids accumulate in the basket and are compressed by the centrifugal force, but they are not dewatered. When the rotation of the bowl is stopped, the residual liquid will drain out (including some from the interstices of the solid), and the layer of solids may be removed manually, by scraping or shovelling, or by lifting out a

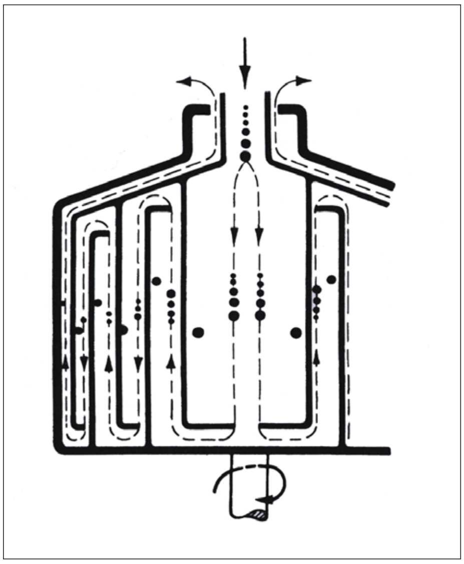


Figure 3: Classifying effect of a chamber bowl.

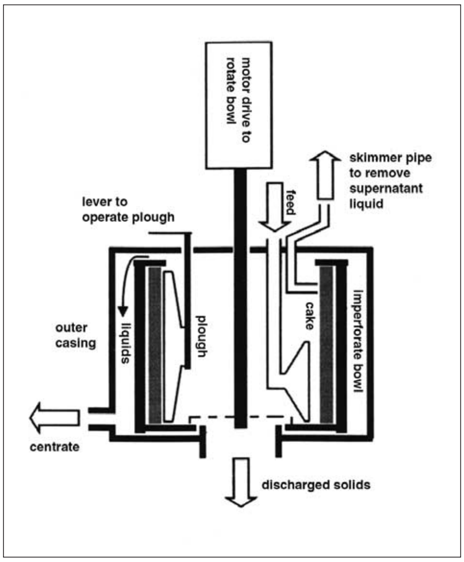


Figure 4: Operating principles and general forms of the imperforate basket centrifuge.

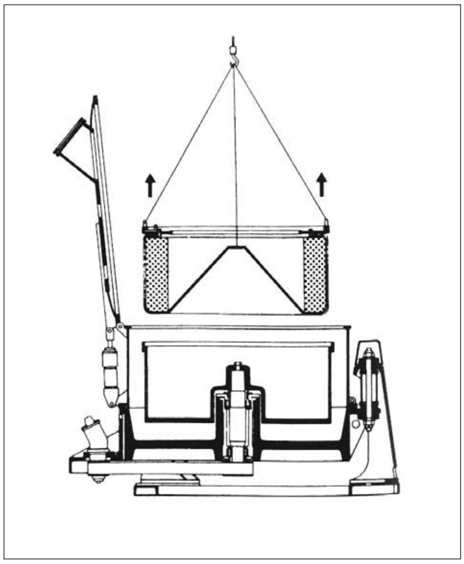


Figure 5: Three-column basket .centrifuge, with top discharge by bag withdrawal.

lining bag. Unloading can be achieved semi-automatically, without need to stop the machine, first by use of a skimmer pipe to remove the residual liquid, and then by lowering a knife blade into the solid and so cutting it out of the bowl. As the solids have then not been dewatered at all, they may be fluid enough to flow out through the same skimmer pipe.

Higher solids contents can also be accepted by the **disc stack separator** (*see figure 6*) when it is fitted with a means for automatic discharge. This machine type started life as Gustav de Laval's cream separator and took on its modern form once he had acquired rights to the stack of conical 'discs' within which the bulk of the separation occurs. Separation of the solids from the liquid is much more efficient, because of the higher centrifugal forces, but the solids are still fairly saturated with liquid at the point of discharge.

The simplest design has a closed bowl, containing the disc stack, with any solids present collecting at the outer part of the bowl, from which they have to be removed manually after stopping rotation. The automatic versions have solids discharged from the bowl's periphery by a number of methods, including the basic use of nozzles, which are open continuously, allowing a thick slurry to discharge.

A more complicated design uses valved nozzles that open automatically when the solid depth in the bowl reaches a pre-ordained figure, and then close again once most of the solids have been discharged. The most complex form uses an opening bowl design, in which the bowl shell splits circumferentially, at the widest part of its periphery, for a short period, with the opening also controlled by solid depth within the bowl.

The **decanter centrifuge** (*see figure 7/8, above*) is the only sedimentation centrifuge designed from the start to handle significant solid concentrations in the feed suspension.

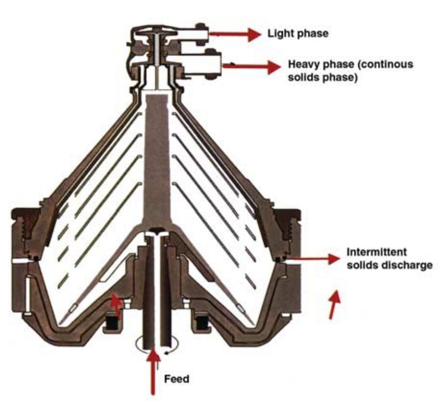
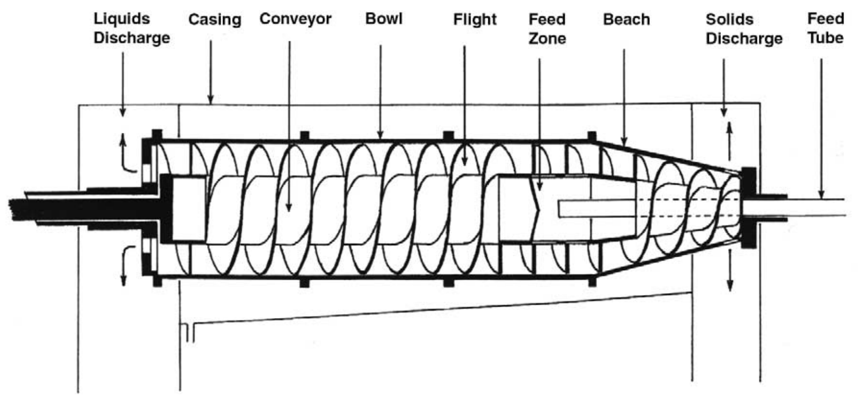


Figure 6: Disc stack separator.



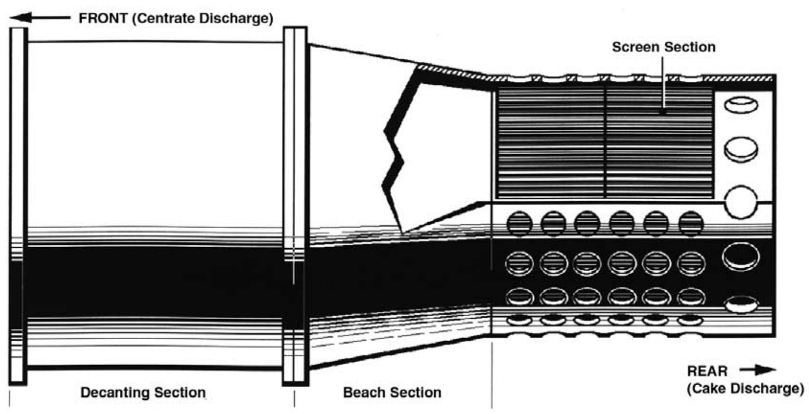


Figure 7 (top): The main operating parts of a decanter centrifuge.
Figure 8 (bottom): A screen-bowl decanter.

At the same time it can achieve quite good degrees of clarification of the liquid centrate (or, in the three-phase decanter, of both liquids). As with any sedimentation centrifuge it has a solid bowl wall, but there is now a screw conveyor moving slowly within the bowl, which carries the settled solids along the bowl, away from the liquid discharge end, and up an inclined section (or beach), which acts as a drainage zone, so that the discharged solid is partially dewatered – and with lower moisture levels possible in the **screen bowl decanter**. Considerable design ingenuity has recently gone into producing as dry a solids discharge as possible.

Centrifugal filtration

The separation achieved in a centrifugal filter is similar in principle to that achieved in a gravity filtration process (i.e. one using the hydrostatic head of liquid as driving force), but with the much higher force resulting from the rotation of the liquid. In this case, the filtrate is driven through the filter medium, and any cake built up on it, with a force of 100 to 2500 times that of gravity. Centrifugal filters are intended to handle feed suspensions with high concentrations of solids, but are best suited to solids that filter and drain easily. As already noted, their design complexity is highly correlated with the ease of solids removal from the filtration zone.

There are two main types of centrifugal filter, the fixed bed designs (in which solids once separated from suspension remain in place on the filter medium until discharged) and the moving bed designs (in which the separated solids move across the filter medium continuously, or effectively so, until they reach a discharge point). The fixed bed type, usually known as a **perforated basket centrifuge**, again, has two major variants, according to whether the separated solids are discharged manually or automatically.

The perforated basket design, as its name implies, is a cylindrical drum, open at one or

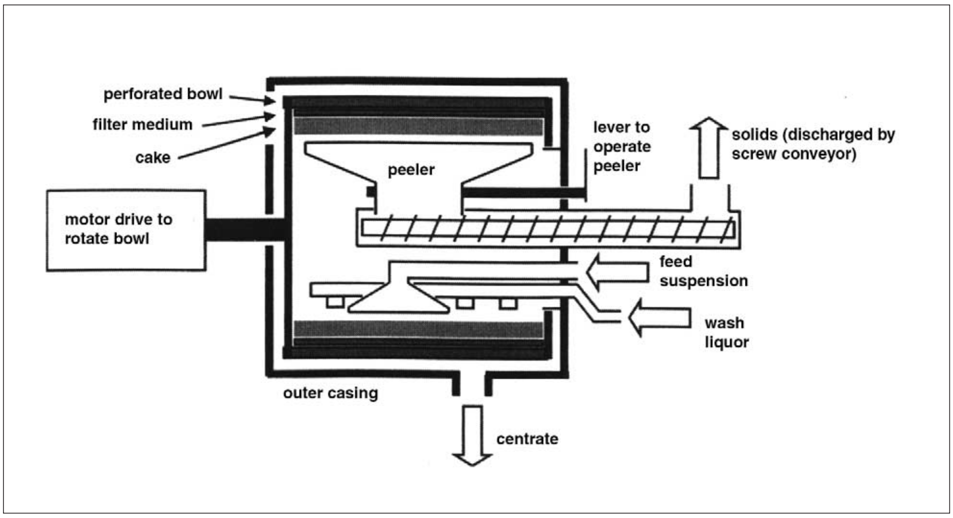


Figure 9: The general form of a horizontal axis peeler centrifuge

both ends. At the open end is an annular rim to contain the feed slurry whilst it is filtered through the filter medium on the wall of the drum, the medium being usually a coarse wire mesh or perforated plate, sometimes fitted with a fabric bag. The drum can be rotated about a vertical or horizontal axis during filtration, and in the vertical case, the drive may be above the drum, which is then suspended on the drive shaft, or below it, with the machine supported on vibration resisting mountings. For basket centrifuges with manual discharge of solids, the machine operates batch-wise. When the accumulated solids reach a certain level, the feed is stopped and the cake of accumulated solids can be washed and then allowed to dewater by drainage. The centrifuge rotation is then stopped, and the solids are either dug or scraped out (to fall, usually, through the open base of the drum), or lifted out in a bag of filter medium. The drum (or filter bag) is washed and the process repeated.

Great care is needed to ensure that the discharged solids can be completely recovered from the casing, and do not build up immovable deposits within it.

This simple arrangement can be automated by having the scraper knife mounted on an arm (usually in a vertical-drive orientation), which carries the knife slowly into the depth of the filter cake, to cut it out. This can be done whilst the drum is still rotating, if more slowly than during separation, and the solids will again fall through the open base. The movement of the arm and knife may be triggered manually, or it can all be fully automatic.

A more advanced form of the automatic knife discharge is exemplified by the widely-used **peeler centrifuge**, (*see figure 9*), which has a horizontally rotating drum, fully contained in an external casing. The knife action occurs at the top of the rotation, and the cut cake falls into a chute below the knife, and from there out into the casing. The filtration, washing, dewatering and cutting out can now all occur at the same rotational speed, on a constant, semi-continuous cycle. In any knife cutting-out system, but especially with the peeler centrifuge, it is necessary to leave a thin heel of cake on the filter medium, to protect its surface from abrasion by the knife.

A quite different form of automatic discharge is achieved in Heinkel's **inverting basket centrifuge** (*see figure 10*). Here a horizontally rotating perforated basket is lined with a flexible fabric that acts as the filter medium. When the cake is thick enough and sufficiently dewatered, the fabric is pushed out of the basket by a plate to which the inner end of the lining is attached. The medium is thus turned inside out, releasing the separated solids into the casing of the centrifuge.

Moving bed filters

The most complex of the centrifugal filters are those in which the separated solids move along the filtering surface, from the feed end of the basket to the opposite end, where they are discharged into the surrounding casing. To make this movement easier, the screens that do the filtering are usually made of wedge wire bars, mounted lengthways in the screen. During the passage along the screen, the solids are filtered, washed and dewatered, and the system must ensure that sufficient time is available for these functions all to occur to the necessary degree.

The **cone screen centrifuge** (*see figures 11/12 on page 20*) is, as its name implies, fitted with a screen in the shape of the frustum of a cone, which rotates about the axis of this cone (and which can be mounted with the axis of rotation horizontal, inclined or vertical). The slurry is fed to the narrow end of the screen, and the solids tumble "down" the inner surface of the cone to the widest end. The component of the centrifugal force that is perpendicular to the screen at any point provides the filtering force, and the component parallel to the surface controls the movement of the solids across the screen. This latter component is obviously the greater, the wider the angle of the cone, and if this angle is greater than the angle of repose of the wet solids, then they will move. The solids movement, however, in this slip **discharge cone screen centrifuge**, is very dependent upon both the nature of the separated solids and the degree of dewatering of these solids.

It follows that a particular separation task would require one specific cone angle, which might then only be suitable for a very limited range of other solids, so that the makers of cone screen centrifuges would need to have a wide range of models with different angles. In fact these centrifuges mostly exist with an ingenious range of devices to speed up or slow down the movement of the solids. These devices enable the effect to be varied over a range of magnitudes so as to deal with differing slurries. They include:

- **conveyor discharge** in which a screw conveyor inside the conical screen, the

Figure 10: Inverting basket centrifuge.

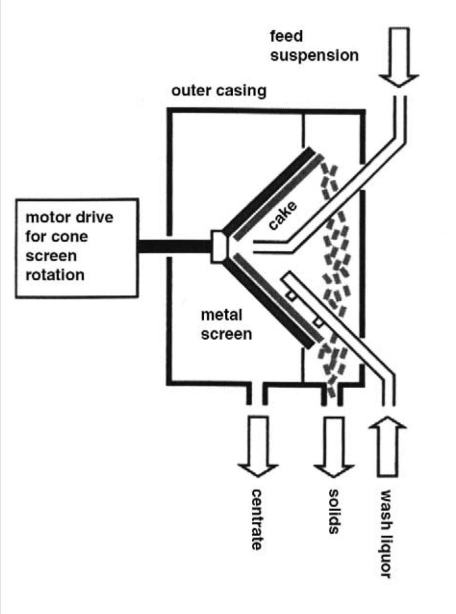


Figure 11: Slip discharge cone screen centrifuge.

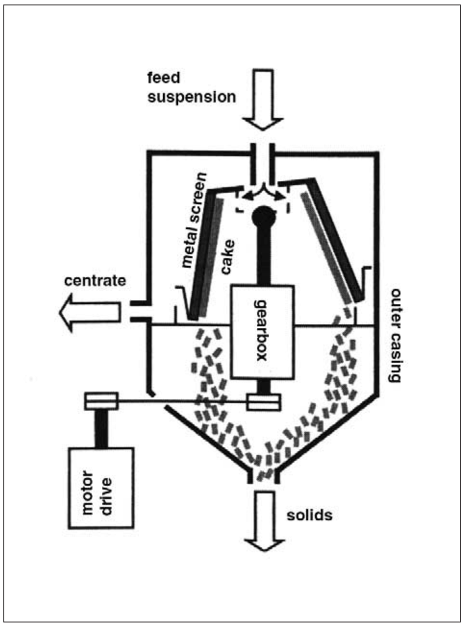


Figure 12: Tumbling centrifuge.

tips of whose flight come close to the screen surface, scrolls the solids across the screen (and can be used to speed up or slow down the solids flow);

- **directed flow cone screen centrifuge** in which a conical insert, fixed close inside the screen, has a number of vanes extending down close to the medium surface, which channel the solids flow in a manner to decrease the rate of movement of the solids over the screen;
- **vibrating centrifuge**, which has no mechanical inserts within the screen, but uses an axial vibration, with a relatively small amplitude, to increase the rate of solids movement (as does a variant on this in which torsional vibration is applied in the direction of rotation); and
- **tumbling centrifuge** in which the whole screen assembly not only rotates about its central axis, but that axis also precesses (rotates about the central axis), so that the solids are exposed to a tumbling motion which both speeds them up and improves the dewatering.

A related machine is Krauss-Maffei's **baffle ring centrifuge**, in which the screen is divided into annular segments, with a sharp increase in diameter at the start of each segment. As the solids flow over each step, they are loosened so that dewatering is again improved.

The other main form of continuous centrifugal filter is the **pusher centrifuge**. (*see figure 13*.) Here, the basket rotates about a horizontal axis, and the screen is in the form of an open drum, but the drum is in two or more annular segments, each of a larger diameter than the previous one. These segments move backwards and forwards across or behind one another, pushing accumulated heaps of solid ahead of them. In this way, the solids are moved along the totality of the screen, and over the edge of the final stage, and the pusher can provide very effective washing and dewatering of the solids.

For almost all of these different types of sedimenting centrifuges or centrifugal filters, separated solids are discharged from a rapidly moving basket or bowl, and are then collected in the stationary casing of the centrifuge. Great care is needed to ensure that the discharged solids can be completely recovered from the casing, and do not build up immovable deposits within it. ●

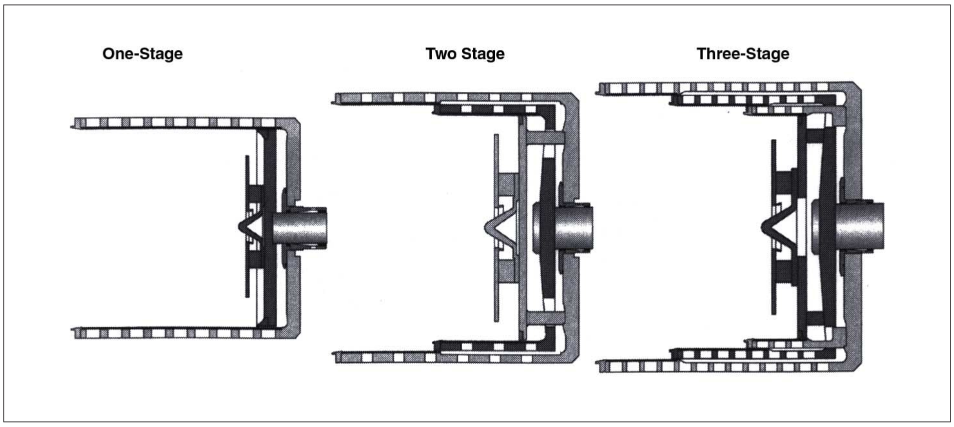


Figure 13: Single stage and multi-stage rotors in typical pusher centrifuges.

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Ken Sutherland has run his process engineering and market research consultancy, Northdoe, for over 25 years. Northdoe is largely concerned with filtration and other such separation technologies. He was a co-author of Elsevier's *Decanter Centrifuge Handbook*, and has also written the second edition of Elsevier's *Handbook of Filter Media*. Most recently he has written Elsevier's forthcoming *Filtration: A - Z*.
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