CENTRIFUGE SAFETY AS IT APPLIES

TO HIGH SPEED DISC MACHINES

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Before getting into our subject, I thought it appropriate to discuss centrifuges in general. The McGraw Hill Chemical Engineering Series Book on Separation Processes provides the following definition for centrifugation:

> "A solid in liquid suspension is whirled rapidly. The Centrifugal Force from the rotation aids the phase separations. Centrifuges may operate on a settling principle, where in the denser phase is brought to the outside by centrifugal force, or on the filtration principle, as in a basket centrifuge, where the mesh or the basket retains the solids particles and the centrifugal force makes the liquid to flow through the solids more readily than in an ordinary filter".

That is an appropriate definition and the word I like is "whirled".

Gravity vs. Centrifugal Force

In normal gravity settling, the only force acting on the separation is the normal pull of gravity, or the weight of the object. This is a constant force and cannot be altered.

The force generated by a centrifuge is thousands of times more powerful.

An object rotating around an axis at distance "r" from the axis at an angular velocity, "w," has an acceleration, "a," in the radial direction according to the following formula:

$$a = rw^2$$

In multiples of "g" (the acceleration due to gravity), this becomes:

$$\frac{a}{g} = \frac{rw^2}{g} = \text{the centrifugal force,}$$

commonly called "the number of g's."

In actual usage, this formula is modified by replacing the angular velocity (w) (radians/sec) with the RPM (n). The formula then becomes:

$$\text{"G"} = \frac{r}{g}\left(\frac{2 \times 3.142 \times n}{60}\right)^2 = .011 \times \frac{rn^2}{g}$$

In a typical case where r = 1 foot, g = 32.2 ft/sec^2 and n = 3,000 RPM:

$$"G" = .011 \times \frac{1}{32.2} \times (3{,}000)^2 = 3100.$$

Thus, in a modest centrifuge we can improve on gravity by a factor of 3,100 to 1.

Stoke's Law

Stoke's Law provides a formula for the rate of sedimentation. The law states that as a solid or liquid particle moves through a viscous material under the influence of gravity, it will attain a constant velocity. This is the sedimentation rate, or V_g.

Using a formula derived from Stokes' Law, the sedimentation rate can be calculated if the following information is known

- D - particle diameter
- d_p - particle density
- d_l - density of continuous phase
- u - viscosity of continuous phase
- g - gravitational acceleration

The following formula is used:

$$V_g = D^2 \frac{(dp - dl)}{18u} \times g$$

By applying the formula, we can reach the following conclusions:

1. The larger the particle diameter, the greater the sedimentation rate.

2. The greater the difference in density between the particle and the continuous phase, the greater the sedimentation rate.

3. The lower the viscosity of the continuous phase, the greater the sedimentation rate.

We will mainly be discussing the high speed disc machines which operate on the sedimentation principle. However, before getting into this, a brief early history and then a short review of various centrifuge types, would be appropriate.

Brief Early History

The continuous separator was invented in Sweden in 1878 and was first applied in the dairy industry. The machine consisted of a rather crude hollow or empty bowl which was rotated at high speed (6,000 RPM).

In 1888 the German engineer, Clements Von Bechtolsheim, invented the conical disc stack. These were incorporated into the centrifuge bowl and have been standard with some variations ever since.

Some of you, who were raised on a farm, may be familiar with the old hand cranked cream separator. This unit had a clapper bell arranged in the crank, which rang if it was not being turned fast enough. Such cream separators were the first application of continuous separators or centrifuges.

Solids-Retaining Centrifuges

This is the original disc-type high-speed centrifuge. It is used primarily for separating two liquid phases, with or without simultaneous removal of small quantities of solids; or for clarifying liquids with a low solids content. Feed and liquid phase discharges are continuous; solids remain in the bowl for cleaning at intervals.

For clarification of a single liquid, these centrifuges are equipped with discs and one liquid outlet. For separating two liquids (skimming or purifying), they are equipped with holed discs and two liquid outlets.

Solids-Ejecting Centrifuges

These disc-type centrifuges are designed for the high-speed, continuous removal of fine or soft solids from liquids. Besides separating liquid/liquid/solid phases and clarifying liquid/solid phases, they can be used to concentrate solids. Liquid discharge is continuous; solids discharge is intermittent.

The solids-ejecting centrifuge resembles the solids-retaining machine, except the configuration of the bottom of the bowl. Intermittent cleaning of accumulated solids is achieved by split-second opening of the bottom half of the bowl while the machine is running at full speed. Internal pressure forces the solids out through discharge ports.

The period between solids ejection (shots) is usually controlled by a timer. The bowl opening mechanism is operated by a water hydraulic mechanism using pressure developed by centrifugal force. More sophisticated versions are able to sense the solids volume in the bowl and discharge automatically. Such systems are known as "self thinkers".

Continuous Solids-Discharging Centrifuges (Nozzle Type)

These centrifuges, also termed nozzle centrifuges, are designed for the continuous feed of liquid/solid mixtures and continuous discharge of both liquid and solid phases. One or two liquid phases can be handled. They can be operated for long periods without being shut down and dismantled for cleaning.

Nozzles, normally mounted in the widest part of the bowl, discharge solids continuously as a concentrated slurry. Discharge concentration is controlled by using nozzles of different sizes. Nozzle size is determined by the amount of solids present in the mixture and the particle size of the solids. The number of nozzles required is determined by the angle of repose of the solids between nozzles.

Decanter Centrifuges (Conveyer Type)

These horizontal bowl centrifuges are designed for continuous concentration and removal of solids from a slurry or suspension.

These machines are composed of a rotating cylinder, slightly tapered on one end. A close-fitting helical screw conveyer inside the cylinder rotates in the same direction as the cylinder but at a slightly different speed. Feed is through the center of the conveyer screw.

The mixture to be separated enters the machine and is forced to the rotating cylinder wall. Centrifugal force concentrates the solid phase against the wall, and the conveyer screw moves it toward the solids discharge. Tapering the cylinder near the solids discharge end provides further centrifugal draining above the liquid level. The liquid phase, clarified or solids, is continuously displaced by the incoming mixture and flows out the liquid discharge ports at the other end of the centrifuge.

Basket Centrifuges

These centrifuges are designed for the automatic batch separation of solids from liquids. Advantages include high residency time for solids requiring high purity.

Perforate-type basket centrifuges are designed with a rotating basket, lined with a heavy-duty, filtration screen. In operation, a feed pipe opens to a feed cone that uniformly directs the mixture over the entire surface of the screen. Here centrifugal force draws the liquid phase through, leaving solids in the basket for washing and thorough dewatering. The solids are plowed out through the bottom of the basket.

Another version, the imperforate basket, does not have the filtration screen in the basket wall. In discharging, clarified liquid decants over the top of the basket.

Pusher Centrifuges

These centrifuges are designed for continuous filtration of solids from liquids, where extremely dry solids are desired. Separation, washing, and drying take place in the same continuous process. These are really a form of basket centrifuges.

Pusher centrifuges consist of a rotating basket, closed at one end by the push plate. The opposite end of the basket is open. A heavy-duty, self-cleaning screen lines the basket (wedge wire type). Feed is through a pipe which opens to a cone. An adjustable wash pipe provides thorough cleaning of solids.

The push plate and the basket rotate at the same speed. Moreover, the push plate reciprocates a number of times per minute. The mixture enters the feed cone, is accelerated circumferentially as it travel radically to the speed of the basket, and is deposited gently on the screen surface. The liquid is centrifuged through the screen, while solids are pushed progressively toward the open end of the basket. Wash water directed over the moving solids provides effective displacement of mother liquor.

Selecting The Right Centrifuge

To this point, centrifugal separation has been presented as a rational science based on Stokes' Law. There are, however, subtleties which border on making it an art.

Temperature, density, and viscosity play a role in achieving efficient separation. If two phases of a mixture have equal densities, they cannot be separated. But it is often possible to change the density of one phase by changing the temperature of the mixture.

Particle size also plays a significant role in separation. If centrifuging is designed to separate a certain size particle from a liquid, it will take four times as long for a particle half that size to settle out of the liquid as one of equal size.

Particle size is the most important factor in determining whether a centrifuge can be successfully applied to a specific separation problem. (Note that it is a major factor in Stoke's Law.) Virtually any particle size can be handled up to the physical limits of the machine. Particle shape, hardness, and distribution can also influence the separation result.

Another variable in separation is the combination of desired characteristics of the final separated phases. Examples of such characteristics include: maximum clarity of the liquid phase; maximum recovery of the liquid or solid phase; maximum dryness of the solid phase; maximum clarity recovery of the light or heavy liquid.

Other factors that should be considered in separation include the chemistry, erosiveness, corrosiveness, and temperature characteristics of the materials to be separated.

For new applications the most satisfactory way to select a centrifuge is first by laboratory evaluation. This would then be followed by a field trial, if necessary. Once flow rates have been established on the trial machine, then a successful scale up to the production machine can be made.

General Tabulation of Feed Steam Criteria
In Selecting A Centrifuge Type

Type	**Description**	**For Separating Phases Composed Of:**	**Solids Content Range % By Volume**	**Particles Size Range Microns**
Solids-Retaining	High-Speed Continuous Sedimentation	Liquid/solid Liquid/Liquid/Solid Liquid/Liquid	0-1	0.8-800
Solids-Ejecting	High-Speed Continuous Sedimentation	Liquid/Liquid/Solids Liquid/Solid	0-10	0.8-800
Nozzle	High-Speed Continuous Sedimentation	Liquid/Liquid/Solid Liquid/Solid	5-60	0.8-800
Decanter	Continuous Sedimentation	Liquid/Solid Liquid/Liquid/Solid	1-40	1-20,000
Pusher	Continuous Bulk Filtration	Liquid/Solid	10-80	70-40,000
Peeler	Batch Filtration & Sedimentation	Liquid/Solid	1-60	1-10,000
Basket	Batch Filtration & Sedimentation	Liquid/Solid	1-60	1-10,000

Disc centrifuges are capable of making liquid/solid separations and liquid/liquid/solid separations. The latter, is known as a 3 phase separation.

When making a 3 phase separation, the centrifuge is called a separator and when making a 2 phase separation the centrifuge is called a clarifier. These machines are powerful and capable of producing artificial gravities up to 6,000 to 8,000 G. They can thus accomplish separation; which, by gravity may take an extended period, or in some cases may never occur.

The bowl is the business end of a disc centrifuge. It is an enclosed vessel rotating at high speed. The separation occurs inside the bowl. Small disc machine bowls turn at speeds up to 6,000 RPM and some are up to 18" in diameter. The larger bowls would turn at about 4,000 RPM. These larger bowls, 30-36" in diameter, could weigh 2,000 lbs. or better.

As can be seen with the weights and speeds involved, large quantities of kinetic energy (rotational momentum) are stored in the rotating bowl. Some centrifuges can coast for 10 to 20 minutes before coming to rest. This stored kinetic energy has the potential to be extremely destructive if not properly controlled and directed.

However, before getting into that topic, I would like to touch on the concept behind the discs or conical discs in the disc centrifuge. The discs are spaced using calks or spacers. These can go from -30 thousands of an inch up to perhaps 1/8 inch or more in thickness depending on the product. The concept is to stratify the flow into thin layers. The centrifugal force is concentrated on each of these layers with a relatively short settling distance. (Note: Settling is occurring horizontally.) The solids settle out on the under side of each disc with the clarified liquor passing beneath. A counter current flow is established through the disc stage with the solids passing outwards and the liquid phase passing inwards.

As discussed in the section on centrifuge types, disc centrifuges fall into three categories. The solid bowl type which had to be manually cleaned and was, therefore limited in its ability to handle solids. Next there is the solids ejections type which uses a peripheral opening to intermittently discharge solids. Then there is a nozzle type which continuously discharges solids and some liquor through the peripherally placed nozzles.

From that very quick overview of disc centrifuge types we return to our subject which is centrifuge safety. In discussing centrifuge safety, the aggressiveness of the product to the materials of construction on the centrifuge must be considered. Corrosion and erosion are the enemies and they usually go together to attack the bowl shell.

A comprehensive maintenance program is required. It should be noted that the bowl is balanced as an assembly when manufactured and parts should not be intermixed from one bowl to the other. Bowls usually have liners and wear plates in key areas to protect against erosion.

Whenever a bowl is dismantled for cleaning, all parts should be inspected for wear. The manufacturers have limits for what is and is not within safe tolerance. These values should be obtained from the manufacturer.

Most bowls today are forged in 329 stainless steel. This is a heat treated steel which has superior strength to 316 stainless steel, but approximately equal corrosion resistance. The yield on 329 stainless is 76,000 psi. The normal design stress in the bowl is about 70% of yield. The newest machines are using 329 TN stainless for bowl forgings which exhibits fatigue resistant qualities. Being a heat treated steel, it should never be repaired by welding. Heat from welding would also cause distortion on the precision machined components. Chlorides and Fluorides are both halogens and are highly detrimental to stainless steels. They are responsible for stress corrosion. The exact mechanism is not well understood. Stress corrosion takes the form of cracking in highly stressed areas, such as lock ring threads or on the posts between discharge slots on a desludging centrifuge.

These stresses could have been induced during machining operations, when the bowl was first manufactured. Design detail and the elimination of stress raising corners and the avoidance of tool marks are some of the techniques used to counter the problem. Shot Peening after machining has also been used. This puts the surface into compression and supposedly relaxes the stresses at the metal surface.

It is usually best that the bowl be returned to the manufacturer's shop for a complete inspection and assessment of its condition at regular intervals. The bowl is given a thorough inspection and is checked using magnetic particle or other methods for crack detection. Sometimes the manufacturer will "condemn" a bowl if it is found to be in poor condition. It is usually best to respect this judgment.

"Disc Stack compression" is another item that has to be checked from time to time. If the stack is loose within the bowl then rough running can be expected. The stack compression is adjusted by the addition or removal of discs. A loose disc stack can be suspected, if on assembly the bowl lock ring tends to go past its match mark.

In operating centrifuges, a high order of maintenance is called for. A centrifuge is a precision built machine. For industrial service, the bowl is balanced as an assembly to within 15 grams. Military service (the Navy) balance to within 10 grams is specified.

On a new machine a vibration level at the top of the frame is around 2 Mils. As the machine ages, this deteriorates to about 7-8 Mils. The top spindle bearings on bottom driven centrifuges is supported with an arrangement of buffer springs to absorb shock from imbalance.

The contents of the centrifuge, usually the settled solids can cause the bowl to go out of balance if they are not evenly distributed. The imbalance in a nozzle machine, can be caused by one or several plugged nozzles and in the solids ejecting machine, by what is known as a segmental discharge. This is usually the result of overly compacted solids, particularly crystalline solids. Either condition can be very dangerous, because of the high speed and large amounts of stored energy (discussed earlier). Operating techniques, to avoid this, should be followed. Smaller more frequent ejections help to prevent the solids from compacting in the case of the solids ejecting type machine. In the case of the nozzle machine effective straining of the feed stream and the maintaining of a liquid flow of water or product on the nozzles helps to prevent nozzle pluggage.

The unrestricted availability of this liquid, usually water, is absolutely essential. In addition to providing a flushing function for the nozzles, it compensates for the imbalance within a dry or unevenly loaded bowl. Such a bowl could be wildly out of balance. By filling the void within the bowl with liquid, the out of balance can be partially corrected or compensated for. Some dampening also results.

The maintenance and availability as stated before, at all times of such a supply, is absolutely mandatory. It would rank as being even more important than any braking system. Such a system could be either mechanical or regenerative through the motor. Braking systems are slow to operate, often do not work in a power outage and do not correct or even partially correct the imbalance. The addition of liquid to the bowl does satisfy these last requirements. (Just for information, the braking system can either be the spring loaded friction shoe type or the regenerative type. Regenerative

Regenerative braking (counter E.M.F.) is accomplished by attempting to reverse the motor direction on forward coast down. Regenerative or counter E.M.F., braking is usually applied, after some 200-250 seconds of coast down. It is only applied in the "Y" mode in a "Y" delta starter circuit. This means that only 1/3 of the available torque is being developed.)

Such emergency liquid or water supplies can come from a piping system or a city water main in the case of water. However, these systems have to be absolutely reliable. If reliability cannot be assured, then a gravity bowl flood systems has to be considered.

A gravity flow system would utilize a head tank and with the use of normally open valves (i.e., fails open). This means that in the event of a power outage, we have a way of getting liquid or water to the bowl to provide protection during coast down. A head tank gravity system is probably the most reliable type of system.

The selection of the liquid or water for bowl flood is important. Water is the most commonly used liquid due to its availability and reliability. At times clarified product liquor need be considered. However, product's sedimentation characteristics, even if it has been clarified, have to be evaluated. Post precipitation can continue, particularly with saturated solutions, as they cool. The emergency flood system can remain inactive for weeks, depending on the length of the production run. It must operate without fail, every time. It is also good practice, when the centrifuge is clean and is being started, to check the function of all of the mechanical and electrical components in the bowl flood system. Such systems usually depend on logic from the starter (i.e., auxiliary contacts, etc.)

The six machines in the merchant acid clarification area at New Wales use a gravity system. However, as originally designed, clarified acid from the centrifuge was routed to the gravity head tanks and then overflowed to the Merchant Acid Product Tank. This system proved to be seriously defective, in that the down comer lines from the Head Tanks to the Centrifuges would plug with acid crystals. This was particularly the case in the vertical sections of the line. The result of this was that no stabilizing liquid was available as the machines coasted down. Although there were never any injuries, a considerable amount of expensive damage was done to the centrifuges at different times.

This problem was presented to Plant Engineering. The proposed solution was very simple. (Go to the accepted norm.)

The gravity system was switched over to process water and the clarified acid was routed directly to storage. The result of this change has been an almost 60% reduction in maintenance costs. The change over to water highlighted the importance of liquid always getting to the bowl while in operation. Some plant operating procedures were also revised and they, too, contributed to the savings.

Process water rather than pond water was selected because of concern for sedimentation even from pond water. This may be overkill, but having come from a bad situation with acid sedimentation, we did not want to risk any sedimentation. Since the system is basically static (i.e., no flow) 99% of the time, there is no penalty in using process water. Product dilution has not been a problem. The bowl flood system is normally operated through the centrifuge starter logic (interlocks). Basically, the emergency liquid supply is activated when the machine is started and stopped. It is also activated when the feed to the centrifuge drops below a predetermined amount. At New Wales this is 60% of full flow.

Most centrifuge manufacturers recommend the use of vibration switches on their machines. These switches are very sensitive and provide a way to detect above the normal levels of vibration. They are normally set to activate at about 40% above the machines normal vibration level. Shut down occurs at 60% - 80% above normal vibration level. Dependent on the switch location, this usually equates to about 1 G acceleration. They can be arranged to give a warning followed by shut down if the vibration intensity increases.

These switches are normally provided with reset/hold on coils to provide override capability as the machine comes up to speed, i.e., through its critical speed ranges. This same coil also provides the same facility in the solids ejecting machine when it shoots (ejects). (This usually causes a shock.)

From the foregoing, it can be seen that the industrial centrifuge is a powerful and compact settling device for the chemical processing industry.

Each of the 6 Clarification Centrifuges at New Wales has the theoretical settling area equivalent of 100,000 square meters.

< 119599.4 square yards
< 24.71 acres

This is a theoretical number calculated by the manufacturer. It includes such variables as machine speed, cone angle, disc spacing, etc. However, it is a useful device in comparing machine types and sizes. Taking the six machines in total at New Wales their combined settling area equivalent would exceed the New Wales Chemical Plant total area by approximately 40%. (This excludes our Gyp Stack Area.)

It can be seen that when applied properly and correctly maintained (including all safety devices), the Centrifuge can be a safe and productive tool.

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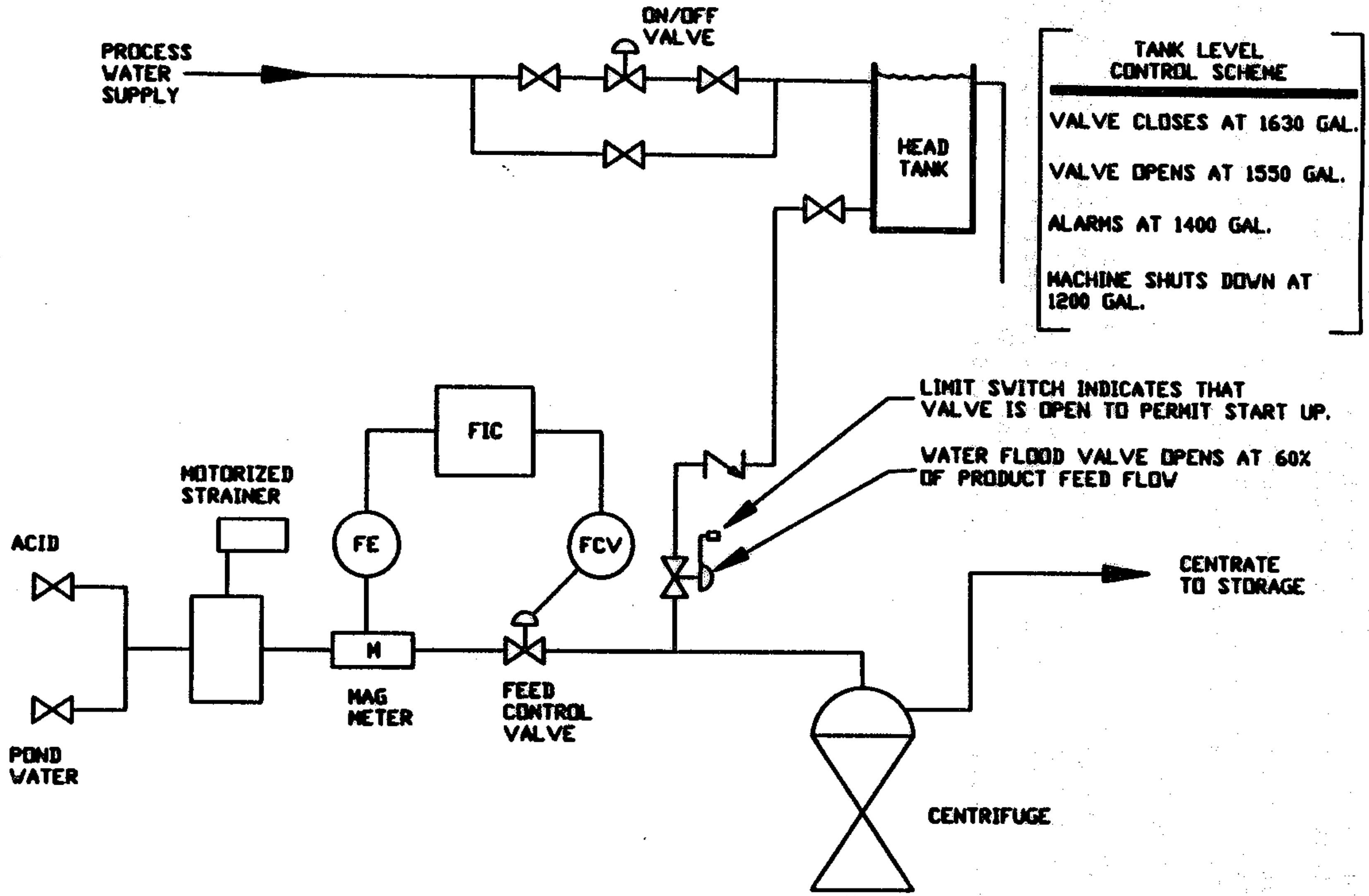
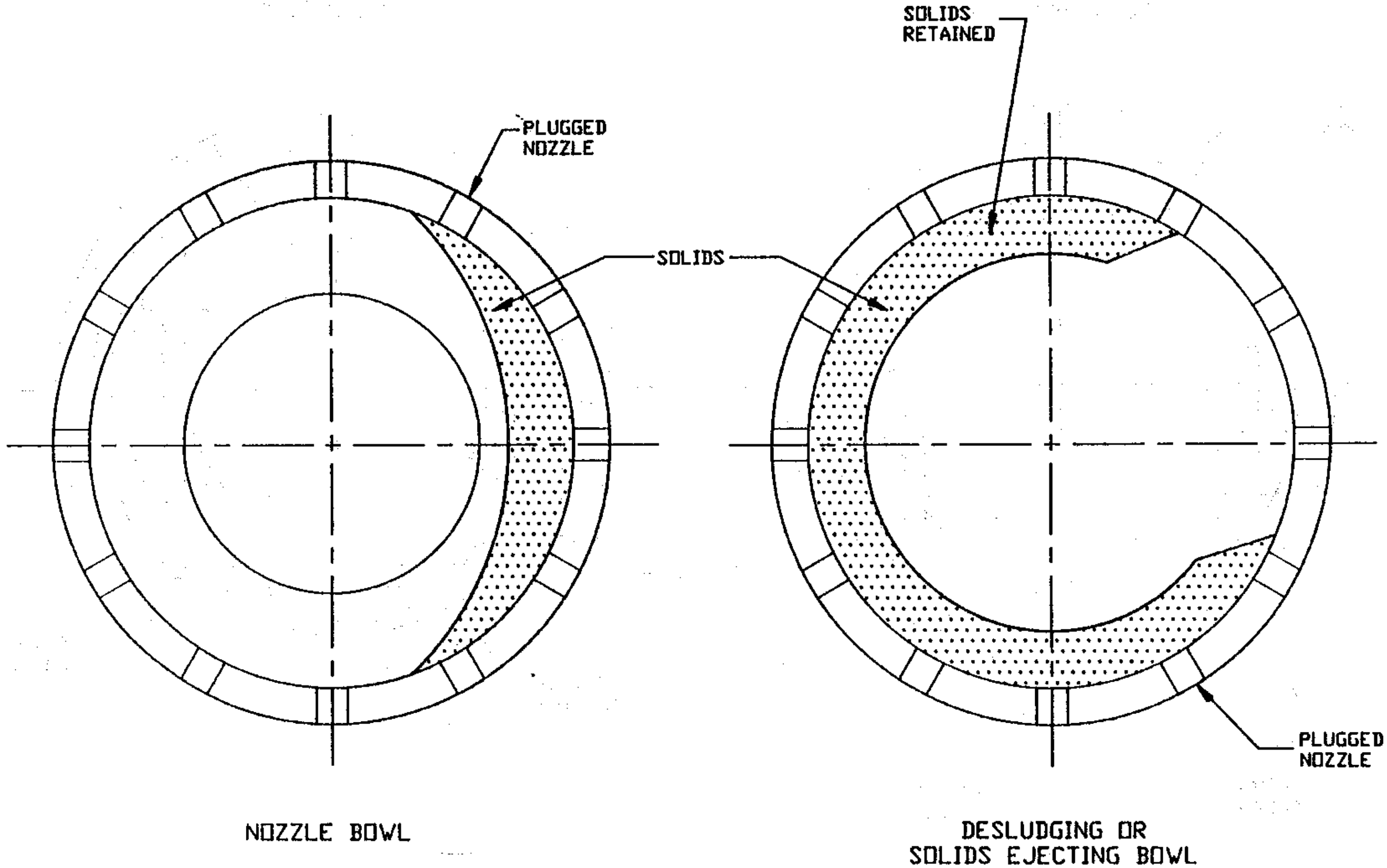
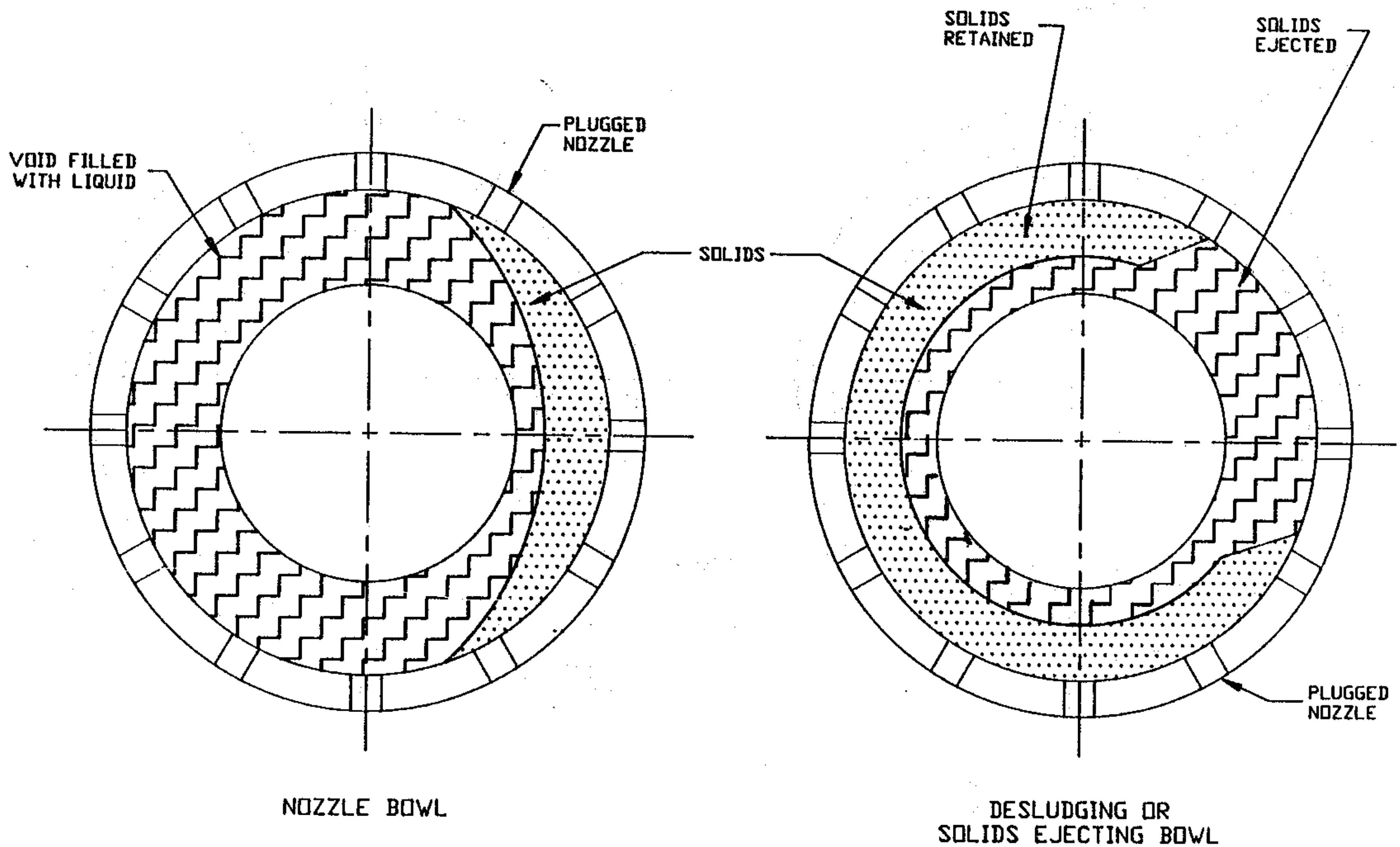


SIMPLIFIED CENTRIFUGE SCHEMATIC

(FOR ONE MACHINE)



BOWL IMBALANCE DIAGRAMATIC I



BOWL IMBALANCE DIAGRAMATIC II