MODERN TRENDS IN CONTINUOUS CENTRIFUGAL SEPARATION AND CLASSIFICATION

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Theoretical methods of centrifugal separation are discussed, and general equations which can be used to assess centrifuge performance are derived. Centrifuge types are reviewed, and their range of application is indicated.

Introduction

Of all the unit operations carried out in process plants, it is probably true that the most common are the operations of mixing and separation. There are few plants indeed which do not require, at some stage, both of these operations. It is a surprising fact, however, that much less attention has been paid to the fundamentals of these operations than to the rather more esoteric operations such as distillation. Much of the blame for this rests with our schools and universities who cover this ground rather inadequately but undoubtedly also with the chemical engineers who design this equipment since in the past they have seemed reluctant to publish their theoretical data. This is particularly true in the field of centrifugal separation, and as a result large sectors of industry are only familiar with the laboratory centrifuge and do not realise the advanced stage of technical sophistication which has been reached in machine design and application.

Theoretical Methods of Centrifugal Separation

It is important to realise that centrifugal force differs from gravitational force only in intensity and direction. Thus all centrifugal operations have their gravity analogue.

There are two basic methods of gravitational or centrifugal separation. Firstly, the mechanism of filtration where the liquid passes through some form of retaining mesh which retains solids. This mechanism is independent of the difference in specific gravity between the solid and liquid. As a mechanism, it is not suited for liquid-liquid separation or the resolution of emulsions. It is not proposed to discuss centrifugal filtration in any detail since it has little application in the cosmetic industry. The second and more important mechanism is that of centrifugal sedimentation. Here, there is a separation of two or three phases due to differences in specific gravity of the phases and this can apply either to liquid-solid, liquid-liquid, or liquid-liquid-solid systems. Obviously if the sedimentation treatment is continued

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long enough, there will be a complete division of the phases and this would normally be referred to as clarification or separation. If the process is not carried through to completion but stopped at some intermediate point there will be a phase gradient across the system. This is normally referred to as classification.

The rate of separation or the ability to resolve emulsions is a function of the gravitational force applied. The use of the Earth's gravity would appear to have many attractions because it is available at no charge. In fact, a detailed analysis often shows that the size of settling tanks required, and the space taken up represents a considerable capital investment. In addition, the inventory of material in this system becomes extremely high and, perhaps more important, it is often difficult to introduce continuous operation. For these reasons, centrifuges are being increasingly applied to these problems.

In the case of centrifuges, as is true of the settling tank, there are two types of forces, acting on the particles of the discontinuous phase suspended in the continuous fluid phase. For small particles, the viscous resisting force is directly proportional to the velocity of sedimentation. For larger particles, when the Reynolds' number, $\frac{DV\rho}{\mu}$, is greater than the critical transition value, the viscous resistance becomes negligible compared with the turbulent resistance which is proportional to the square of the velocity of movement of the particle relative to the liquid.

In analysing centrifuge performance, when a high degree of clarification or separation is important, the behaviour of the smallest particles in the system is usually the controlling factor. Viscous resistance may therefore be considered to be of prime importance.

The effective force acting on a given particle in a centrifugal field is :—

$$F_{CF} = (m-m_1)\omega^2 r \qquad (1)$$

Where

m = mass of the particle

m_1 = mass of fluid it displaces

ω = angular velocity about the axis of rotation,

r = distance of the particle from the axis of rotation.

If the particle is a sphere, the force is

$$F_{CF} = \frac{\pi}{6} D^3 \Delta\rho\omega^2 r \qquad (2)$$

Where

D = diameter of the particle,

$\Delta\rho = \rho - \rho_1$ = difference between the density of the particle and that of the fluid in which it is suspended.

The force opposing the sedimentation of the particle, assuming that it is small and that its velocity is low, is given by Stokes' Law. This is the viscous drag force.

$$F_D = 3\pi\mu D V_p \qquad (3)$$

Where

μ = viscosity of the fluid phase,

V_p = velocity of the particle relative to the fluid phase.

When the force causing sedimentation reaches equilibrium with the resisting force, the relative velocity of the particle becomes constant.

$$V_p = \frac{\Delta\rho D^2\omega^2 r}{18\mu} \qquad (4)$$

Or when the particle is not in a centrifugal field, but is in the gravitational field, as, for example, in a gravity settling tank

$$V_g = \frac{\Delta\rho D^2 g}{18\mu} \qquad (5)$$

Consider firstly the tubular bowl type centrifuge, operated as a clarifier, in which fluid is fed in one end, and discharged from the other. In such a rotor V_p is the velocity with which the particle approaches the rotor wall, or if $\Delta\rho$ is negative, the velocity with which the particle approaches the liquid surface. If the thickness "S" of the liquid layer is small compared with the radius of the cylindrical rotor, then V_p will be approximately constant, and the distance the particle will move during the time it is in the bowl will be given by

$$x = V_p t = \frac{\Delta\rho D^2\omega^2 r}{18\mu} \cdot \frac{V}{Q} \qquad (6)$$

Where

t = time

V = volume of liquid in the bowl,

= $\pi l\,(r_2^2 - r_1^2)$

Q = rate of flow of liquid through the bowl,

r_2 = outer radius of the liquid in the cylindrical rotor,

r_1 = radius of liquid surface in the cylindrical rotor,

l = length of the cylindrical rotor

Also, let S = thickness of the liquid layer.

If x is as great as, or greater than, the initial distance of the given particle from the wall of such a rotor, it will be deposited against the wall and removed from the liquid phase. In an ideal system, when $x = S/2$, half the particles of diameter D will be removed from suspension, and half will not. This condition is called the "cutpoint", and at the "cutpoint", by substituting and rearranging equation (6), one obtains

$$Q = \frac{\Delta\rho D^2}{9\mu} \cdot \frac{V\omega^2 r}{S} \qquad (7)$$

from which the critical diameter of the particles at the "cutpoint" is given by : --

$$D = \sqrt{\frac{9\mu Q}{\Delta\rho} \cdot \frac{S}{V\omega^2 r}} \qquad (8)$$

This is the diameter of particles, half of which will be removed, and half of which will pass through the rotor with the liquid phase.

Referring back to equation (7), it will be noted that the factors in the first group of the right hand side of the equation are concerned only with the parameters of the system being processed : diameter, viscosity and density. The factors in the second group are concerned only with the parameters of the centrifuge : volume, rotational speed, radius and settling distance.

Equation 8 may be rewritten

$$Q = 2V_g\Sigma \qquad (9)$$

in which, as in equation (5),

$$V_g = \frac{\Delta\rho D^2 g}{18\mu} \qquad (10)$$

and

$$\Sigma = \frac{V\omega^2 r_e}{g\, S_e} \qquad (11)$$

Where

r_e = effective radius of the liquid layer in the rotor,

S_e = effective settling distance in the liquid layer.

It will be seen that equation (9) gives the capacity of the centrifuge in terms of

Σ , which is an index of the capacity of the centrifuge, and

V_g, which characterizes the solid/liquid system being handled.

It will be seen that Σ has dimension of length to the power of 2. This equation thus represents the potential separating ability of a centrifuge in terms of the equivalent area of settling pond.

This general equation can be applied to any sedimentation process, either gravitational or centrifugal. In order to make it usable it has to be calculated for each class of centrifuge using parameters which can be readily measured. Space does not permit me to derive this analysis here, and I will confine myself to quoting the Σ equation for the main classes of centrifugal sedimentor.

General case $Q = 2V_g\Sigma$

Bottle centrifuge $$\Sigma = \frac{\omega^2 V}{4.6 \log \left(\frac{2r_2}{r_1 + r_2}\right)}$$

Tubular bowl centrifuge $$\Sigma = \frac{\pi l \omega^2}{g}\left(\frac{3}{2}r_2^2 + \frac{1}{2}r_1^2\right)$$

Disc bowl centrifuge $$\Sigma = \frac{2\pi n \omega^2 (r_2^3 - r_1^3)}{3_g \tan \theta}$$

Some of the uses of the Σ concept will now become apparent. It reflects the capacity of a continuous centrifuge as a function of two groups of parameters. One is concerned entirely with the geometry of the centrifuge, and the other with the physical progenities of the dispersion or emulsion being treated.

In considering the sigma value of a centrifuge, it is important to realise that it presents the *potential* separating power in terms of an equivalent settling pond. It does not necessarily follow that this potential can be fully realised.

Using a gravity analogy, it is obvious that a water reservoir has a certain potential ability to sediment solids. The potential will not, however, be realised if one takes a high speed motor boat and drives about on the reservoir. In the same way, turbulence and other mechanical effects within the centrifuge make it impossible to meet the theoretical sigma value; but for similar basic types of centrifuge the departure for theory should be constant.

The sigma equation is commonly used in one of two ways. In a two-phase system which has to be separated, trials can be carried out on a laboratory centrifuge and the sigma equation may then be used to scale up to full size plant equipment. Thus for any given two-phase system.

$$\frac{Q_1}{\Sigma_1} = \frac{Q_2}{\Sigma_2}$$

Alternately one may determine what will happen if a centrifuge which is performing a certain separational job on one system, has to be changed to operation on a new system. In that event, the sigma value remains constant and the degree of separation which will be achieved on the new material can be determined.

In addition, these fundamental equations serve as a basis to enable us to use centrifuges to determine particle size and in general terms this can be done both for solid liquid systems and also for liquid emulsions.

The brief mathematical treatment given has assumed the separation of small solid particles from a liquid. It does, however, remain valid for the separation of small dispersed liquid globules from a continuous liquid phase. The assumption is made that there is no interaction between particles, and undoubtedly with very small particles the phenomenon of Brownian movement can be come important. In addition, when dealing with two liquid systems, it becomes necessary to maintain a hydrostatic balance between the phases in the centrifuge so that they may both be discharged continuously (*Fig. 1*).

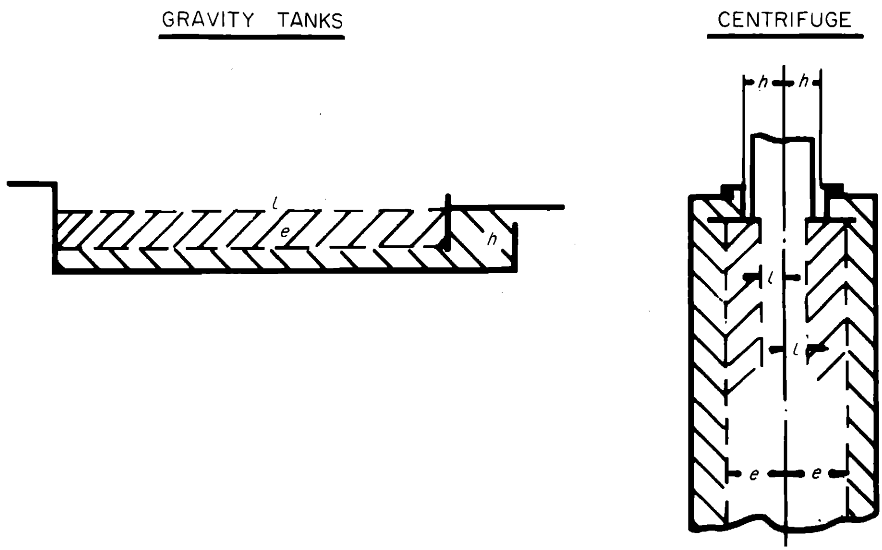


Figure 1

It should be noted that with the case of the gravity tank, the system is in hydrostatic balance when the dimension e — l multiplied by the density of the light phase equals the dimension e — h times the density of the heavy phase. This general equation only applies because the variations in the Earth's gravitational field between the points l and h is negligible. The general formula

$$\int_{r=e}^{r=l} \rho_l f(r)dr = \int_{r=e}^{r=h} \rho_h f(r)dr$$

is applicable. In the earth's gravitational field the values of f(r) on each side of the equation are almost identical and cancel out so that

$$\rho_l\,(e - l) \simeq \rho_h\,(e - h)$$

With centrifuges this does not apply and

$$\frac{\omega^2 \rho_l\,(e^2 - l^2)}{2} = \frac{\omega^2\,\rho_h\,(e^2 - h^2)}{2}$$

or

$$E = \frac{\rho_h}{\rho_l} = \frac{e^2 - l^2}{e^2 - h^2}$$

Types of Application

There are two types of application. The first is clarification where the object is to remove the solid material in suspension in a liquid; either to recover product or to remove an undesirable contaminant from the liquid phase. Typical examples would be the recovery of organic dyes from reaction liquors, and the clarification of waxes and fats.

A second main type of centrifugal operation is to classify liquid-solid systems. This usually occurs when it is desirable to have a dispersion of a solid in a liquid but where the product requirement stipulates that the maximum size of the solid dispersed shall be limited. The classic example of this type of centrifugal operation is in the classification of pigmented liquors. It may be desirable, for example, that a pigment should have no agglomerates of more than 2 microns in size, and a centrifuge is therefore used to remove all particles above this critical size.

The same basic applications exist in binary liquid systems. Sometimes the objective is to totally separate two phases. On other occasions when dealing with emulsions, it is desirable to remove globules which have coalesced, or to concentrate the emulsion.

A typical example of the first case would be the use of centrifuges after the water washing of vegetable oils and the classic example of the second mechanism is, of course, the centrifugal cream separator.

Centrifuges are very widely used for treating emulsions and I am very conscious that my own interests are almost completely the reverse of your own. We are basically concerned with machines for breaking emulsions whereas you are presumably far more interested in promoting emulsions. I do think, however, that both operations are concerned with the overall stability of emulsions and we are therefore all interested in their nature. The centrifuge can only separate an emulsion if there is a difference in specific gravity between the disperse phase and the continuous phase. In general, the density differences are low and since the emulsion globule size is often in the sub-micron region, it represents a difficult problem. We are concerned with complex emulsions which include a third component which could be either liquid or solid located at the interface.

The stability of an emulsion is influenced by :—

1. The interfacial tension and by the emulsifying agent present at the interface.
2. By the extent of Brownian movement which would lead to particle collision.
3. By the electrical double layer causing repulsion.

There are three ways in which an emulsion can become less homogeneous.

1. By concentration of globules of the disperse phase due to density differences. I would not normally regard this as emulsion breaking but rather as emulsion concentrating.
2. By the flocculation of aggregates where the globules retain their identity.
3. By coalescence to form larger globules.

To break emulsions it is necessary either to increase the chances of globule contact or to change the resistance of the emulsifier film towards coalescence.

Although the analogy between gravity and centrifugal force has been stressed above, and the performance of centrifuges have been related to the performance of gravity settling tanks, we now have an example of where this theory does not remain completely valid. We have all experienced emulsions which can be left for long periods of time in gravity tanks without changing their character. Stabilised water paraffin emulsions show this behaviour, but the emulsion can be partially resolved by agitation. This phenomenon is encountered very frequently in the centrifugal treatment of emulsions. For instance, we were faced with many thousand tons of a tar-water emulsion which had been in gravity tanks for many years in an attempt to break the emulsion and recover the tar. Over this period of time no separation was possible. A centrifuge was installed and a complete resolution was immediately possible. The centrifuge obviously possesses some features which the simple analogy to a gravity tank ignores. We believe that the ability of the centrifuge to break emulsions is probably caused by :—

1. A mechanical shearing effect which ruptures the interfacial film.
2. The need to achieve a terminal settling velocity which is sufficiently great to overcome the effects of Brownian movement.
3. The ability to operate at elevated temperatures with a subsequent reduction of viscosity, and to employ settling velocities which are again in excess of those induced by convection currents.

The centrifuge as an emulsion breaker represents an interesting method of carrying out an accelerated stability determination.

Centrifuge Types

Centrifugal Sedimentors

The Super Centrifuge (*Fig. 2*)

This is a ***tubular bowl type*** centrifuge designed to combine simplicity of bowl design and a minimum number of moving parts with the application of a very high centrifugal force to the material being treated. The ratio of bowl

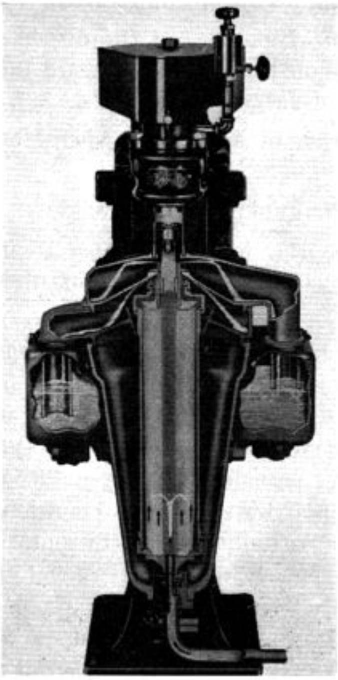


Figure 2

length to bowl diameter ranges from 4-8 and bowl speeds vary from 15,000-50,000 r.p.m. These speeds correspond to a centrifugal force of from 12,000 times the force of gravity, up to 65,000 times gravity, which is considerably greater than that developed in the other types of continuous industrial centrifuge.

The tubular bowl centrifuge is ideally suited to the separation of two immiscible liquids, and to clarification applications where the quantity of solid phase is less than, say, 1%, and where the particle size of the solids is small enough to warrant the use of the high centrifugal force. Examples of such applications are the clarification of fats and waxes, the continuous purification of lubricating oil, clarification of cider and fruit juices, and multitudinous other operations in the chemical and process industries.

Another operation which can be successfully carried out on the tubular bowl centrifuge is that of classification, since a sharp cut-off is obtained between oversize and undersize particles. Lacquers, enamels, dye-pastes, pigmented liquors and similar substances can be treated in the centrifuge to remove oversize particles and agglomerates of particles.

Apart from the low cost of the machine per unit throughput, its ease of operation and maintenance, etc., the tubular bowl centrifuge is widely applicable in industry due to its versatility, and the fact that its simple construction permits fabrication in corrosion-resistant materials. In many plants producing small annual tonnages of a variety of materials, one machine is used for a number of different operations, depending on the chemical in current production.

The tubular bowl centrifuge can also be used as a "polishing" machine for removing small quantities of solids from the liquid effluent from one of the other types of centrifuges, such as the solid bowl scroll discharge type, described below. These large continuous machines serve to remove the bulk of coarse particles, whilst the tubular bowl centrifuge is used to remove the remaining traces. The advantages of such a system are that each machine is operating on the range of particle sizes most suited to its characteristics.

Liquid discharge from the tubular bowl centrifuge is continuous. The solids remain in the bowl and have to be periodically removed as a bowl cake. This operation of periodically cleaning the bowl, however, only occupies approximately fifteen minutes, and can in fact be carried out in five minutes if two bowls are used, one being cleaned while the other is being used.

Disc-type Centrifuge

In an attempt to reduce the distance through which a particle has to settle, plates or baffles may be introduced into the centrifuge bowl. This produces the so-called "disc-type centrifuge". Whilst these discs could in theory be introduced into a tubular bowl centrifuge, in practice the height of the bowl in the disc-type centrifuge is reduced as the diameter is increased, and the speed and centrifugal force is greatly reduced. In consequence, whilst the direction of flow of the fluid in a tubular bowl centrifuge is generally parallel to the axis of rotation of the bowl, in a disc-type centrifuge the liquid is flowing inwards at an angle of 35°-45° to the axis of rotation, to a smaller diameter. The solid particles, on the other hand, proceed outward in an approximately radial direction, until they strike the underside of a disc.

Depending on the nature of the particles and the angle of the discs, these particles either collect on this under-surface, or else slide outwards down the underside of the discs in a thin layer. When they leave the disc stack they either flow to the wall of the bowl where they collect or else they are re-entrained by the liquid passing up into the disc stack. The phenomenon of re-entrainment causes disc centrifuges to be much less efficient than would appear from a simple calculation of separational efficiencies based on centrifugal force and settling distance. This, combined with the high capital cost of batch disc centrifuges as compared with an equivalent tubular bowl machine, maintenance cost, mechanical complexity, and the difficulty of cleaning, accounts for the fact that their use is generally less favoured in the chemical and process industries. Modifications to the disc principle, however, do permit the solids to be continuously discharged, and it is in this function, rather than in its use as a "batch" type centrifuge, that the disc machine finds its best field of application.

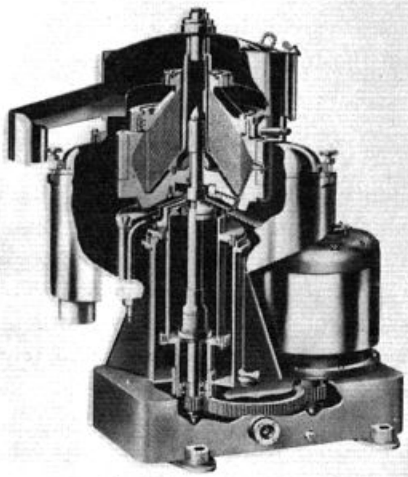
Nozzle Discharge Type (Fig. 3)

Where continuous solid discharge is required, the low length to diameter ratio of the disc centrifuge lends itself to the provision of orifices in the periphery of the bowl through which the solids can be discharged.

The bowl shell is modified so that the solids deposited are guided down towards the nozzles. The angle of this bowl wall must be sufficiently steep so that the solids will flow down. If too shallow an angle is used for solids having a high angle of repose, then small mounds will build up until the solid itself provides an appropriate angle. This in itself is not harmful, but the danger exists in such a case that the solids will build back into the disc stack, thus causing a serious loss of efficiency due to blanking off part of the stack.

In a similar manner, solids will build up in between nozzles to form their own angle of repose. For a given angle of repose the height of such accumulations of solids will depend on the distance between adjacent nozzles and, for a given bowl diameter, on the number of nozzles. Thus, in order to avoid the apex of such accumulation from penetrating the disc stack, one has to regulate the number of nozzles according to the nature of the solids. In general, the use of from 4 to 12 nozzles is found to be desirable for most of the types of solids handled on this class of centrifuge. The pressure of fluid at the nozzles is relatively high, being of the order of 1,000 p.s.i. In consequence, to avoid excessive liquid flow through these nozzles, they must be of small diameter. For operation at capacities of 1,000-10,000 gallons per hour feed to the centrifuge, the nozzles used range from 0·030″ to 0·070″.

In order to recover some of the energy lost in the liquid leaving the nozzles, and thus to reduce the power requirements of the unit, it is usual to



The DH-3 HEAVY DUTY NOZLJECTOR.

Figure 3

arrange these nozzles to point tangentially backwards operating on the principle of the reaction turbine.

THE RECYCLE NOZZLE TYPE

In many cases, it is desired to obtain a high ratio of concentration of the inlet slurry to that of the material discharged through the nozzles. This could be accomplished by reducing the diameter or number of nozzles, but often this solution is unacceptable due to the physical characteristics of the solids being handled. A recycle bowl may be used to overcome this. This is designed so that part of the nozzle discharge can be returned to the bowl to discharge at a point adjacent to each nozzle. In this way, an artificially high concentration of solids is built up adjacent to the nozzle, and the discharge capacity of the nozzles is satisfied, whilst still maintaining the net discharge of nozzle liquor from the system at a sufficiently low rate that the desired overall concentration ratio may be obtained.

Whilst this principle of recycling has wide application, with some solids which form light agglomerates it cannot be used since the force of discharge from the nozzles is sufficient to break down the agglomerates. In consequence, a material which would separate well on its first passage through the centrifuge would not separate if recycled to the bowl, and a fall-off in liquid clarity would be observed.

As with the tubular bowl and batch disc centrifuges, the nozzles and recycle nozzle type machines are widely used for separation, clarification and classification operations—especially in cases where the high concentration of solids would result in too frequent cleaning being necessary in the former types of machines.

Valve Nozzle Type (Fig. 4)

Due to the possibility, referred to above, of breakdown of agglomerates during discharge from the nozzles, and the limitation of ultimate concentration of nozzle discharge imposed by the characteristics of the recycle system, the use of the recycle nozzle type centrifuge has some limitations in its field of use. To overcome some of these objections a different approach has, in recent years, been made to the problem. Instead of reducing the diameter or number of the nozzles to restrict nozzle discharge, a control is applied on the time for which the nozzles are open, by building valves into each nozzle. This permits very high concentration ratios to be achieved, even with the slurries consisting of relatively fragile agglomerates. It also enables a higher nozzle discharge concentration to be ultilised than would be possible with a recycle bowl.

Two types of valves are commonly used. In both types, each nozzle has a separate valve. In the case of the automatic valve type centrifuge, the depth of solids deposited in the bowl controls the opening and closing of the valves, by means of a hydraulic self-operating mechanism in the valve itself. The centrifuge can thus automatically compensate for variations in feed rate and concentrations of solids in the feed, and still deliver a sludge of constant-composition. The operation of this type of valve is, however, somewhat sensitive to the type of solids being separated, and for this reason its field of application is limited.

The valves in the externally actuated valve type centrifuge, however, are positively operated by a hydraulic control mechanism. Mounted outside the centrifuge, it can be time-cycle, manual, or operated by means of a photoelectric cell operating on the clarity of the liquid phase effluent. The frequency and duration of the opening of the valves can thus be controlled to discharge very high concentrations of sludge from the nozzles and, in fact, as a result of this degree of control of nozzle discharge, the valve nozzle type centrifuge can be operated to produce the highest concentration of discharge obtainable with centrifuges operating on the disc principle.

The Opening-Bowl Centrifuge

An alternative approach to the problem of controlled solids discharge is

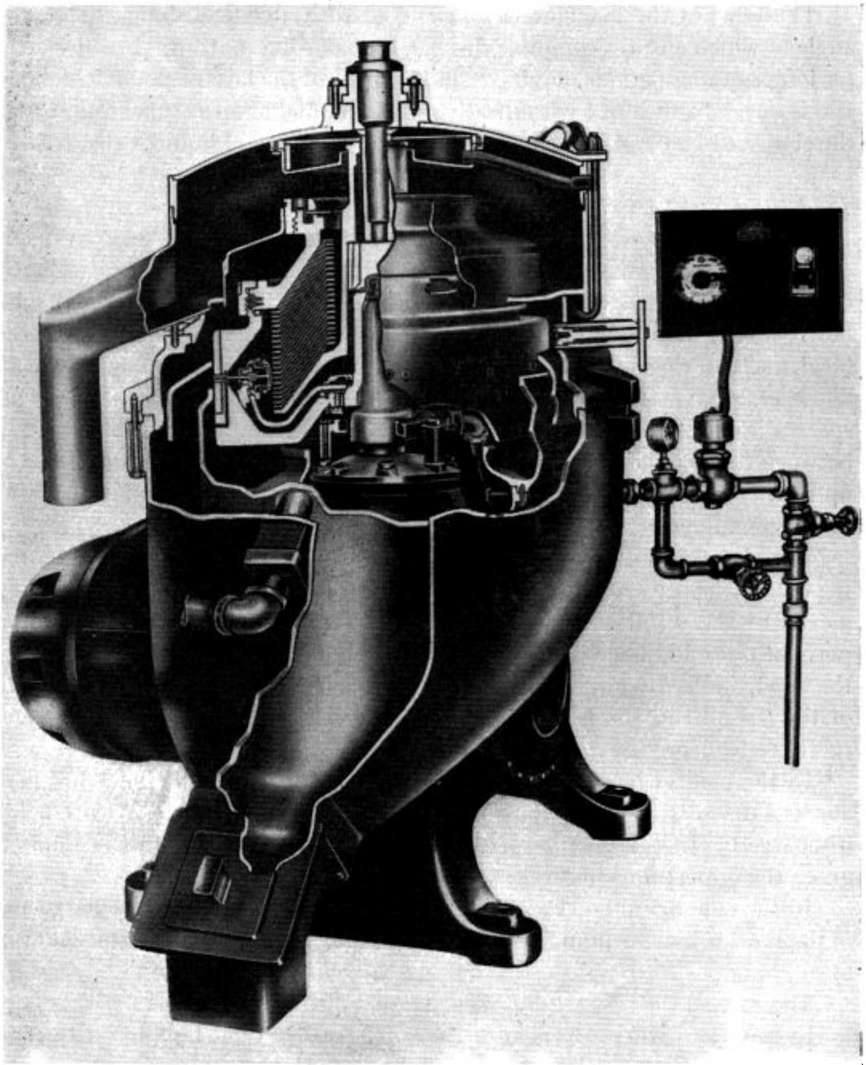


Figure 4

exemplified by the opening-bowl centrifuge. In this case, instead of employing valve controlled nozzles, the solids discharge is regulated by means of an annular ring valve. This type of unit is designed to give constant high separating efficiency comparable to that given by centrifuges using the disc type bowl, but having the facility of discharging the solids intermittently as required without the machine being stopped.

The bowl of the machine is constructed with a conical sludge space, the angle of which ensures complete discharge of all solid matter. It is designed for long running periods, having a sludge space of the largest possible volume and is opened and shut hydraulically. The method of operation ensures that the sludge discharged contains the minimum quantity of liquid.

Solid Bowl Scroll Discharge Type (*Fig. 5*)

In the solid bowl scroll discharge, or "decanter" type of continuous centrifuge, a combination of centrifugal settling and centrifugal filtration is taking place. The decanter type consists of a cylindrical or conical solid bowl rotating about a horizontal axis between two fixed bearings. Inside the bowl, and rotating about the same axis is a helical scroll conveyor which, however, rotates at a differential speed as compared with the bowl. This speed differential is achieved by means of an epicyclic gearbox operating between the bowl and the conveyor drive. A centrifugal separating force of up to approximately 3,000 times the force of gravity is generated in the bowl of the centrifuge.

The slurry to be separated is fed to the inside of the bowl. The centrifugal force deposits solids on the bowl wall. These are moved up the bowl by means of the scroll conveyor, and are discharged through circumferential ports at one end of the bowl. The clarified liquid passes to the other end of the bowl, and is discharged over an adjustable weir which regulates the depth of the "pond" in the bowl, thus controlling the liquid residence time and thereby the degree of clarification obtained.

In the conical bowl version, the solids are moved up the bowl and pass across a dry section above the liquid level, known as a "beach", before being discharged. In this section of the bowl the liquid trapped in the solids is given the opportunity to drain away.

In the cylindrical bowl version the solids move to the solids discharge end of the bowl below the liquid level, and extrusion plays a part in the mechanism of discharge.

The conical type decanter is to be favoured where the solids separated are fairly firm, and where dryness of the solids rather than liquor clarity is of primary importance. For plastic solids and in cases where good liquid clarity is essential, the cylindrical decanter is preferred.

In both types, the decanter can either be used as a clarifier to remove all the solids, or as a centrifugal classifier to discharge large particles as a solid phase, whilst allowing fine particles to remain in suspension. By careful selection of throughput and operating conditions, a reasonably good "cut" can be obtained at the desired particle size. By using a special design of double feed tube, wash liquor can be deposited on the solids beach and a degree of wash thus effected. This is not as thorough as that obtained in a perforated basket type machine and, in addition, the wash liquor mixes with the mother liquor and discharges with it. Where a high degree of washing efficiency of the product is required, or where the wash liquor must not mix with the mother liquor, it is usual to employ a re-slurry technique, using two stages of centrifugal decanters.

Often the decanter is used as a "roughing" centrifuge for separating the coarse and relatively easily removed solids before feeding the liquor to one of

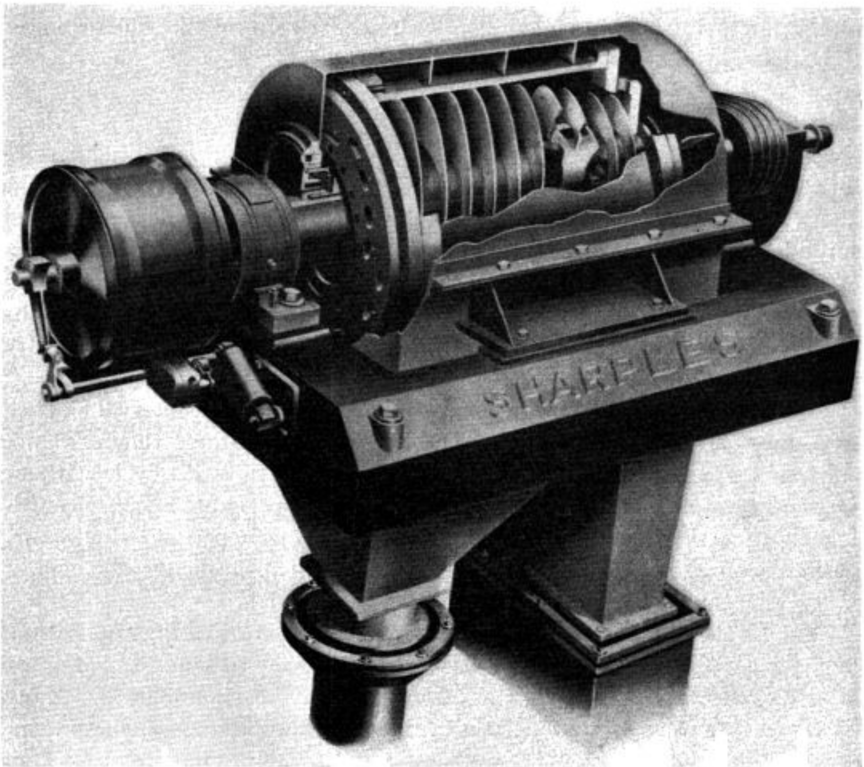


Figure 5

the other types of machines, such as a tubular bowl centrifuge or one of the nozzle type centrifuges, for "polishing".

Centrifugal Filtration

The centrifugal filter only differs basically from ordinary filters in that the driving force which causes liquid to flow through the filter medium is obtained centrifugally. The centrifugal force may be many times that produced by the acceleration due to gravity, and consequently much speedier drainage can be obtained, and a drier cake produced.

In the perforated basket continuous centrifuge, a different mode of action is involved from that in the centrifugal sedimenters which have already been described. In the centrifugal sedimenter, the solids are separated from a continuous liquid phase or phases by a centrifugal settling process, and for separation to be effected, destiny differential is essential. The perforate basket machine is, however, a true centrifugal filter in that the solids separated from the mother liquor act as a filter bed in most cases. A density differential between the solid phase and the liquid phase is no longer necessary and, in fact, slurries can be handled where the density of the solids is lower than that of the liquid.

Automatic Knife Discharge (Fig. 6)

The centrifugal filter, in its simplest form, consists of a perforated basket, lined with a suitable filter medium. This basket rotates on fixed bearings about a horizontal axis. Slurry feed and wash are fed to the basket through suitable nozzles, while discharge of the cake is effected by means of a piston-operated underloader knife. Almost any degree of complexity of operating cycle can be achieved, but a typical example of the manner in which the machine is used is, (i) screen rinse, (ii) loading, (iii) cake rinse, (iv) spin dry and (v) unloading.

The cycle is controlled by automatic timers, and the time interval for each step may be altered at will by appropriate setting of these timers. Once started, the centrifuge operates continuously, repeating this cycle without further attention. The advantage of this type of perforated-basket centrifuge is that the flexibility of the control mechanism permits almost any desired sequence of operations, and since the timers can be reset at will, it is also adaptable for dealing with off-standard material.

The length of the cycle varies according to the nature of the application, but is generally between 30 seconds and 3 minutes. In some special cases, however, cycle times of as long as 20 minutes have been employed. Many variations can be incorporated in the cycle. For example, more than one type of cake rinse can be used. Where necessary, the mother liquor can be kept separate from the rinse liquor or liquors. The spin-dry stage in the cycle can be varied at will to obtain the desired crystal dryness or crystal purity.

In general, this type of centrifuge is used for the recovery and dehydration of crystals where the desired product is the solid phase. A characteristic of the knife-discharge perforated-basket centrifuge is that excellent washing can be obtained. It has, however, been successfully used for the separation of microcrystalline and amorphous solids where special considerations such as toxicity, hygiene, vapour hazard, etc., have applied. Another interesting application has been the handling of crystal separation problems at very low temperatures.

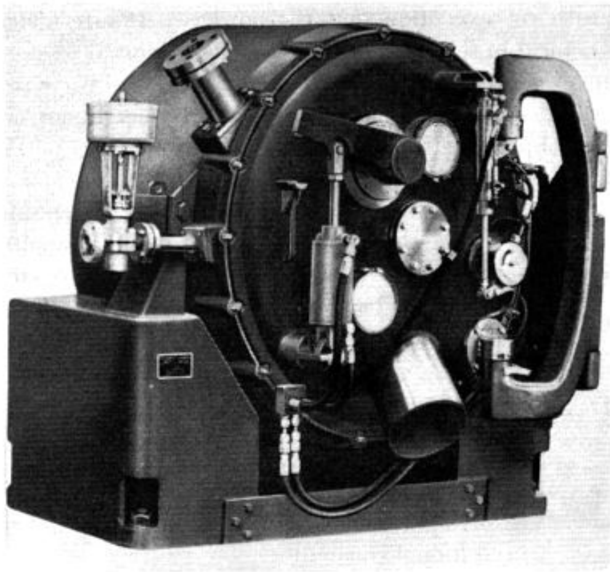


Figure 6

Scroll Discharge (*Fig. 7*)

Another interesting centrifugal filter utilises a fully continuous scroll discharge. It therefore resembles the decanting type centrifuge described

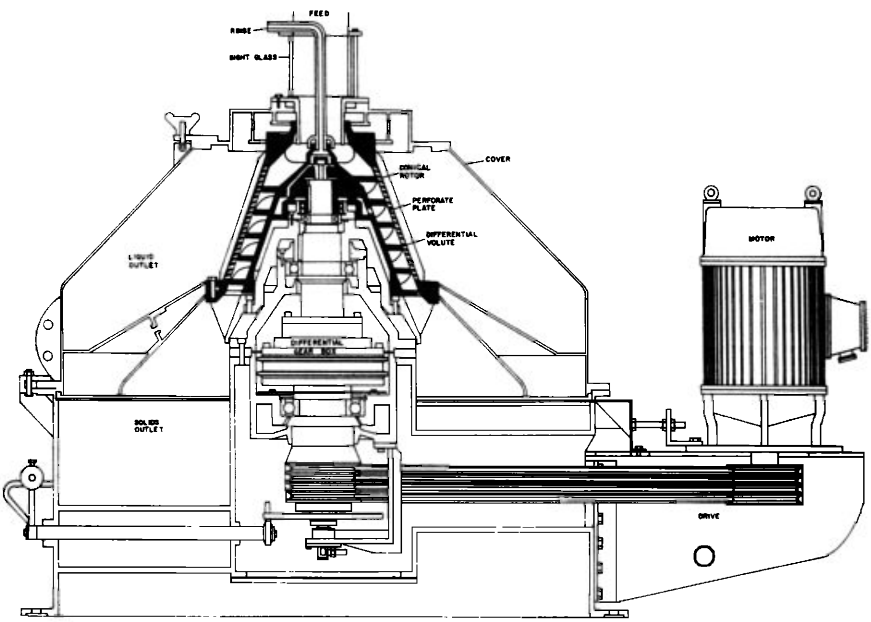


Figure 7

previously, with the exception that the bowl is perforate instead of solid. The bowl is conical in section, and fitted with perforated or slotted screens. The solid moves continuously through the machine and is controlled by the differential speed of the internal scroll. The mother liquor is discharged under centrifugal pressure through the perforate bowl.

The machine has the advantage of low cost per unit of capacity and is of great value when large crystals or fibres are to be de-watered. Its use on fine crystals is limited since there will be a loss of solid in the filtrate. Since the machine does not use cyclic operation it cannot give the same degree of washing as the centrifugal filter previously described.

(*Received : 8th March 1962*)

Notation

E	$\frac{\rho_h}{\rho_e}$
F_{CF}	Effective force acting on a particle in a centrifugal field.
F_D	Viscous drag force on a particle.
g	Gravitational constant.
n	Number of spaces between discs in a stack.
θ	Disc half angle.
ρ	Density of a particle.
ρ^1	Density of a liquid.
ρ_l	Density of light phase liquid.
ρ_h	Density of heavy phase liquid.
$\Delta\rho$	$\rho - \rho_1$
Σ	Sigma value.
ω	Angular velocity of cylinder or rotor about its axis of rotation.

Discussion

Mr. H. B. Heath : (1) In a liquid/liquid separation of say an oil and weak alcohol, is it always necessary to prime the centrifuge with water, as added water will alter the concentration of the aqueous phase which is the product ?

(2) One frequently gets air entrainment in a diluted alcoholic product which can lead to alcohol loss. Can this be avoided ?

The Lecturer : (1) When carrying out a two-phase liquid separation it is necessary on start-up to prime the bowl with some heavy phase liquid in order to achieve a hydrostatic seal. On many occasions, water is the heavy phase and therefore on those occasions water would be used for priming. Where the heavy phase is a weak alcohol it would be perfectly in order to prime the bowl using some of the weak alcohol which had previously been separated. This would avoid the dilution of the alcohol by use of water as a priming fluid.

(2) The discharge of liquid from the centrifuge bowl into covers which are filled with air sometimes gives rise to problems of air entrainment. If the difficulty caused is due to foaming this can be eased by using a "no foam" Super-Centrifuge. If the problem is one of loss of vapours, this can be handled by using a Vaportite Super-Centrifuge. In extreme cases it may be necessary to consider the use of a fully pressurized system to avoid these problems but the need for this is very rare.

MR. G. H. BURNETT : (1) Are there limitations to the rate of throughput of a super centrifuge ?

(2) Can one pump into a centrifuge and still have a pressure head to feed a distillation unit ?

THE LECTURER : (1) Any centrifuge has basically two limits which are imposed on its throughput which in general are quite unconnected. The first limit is simply a question of centrifuge design and in general is concerned with the pressure drop through the centrifuge, the size of the motor operating the centrifuge, and the size of pump feeding to the centrifuge. The second and more important limit on the centrifuge is its ability to carry out a given separation problem, and the capacity in this case is fixed by the sigma value of the centrifuge and by the physical constants of the material being separated.

It may thus be perfectly practical to pump 2000 g.p.h. of feed through a centrifuge. If, however, the separation performance can only be achieved at a rate of 200 g.p.h. then the second capacity is obviously the limiting one.

(2) The normal open type centrifuge discharges at atmospheric pressure and therefore it would be necessary to pick up the discharge by a pump in order to get sufficient head to feed further process stages. It should be noted that many centrifuges can have integral feed and discharge pumps fitted to the centrifuge to enable this to be carried out. Centrifuges can also be supplied as fully pressurized systems, in which case it then becomes possible to carry out direct feeding to a later stage without the use of a pump.

MR. E. W. CLARK : What is the actual volume of solids which can accumulate in the tubular bowl type of centrifuge before cleaning becomes necessary? Does the efficiency of the centrifuge fall off as a result of the progressive reduction in effective diameter as the solids build up ?

THE LECTURER : The standard No. 6 Super-Centrifuge has a solids capacity of 210 cu. in.

It is indeed correct that the efficiency of the Super-Centrifuge falls off as progressive solids build up takes place. I have given the sigma value of the Super-Centrifuge as :—

$$\Sigma = \frac{\pi l \omega^2}{g}\left(\frac{3}{2} r_2^2 + \frac{1}{2} r_1^2\right)$$

Let us consider a 4″ diameter bowl in which the liquid depth is normally 1″. Under these conditions $R_1 = 1''$ and $R_2 = 2''$. Substituting in the sigma equation we find that $\Sigma =$ constant $\times 6\frac{1}{2}$. Let us now assume that the solids have built up to a thickness of $\frac{1}{4}''$. R_1 is still 1″ but R_2 now changes to $1\frac{3}{4}''$. Substituting again in the equation we have the $\Sigma =$ constant $\times 5\frac{3}{32}$. There has, therefore, been a fall off in effective separating ability of the centrifuge due to solids build up.

In practice solids are not deposited evenly along the length of the bowl since the heavier solids come out of the bottom of the bowl. As these solids build up, it means that the heavy solids tend to get deposited a little further along the bowl and therefore, for a very wide range of applications, this reduction in efficiency is not critical.

MR. W. R. WEBB : (1) Could the centrifuge replace the filter press for separating bleaching earth and fat-stock for soap manufacture, and could advantages and possible disadvantages be indicated ?

(2) Is this method used for the separation of bleaching earth and fat-stock in the Sharples continuous saponification process ?

THE LECTURER : (1) Extensive test work has been carried out using the Super-D-Canter centrifuge for the removal of bleaching earths from vegetable and animal fats. A very high percentage of the earth can be recovered continuously but since the particle size distribution curve for bleaching earth is very wide, traces of very fine material pass out with the fat. Whilst this is not acceptable for edible oil refining where the bleaching stage is at the end of the process, it may well be acceptable in the case of soap manufacture where the bleached fatty material is subjected to many more separational stages.

(2) We do not normally employ this method of separation in conjunction with the Sharples continuous soap process. Indeed, since the process contains four washing stages it is rare that any bleaching operation is carried out. Where the fat quality is extremely poor, pre-bleaching is employed but we then employ a simplified Sharples continuous caustic washing system which relies upon caustic soda as a bleaching agent. There is no reason, however, why the adsorption method of bleaching should not be rendered continuous by the use of centrifuges.