Selection of Centrifuges for Chemical Processing

JULIAN C. SMITH[1]

E. I. du Pont de Nemours & Company, Inc., Wilmington, Del.

The semiempirical test methods used in selecting centrifuges for chemical processing are described. The procedure for estimating the capacity of a batch centrifuge from test data is given in detail.

CENTRIFUGAL separation has been extensively utilized in some industries for many years, and at present it is finding ever-increasing use in chemical processing. However, as Maloney (*2*) pointed out in reviewing centrifuging as a unit operation, little has been published on the use of centrifuges in the chemical industry. Fairly complete descriptions of the various types of centrifuges on the market are available (*1*, *3*), but the semiempirical methods used by centrifuge manufacturers in estimating the capacity of a given machine are not generally known.

The purpose of this paper is to describe some of these test methods and to present typical data from actual tests. Preliminary tests are useful merely in distinguishing between promising and highly unpromising applications, and should not be interpreted too literally by anyone who has not had considerable experience in selecting centrifuges. Often minor changes in operating conditions greatly change the centrifuging characteristics of a material. Confirmatory large scale tests are often required before a centrifuge can be selected with confidence. However, if properly applied, the "screening" tests should avoid extensive testing of materials to which centrifugal separation is obviously unsuited and should lead to the increased use of centrifuges for the solution of industrial problems.

TYPES OF CENTRIFUGES

The various centrifuges used in chemical processing are classified in Table I according to the nature of the separation they perform. Batch and continuous centrifuges are available for each type of separation. This does not mean, however, that all separation problems can be solved by centrifuges, even though recent improvements have greatly increased the usefulness of centrifugal machinery. Tests are essential before a centrifuge is specified for any but well established services.

The principal manufacturers of centrifuges for chemical processing are listed in Table II. Other companies, not listed, make more or less specialized centrifuges for the sugar, food, coal, and other industries. These machines find occasional application in chemical manufacturing. Bottle centrifuges, used in laboratories or for very small scale production, are manufactured by a number of laboratory equipment companies.

Centrifuges may be divided into three main types, each with a broad general field of application. These are (*a*) high speed, small diameter, vertical solid-bowl centrifuges, (*b*) large diameter batch centrifuges, and (*c*) continuous centrifuges. The first type is used for liquid-liquid separations and for clarifying liquids; the last two are primarily for dewatering solids. The nature of the separation problem determines which general type of centrifuge is applicable, and the test work is conducted accordingly.

The test equipment used by centrifuge manufacturers for specifying centrifuges consists of three laboratory units. For obtaining preliminary indications of settling rates and amount of suspended solids, a bottle centrifuge developing two thousand times gravity is used. It is generally provided with an oversize motor and a brake to permit rapid acceleration and stopping. A 12-inch batch centrifuge, provided with a variable-speed drive and both perforate and imperforate baskets, is used for specifying large-diameter batch machines and for obtaining preliminary data for selecting some continuous centrifuges. Test data for choosing high speed, small diameter centrifuges are obtained from a laboratory model.

HIGH SPEED, SMALL DIAMETER CENTRIFUGES

Actual performance of this type in a given service can be determined only by tests in a laboratory model or in full scale equipment. Preliminary indications are obtained from observing the rate of separation by gravity or in a bottle centrifuge. If separation is relatively rapid, this type of machine can be specified with considerable assurance. Even though separation is poor in the bottle unit, however, centrifugal separation may still be feasible, since very high forces can be developed in commercial equipment. The Sharples supercentrifuge, for example, develops thirteen thousand times the force of gravity, and will often break troublesome and apparently stable emulsions. On the other hand, certain flocculent solids separate more readily in the bottle

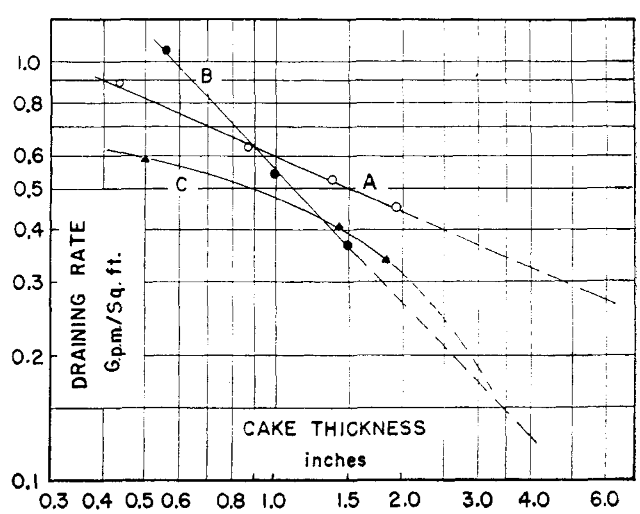


Figure 1. Draining Rate *vs.* Cake Thickness for Three Slow-Draining Materials

[1] Present address, Cornell University, Ithaca, N. Y.

centrifuge than in the high speed machines, since the flocs tend to break up in being fed to high speed centrifuge.

Tests in a laboratory unit consist of feeding representative samples of material to the machine under varying conditions of feed rate, bowl speed, and feed temperature, followed by analysis of the effluent streams. The size of the ring dam, which alters the position of the liquid-liquid interface inside the bowl, is also varied. After the best conditions for separation have been established, several liters of feed are processed through the test unit at the maximum rate. The machine is then stopped, and any solids which have collected in the bowl are removed, weighed, and analyzed. The weight of solids collected from a known amount of feed determines how long a production machine may be run between bowl cleanings.

For each make of centrifuge there are known factors for scaling up the laboratory results to full scale machines. The laboratory unit usually gives better separation than the production machines at the same centrifugal force, and confirmatory full scale tests are usually desirable.

If the separation must be made at elevated temperatures, satisfactory results may be difficult to obtain in the laboratory unit, even though full scale operation would be feasible. Temperature variations are minimized in the larger machines, and if a steam-jacketed casing is used, the temperature drop through the machine usually does not exceed 1° or 2° C.

The capacity of the very high speed supercentrifuges is limited by their necessarily small diameter. Feed rates of 60 to 600 gallons per hour are usual. Where very high centrifugal force is not needed, larger diameter disk-type centrifuges may be used, in which the liquid in the bowl is separated by disks into thin layers. For some materials this type of unit gives better separation than a supercentrifuge at the same centrifugal force. Machines of this type are available which develop seventy-five hundred times gravity, and which have about twice the capacity of the supercentrifuge.

Unfortunately most industrial liquids contain some suspended solids, which eventually plug a separator centrifuge. The supercentrifuge bowl holds only 5 to 10 pounds of wet solids, and cleaning a centrifuge bowl containing forty to one hundred disks is tedious and time consuming. Consequently the usual separator centrifuges are not used when the solids are more than a few per cent of the feed. Two general types of machine are available for continuously separating two liquids and simultaneously discharging solids, both of which, however, have rather limited application. In one type, of which the De Laval Nozzle-matic is an example, solids are discharged as a slurry through nozzles set in the periphery of the bowl. The feed rate to the smallest of these machines must be at least 400 gallons per hour. The maximum slurry concentration of the discharged solids is about 10%. The other type, exemplified by the Sharples Autojector, discharges a fairly dry cake of solids through valves set in the bowl, which open when a certain amount of solids has accumulated. Without considerable experience it is impossible to estimate whether a given solid will discharge properly from these machines, and except for full scale tests, there is no satisfactory way of determining whether they are applicable.

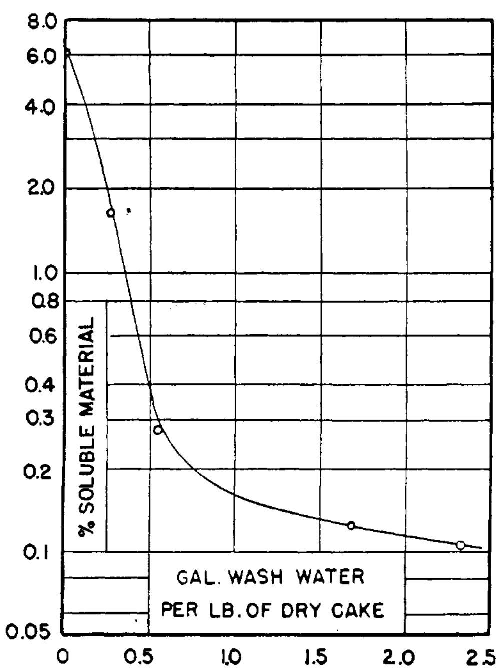


Figure 2. Washing Test Data for Material A

Table I. Classification of Centrifuges[a]

Type of Separation	Batch	Batch Automatic	Continuous
Liquid-liquid	Bottle type	....	Supercentrifuge (8), disk type (6, 8), CME continuous (5)
Liquid-liquid-solid	Bottle type, supercentrifuge (8), vertical solid bowl (1, 2, 4, 7, 9, 10)	....	Nozljector (8), Autojector (8), Nozzle-matic (6), Multi-matic (6)
Liquid-solid	Bottle type, vertical perforate basket (1, 2, 4, 7, 9, 10), vertical solid bowl (1, 2, 4, 7, 9, 10)	Super-D-Hydrator (8), ter Meer automatic (3), ter Meer clarifier (3)	Slurry discharge: Nozljector (8), Nozzle-matic (6) Dry solids discharge: Autojector (8), Multi-matic (6), Bird solid bowl (4), Bird screen (4), CME continuous (5), Super-D-Canter (8), ter Meer continuous (3)
Liquid-solid-solid (classification)	Supercentrifuge (8), vertical solid bowl (1, 2, 4, 7, 9, 10)	....	Bird solid bowl (4), CME continuous (5) Super-D-Canter (8)

[a] Numbers in parentheses refer to the centrifuge manufacturers in Table II.

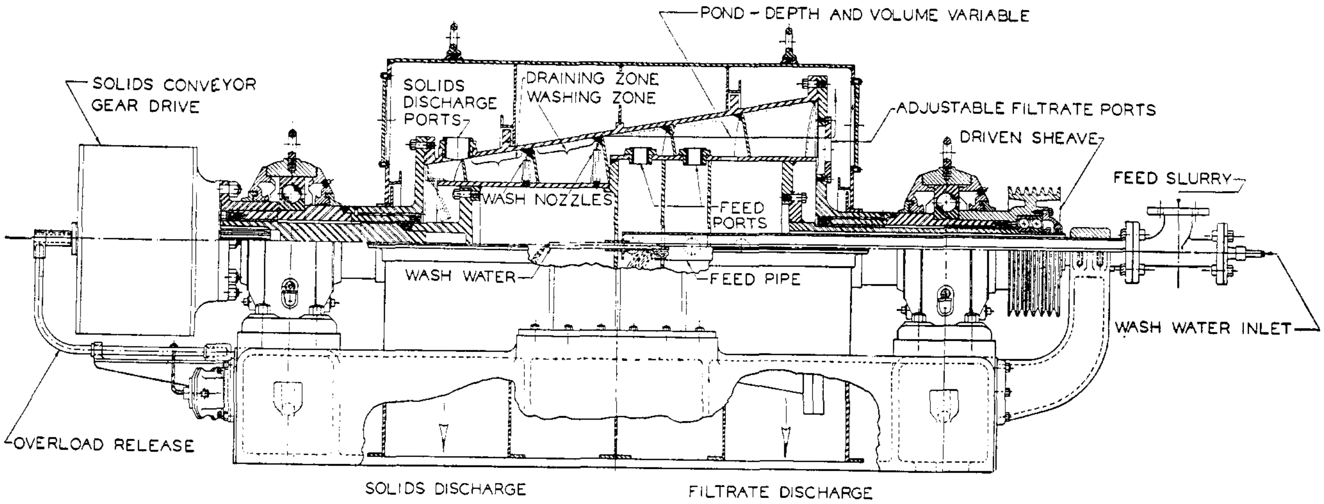
Table II. Principal Manufacturers of Centrifuges for Chemical Processing

Number	Company	Address
1	Am. Laundry Machinery Co.	Norwood Station, Cincinnati, Ohio
2	Am. Tool and Machine Co.	30A Church St., New York, N. Y.
3	Baker Perkins, Inc.	Fraser and Young Sts., Saginaw, Mich.
4	Bird Machine Co.	South Walpole, Mass.
5	Centrifuge Mechanical Equipment, Inc., N. J.	95 River Street, Hoboken, N. J.
6	De Laval Separator Co.	165 Broadway, New York 6, N. Y.
7	Fletcher Works, Inc.	205 Glenwood Ave., Philadelphia 40, Pa.
8	Sharples Corp.	2300 Westmoreland St., Philadelphia 40, Pa.
9	Squire Mfg. Co., Geo. L.	506 Broadway, Buffalo 5, N. Y.
10	Tolhurst Centrifugal Div., Am. Machine and Metals, Inc.	701 Tolhurst St., East Moline, Ill.

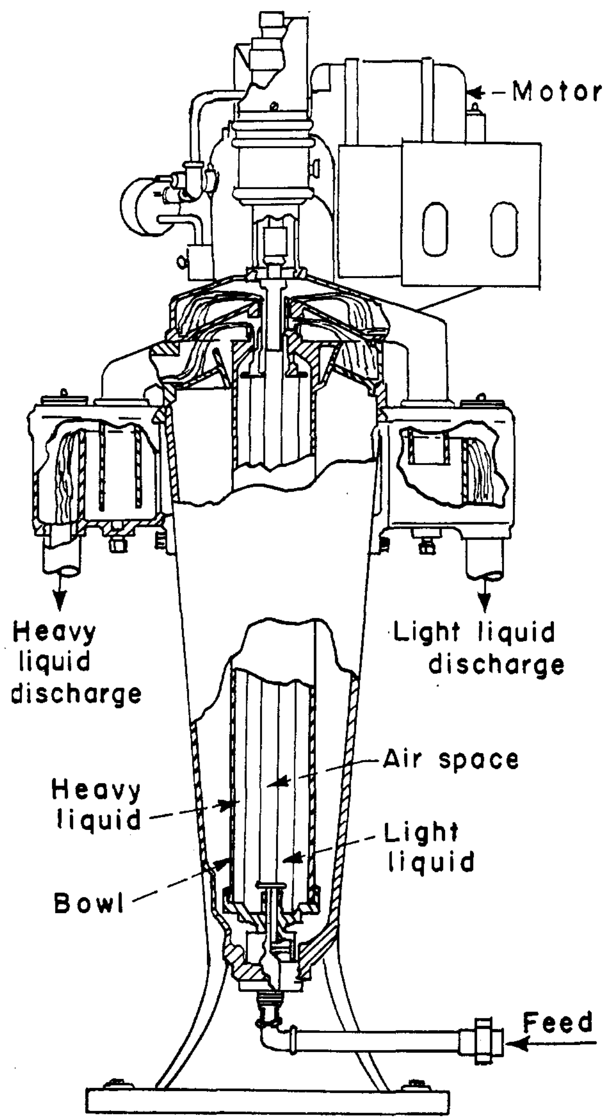
Although the preceding discussion has referred to liquid-liquid separations, similar tests are made when the removal of a small amount of solids from a single liquid is desired. High speed machines are also utilized for classifying extremely fine particles. Tests in a laboratory model are used for studying such applications. In classification tests one specific combination of feed rate and centrifugal force generally gives the best results.

LARGE-DIAMETER BATCH CENTRIFUGES

This type is principally used for dewatering and washing relatively large amounts of solids. Both solid-bowl and perforate-bowl machines are available; the latter is more common and is used chiefly on fibrous and crystalline materials. Data for estimating the performance of this type of centrifuge are obtained



Horizontal, Continous, Solid Bowl Centrifuge (Bird Machine Company)



Supercentrifuge (Sharples Corporation)

from a basket centrifuge at least 12 inches in diameter. Smaller centrifuges may be used for qualitatively determining the centrifuging characteristics of a material but not for obtaining design information.

In the perforate-basket type of batch centrifuge, a slurry of solids and liquor is fed into the rotating basket. The liquor passes through the filter medium and leaves the solids behind. When sufficient cake has been formed, the feed is shut off and the cake is washed. The basket is then spun to expel liquor from the cake, the machine is slowed down, and the solids are unloaded, generally through an opening in the bottom of the basket. The cycle is then repeated.

In this type of centrifuge most, if not all, of the liquid must pass through the cake of solids. In the case of coarse crystalline materials, the cake offers relatively little resistance to the flow of liquid, and the hourly capacity of the centrifuge is largely determined by the time required to remove the residual liquid from the solids. In the case of finely divided solids, however, the principal factor determining the capacity is the draining rate of the cake. This is expressed in gallons per minute per square foot of filter area and is a measure of the resistance of the cake to the flow of liquor through it. Obviously in this type of machine a concentrated feed slurry and a minimum amount of wash liquid lead to high productive capacity.

The test centrifuge is run at a speed to develop the centrifugal force which would normally be developed in full size machines. Centrifugal force may be calculated from the relation:

$$F = 0.0000142\ DN^2 \tag{1}$$

where F = centrifugal force, expressed as number of times the force of gravity
D = basket diameter, inches
N = basket speed, r.p.m.

The usual centrifugal force developed in a 40-inch basket centrifuge is 820 times gravity; in a 48-inch machine, 550 times gravity. These correspond to speeds of 2200 and 1800 revolutions per minute in a 12-inch test centrifuge.

The draining rate is measured as follows. A representative sample of slurry is made up and, preferably, used under conditions approximating those in the proposed process as closely as possible. The filter medium, usually canvas, is carefully fitted in the test centrifuge basket, and the basket is brought up to speed. An amount of slurry containing about half a pound of solids is fed into the rotating basket, and a little of the effluent liquor is recycled if necessary to obtain a clear filtrate. It is not necessary to measure the feed rate during this period; care is merely taken that all of the liquor passes through the cake and none of it over the lip of the basket. After the cake from this amount of slurry has been formed, the mother liquor is recycled in order to determine the draining rate. Clear liquor is fed to the basket at such a rate that a thin layer of liquid is constantly visible on the surface of the cake. Under these conditions the effluent rate from the machine is equal to the draining rate of the cake for that cake thickness. This rate is measured by noting the time required to collect a known volume of effluent liquor.

The centrifuge is then allowed to run until there is practically no more discharge of liquor; then it is stopped and the thickness of the cake is measured. Another sample of slurry containing about the same amount of solids as the first is fed with the machine rotating at full speed, and the draining rate and cake thickness are determined as before. This procedure is repeated until a cake 2 inches thick has been formed, which is about the maximum cake thickness possible in a 12-inch centrifuge. Figure 1 shows the results of such tests on three rather slow-draining materials. In addition to these measurements, the gross weight of a cake of known thickness and the moisture content of the cake are determined. The time required for a 2-inch cake to stop draining after the feed is stopped is noted.

Washing effectiveness is determined by a series of tests in which a cake about 1-inch thick is formed, spun as dry as possible, and then washed at full basket speed with a known amount of wash liquor. Approximately the same amount of slurry is used in each run, the amount of wash liquor being increased in successive tests. The entire cake from each test is removed from the centrifuge, weighed, and analyzed for moisture and for the soluble material being washed out. In this way the required amount of wash liquor per pound of dry solids may be established. Figure 2 shows typical washing test data; the use of such data in estimating the capacity of a large batch centrifuge is illustrated in the example given later.

As Maloney (*2*) pointed out, the small diameter of the test centrifuge leads to changes in effective filtering area and centrifugal force during the formation of a 2-inch cake. Draining rate data obtained on a 12-inch centrifuge, when extrapolated from a 2-inch to a 6-inch cake thickness, are about 15% conservative if based on the area of the filter medium instead of the true effective filtering area. The decrease in radius as the cake is formed in the test centrifuge decreases the effective centrifugal force. No satisfactory way of correcting for this is available, and its effect is usually neglected. However, it also tends to make the test results conservative when extrapolated.

For many materials, typified by materials A and B in Figure 1, the following empirical relation is true:

$$R = Kt^{-n} \qquad (2)$$

where R = draining rate, gallons/minute, square foot
t = cake thickness, inches
K, n = constants

This equation is useful for extrapolating draining rate data to thick cakes, although where n is large, as in the case of material B, the use of very thick cakes is not economical. With other solids, typified by material C, the draining rate falls off rapidly above a certain cake thickness. In the case of materials B and C the centrifuge manufacturer recommended a maximum cake thickness of 3 inches. The following example demonstrates how the data on material A would be used in estimating the capacity of a large batch centrifuge.

Problem. The problem is to estimate the capacity of a 48-inch vertical, perforate-basket batch centrifuge, provided with an unloader for bottom discharge. The basket is 24 inches deep, contains 25.1 square feet of filtering area, and has a lip 8 inches wide. A 6-inch cake thickness is assumed. The specific gravity of the mother liquor is 1.10. The feed slurry contains 15% suspended solids and 20% dissolved solids by weight. The bulk density of the wet cake is 35 pounds per cubic foot. The cake contains 30% moisture, wet basis. The soluble material in the cake is to be reduced to 0.25%. The spinning time for a 2-inch cake is 1.5 minutes. Draining rate and washing data are given in Figures 1 and 2.

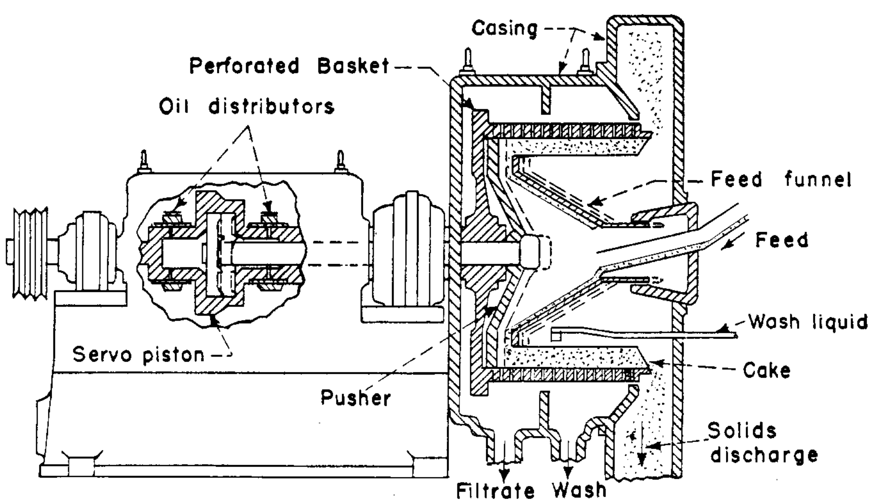
Solution

1. Batch size
   Vol. of cake: 6-in. cake thickness = 10.8 cu. ft.
   Wet weight: 10.8 × 35 = 378 lb.
   Dry weight: 378 × 0.70 = 265 lb.
2. Mother liquor per cycle
   Weight: 265 × (85/15) = 1500 lb.
   Volume: 1500/(8.34 × 1.10) = 164 gal.
3. Wash water per cycle. From Figure 2, 0.6 gal./lb. dry cake is required:
   Volume: 0.6 × 265 = 159 gal.
4. Time to form cake. This is calculated from the draining rate of a 2-inch cake, which in this case is 0.43 g.p.m./sq. ft. (Figure 1):
   Time: (164)/(25.1 × 0.43) = 15 min.
5. Washing time
   Draining rate for 6-in. cake (Fig. 1) = 0.26 g.p.m./sq. ft.
   Time: (159)/(25.1 × 0.26) = 25 min.
6. Spinning time: 1.5 × 6/2, say 5 min.
7. Cycle (total)

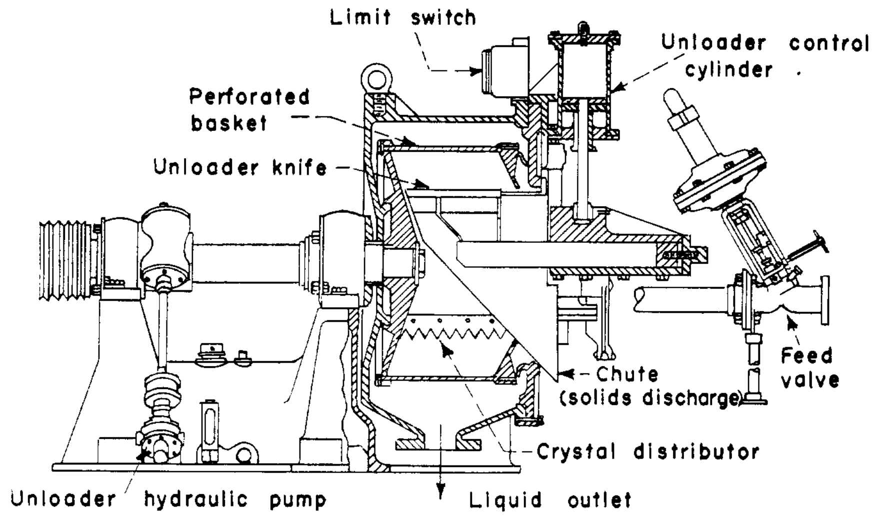
Accelerate basket	0.5 min.
Form cake	15.0
Wash cake	25.0
Spin	5.0
Brake and unload	2.5
Total	48.0 min.

8. Capacity
   265 lb. × 60/48 = 330 dry lb./hr.

This value would be conservative, because as previously discussed, the draining rate is uncorrected either for changes in effective filtering area or centrifugal force in the test machine. Furthermore, if the solids tend to settle rapidly and give a clear supernatant liquor, it is possible to spill clear liquor over the lip of the basket while loading the centrifuge. In the example cited,



Ter Meer Continuous Centrifuge (Baker Perkins, Inc.)



Super-D-Hydrator Automatic Centrifuge (Sharples Corporation)

the loading time could probably be reduced to 10 minutes or less if all the liquor did not have to pass through the cake.

With this in mind, it is always desirable to settle the feed to as heavy a slurry as possible before centrifuging. Supernatant liquor from the settling tank can be pumped rapidly through the centrifuge while decanting in order to remove traces of unsettled solids. When extremely good washing is required, it is sometimes desirable to repulp the centrifuge cake in fresh wash liquor and recentrifuge. In the example, attainment of a 0.1% soluble content by washing the cake in place would have resulted in very long batch cycles and very low capacity.

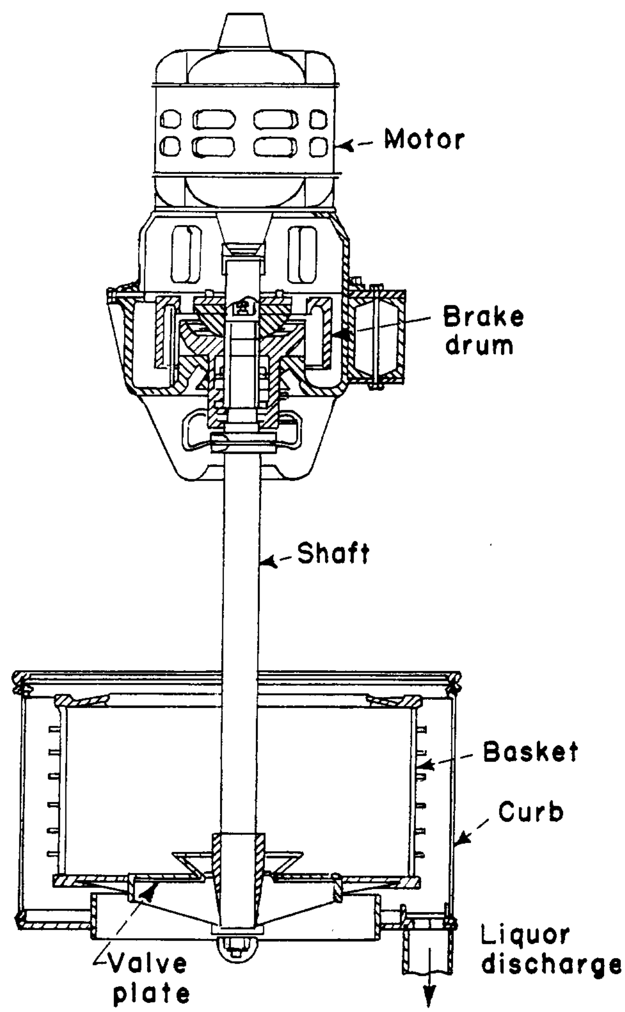
CONTINUOUS, AUTOMATIC CENTRIFUGES

Three main types of centrifuge are applicable to the dewatering of solids in continuous processes: batch automatic centrifuges which, while not strictly continuous, are completely automatic and operate on very short batch cycles; the shove-type continuous centrifuge, in which a layer of solids is moved over the metal screen filtering medium by a reciprocating pusher; and the horizontal, tapered, solid-bowl type, in which a helical conveyer moves the solids out of a pond of liquid.

The capacity of the first two types is primarily limited by the draining rate of the cake, and consequently information obtained from the batch centrifuge tests can be applied to the selection of these machines. However, their economical operation demands a free-draining, crystalline cake, generally with solids not finer than 100 to 150 mesh. In addition, the batch automatic type requires a dry cake for satisfactory discharging: More than 15% moisture in the cake makes automatic unloading difficult; with more than 20% it is usually impossible. In certain cases the character of the residual cake left in the basket after unloading greatly affects the draining rate of succeeding batches. For high throughput it is essential that the feed slurry be as concentrated as possible. Effective washing is possible in these machines, and final cake moisture contents of 3 to 5% are common.

In horizontal solid-bowl continuous centrifuges the capacity is not determined by the draining rate, since all the liquid does not pass through a layer of solids. Instead the solids are thrown out of the liquid against the inner surface of the bowl and are moved by the conveyer out of the pond of liquid up the so-called beach, and are discharged through slots in the wall of the bowl. The capacity is thus determined by the settling rate of the solids in the liquid or by the power required to convey the solids. Over a wide range the concentration of solids in the slurry has little effect on the capacity of this type of machine. Also, since no filter medium is used, the particle size of the solids can range from coarse to very fine. The solids, however, must be heavier than the liquid.

It is difficult to estimate the operating characteristics of this type of centrifuge on a given material without making full scale tests. Preliminary indications can be obtained by centrifuging a sample of slurry in a laboratory bottle centrifuge, preferably arranged so that it may be rapidly accelerated and stopped. If in such tests the solids are thrown down to give a clear liquor in 30 seconds or less, separation is probably feasible; if more than 60 seconds is required, good separation is unlikely. However, even materials which appear promising in the preliminary test may not dewater satisfactorily in the actual machine, since the conveyer tends to resuspend them in the liquid. This tendency may also be estimated from the bottle tests; if the cake in the bottom of the centrifuge bottle is firm and hard-packed and not easily resuspended in the liquor with a glass rod, the cake will probably convey properly; other-



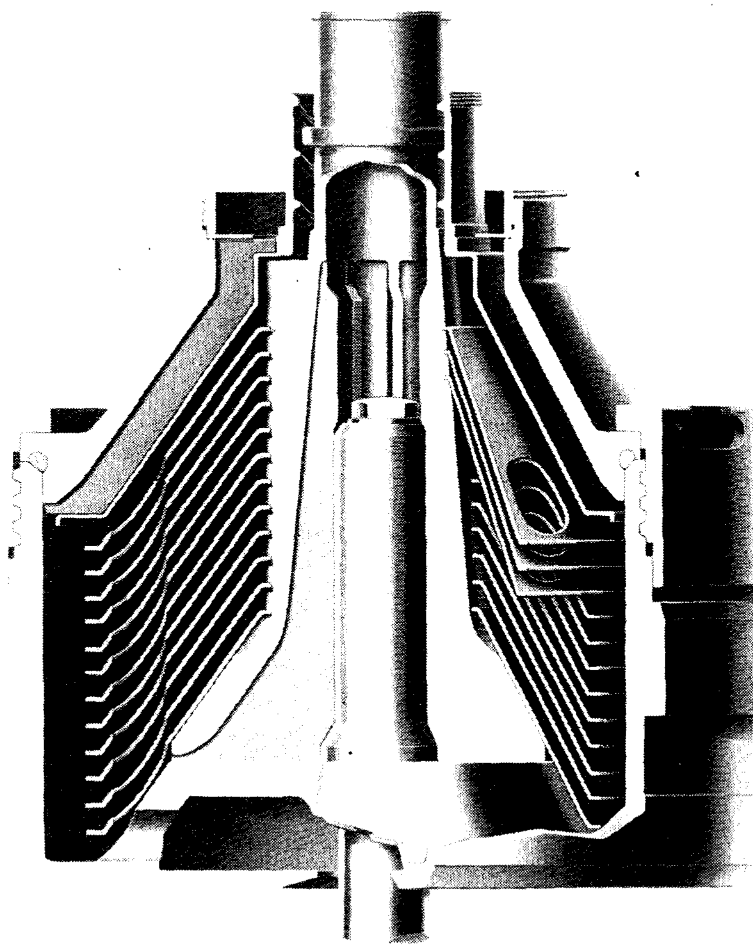
Suspended Batch Centrifuge (American Tool & Machine Company)

wise, it may not. As mentioned above, full scale tests of this type of machine are usually required.

It is unwise to assume that this type of machine will not work, in spite of unpromising preliminary tests, since frequently minor modifications in processing conditions greatly affect the performance. Higher feed temperatures, dilution of the feed, increase in particle size of the solids, or addition of flocculating agents often permit satisfactory separation where the initial test gave little or none.

In this type of centrifuge wash liquor is sprayed on the cake as it is conveyed up the beach. The wash liquor flows into the pond, mixes with the mother liquor, and overflows with it out of the bowl. Since the wash liquid does not pass through the cake as in a basket centrifuge, washing, particularly of fine solids, is usually less effective in this type of machine. Actual washing effectiveness can be determined only by full scale tests. Very effective washing can be obtained with some materials; with others, repulping and recentrifuging are necessary.

The solid bowl continuous centrifuge is finding increasing use as a classifier in conjunction with wet milling operations. By balancing feed rate and bowl speed, even very fine solid particles can be classified according to specific gravity or particle size. Again, while preliminary indications can be obtained from bottle centrifuge tests, full scale tests are essential for determining the actual operating characteristics.



Disk Bowl Centrifuge (The De Laval Separator Company)

GENERAL FIELDS OF APPLICATION

Although the selection of a centrifuge to perform a given separation is influenced by a number of considerations, any one of which may be the determining factor in specific cases, certain generalizations may be made regarding the applications of the various types. The high-speed, small-diameter machines are used for liquid-liquid separations that take place very slowly in gravity settling equipment and for removing small amounts of fine solids from a liquid. Where the flow of liquid and the amount of solids are relatively large, the nozzle discharge centrifuge may be applicable, although its use is limited to a rather small class of solids. For dewatering solids the chief advantage of large batch centrifuges over other types of filters is the lower moisture content of the cake. For moderately high production rates they offer considerable advantages in operating labor over filter presses and Nutsch filters.

Continuous centrifuges find application where the production rate is high, 200 to 300 pounds per hour usually being the lowest rate at which such equipment can be justified. The automatic batch machines and the shove-type continuous centrifuge are limited to free-draining crystalline materials; the horizontal solid-bowl machines handle a wide range of particle sizes, but require that the solids settle rapidly and convey satisfactorily.

Not all separation problems can be solved by centrifuges. Continuous centrifuges are not applicable to the dewatering of fine light solids, particularly where very good washing of such materials is desired. Certain solids pack tightly under centrifugal force, which completely prevents the flow of liquid through them, and consequently cannot be dewatered in perforate-basket centrifuges. Since there is some crystal breakage in almost all centrifuges, other types of dewatering equipment must be used where the crystal form of extremely fragile crystals must be preserved. Also, centrifuges rarely separate solids and liquor completely; where such separation is essential, a filter should be used in conjunction with the centrifuge in order to avoid inadvertent losses.

On the other hand, many types of materials can be better handled centrifugally than by any other method. Gelatinous solids which quickly plug a filter can be removed from a liquid by a high speed centrifuge. High speed centrifuges will separate certain emulsions that cannot be separated so satisfactorily by other means. Crystalline materials can be drained freer of their mother liquor by a perforate-basket centrifuge than by a filter, which reduces the amount of liquid to be removed by heating, and may lead to substantial economies in investment and operating costs.

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