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Synopsis.

The selection and operation of a centrifuge - even in this technological age - tends to remain more an art than a science. This being the case, it can be seen that pilot plant work and previous experience of similar products is essential when matching a centrifuge to a new unknown or unidentified product. That is in spite of established scientific formula for selecting centrifuges, the reality is that, because a particular product rarely approaches what might be called a uniform standard slurry, its characteristics cannot be neatly plugged into a formula, and so there is no real substitute for tried and tested 'suck it and see' experience.

This paper therefore covers the more practical approach to the selection and operation of - in particular - vertical spindle basket batch filtering centrifuges, and surveys both the advantages and disadvantages. At the same time it will touch on factors affecting filtration, means of improving performance, typical applications and small scale pilot plant tests.

Introduction.

Historically a wide range of centrifuges have been developed to meet the increasing variety of solid/liquid and liquid/liquid separations in the chemical process and associated industries. The diversification continues as established designs are improved, and new centrifuges are developed.

The main centrifuge types essentially differ in their ability to recover solids or clarify liquids, in their ability to operate continuously or on a batch basis, and in their ability to act as a filter or sedimenter.

Because of the complexity, assessing the relative merits of machines becomes difficult, especially when a wide variety of process and machine parameters can affect levels of performance. In addition to the many process parameters associated with a given separation problem the centrifuge user may have one or more key objective for the separation. Typically these are one or more of :

- Washing efficiency.
- Cake dryness.
- Mother liquor recovery.
- Minimum power consumption.
- Maximum throughput.
- Minimum operator intervention.
- Minimum cost.
- Etc. etc.

In fact few centrifugal applications can be completely decided by the mere use of scientific formula, and much research work remains to be done in order to refine existing formula, useful though they are. In the meantime the combination of scientific principles, scaled up process laboratory experiments, on-site pilot trials along with user and manufacturer experience is required to find the best type of centrifuge for a specified process duty. Operation on a full scale centrifuge on a specific duty is usually fine tuned during commissioning on product.

Prior to discussing some practical aspects of centrifuge use the basic types of vertical batch basket centrifuges are described.

Basic Types of Vertical Spindle Basket Centrifuges.

A. Underdriven top discharge (See Fig 1.)

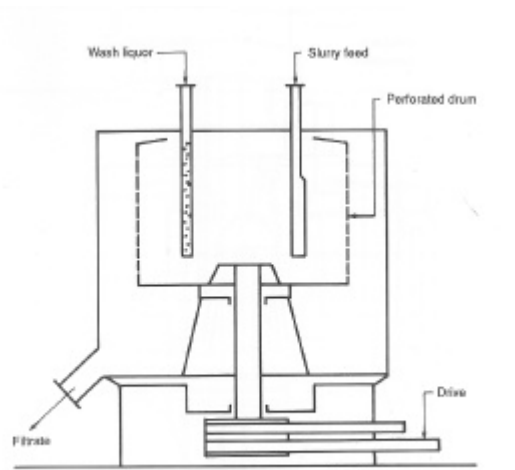


Fig 1. Simple underdriven top discharge.

This is a simple vertical spindle rigid bearing, small filtration centrifuge typically used for laboratories, pilot plant and small batch production. It is normally operated manually (with safety interlocks) with the separated solids discharged through the outer casing top, by either digging out or by removing a complete filter bag. The highest basket speed usually gives around 900 times gravity, with the feed speed being approximately half the top speed. An inverter drive system is an energy efficient way to provide a wide range of speeds for test purposes.

B. Underdriven bottom discharge (See Fig 2.)

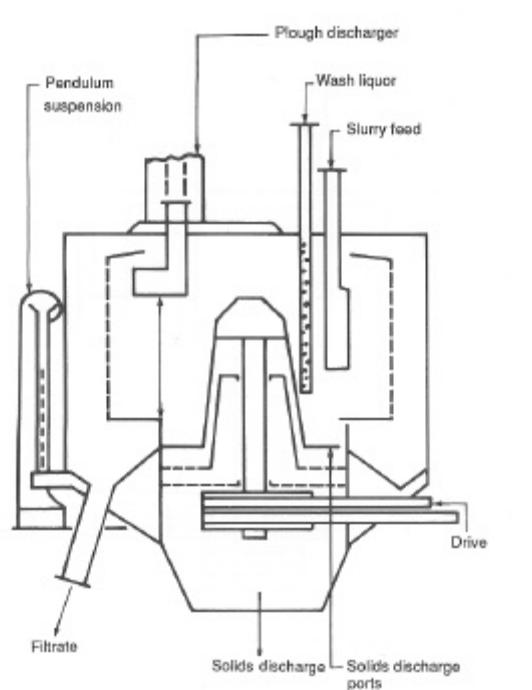


Fig 2. Underdriven bottom discharge.

Fig 2 shows a larger, more versatile, suspended filtration centrifuge for handling bulk batches with the discharge of the separated solids through the basket bottom by means of a traversing plough mechanism.

The underdriven bottom discharge centrifuge is usually operated in a semi or fully automatic mode with the basket speed being infinitely variable to produce from zero to approximately 900 times gravity. Therefore, feed, wash, spin and plough speeds can be fine tuned for a specific process duty. Solids discharged at a very slow basket speed avoids crystal breakage. Again this type of centrifuge can be provided with a lift out filter bag if required. The machine has a 'pendulum' or spring gas damped suspension giving maximum stability under possible liquor loads (i.e. when low cake filtration rates results in free liquid forming on the cake surface) or unevenly distributed cakes. This type of suspension also give an ability to withstand an amount of out-of-balance during operation and reduces floor loading forces when running under such conditions.

It has a very wide use on general chemical and fine pharmaceutical products and on a freely filtering material can produce up to several tonnes/hr of dry product. Such centrifuges are suitable for hazardous locations and can be inert gas blanketed if required.

C. Overdriven bottom discharge (See Fig 3.)

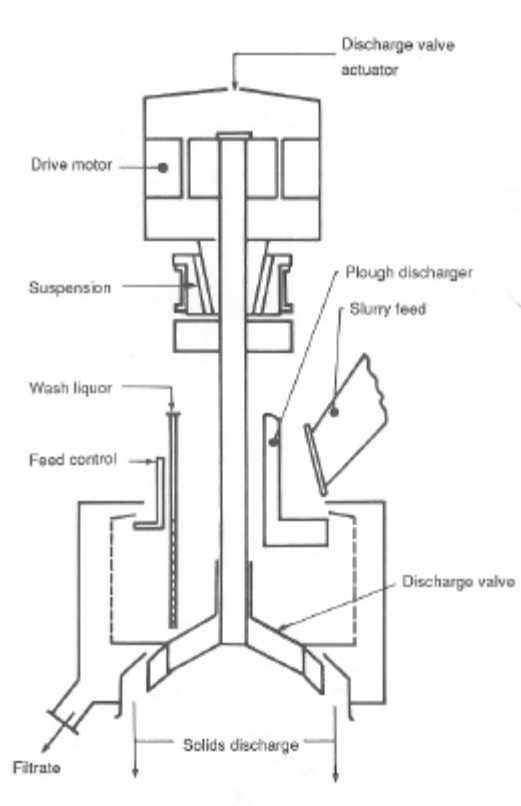


Fig 3. Overdriven bottom discharge batch centrifuge.

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This is an example of a large filtering centrifuge highly developed for the bulk separation of sugar from molasses. The machine is operated fully automatic, flexibly supported from an upper single suspension point to allow continuous operation with a degree of solids unbalance.

Basket speed is variable over a wide range to provide a separating force of up to 1500 times gravity. To avoid crystal breakage solids are discharged at low speed through the basket bottom by means of a traversing plough and a valve located in the basket bottom.

Whilst this type of centrifuge is principally used on sugar and dextrose products at throughput rates at up to 40 T/hr it has over more recent years been applied to certain chemical applications. These non sucrose applications are restricted to large bulk separations of relatively coarse solids, which are very free filtering from thick slurries where there is no possibility of free liquid forming on the cake surface.

Principle of operation of vertical batch centrifuges..

Whilst the three centrifuges (described above) differ in mechanical design the basic operating principles remain the same. The separation takes place in the basket which contains a filter medium (e.g. fine wire mesh or cloth) through which the crystals in the feed cannot pass. The mother liquor is able to flow between the gaps in the crystals and through the filter medium and out of the centrifuge. The driving force pushing the mother liquor out of the centrifuge is large and is created by the centrifugal effect of the basket spinning at high speed.

In all cases feed slurry is fed through the top opening of the basket, which is normally rotating at a reduced speed. Depending on the type of slurry being treated the feed is either introduced directly into the basket, or via a tangential pipe or a 360 degrees distributor cone. The feed rate and/or basket speed is adjusted so that the feed rate matches the filtration rate and slurry covers the basket wall top to bottom forming an evenly distributed cake. In some instances several burst of feed maybe introduced to fill the basket to maximum capacity.

At the end of feeding it is usual to introduce a cake wash through a static wash pipe fitted with a series of spray nozzles. Any wash should be applied prior to the cake drying out completely thus preventing cracks forming in the cake surface, which would provide a short circuit path for the wash medium giving poor washing results.

Washing can be carried out at a reduced basket speed, whilst the basket is accelerating to full speed and/or at full speed. The original mother liquor and wash liquors can be easily separated if required by the means of a diverter valve on the outlet pipe. After washing the final cake dewatering takes place with the basket spinning at full speed.

At the end of dewatering the processed cake must be removed from the basket and this is where the major difference occurs between the centrifuge types. The top discharging centrifuge (Fig 1) must be emptied manually when the basket is at rest. The bottom discharge centrifuge (Fig 2 or 3) is normally emptied automatically and by the use of a traversing plough mechanism. The basket is usually reduced from full speed to 40~70 rpm before the plough scrapes the solids from

the basket wall and directs them through the spoked basket bottom. The basket is then ready to accept the next cycle of feed slurry upon reaching the selected rpm when the procedure is repeated. In the case of a ploughing centrifuge the residual bed of solids is either removed after each cycle or at predetermined intervals. This can be achieved either by the use of an pneumatic device placed behind the plough or by wash jets.

Advantages of Batch Type Filtering Centrifuges.

In general it may be said that centrifugal filters can give drier cakes than other types of filters and that they are more versatile and compact relative to their throughput.

The wide selection of feed, wash, spin and plough speeds available from the drive system of a modern basket centrifuges makes them very adaptable to an wide range of slurries and chemicals.

In addition flexible selection or adjustment of feed, wash, spin and plough times, along with wash quantity, extends centrifuge versatility. Any changes in feed condition or changes from product to product (in the case of multipurpose installed units) is easily achieved, especially by the use of PLC control when changes can be made in with great rapidity.

With the current generation of centrifuges, power consumption is also now much reduced over earlier electrical or hydraulic drive systems. This is achieved by the use of inverter drives which minimise the energy required to run accelerate the centrifuge and, if required, save additional energy by regenerating power during the braking cycle of the basket.

Two major advantages of basket batch centrifuge are the ability to give a very efficient wash of the cake solids using the minimum of wash fluid, and to discharge the separated solids at low basket speed hence ensuring negligible breakage of delicate crystals. The wash liquor and extracted mother liquors are also easily segregated at separate stages of the batch cycle.

Given the correct feed conditions, feed speed and filter cloth basket centrifuges can dewater solids from 1 to 10,000 microns. Basket centrifuges can also be fully sealed and purged for safe operation and on fully automatic operation minimum operator input is required. There is also no need for physical contact with the product or for exposure to possibly toxic fumes. (See Fig 4)

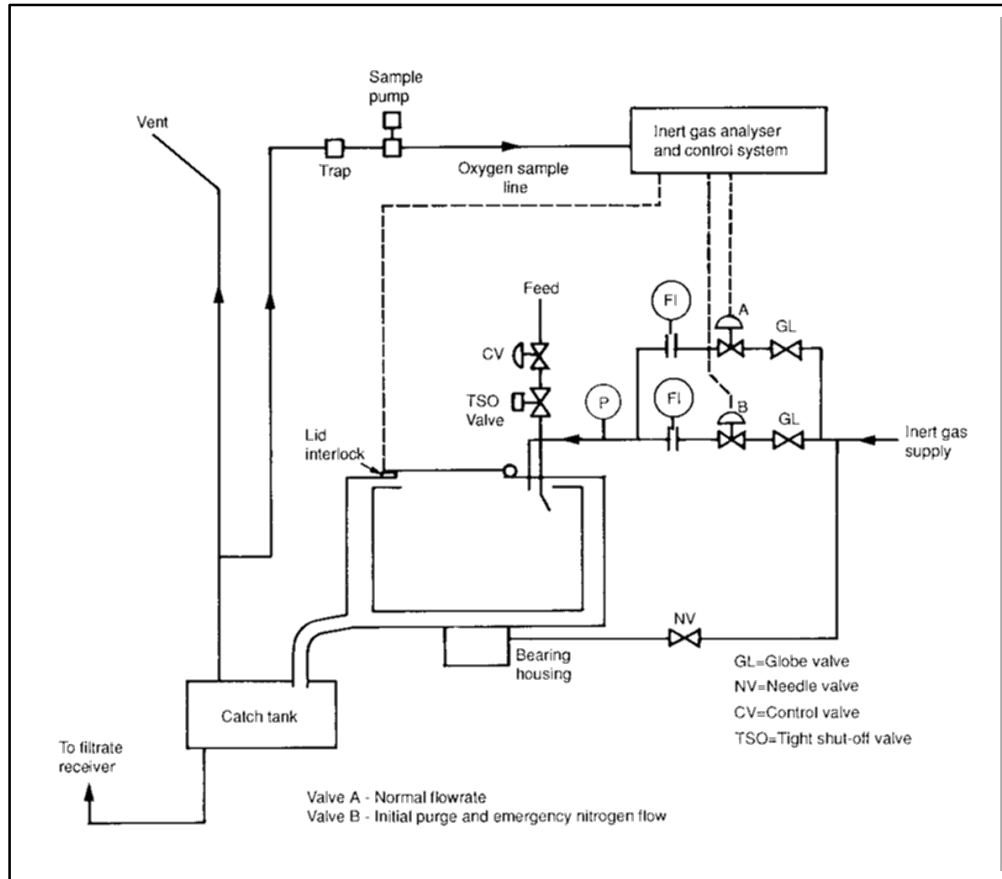


Fig 4. Typical oxygen monitoring system for a batch centrifugal.

Disadvantages of Batch Type Filtering Centrifuges.

The first obvious disadvantage is the fact that the unit does not operate continuously. Hence buffer tank/storage may be required upstream and downstream of the centrifuge.

To achieve reasonable solids throughput/hour the slurry should be fairly readily filtering and slurry should not be too dilute. In addition the separated solids have to be 'free flowing' to enable them to be discharged from the basket wall. Any tendency for the ploughed solids to be sticky or sludge like and discharge from the plough in a 'ribbon' form dictates that certainly automatic operation may not be possible.

A further disadvantage on some plough discharge centrifuges is the residual bed of solids left on the basket wall, typically 6~10mm thick. The residual bed surface can become glazed after several operations and then has to be removed to prevent reduction in filtration rates. Fig 5 shows the reduction in filtration rate of certain materials caused by this effect. The PVC sample shows no reduction in filtration rate, whereas the other two samples show a marked reduction. However for a wide selection of materials the residual bed can be removed automatically with the special plough designs and/or air knife jets trailing the mechanical plough.

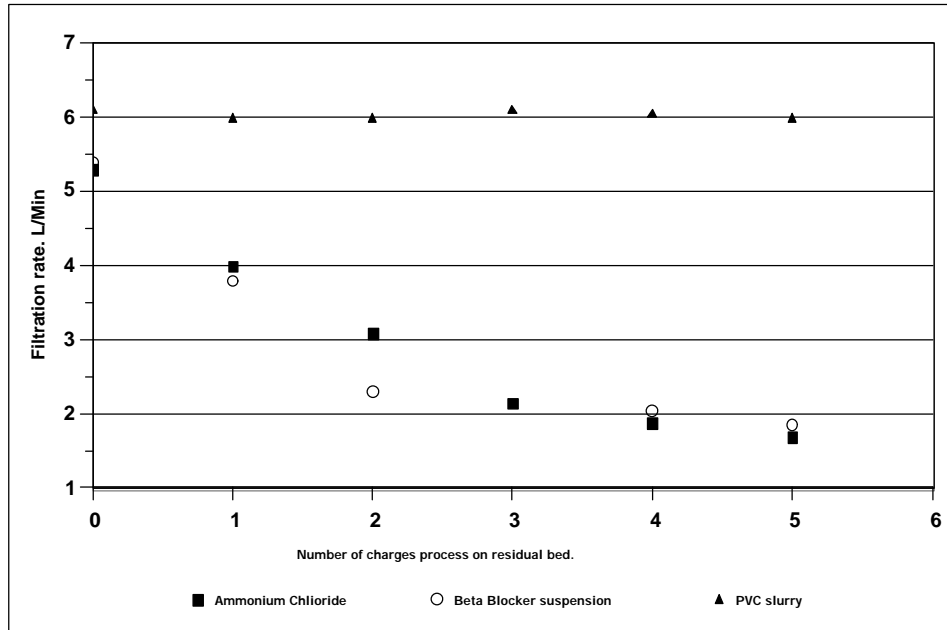


Fig 5. Typical filtration rate versus batches processed on the residual bed.

Factors Effecting Filtration and Capacity.

Factors effecting filtration/capacity can be split into two convenient sections; process and mechanical. The cycle time of a batch centrifuge is firstly process time. This is the time when feeding, washing, spinning and ploughing takes place. The remainder of the time cycle is 'dead time' taken up by either accelerating or decelerating the basket in readiness for the next process function. The throughput of a basket centrifuge is dependent on basket capacity and the total cycle time required to treat one batch. The process section of the cycle will be strongly dependent on the feed slurry characteristics and final specification requirements of cake quality and cake dryness. The time to plough the solids out the basket can be a function of either process or mechanical limitations. The plough action can be carried out in a minimum mechanical time, which usually is the limiting factor. However, on certain products the cake can be sufficiently hard to remove that the plough traversing action has to be slowed down so as not to stall the basket.

The non processing section of the cycle is usually fixed (i.e. acceleration/deceleration) and there is very little scope to reduce this time from that built-in by the manufacturer. Nevertheless this dead time can be reduced at the expense of increasing the drive motor size within certain limits.

Without any doubt the process time of the cycle is the major influence on capacity. Product factors influencing processing are:

- Solids concentration of the feed slurry (See Fig 6).
- Particle size and shape of the solids.

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- Compressibility of the formed cake.
- Impurities requiring washing from the solids.
- Effects on filtration in the case of a residual heel of solids.
- Ploughability of the cake.
- Final acceptable cake moisture.
- Quality of wash medium being used.

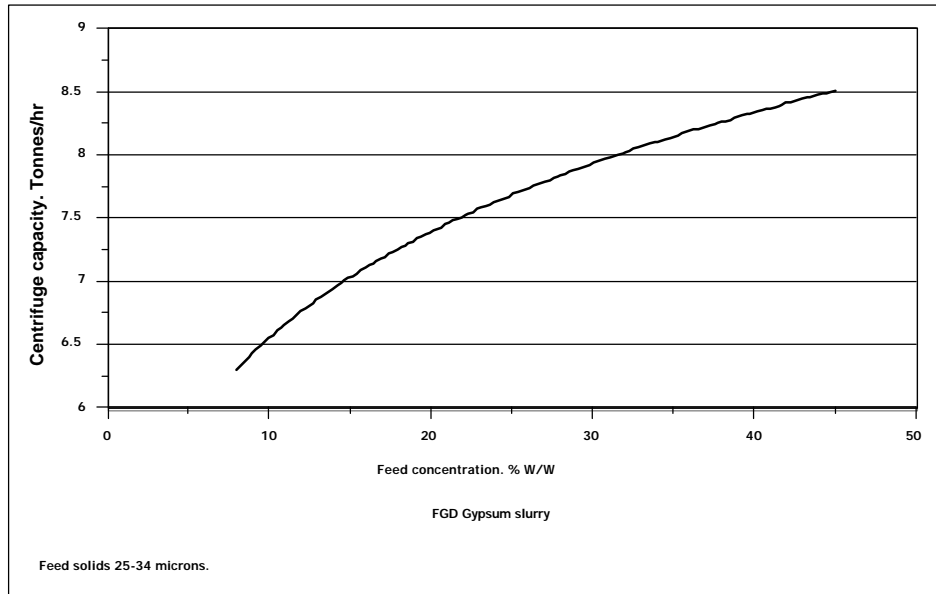


Fig 6. Effect of feed concentration on centrifuge capacity.

Changes to the feed slurry, where possible, can have a large effect on centrifuge performance and capacity. Factors which increase centrifuge capacity are :

- Increasing particle size.
- Altering the shape of the solids to avoid needles.
- Increasing the feed solids concentration.
- Ensuring the basket is filled to a realistic capacity and cake is evenly distributed during feeding.
- Increasing temperature.
- Reduction of any impurities prior to centrifuging.
- Choosing an alternative filter medium.
- Increasing the separating force in the basket.

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Actions to be avoided are:

- Pumping the feed slurry prior to centrifuging to avoid crystal degradation and over agitation in slurry tanks
- Feeding or spinning at too high a speed which could compact the cake, or give uneven cakes
- Washing too late after the cake has de-liquored from feeding
- Building liquor loads on the cake surface either during feeding or washing. This can cause the unit to go out of balance.

Washing of Centrifuged Cake.

Wash performance is one of a batch centrifuge major advantages. Washing of the recovered solids to remove impurities or displace the original mother liquor is ideally carried out in a basket batch centrifuge.

There are three types of wash:

- 1) Displacement Wash. The original mother liquor present in the pores of the centrifuged cake is displaced by the wash liquid.
- 2) Diffusion Wash. Dissolved materials, retained in the capillary liquid and in the surface liquor are transferred to the wash liquid.
- 3) Dissolution Wash. Parts of the solid, which consist of components of varying solubility, are dissolved in the wash liquor.

It may be that more than one or more or even all of the above occur at any one time depending on the material being washed and the wash liquor being applied. Indeed on some processes two distinct wash liquids may be used, the first being a displacement wash followed by a diffusion or dissolution wash.

Irrespective of the above three types of wash, two different methods of applying the wash within the centrifuge are used. These are:-

Flood Washing.

At the start of washing, the voids within the filter cake are still full of the mother liquor. The wash liquor is introduced at a slightly higher rate than which it can filter through the cake. The wash liquid forms a thin liquid level just covering the cake top to bottom.

This ensures that distribution of the wash liquor over the total cake is carried out and is excellent as a form of displacement washing. The high differential pressure formed by this method gives good rates of flow through the cake and is also ideal for displacing high viscosity mother liquors.

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However, to obtain a good flood wash the cake must be evenly distributed within the basket as the wash fluid would seek the path of least resistance on non-uniform cakes. There must also be room within the basket to hold a head of wash liquor, hence the full capacity of the basket can not be filled with cake product. Care must be taken to avoid a thick surface layer of liquid as instabilities can occur in thick layers.

Spray Washing.

Spray washing is exactly as it sounds. Wash liquor is supplied through a series of spray nozzles directed towards the cake in the centrifuge basket. This form of washing is ideal when say the amount of wash water to be consumed is small at up to 30~35% of the volume of cake to be washed, and especially if the cake is extremely free filtering. Spray washing is probably the most effective wash method when minimum amounts of wash water are demanded by the process and is the only effective way of washing cakes which are non-uniform in shape from top to bottom of the basket.

Centrifuges generally require less wash medium than other forms of filters for a given reduction of impurities or volume of solids being washed. Excess wash water should be avoided, the most effective removal of impurities occurs early in the wash cycle - extensive washing can be wasteful and ineffective. Many types of material when centrifuged to remove the original mother liquor either dry out and can become difficult to re-wet out, or form cracks in cake. Therefore it is important that any wash medium is applied as soon as the original mother liquor has drained from the cake. This prevents the wash liquid from tracking through the cake locally at the crack and from impairing the effectiveness of the wash. Severe cases of local tracking of mother or wash liquors can cause out of balance conditions to occur. With the aid of a diverter valve and pipe work on the centrifuge outer casing outlet, mother liquors and wash liquors are easily segregated if required.

Alternatively the cake can be de-watered from the original mother liquor, ploughed out into an agitated tank full of wash medium liquid and then re-centrifuged. This type of washing is very rare when operating batch type centrifuges

Centrifuge Pilot Plant Test.

To fully ascertain if a product can be successfully treated in a basket centrifuge, especially if there is no previous history of centrifuging of the product available from other reference sites, it is essential that pilot tests are carried out. All reputable manufacturers provide either pilot plant centrifuges for on-site work or have process laboratories within their organisation where samples can be submitted for trials.

Prior to tests commencing the required performance for a particular application should be specified. Generally the performance requirements falls into one of the following cases :

- Maximum throughput of solids with some specified level of cake moisture and clarity of filtrate
- A clear filtrate at maximum rate where the cake moisture content may or may not be critical

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- Maximum throughput where cake moisture may or may not be critical
- Removal of mother and wash liquors from a cake to reduce impurities down below a specified level and possibly cake moisture level

Due to the variations available on both basket speeds, feed rates and the adjustment of the duration of each part of the cycle testing to fine tune the operation of the centrifuge can be complex.

As a minimum test work should investigate and record performance in the following areas :

- Mechanical data on the filter basket, dimensions, speed, 'G' factor at each part of the cycle, filter media type etc.
- Slurry data, i.e. solids content, particle size and shape, pH, impurities, specific gravity, temperature etc.
- Feed rate, volume and duration of feed
- Filtration time, rate and volume of filtrate
- Wash time, rate and volume of wash media
- Final spin time and extraction rate of liquid
- Cake thickness, volume and bulk density of cake as packed in the basket
- Discharge properties of cake from the basket

Several repeat runs should be made to determine impact on filtration rate of residual heel of solids remaining in basket. From the data collected a 'mass balance' can be produced and hence throughput capacity can be determined. Sealed samples of feed, wash liquors, filtrate, cake and the residual heel should be taken from each run for analysis to determine performance.

Further detailed investigations may be carried out on key parameters such as wash volume, spin time and/or spin speed and cake moisture content. This extra data will assist in determining the final centrifuge parameters required to meet the end users guaranteed process performance requirements. (See Figs 7 and 8)

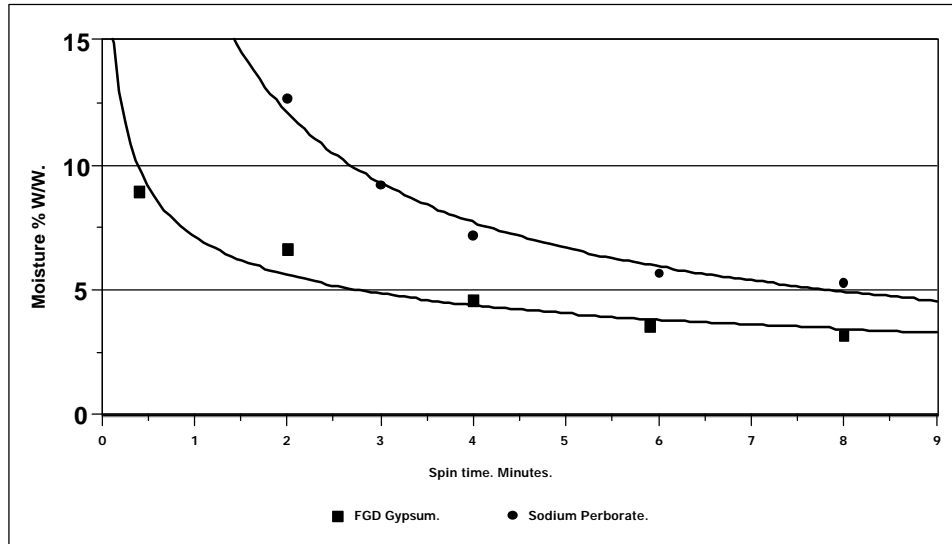


Fig 7. Variation of cake moisture against spin time.

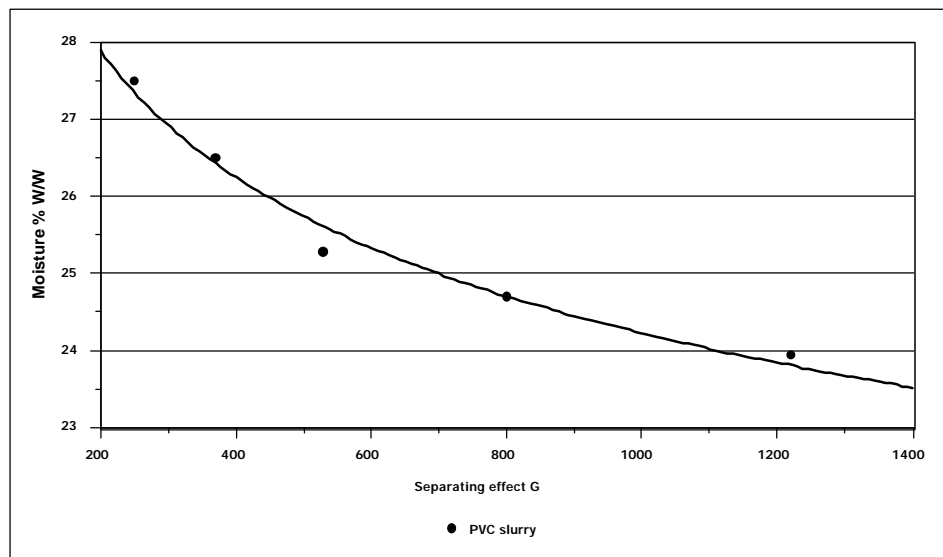


Fig 8. Cake dryness against separating effect (G).

It is important that the feed slurry used in any test is representative of the material to be produced at full scale. Any discrepancies at the testing stage can result in the wrong selection of centrifuge size and/or number required at full scale. This in turn can lead either to the under sizing of equipment and loss of production / inferior process results or alternatively over capacity of equipment.

On green field projects large samples of proposed product may not be readily available and typically only volumes of 1 to 2 Litres are available for test. It may therefore be necessary to make do with a paper specification. In this case prediction of process results and final sizing of equipment is more difficult. Bench type laboratory tests can be carried out to determine filtration

characteristics on very small samples. However predictions on performance and of equipment type and size based only on a small samples are difficult and liable to error. Predictions of performance and of equipment type and size based only on small samples or on a product specification are best left to the process experts of an organisation manufacturing separation equipment or other organisations with a wide range of process experience. Usually manufacturers have a wealth of process knowledge data/test reports they can draw on from previous pilot plant work on a multitude of similar products.

If reasonably sized pilot plant tests have been conducted then predicting size, type and number of centrifuges required from within the manufacturers range for a specific process duty is reasonably straight forward. As centrifuges from one supplier are usually geometrically similar the procedure for scale-up is to determine 'G' force, cake thickness, feed solids content, wash liquid volumes, number of basket fillings, filtration area and the timing of the various operations (including processing time and mechanical acceleration/deceleration and solids removal times).

Add this to the supplier's process knowledge and experience of his centrifuge range, and on the majority of enquiries a successful full scale plant operation is achieved.

Typical Applications.

Basket centrifuge applications are extremely wide and diversified. Generally crystalline or discrete particle slurries make up the majority of applications especially where good washing of the cake and minimum damage to the solids is a prerequisite. Typically the product is of high value, hence batch type operation in medium to low volumes is acceptable, as in the fine chemical or pharmaceutical industries. Throughput rates can be as low as a few hundred kilograms per hour. However, there are exceptions to both the need for crystalline type products and medium to low volumes. These range from such applications as ice cream removal from its packaging, nitro cellulose, animal bile, blood plasma separation to such applications as tonnage volume manufacture of sugar crystals and wall board quality gypsum crystals - the latter as a by product from the limestone flue gas desulphurisation process at coal power fired stations. The last two process applications usually involve a battery of automatic basket centrifuges in relatively large numbers operating in sequence.

Throughput rates on an individual sugar centrifuge can be upto 40 tonnes/hour of sugar and on the gypsum process in the range of 5.0 to 8.5 tonnes/hour of dry solids depending on the quality of gypsum to be processed. (See Fig 6).

Other Considerations for Selection.

Having satisfied the process aspects of the application other considerations should be taken into account when selecting the centrifuge type and manufacturer to ensure the overall plant installation conforms to the end user's total requirements.

These include:

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- 1) Controls - are they flexible, latest technology and compatible with other or existing PLC systems on the plant. Is the PLC programming carried out by the manufacturer and can changes to the cycle time/basket speed/feed and wash volumes be easily adjusted?
- 2) Drives - is the drive economical, suitable for Exd atmospheres and reliable? Are the feed, spin and plough speeds infinitely variable and can power be regenerated during the braking sequence to save on running costs?
- 3) If required can the centrifuge be sealed or pressurised to contain vapours. Can the unit be purged with an inert gas system?
- 4) Automation - is the unit capable of fully automation operation with the minimum of manpower and physical contact with the product?
- 5) Will the unit handle out-of-balance loads, shut down safely if such a condition occurs and also consider the type and position of installation requirements to withstand out of balance loads i.e. ground or upper floors etc.?
- 6) Materials of Construction - will the centrifuge process contact parts interact with the material being treated? Which other construction or protection materials are available with one compatible with the product and can be used as part of the centrifuge manufacture at a realistic cost?
- 7) Noise - is the centrifuge under consideration within guideline limits of noise emission or will extra noise reduction cladding etc. be required?
- 8) Maintenance and Service Support - is the unit easily maintained and mean time between failures (MTBF) acceptable along with an access to the internals of the centrifuge for cleaning and changing filter cloths?
- 9) Can the supplier provide adequate back up spares, service and process knowledge to support the unit during installation, commissioning, operation and troubleshooting?
- 10) Safety - Will the unit cover all safety aspects of interlocking to prevent over speed, access during operation, motor and belt guards access, out of balance, purging, pressure loss detection etc.?
- 11) Finally and probably closest to most peoples hearts is price and delivery. Is the unit value for money both process and technically? Will it satisfy the duty within budget and be available within the project time scale to launch a new product onto the market at the right time and price?

Conclusions.

The basket batch centrifuge has the flexibility to satisfy a wide range of process duties giving excellent removal of the solids and giving clear filtrates over a wide particle range of solid material.

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Washing of the cake and separation of the solids without damaging the crystals is without doubt the key factor in the favour of multi-speed basket filtration centrifuges.

Pure theory alone is of limited help in the application of filtering centrifuges. Laboratory bench tests on the product to be treated can assist if the data is inserted into the theory. Theoretical work can indicate the direction that pilot test work should proceed, but further research work is required before theory becomes accurate enough to scale and predict the size, type and number of centrifuges to give a specified process duty including process performance.

Pilot plant scale tests are necessary to obtain accurate scale-up operation and performance data, unless the process is already a well proven application and reference data can be utilised. Even then similar named products can vary in particle size, solids concentration, washing requirements and hence processing times can vary.

It is the combination of application and operational experience, pilot plant laboratory testing, and design plus analysis capabilities of the centrifuge manufacturer combined with the end users specialised knowledge of their material which ensures that the full size process plant installation is producing the quantity and quality of product economically and on schedule.

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