Is it right to blame the Centrifuge?

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Synopsis
It is almost universally accepted by those involved in the separation processing industry that the separation of liquid-solid suspensions is a highly complex subject matter. This, in part, is due to the almost infinite and diverse nature of materials available for processing, coupled with the vast array of separating equipment currently available on the market.

Many knowledgeable and learned individuals have, over the years, gone to great lengths to examine and study the field of liquid-solid separation, producing detailed technical papers, formulae and theories. Whilst not attempting to undermine or vilify their valuable contributions in any way what so ever there is also, just as importantly, a highly practical aspect to this field.

It is therefore the intention of this paper to cover the practical issues surrounding the vertical batch basket filtering type centrifuge, although most will apply to similar equipment, that must be addressed if a safe and efficient separation process is to be realised.

1. Introduction

Solid-Liquid separation is a truly ubiquitous unit operation. It is almost impossible to consider any chemical or pharmaceutical manufacturing process that does not have at least one such separation stage somewhere in the making. In addition to this there is a large effluent and environmental market also utilising such technology.

Yet, as common as it is, the field of solid-liquid separation is generally not well understood. In part this is because of the very complex nature of fluid-particle systems. This lack of detailed understanding, not surprisingly leads to many problems within the industrial processing plant.

With greater demands constantly being placed on the process efficiency and improved final product quality it is imperative that 'engineers' gain a better understanding of this technology.

Thanks to industrial magazines, exhibitions, organisations such as the IChemE, Filtration Society and many others there has been a substantial growth in recent times in the amount of relevant information being made available.

Complimenting this upsurge in information, manufacturers are continuously pushing out the boundaries with a plethora of innovative equipment designs for the industry to select from.

Despite the increase in available information on the subject, the situation still presents a tough challenge for an end user who is seeking to realise the full potential of his or her separation equipment.

It is the object of this article to go some way towards assisting the process/plant engineer in this, at times, complex subject matter. Whilst it is fully appreciated that there is a great number of different makes and types of liquid-solid separation equipment it is the intention of this particular paper to concentrate solely on the operation of the batch filtering type industrial centrifuge.

Many's the time centrifuge manufacturers or centrifuge experts are called to the process plant to evaluate a batch basket filtering centrifuge that is reportedly causing problems to the process plant and its operators. Experience has told the visiting process engineer that in the majority of cases it is not necessarily the actual centrifuge that is causing all the problems.

Before embarking on work of any kind at the centrifuge it is strongly recommended that time is spent with the operators/supervisors so as to establish a clearer picture of the situation. Once all data and a detailed evaluation has been collated one can then begin to look at the centrifuge and installation as a whole.

A centrifuge will tolerate a certain amount of minor problems but if not fully optimised will quickly acquire a very bad name, irrespective of all the latest refinements a manufacturer incorporates in its designs. There are many influencing factors that individually or collectively go towards a successfully optimised centrifuge.

Whilst this article is not specifically aimed at centrifuge optimisation, an understanding of the potential influencing factors surrounding the centrifuge will go a long way towards achieving this.

With regards to the integrity of the centrifuge one must systematically carryout checks in two key areas. Firstly there is the mechanical integrity and secondly the electrical integrity. It may be that the actual problem becomes clear very quickly. In such instances these can be rectified almost immediately.

It is worth noting at this point that if any problems could cause, or even suspected of causing, injury to operators or breach Health and Safety issues then the centrifuge must be shut down and isolated immediately. This must remain the case until such issues are fully addressed.

The following article therefore systematically covers several key areas, often overlooked, that may lead to problems with the operation of the centrifuge. The list is by no means exhaustive but is considered to cover the majority of the influencing factors both upstream and downstream that affect the smooth operation of an industrial batch filtering centrifuge.

2. Impeller and Vessel Design

The first thing to acknowledge is that both these areas go hand in hand. Correct mixing vessel configuration, impeller type, size and position have all to be considered collectively if the needs of a particular mixing operation are to be successfully met.

In short, the first priority is to match the impeller to the total mixing requirements of the entire process in question. Secondly, and just as importantly, is to meet mixing requirements at a minimal capital expenditure at minimal cost of operation. Therefore creating maximum mixing efficiency at minimal cost.

The following should serve as a guide for attaining these two most important goals in the design of fluid mixing systems experienced in virtually all such process's.

2.1 Common Impeller Characteristics

In essence there are two fundamentally different impeller designs, one that specifically provides Axial flow the other Radial flow.

2.11 Radial Turbine (also called Straight or Flat)

- Discharges flow radially across blade tips
- Moderate shear
- Modest pumping capability
- Not considered efficient hydraulically (i.e. Pumping)
- Flow enters impeller from above and below, unless turbine is shrouded, creating 2 flow patterns
- May be preferred for low aspect ratio vessel or low operating levels

2.12 Standard Pitched Blade (32^0 or 45^0 turbines)

- Discharges flow primarily axially
- Lower shear device
- Moderate pumping capacity
- Considered reasonably efficient pumping device
- Flow enters one side, typically above, of the impeller and discharges at the opposite, below, developing a single flow pattern

2.13 Hydrofoils

- Discharge is highly axial
- Very little shear
- High pumping capabilities
- Considered an efficient pumping device
- Flow pattern as with pitched blade turbine above
- More sensitive to Reynolds number (fluid viscosity) than standard pitched blades, therefore, not generally appropriate for higher viscosity's
- More sensitive to proximity to tank bottom and therefore generally not suitable for low level mixing

Impeller design is continually being developed to further improve process performance and reduce processing costs. In addition to the most common impellers outlined above there are other designs, such as the propeller, gasfoil, counter current, draught tube and pump mixing impellers to name but a few, all of which are employed on more specific process applications.

It can not be emphasised enough that the choice of an impeller is heavily dependant on the tank geometry, fluid characteristics and desired process results. Therefore before deciding upon a specific design of impeller the application under consideration must be clearly defined and understood.

2.2 Process Application

Process Requirements
Generally speaking there are 3 fundamental classes that mixing applications can be assigned to. Many applications may actually involve a combination of those shown below.

- Blending - Liquid/Liquid - final fluid rheology
  - a particular blending time, if critical
  - any heat transfer criteria, again if critical
  - a need to promote reaction

- Solids - Solid/Liquid - maintain uniformity
  - level of suspension required
  - to promote mass transfer/reaction

- Gas Dispersion - mass transfer
  - to promote reaction

2.3 Size of Application
In addition to having a detailed understanding of the process requirement it is necessary to quantify the physical size of the application.

Impeller manufacturers determine size of an application from what they call the ‘equivalent volume’. This is the product of the actual volume and the fluid specific gravity. As the impeller is transferring momentum to the fluid it is reasonable to include the liquid density.

2.4 Degree of Difficulty
The degree of difficulty is determined from the fluid/solid/gas properties encountered in the application.

For blending fluids the specific gravity's and viscosity's of the components, and the required blend time, determines the difficulty. The size and rate of component addition can also influence impeller selection and power installed

A liquid/solid on the other hand encounters difficulties such as the rate at which the solids settle in the suspension liquor. Obtaining data such as the particle size distribution (PSD), density of solids and the liquid will allow the impeller manufacturer to calculate the settling rate of the solid phase matter. The required degree to which the solids must be suspended also contributes to the difficulties especially with regards to the impeller size.

For a gas dispersion application, the rate at which the gas is being introduced will be a measure of difficulty as well as the required degree of dispersion

Non Newtonian fluid characteristics, difficulty in wetting out solids, agglomeration of solids, and many other factors impact on the difficulty of a particular application.

2.5 Dynamic Response

After classifying the application, determining the size and difficulty of the mixing problem it is necessary to provide the appropriate dynamic (fluid motion) response to achieve the desired process results.

The vast majority of mixing applications involve blending, bulk motion and/or suspension of solids. The appropriate dynamic response for all of these mixing classifications is fluid velocity which is achieved by investing torque. These are called ‘flow sensitive’ or ‘flow controlled’ applications.

Gas dispersion applications, which are mass transfer applications, and mixing of immiscible fluids require shear and are more power dependant - these are ‘shear sensitive’ or ‘shear controlled’ applications.

2.6 Scale Up

The above process can be greatly simplified if existing successful process data or experience can be provided, something often omitted from enquiry specifications.

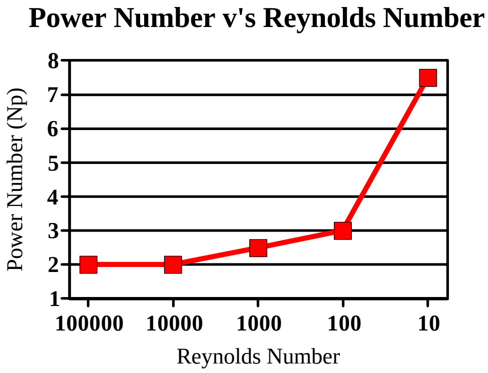
2.7 Power Number

Irrespective of which impeller is ultimately selected, mixing efficiency is the primary criteria in choosing an impeller type/design. Associated with this is the Power Number (Np). A low power number impeller must be larger in diameter than higher power numbers for a given motor size (hp) and impeller rotational speed. Although low power number impellers are generally regarded as the most efficient, if the impeller diameter exceeds 40-50% of the vessel diameter, pumping power falls of sharply. High power, high intensity mixing requirements usually call for a high power number impeller to be selected in order to reduce the overall impeller diameter.

The power number, Np, is defined as: $$Np = \frac{P \times 6.12 \times 10^7}{Sg\ N^3\ D^5}$$

Where,
- P = impeller power (hp)
- Sg = specific gravity of fluid
- N = impeller speed (rpm)
- D = impeller diameter (ft)
- μ = viscosity (cp)
- NRe = $1550 \times N \times D^2 \times Sg/\mu$

Power number, Np, tends to be constant for a given impeller for Reynolds number in excess of 10,000. It is this constant value that is referred to as the impeller's power number. However, power number increases at low Reynolds number (small vessels and/or high viscosity).



3. Vessel Design Considerations

3.1 Feeding/Charging of Vessel

Feed lines to a large percentage of tanks, where solids must be kept in suspension by impellers come directly into the tank tops. If the feed inlet is at some other point on the tank, this need not necessarily affect mixing requirements but extra care must be taken. Practical considerations include avoiding feeding directly into particular tank areas- such as behind a baffle where build-up of solids would be likely. Also, of course the solids must be pre-slurried in the feed stream, or the controlling mixing requirement may be wetting out of solids, rather than solids suspension.

3.2 Draw off points

Careful selection of draw off points from vessels is extremely important for the success of a solids suspension operation. The best draw off point is usually near the bottom of the tank straight.

Special cases may see a need to position the draw off line higher on the side of the tank. It may be necessary to extend the outlet pipe inward from the wall of the vessel, and make other careful adjustments to achieve as close as possible an average outlet slurry consistency to that in the vessel.

Some continuous flow mixing operations may make it mandatory to overflow from the vessel. This would necessitate maximum solids suspension mixing requirements.

The bottom centre of the vessel is generally regarded as a relatively poor draw off point. Where a bottom centre take off is employed it may be beneficial to install an inverted cone for deflection of the impeller flow and protection of the outlet from blocking.

3.3 Vessel Baffles

Anti-swirl baffles are an absolute must for developing the vertically upward flow streams required for development of best suspension uniformity of solids in a mixing vessel. Always use such baffles, unless there is some reason why they can't be tolerated.
For 2, 4, 6 or 8 bladed impellers four baffles should be used. Each baffle should be spaced 90^0 to each other, with each baffle 1/12th tank diameter in width, always set out from the tank wall (to a maximum of 30% of the baffle width). Note, that for 3 bladed impellers there should be 3 off baffles, 120^0 apart and of increased width.

Higher solids content slurries generally become more viscous and non Newtonian and will require more individual consideration of impeller and baffle recommendations. Usually narrower and bolted design baffles are recommended.

Where the solids have any floating tendency or in any operation where wetting-out of solids is a requirement, the baffles should be terminated well below the initial liquid surface. This will promote surface vortexing for better draw-down. An upper impeller may also be desirable for such operations.

A flat bottomed tank is a very effective shape for the suspension of solids. If a dished bottom is used, the deepest such bottom tolerable for good suspension of solids is the semi elliptical dish. The more difficult application applications in such dished heads may see a need to extend and contour the anti-swirl baffles into the dished bottom, to extend the mixing impeller downward and/or to fit a tail turbine design. Deep cones are not beneficial to solids suspension and should not be employed.

Corner fillets in flat bottomed tanks will minimise the problems of clean out of such tanks and failure to keep material in suspension.

3.4 Other Considerations

Most solids suspension applications are best satisfied by vessels having a slurry height to diameter aspect ratio less than 0.9-1.1.

In continuous flow systems, the basic requirement is to establish an equilibrium in the vessel such that the consistency of the outlet mixture will be equivalent to the average materials being added. This may not require that the vessel contents be ‘uniform’ at any time, simply that the system is stable and not building up in total weight % of solids or % of the larger solids. Where other fluid mixing processes are involved i.e. leaching , mass transfer etc. High degrees of uniformity are usually necessary. Continuous suspension process systems particularly those where reactions and systems in series are involved may use top level or intermediate level outlets. These may be benefited by the use of upcomers to feed the slurry from the tank bottom to the elevated outlet.

With tall tank continuous flow systems benefits may also be gained by considering draught tube mixer designs which can offer increased mixing process efficiency and reduced capital costs.

By keeping these criteria in mind, and letting them guide you accordingly, one will be far ahead in the selection of the most appropriate impeller design for the mixing needs in question. All of which will lead to a homogeneous slurry mix moving forward towards the centrifuge for separation.

4. Slurry Delivery Pump

Having now incorporated a vessel and agitation system that will produce a homogeneous mix with minimal degradation to the suspended particles it is vital that all that good work is not undone by selecting an inappropriate type of delivery pump that will move the slurry forward to the centrifuge.

4.1 Centrifugal Pump

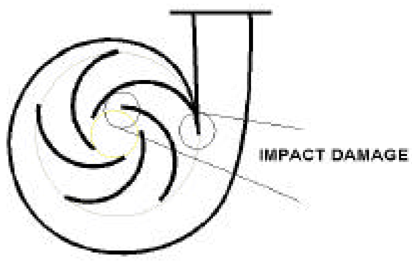
Experience has shown that when faced with the problem of pumping a liquid/solid suspension the first reaction by most processing plants is to consider selecting a conventional 'Centrifugal' pump.

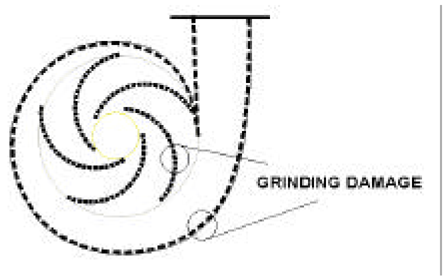
If the solids are hard and robust in nature then this is fine, with many specialised versions of such pumps widely available fit for this purpose. However there are large risks, especially when processing the more delicate and fragile solid particles frequently found in the Chemical and Pharmaceutical industries.

Conventional centrifugal pumps function by enclosing a rotating vaned impeller inside a stationary casing. This means that the suspended solid particles will make contact with the rotating impeller. Contact will be made with the impeller in two ways.

- Firstly the particles impact on the sharp inlet edges of the impeller vanes.
- Secondly they impart a grinding action as they flow along the surface of the impeller vanes.

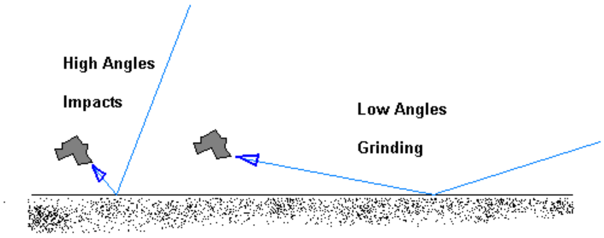
In addition to this further damage is caused as they leave the impeller and grind along the internal surface of the pump casing. Finally they impact on the discharge connection of the casing.



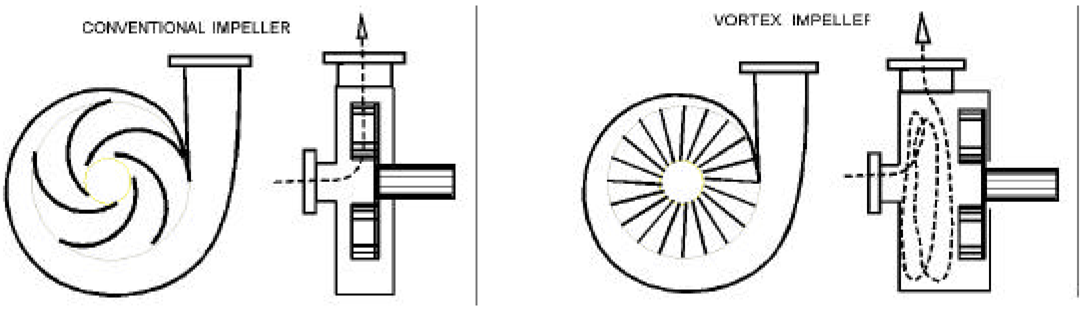


In impacts, the particles strike the surface at a very high angle and most of its kinetic energy is dissipated in fracturing the material surface, as well as itself. The damage intensity for brittle solids is related to the rotation of the impeller/particle hardness. If the particles are soft or fragile but with low hardness then particle damage may well be extensive.

In grinding action the particles strike the surface at very low angles. This tends to rapidly spin the particle. The particle damage intensity is less intense, since not as much of the particle kinetic energy is dissipated.



All this said there is a derivative of conventional centrifugal impeller pumps which replaces the vaned impeller with a vortex-generating impeller. The impelling action exerted directly by the vanes is replaced by a strong forced vortex in the casing. This is generated by the indirect action of an impeller that is largely buried away from the main flow. Such designs are called ‘Recessed Impeller’ pumps.



The advantage of this concept means that there is little, if any, direct physical contact between the particles and the rotating impeller thus allowing soft fragile particles to be transferred with significantly reduced attrition.

The impelling action consists of shear in the fluid rather than direct hydromechanical action. In conventional pumps the designer tries to eliminate fluid shear as much as possible, as this represents losses.

Recessed impellers actually turn this mechanism to its advantage. Since shear forces are a less efficient work transfer mechanism, the pump efficiency turns out to be somewhat lower than in a conventional pump. The shear mechanism is of no concern if the particles are robust but if they are very soft then the structure may still be damaged.

4.3 Progressive Cavity
As an alternative, and probably a more commonly employed delivery pump, is the ‘Positive Displacement, Progressive Cavity’ type.

Like all progressive cavity pumps they are a type of rotary, positive displacement pump. They have a unique characteristic design which is the special configuration of the two main pumping elements and their respective relationship to each other with each shaft rotation.

4.31 The Rotor - This is the only moving element, which is a single external helix that is circular in its cross section. It also maintains a circular eccentric motion as it rotates, hence the name, rotor.

4.32 The Stator - This is the stationary pumping element with an internal helix. When the stationary element, the stator, is combined with the rotor cavities are created. As the rotor revolves these cavities progress in a spiral motion through the length of the pump. Complementary cavities are formed, so as one cavity is finishing its cycle another is beginning its cycle. This results in an uninterrupted, continuous flow of material through the pumping elements.

4.33 The Function - Due to the compression fit between the rotor and the stator and the combination of the helical forms, discrete cavities which are positively sealed are formed. The sealing lines defining the cavities will hold pressure even when the pump is not running.

Since the cavities are completely sealed, positively isolating the suction and discharge conditions from each other, the pump is capable of high suction lifts and relatively high pressures, independent of its operating rotational speed.

Their positive displacement and flow proportional to speed characteristics, together with their ability to pump against pressure, at very low speeds, along with very low mechanical damage to fragile suspended solids, make these pumps ideally suited to feeding most, if not all, material encountered by filtration type industrial centrifuges.

There are undoubtedly a plethora of different types and variations of pump but those mentioned above are, based on experience, recommended for consideration for the delivery of relatively fragile particles to industrial centrifuges.

It will be argued by some that a diaphragm pump is also capable of delivering material to the centrifuge without any significant particle degradation. However by the shear nature of their operation this type of pump produces a pulsating flowrate. This can be virtually eliminated by employing longer pipework runs.

With specific regard to centrifuging both pulsating delivery flowrate rates and long pipework runs between the pump and the centrifuge must be removed if at all possible if smooth operation is to be achieved.

If considering, for example, a new installation then gravity feeding is a desirable option and would require no pump at all.

5. Pipework

The combination of appropriate slurry vessel, agitation and delivery pump selection will result in a homogeneous mixing and pumping regime that will produce a constant, consistent and none pulsating flowrate plus minimal damage to the suspended solid particles. It is now vital that the slurry is delivered to the centrifuge as quickly, but gently, as possible.

In order to achieve this one should aim to produce a slurry delivery pipework line that is as;

- Straight as possible
- Steep as possible
- Short as possible

As briefly mentioned above a gravity system is the more desirable as it removes the likelihood of having to use a feed pump and all its associated potential problems plus it will almost guarantee that the feed line will in deed be straight, steep and as short as possible.

As we all know to well this is not always possible therefore careful consideration must go into the pipework and its routing. Any possibility for solids to settle out or crystallise in the pipework will cause significant problems, (vibration) to the operation of the centrifuge due to the inconsistent ‘plug’ or restricted flow of slurry.

In order to remove this potential the pipework must comprise of minimal vertical and horizontal lengths and not have to travel more than a few metres before arriving at the centrifuge. 90^o bends or elbows should also be removed from the pipework and replaced with more gentle sweeping bends. This will not only maintain a steady feed velocity, also very important, but it will also further assist in reducing particle damage.

If the material being processed in a centrifuge or any other separation equipment is subject to electro static issues it is advisable to avoid the employment of non-conducting pipework but if this is unavoidable, say for corrosion reasons, any non-conducting sections of the pipework run should incorporate an earth continuity conductor.

6. Installation

All centrifuges must be installed on level, well prepared foundations. In the case of suspended pendulum type centrifuges, or centrifuges supplied with vibration dampers, the requirement for the base are not very onerous. Rigidly mounted centrifuges on the other hand require substantial foundations.

Vibration analysis of the structure should be made to ensure that it does not contain resonant frequencies in either the horizontal or vertical axis which could be excited by the movement of the centrifuge.

External connections to the centrifuge such as process and filtrate pipes, solids discharge chutes, electric and hydraulic connections must all incorporate plenty of flexibility to allow for the movement of the centrifuge under the influence of out of balance forces, without themselves imposing any restrictive loading.

There should also be plenty of space between the centrifuge and other process equipment, a minimum of 150 mm is recommended . Should the centrifuge exhibit high levels of vibration or other forms of movement it must not be allowed to collide with other process equipment close by.

7. Downstream factors

The final section looks briefly at potential problematic areas downstream of the centrifuge. Having managed to finally get the slurry into the centrifuge it is just as important that it is adequately catered for as it leaves the centrifuge during and after processing.

Unlike the single stream of the slurry one is now faced with primarily two separate streams, the solid phase and the filtrate phase. (If a product wash is applied it may mean a third or even more streams are to be considered).

Most vertical basket type centrifuges discharge the final solids, cake, through an opening in the bottom of the centrifuge which is then catered for in many ways. It can , for instance, fall directly into a dryer, onto a conveyor or directly into catchment containers such as bags or kegs.

The key point to make is that what ever system employed to look after both the solid and liquid phases it must under no circumstances delay or slow down the upstream processing. Delays in removing them from the centrifuge prevents the centrifuge from processing another batch immediately this means that the slurry at the beginning of the process is receiving unnecessary agitation. This will lead to particle degradation which will ultimately mean possible separation problems when it does eventually reach the centrifuge. This problem will be compounded further if a ring main feeding system is being employed as the slurry is re-circulated through the pump and pipework.

8. Hopper Design

One very important property, often overlooked, is the flowability of the final cake solids as they are discharged from the centrifuge. Factors such as particle size distribution, cohesion and friction between the particles and the hopper walls affect hopper emptying behaviour. This friction and cohesion between particles will almost certainly lead to bridging or choking, piping and a none uniform flowrate if the hopper is not designed accordingly.

Knowledge of the cakes flowability index will assist in the hopper design. Especially with regards to wall angle, length of hopper, and size of opening. It may be necessary to coat the inside surface of the hopper with say Teflon or PTFE to reduce the possibility of unwanted solids sticking.

9. Filtrate Line

Virtually all of the issues outlined in Section 5, Pipework, should be followed here also. In addition to this the following should also be employed.

The first additional key point to note is that under no circumstances should the pipework be reduced from the outlet size provided by the centrifuge manufacturer. Due to high energy and difficult to easily predict windage patterns in and around the centrifuge it is imperative that the filtrate is allowed to get away from the machine as quickly as possible.

Any restrictions or reduction in the pipework may lead to the filtrate building up into the centrifuge. This is a very serious scenario and will result in extremely high and potentially dangerous vibrations as the liquor comes into contact with the rotating basket. Filtrate should leave the pipework from an open end, well above the level of catchment tank and not allowed to become submerged.

10. Conclusion

The batch basket filtration type centrifuge is a very versatile piece of liquid-solid separation equipment. It has the flexibility to satisfy an extremely wide range of applications providing excellent segregation of the solids whilst maintaining essentially clear filtrates.

It is all too common for the end user to view the centrifuge with a mild case of 'tunnel vision' and quickly call in the centrifuge experts. It can be clearly seen from the above that there are many factors, both up stream and downstream, that have a bearing upon the performance of any piece of separation equipment.

Pure theory alone is of limited help in the application of an industrial centrifuge. It is more a combination of application experience, testing and design capabilities of the centrifuge experts combined with the end users invaluable knowledge of their material which ensures that the centrifuge installation will produce a product on schedule, of the desired quantity and quality, economically and above all safely.

Finally therefore we finish where we started by asking the question, 'Is it right to blame the centrifuge?'

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