AIChE

EQUIPMENT TESTING PROCEDURE

CENTRIFUGES

A Guide to Performance Evaluation

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Prepared by the
Equipment Testing Procedures Committee

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ABSTRACT

A procedure for testing and evaluating centrifuges and their performance is presented. This includes: the purpose and scope of the tests, definitions of relevant terms, test planning, appropriate methods for measurement and sampling, test procedures, computation and interpretation of results and typical calculations.

The data required to evaluate the performance of several representative categories of sedimentation centrifuges and centrifugal filters are detailed. A list of frequent causes of poor performance is included.

Since the procedure is intended to cover the wide variety of centrifuge types that are available, the necessity of tailoring data sheets and the final report to the specific applications is stressed.

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AIChE EQUIPMENT TESTING PROCEDURE FOR CENTRIFUGES

100.0 PURPOSE, SCOPE, ASSUMPTIONS & COMMENTS

101.0 *Purpose*

101.1 This testing procedure provides directions for conducting and interpreting performance tests made on centrifuges. This procedure may be useful to those who are responsible for obtaining data which could be used to improve the operation of a centrifuge. It can assist those who must prepare operating instructions. It may also be useful to the design engineer who must provide the special test connections that must be made during the installation of the centrifuge and its accessories in order that complete performance tests can be readily made.

101.2 Among the reasons for conducting a performance test are the following:

101.2.1 To determine if the specified performance of the centrifuge (s) has been or can be met.

101.2.2 To determine the performance that may be expected of the unit under the design conditions.

101.2.3 To determine the performance that may be expected of the unit under conditions differing substantially from the design conditions.

101.2.4 To determine possible reasons for unsatisfactory performance by putting the unit through a systematic sequence of tests.

101.2.5 To assemble information that may be used to optimize the operation of a unit.

101.2.6 To determine the effect on process performance of scheduled or unscheduled variations from the design conditions. These variations may include, but are not limited to variations in feed flow rate, temperature, viscosity, concentration of solids or other dispersed phase, and the size or size distribution of the particles in the dispersed phase.

101.2.7 To plan shut-downs for cleaning and mechanical maintenance.

101.2.8 To establish whether the auxiliary equipment and piping upstream and downstream from the centrifuge are suitable for the required service and design conditions.

101.2.9 To determine the optimum performance of combined unit operations, e.g. crystallization and centrifugation and thermal drying.

101.2.10 To compare the performance of centrifuges with that of alternative equipment such as filters and gravity settlers.

102.0 *Scope*

102.1 This test procedure is applicable principally to centrifuges which are used for industrial separation processes or which, although small in size, can be used to predict the performance of larger units.

102.2 The categories of centrifuges covered are batch, intermittent, and continuous units of both the sedimentation and filtration types used to separate two liquid phases or liquid and particulate solid phases.

102.3 Excluded from this test procedure are those units which use very high centrifugal forces to separate isotopes or to determine molecular characteristics of substances and bench top bottle centrifuges.

102.4 It is not the intent of this procedure to establish any limits for the permissable deviation of the actual performance, as indicated by the tests, from the manufacturer's predicted performance.

102.5 Further it is not the intent of the procedure to establish limits for permissable deviation between test data and plant operations.

103.0 *Assumptions and Comments*

103.1 This testing procedure assumes that the centrifuge(s) will have undergone and passed any required mechanical tests in the supplier's and/or user's facility, including but not limited to: vibration level, bearing-temperature rise and bearing lubrication, no-process-load power demand, pressure or vacuum containment, and noise level.

103.2 The procedure assumes that the centrifuge(s) has been installed in a manner that is acceptable to the supplier and that the installation meets the safety and other requirements of the user.

103.3 It is assumed that other types of centrifuges have been considered for the application and the centrifuge being tested is an appropriate candidate.

103.4 It is assumed that other types of equipment have been or are being considered for the application. These might include, but are not limited to, liquid cyclones, gravity settlers and filters.

200.0 DEFINITIONS AND DESCRIPTION OF TERMS

201.0 *Bulk Density*: The apparent weight/volume ratio of a discharged solids phase measured at ambient conditions ($g = 9.81\ m\ sec^{-2}$) expressed as kg m^{-3} or ($g = 32.17\ ft\ sec^{-2}$) expressed as lbs ft^{-3}.

202.0 *Centrate*: The separated liquid or solids phases as discharged from a centrifuge.

202.1 Liquid centrate is also referred to as effluent, overflow or filtrate.

202.2 Solids centrate in as discharged condition may also be referred to as discharged solids, cake or underflow.

203.0 *Centrifugal:*

203.1 (adj.) Proceeding or acting in a direction normal to an axis of rotation.

203.2 (noun) A centrifugal or its drum or rotor.

204.0 *Centrifugal Filter:* A centrifuge designed to support and retain a particulate solids phase on the inside of a rotating permeable member through which the liquid phase is free to pass under the action of centrifugal acceleration. Centrifugal filters may be characterized by the mode of discharge of the separated liquid and solids centrates as (a) continuous (both liquid and solids centrates discharge continuously), (b) batch (liquid and solids centrates discharge at different times during an operating cycle) and (c) intermittent (liquid discharge is substantially continuous and solids discharge is cyclic or intermittent).

205.0 *Centrifugal Force:* The force that tends to impel an object or its parts away from an axis of rotation ($F = m\ a = mr\omega^2$).

206.0 *Centrifuge:* A device for applying centrifugal acceleration ($\omega^2 r$) to separate the components of a multi-phase system.

207.0 *Clean in Place (CIP):* The procedure for decontaminating or removing solids residue from a centrifuge by approprate solvent action without manual disassembly.

208.0 *Cycle Time:* The time required for a batch centrifuge to complete one operating cycle. It is usally measured from the start of the feeding phase of one cycle to the start of the feeding phase of the next succeeding cycle.

209.0 *Effluent*: The liquid phase(s) discharge from a centrifuge; also termed overflow, centrate or filtrate.

210.0 *Mother Liquor:* The solution in which the particulate solids are, or have been, suspended.

211.0 *Power Consumption:* The power consumed by the prime mover, preferably measured by means of a motor analyzer and reported directly in watts or kw under the required conditions of process loading. If this instrument is not available power consumption may be reported as V x A x P.F. for single phase or V x A x P.F. x 1.73 for three phase supply; in which V = volts, A = amperes (average per phase), P.F. = power factor and 1.73 is a satisfactory approximation of $\sqrt{3}$. To the power consumption of the prime mover should be added that required by the centrifuge auxiliaries such as lubricating oil pumps, etc.

212.0 *Recovery:* The proportion of dispersed solids phase in the feed that appears in the centrate solids fraction. This may be reported on either a mass fraction or mass per cent basis.

213.0 *Relative Centrifugal Force:* The ratio of acceleration developed by the centrifuge rotor (usually measured at its largest inside diameter) to the gravitational constant. $\omega^2 r/g$.

214.0 *Sampling Thief:* A device for the removal of a sample of centrate solids.

215.0 *Sanitary Construction:* A trade designation for features that facilitate cleaning, such as smooth polished surfaces, freedom from crevices and accessibility to all parts in contract with the process streams.

216.0 *Sedimentation (Centrifugal):* The migration of dispersed particles toward or away from an axis of rotation, depending on whether the density of the dispersed particles is less than or greater than that of the continuous fluid phase.

217.0 *Sedimentation Centrifuge:* A centrifuge designed to separate immiscible phases by virtue of the difference in density that exists between them. Sedimentation centrifuges may be characterized by the mode of discharge of the separated liquid and solids centrates as continuous (both solids and liquids discharge continuously), batch (liquid and solid centrates are discharged at different times during an operating cycle) and intermittent (liquid discharge is relatively continuous and solids discharge is cyclic or intermittent).

218.0 *Sludge:* A term for solids compacted by sedimentation (gravity or centrifugal) in which the liquid phase remains essentially continuous.

219.0 *Supplier:* The manufacturer, distributor or dealer from whom the centrifuge was purchased or leased.

220.0 *Total Solids:* The total solids content of the feed and centrate streams expressed as a weight fraction or per cent. Differs from ''suspended solids'' in that it includes the solute content of the liquid phase present in the sample.

221.0 *Transient Response:* The short term change in product characteristics or some other dependent variable as a result of a disturbance or change in the feed or in other operating conditions.

222.0 *User:* The purchaser or operator of the centrifuge.

223.0 *Washing Efficiency:* The proportionate displacement of the liquid phase (mother liquor) and its content of solute from the solid phase by the application of a suitable washing medium to the separated solid phase. The reference point is the soluble impurity content of the solids centrate during a period when no rinse is being applied.

224.0 *Yield*: The fractional amount of the desired component in the feed that appears in the product centrate. This is usually reported as per cent.

300.0 TEST PLANNING AND DATA AQUISITION

301.0 *General Comments*

301.1 This section covers the factors to be considered in making centrifuge performance tests. For any given objective not all of these factors may need to be considered. A preliminary review will indicate the pertinent items to be included. This review may also indicate additional factors that should be considered in making a specific performance test.

301.2 The conducting of performance tests involves the expenditure of time and money, and possible loss of production. Care should be taken to specify all of the information that will be required in advance of the tests. The requirements should then be transferred to the raw or working data sheets so that the information can be collected in an orderly manner as expeditiously as possible.

301.3 The data to be acquired during a performance test are generally more comprehensive than those reported during normal operation. It is usually economical to make provision for the collection of these additional data during the initial installation rather than to make any necessary modification at a later date.

301.4 A complete outline of all of the calculations that will be required should be prepared in advance of the performance test. The calculations themselves should be made during the test since the answers may reveal problems that can be corrected before the test is ended.

301.5 Every effort should be made to secure sufficient data so that a complete material balance can be run and cross checked. It is recognized that this is not always possible, e.g. obtaining the rate of discharge of hazardous solids centrate. In such instances at least sufficient data should be taken to calculate a mass material balance from the equations

$$M_f = M_o + M_u \text{ and}$$
$$M_f C_f = M_o C_o + M_u C_u$$

301.6 A sketch of the test layout should be prepared prior to the test to show the centrifuge location and that of associated equipment including at least piping and pipe connections, instrument locations and sampling points. This is useful in setting up the raw data sheets in running the test and in reassembling the equipment if the test must be repeated at a later date.

302.0 *Safety*

The test procedure should conform to the latest requirements of all applicable safety standards. This includes, but is not limited to applicable plant, industry, local, State and Federal regulations. User management and centrifuge supplier sould be requested to furnish in writing specific details that should become a part of the test record. It is further recommended that all testing be conducted by, or under the supervision of personnel full experienced in plant and equipment operating procedures, and with a knowledge of the hazards of the materials being processed.

Hazardous factors should be considered in testing centrifuges such as:

302.1 Rotating elements and moving parts.

302.2 Exposure to process streams and vapors during withdrawal of samples or plant upsets.

302.3 Poor accessibility to suitable sampling ports or instrument read-out points from permanent walkways or platforms.

302.4 Difficulty of communication between test personnel because of ambient noise level and physical separation. This problem can be alleviated by the use of inter-coms or walkie-talkie sets.

303.0 *Types of Tests*

303.1 *Performance Tests:* These are conducted to obtain detailed data from which the performance of the centrifuge can be determined. The conclusions derived from the data and calculations may be used to:

303.1.1 Determine the optimum operating condition.

303.1.2 Determine the operating range.

303.1.3 Estimate performance under varying operating conditions.

303.1.4 Develop operating guidelines and operator instructions.

303.1.5 Assist the selection of new equipment.

303.2 *Optimization:*

303.2.1 Determine the optimum operating cycle of a cycle batch centrifuge or the cleaning frequency, under plant operating conditions, of centrifuges from which solids must be removed intermittently.

303.2.2 Determine and optimize the effectiveness of any cleaning procedure to avoid cross contamination from a change in feedstocks, bacterial contamination from accumulated nutrients, or accumulated radioactivity, before maintenance.

303.2.3 Optimize the selection of ring dam size (heavy phase overflow dimension) of liquid/liquid separators.

303.2.4 Optimize the pond setting (liquid overflow dimension) and conveyor differential speed of continuous solids discharge centrifuges.

303.2.5 Optimize the stroke length, stroke frequency and wash rate of pusher centrifuges.

303.3 *Acceptance Tests:* These are a special type of performance test subject to any prior agreement between the supplier and the user. Frequently their only purpose is to determine that the centrifuge will separate the feed into liquid and solid centrates at a stipulated rate and separating effectiveness and that the power requirement is at or below a stipulated value. In some cases the acceptance test may be an extensive one with explicit details prescribed. Any comparison to predefined requirements during an acceptance test is beyond the scope of this Procedure.

304.0 *Test Planning and Operation*

304.1 The personnel involved should establish objectives, agree to procedures and concur on the data required.
304.2 The instruments needed to take the desired readings with the required precision should be procured, calibrated and placed in line. See also Section 400.0.
304.3 Data sheets should be prepared for the orderly recording of readings and measurements taken during the test. These are to record raw data which may require some interpretation, calculations and supplementary analytical data before presentation as a performance summary. They should include the date of the test and the times at which measurements are made and samples taken.
304.4 The test should be scheduled at a time when:
304.4.1 The required personnel are available.
304.4.2 Suitable operating conditions for the test are forecast.
304.4.3 An adequate supply of the process stream is available.
304.5 Convenient access to any necessary analytical facilities (including specialized instrumentation) necessary to evaluate the samples should be arranged. A considerable saving in time frequently can be effected by scheduling analytical work in advance of the test. The results then can be reported promptly to permit making any indicated adjustments while the test is in progress and the test personnel are still assembled.

305.0 *Data Acquisition:*

For a performance test the following data should be secured and recorded.

305.1 General
305.1.1 Revolutions per minute of rotor at no load and at various loads.
305.1.2 Power demand at no load and at various loads.
305.1.3 When applicable, conveyor differential speed and torque.
305.1.4 When applicable, pusher stroke frequency and amplitude.
305.1.5 When applicable, the time for each portion of the cycle of batch centrifuges or of those requiring intermittent solids removal or discharge.

305.2 Feed
305.2.1 Flow rate.
305.2.2 Temperature (measured immediately upstream of centrifuge).
305.2.3 Composition and physical properties including:
(a) Chemical compostion of mother liquor.
(b) Viscosity of mother liquor at feed temperature.
(c) Density of mother liquor at feed temperature
(d) Content (as weight fraction or settled volume at a standard condition), particle size (including measurement of mean size and an indication of size distribution), particle shape or crystal habit, density and composition of dispersed solids phase. Photomicrographs are useful as supporting evidence.
(e) Content, density and compostion of dispersed liquid phase, if present.
305.2.4 Proportionate time of feeding for cyclic or intermittent operation.

305.3 Effluent (or effluents in the case of liquid/liquid separations)
305.3.1 Flow rate.
305.3.2 Composition including:
(a) Content and particle size distribution of unremoved dispersed solids.
(b) Content of unseparated liquid phase, if present.

305.4 Solids
305.4.1 Flow rate, for continuous operation.
305.4.2 Batch size, for intermittent or cyclic operation.
305.4.3 Residual mother liquor content or content of principal component of mother liquor.
305.4.4 Residual content of non-volatile component(s) of mother liquor - applicable when washing in place is conducted.

305.5 Cake wash or rinse liquid
305.5.1 Composition.
305.5.2 Temperature.
305.5.3 Flow rate for continuous operation or volume or weight per batch for intermittent operation.

306.0 *Personnel*

306.1 The presence of the necessary personnel to conduct the tests with a view to meeting the test objectives should be assured. It is desirable that personnel be included who are:
(a) Familiar with the equipment being tested, including its auxiliaries, and capable of making any required adjustments to optimize performance.
(b) Familiar with the product being centrifuged, the process of which centrifugation forms a part, and particularly with any hazards connected with the operation.
306.2 For an acceptance test the presence of contractors involved in the installation and auxiliary equipment suppliers also may be desirable.

400.0 METHODS OF MEASUREMENT AND SAMPLING

401.0 *Introduction*

Results can be no better than the measurements and data from which they are calculated. Advance planning, frequently with some ingenuity and care, is necessary to ensure that the methods of measurement, sampling and analysis are suitable for the proposed tests. Accurate and suitable measuring devices are necessary for reliable results. These devices should be specified by, or reviewed with, personnel knowledgeable about instrumentation and process details.

402.0 *Performance Tests*

The method to be used for performance tests should be agreed to by the participants before the start of the tests.

403.0 *Accuracy*

The degree of conformity to the true value or to an agreed upon standard value is the accuracy. Instruments and measuring devices should be checked over the expected operating range against know standards before and after the tests. The accuracy of all data should be indicated and the effect on the test results determined.

404.0 *Precision*

The degree of exactness or the number of significant digits in a measurement is the precision. In any calculation involving rounded numbers of unequal accuracy, one more significant figure should be retained from the beginning of the calculation in the more accurate numbers than are contained in the least accurate number. The final result should be rounded off to the same number of significant figures as the least accurate number contains.

405.0 *Measurement of Rotational Speed*

405.1 Various types of mechanical and electromagnetic tachometers are available for direct rotational speed measurement when a center or axis of rotation is accessible.

405.2 Stroboscopic tachometers are useful when no such center exists. Many of these may be calibrated accurately against a 60Hz power supply. Care must be taken in their use to avoid a signal that is an integral multiple or fraction of the true speed.

405.3 Some centrifuges come equipped with direct reading tachometers or speed reduction gearing to permit direct speed reading over a measured time interval.

406.0 *Power Demand*

Since, in general, the user is only concerned with the electrical power input to the system of prime mover plus auxiliaries, the efficiency of the moter driver can usually be ignored. When more exact measurement of power input is required, the efficiency of the motor can be taken from the motor test curve available from the motor supplier.

406.1 Wattmeter Measurement: Total power input tothe motor(s) should preferably be obtained with a calibrated wattmeter or motor analyzer.

406.2 Watt-hour Measurement: Particularly for cyclic batch centrifuges power consumption should be measured on a calibrated recording watt-hour meter. The average power demand is the root mean square of the sum of the power required at each phase of the cycle. On relatively short cycles (5 min. or less) most motors will accept an overload of 60%, as during loading and unloading, for up to 30% of the cycle provided the root mean square of power over the total cycle does not exceed the name-plate rating. If there is any doubt regarding a particular motor, consult the motor suppler.

406.3 Ammeter/Voltmeter Measurement: Power input can be determined with reasonable accuracy, in the range of 60% of 125% of full load motor rating, by the use of a calibrated ammeter and voltmeter, corrected by the power factor curve supplied by the motor manufacturer. For a 3 phase supply the indicated power demand in watts is volts x amperes (average per phase) x p.f. x 1.73. Readings with clamp on (tong) ammeters may be in error by +/− 10%.

407.0 *Flow Rate*

Flow rate may be measured by a calibrated flow meter or by outage from or volume added to a tank of known dimensions, or by weight of flow per unit time.

407.1 Flow Meters

407.1.1 Variable orifice types, such as rotameters, are suitable for measuring the flow rate of clean liquids or liquid containing only finely dispersed solids. In the latter case the calibration must reflect any change in density and/or viscosity resulting from a change in solids concentration.

407.1.2 Fixed orifice types, properly calibrated are suitable for measuring the flow rate of clean liquids and slurries containing a wider range of solids with respect to concentration and particle size. Pipe line velocities should be at least 2.5 m/sec (appros. 8.5 ft/sec.) to minimize the settling of solids in the area adjacent to the orifice plate. Performance is frequently improved by installing the orifice meter in a vertical run of pipe.

407.1.3 Venturi type flow meters are best for measuring the flow of slurries containing solids that settle readily. Pipe line velocities should be at least 1.5 m/sec.

407.1.4 Magnetic and ultra-sonic meters may also be used.

407.1.5 No orifices should be installed on the suction side of any pump.

407.2 Flow Measurement From and To Tanks:

407.2.1 Feed rate can be measured by the change in level of the contents of a calibrated tank, or one of known dimensions, over a timed interval. Care should be taken so that during the timed run no liquid is added to the tank or withdrawn from it except through the feed line. If flow from the feed tank to the centrifuges is by gravity, the head change during the timed interval should not exceed 20% corresponding to a flow rate variation during this period of approximately 10%.

407.2.2 Liquid centrate rates can be measured by the change in level of a calibrated tank or one of known dimensions, over a timed interval. Care should be taken so that during the timed interval no liquid is withdrawn from the tank.

407.3 Rinse liquid flow rates can be conveniently measured by a variable orifice flow meter or by timed outage from a calibrated tank.

407.4 Solids centrate flow rate is determined by catching and weighing the discharge solids over an appropriate timed interval. In batch operation the entire unit load of solids centrate discharged should be weighed and then thouroughly mixed prior to sampling. In certain special cases, when the solids can be melted by reasonable temperature elevation, it may be more convenient to measure the volume of the melt as under 407.2.2.

408.0 *Flow Rate Control*

The accurate control of the flow rate of slurries containing medium to coarse solids is most difficult. Every effort should be made in the installation to insure that minimum pressure drop is taken through the control valve and that the valve is operated at as near to 100% opening as possible. Vee notch ball valves have relatively good flow control characteristics. For automatic flow control it may be necessary to superimpose an oscillation on the control valve to keep it from plugging. This will create an instantaneous flow variation of as much as +/− 20% from the mean value and this should be recognized in setting up the performance specifications for the centrifuge.

409.0 *Time*

Mechanically or electrically driven chronometers are generally used for the measurement of elapsed time.

410.0 *Temperature*

Any reliable temperature measuring device that can be installed in accordance with the manufacturer's recommendation may be used after its precision and accuracy have been established. The accuracy of the final reading is dependent on the installation as well as on the sensing element. The sensing element should be installed immediately upstream from the centrifuge to ensure that the measured temperature accurately reflects the viscosity and dissolved solids content of the feed.

410.1 As corollary, it has been observed in continuous crystallization processes that equilibrium solubility at the measured temperature is not always attained. When this is suspected, arrangements should be made to extract a sample of solids free mother liquor from the feed line to determine the exact fraction of dissolved solids in the feed stream instead of relying on an equilibrium solubility/temperature gradient curve.

410.2 Frequently encountered problems with temperature measurement are:

410.2.1 Stratification of the stream being measured. This is especially common in tanks or oversize feed lines.

401.2.2 Radiation errors caused by the sensing element reflecting readings from surfaces at a different temperature from that of the stream being measured such as the cold walls of uninsulated pipe.

410.2.3 Conduction along thermowells and insufficient immersion of the sensing element in thermowell. Short heavy duty thermowells are expecially subject to this source of error.

411.0 *Viscosity*

Viscosity of liquids is usually measured by pressure drop-flow rate methods or by rotational viscosimeters such as the Brookfield type. Oil viscosity is conventionally measured on a standard Saybolt viscosimeter and reported as SSU(Seconds Saybolt universal) at the test temperature.

412.0 *Particulate Solids*

412.1 Mass or number fraction of particles by size may be determined by sedimentation rate vs. time, by microscopic examination, or by wet or dry sieve tests. In dry sieve tests extreme care must be taken to avoid agglomeration of particles during the drying procedure.

412.2 Particle shape can best be determined by microscopic examination.

413.0 *Sampling and Analysis*

The reliability of a performance test depends to a large degree on the securing of representative samples of the several process streams involved (typically feed and liquid and solids centrates), preferably simultaneously*, and analysing them accurately. It is imperitive that the sample be representative of the stream from which is is withdrawn and that it be taken at a low enough rate so that up-stream and down stream conditions are not upset.

413.1 Volumetric analyses, suitable for a rough qualitative indication of performance, as in calibrated centrifuge tubes or a calibrated settling cone can frequently be performed in the field.

*When this is not feasible the preferred sampling sequence is 1) feed, 2) liquid centrate, 3) solid centrate.

413.2 Gravimetric analyses, for a more precise measurement of performance, usually require access to laboratory facilities where the required instrumentation of suitable accuracy is available. These may be as simple as a filter for solids removal, a drying oven and a balance; or as complex as a mass spectrometer.

413.3 Moisture content, as of discharged solids, can be measured locally on a commercially available moisture tester provided the solids are not decomposed by the radiant heat from such a device.

413.4 The use of pear shaped tubes with calibrated small bore tips spun in a high speed bottle centrifuge for an appropriate time is frequently specified for the determination of small amounts of containment, such as water in oil. When reported as gravimetric proportions the appropriate corrections for density must be made.

413.5 The preferred methods of measurement and analyses are:

Quantity Measured	Method
Bulk density of solid centrate	Mass of solid in a container of known volume
Density of liquid phase	Mass of known volume
	Hydrometer
Density of solid phase	Volume of liquid displaced by a know mass of solid*
Flow rate, liquid or slurry	Mass or volume in a measured time interval
	Rotameter
	Venturi meter
	Orifice meter
	Magnetic flow meter
Flow rate, solid centrate	Mass during a measure time interval
Mass	Calibrated scales or volume x density
Particle shape	Microscope
Particle size	Calibrated sieves
	Sedimentation
	Microscope
Power	Calibrated watt meter, watt-hour meter or motor analyser and motor efficiency calibration curves
Pressure	Calibrated pressure gauge
	Manometer
Rotational speed	Tachometer
	Stroboscopic tachometer
	Revolution counter and stop watch
Temperature	Calibrated thermometer
	Calibrated Thermocouple
Time	Mechanical or electrical clock
Viscosity	Ostwald viscosimeter
	Saybolt viscosimeter
	Falling ball
	Rotating cylinder or paddle viscosimeter
	Vibrating reed viscosimeter

*N.B. Liquid used must wet the solids to avoid measurement errors caused by entrapped vapor

413.6 Samples of working fluids should be taken from pipelines in which the velocity is high enough to ensure that the sample is representative of the slurry or other fluid flowing through the pipe. Samples taken from tanks are less satisfactory unless the tank is used for the entire test and can be thoroughly agitated to insure complete dispersal of its contents.

413.7 Sample connections should be as short as possible since they must be completely purged before the sample is taken. The preferred arrangement is a block valve or ball cock, that can be opened to the full diameter of the sampling line, placed immediately adjacent to the pipe line, followed by a second valve to control the flow to the sample container after the sampling line has been purged.

413.8 Sampling rate should be low enough so that process conditions are not upset and composite sampling should be used to average out instantaneous variations.

413.9 Sample volume should be at least twice that required for the projected analytical procedures to allow for any duplicate analyses that may be necessary.

413.10 Sample containers must be clean, constructed of material that will not react with the sample, suitable for sealing immediately after the sample is taken, and preferably filled to not over 75% of their capacity to permit manual redispersion of their contents when subsamples are being withdrawn for analysis.

413.11 The sampling of separated solids is a complex subject that depends on the physical and chemical nature of the solids and whether their discharge from the centrifuge is continous or intermittent (batch wise). The exact method of sampling should be agreed to before the test by the participants.

413.12 Continuously discharging centrate solids can be best sampled with a thief. Several commercial versions of this type of device are available or one can be fabricated to suit a particular location. The length of the opening in the thief should be at least equal to the width of the discharge line it is intended to span. In operation the thief is fully inserted into the discharge line with its open face pointing down, then rotated 180° to receive the sample and then withdrawn with the sample. This procedure can be repeated until sufficient sample for the required analysis is obtained.

413.13 The solids in vertical basket centrifuges can frequently be sampled by stopping the basket just before the unloading phase of the cycle and taking the samples with a large cork borer or its equivalent. The sampler should be inserted radially with care taken to insure that it reaches all the way to the filter medium so that the sample represents the cross section of the cake. Several samples should be taken in this manner from the top to the bottom of the basket and these should be composited for analysis.

413.14 Horizontal centrifugal filters can also be sampled as under 413.13 but it is usually more convenient to discharge an entire load and obtain the desired sample by quartering. In any event the sampling technique chosen must recognize the probable variation in product composition through the radial depth of the cake and the distance from the end of the basket.

500.0 TEST PROCEDURE

501.0 *Pretest Check List*

The following steps should be taken before the centrifuge is operated for test purpose. Many of these will have been completed during the planning phases of the tests.

501.1 Define the test objectives.

501.2 List the test conditions necessary to accomplish the test objectives.

501.3 Prepare data sheets on which the raw data can be conveniently recorded.

501.4 Determine that all necessary instrumentation is installed, calibrated and in working order.

501.5 Determine that the necessary analytical facilities and techniques are available.

501.6 Determine that an adequate supply of suitable clean sample containers is available.

501.7 Determine that all necessary upstream and down stream auxilliaries such as feed and discharge pumps, discharged solids conveyor, control valves and flow meters are in working order and of adequate capacity to accomplish the test objectives.

501.8 Determine that an adequate supply of feed stock is available to accomplish the test objectives.

501.9 Determine that safety and control interlocks are properly installed and are functioning correctly.

502.0 *Preliminary Tests*

After the test planning has been completed, a preliminary test may be desirable to insure the success of the performance test. A complete set of data and samples should be taken during the preliminary test. The samples should be analyzed and the results of the analysis and other data calculated before the performance test is started. The purpose of the preliminary test are to:

502.1 Train the test personnel and instruct the regular operators.

502.2 Determine whether the test can be run as planned and will provide data that are adequate both as to quantity and quality.

502.3 Determine whether the scheduled sampling techniques are adequate and can be accomplished.

502.4 Provide rough data for preliminary calculations to determine that the calculation procedure is satisfactory.

502.5 Determine whether the operating conditions are those desired for the test, such as operation at design conditions.

502.6 Determine whether the desired operating conditions such as flow rate, temperature and pressure can be adequately controlled, measured, and recorded.

502.7 Detect and rectify unusual conditions such as leakage, poor vent control, auxiliary equipment malfunction and improper centrifuge speed control.

502.8 Determine that all safety and control interlocks are performing satisfactorily.

502.9 Many of these items can be covered in The Pretest Check, Section 501.0.

503.0 *Performance Tests*

The tests should preferably be run under the normal operating conditions on which the design is based. Special or unusual situations should be recognized and, if possible, compensated for. If this is not possible the performance tests should be postponed until normal operating conditions are available. Feed stock should be selected to establish normal operating conditions and an adequate quantity should be available for the scheduled duration of the tests.

503.1 Content and Duration of tests

503.1.1 Continuous flow centrifuges generally attain equilibrium quite rapidly and sampling may usually be commenced after three volume displacements after the separated phases are discharging continuously.

503.1.2 When the feed temperature is appreciably different from ambient temperature, either higher or lower, sufficient time should be allowed for the centrifuge to come to thermal equilibrium before sampling is commenced. This may be detected by monitoring the temperature of the effluent liquid phase. The sampling should be delayed until this reaches a constant value.

503.1.3 If the test is to include the effect of a change in flow rate or a change in rinse ratio sufficient time should be allowed after the change and before sampling to permit a minimum of three volume displacements of the liquid and solids content of the rotor.

503.1.4 When the upstream conditions are cyclic, as feed from a salt evaporator/crystallizer between boil outs, the performance test should cover at least one full cycle with sampling, including samples for particle size determination, at 30 to 60 minute intervals.

503.1.5 With a constant feed rate and composition and constant rinse rate (if a rinse is to be applied) conditions, a three hour run with sampling at 30 to 60 minute intervals should be adequate.

503.1.6 When assessment of the effect of changes in feed rate, feed composition and/or rinse ratio is desired, samples should be taken as noted under 503.1.3 and the test extended to cover the spectrum of variables to be examined. Preferably at least two sets of samples should be taken, not sequentially, and the variables, particularly the flow rate, should be randomized.

503.2 Cyclical Centrifugal Clarifiers

503.2.1 Cyclical centrifugal clarifiers are normally operated at constant feed flow rate during the feeding phase of the cycle. As the rotor or bowl becomes loaded with solids during this portion of the cycle, the proportionate removal of the dispersed phase tends to decrease. This decrease is usually slow and may even be zero until a critical solids loading within the rotor is reached. After this the decrease becomes much more rapid until the overflow composition is the same as that of the feed.

503.2.2 The average capture (or its complement, the rejection of dispersed solids to overflow) is an important factor to be determined during the test procedure.

503.2.3 A sufficient number of overflow samples should be taken at regular time intervals to develop the profile of this capture (or rejection) curve. The average rejection is the numerical average of the solids content of these samples. or, the entire overflow during the feed period may be caught in a suitable container, thoroughly mixed and sampled to yield the same result.

503.2.4 The second important factor to be determined during the test procedure is the concentration of sludge accumulated in the rotor. Particularly on soft sludges, this concentration can be improved, with some loss of net capacity, by interposing a spin time between the termination of feeding and unloading of the solids to compact the sludge. For maximum benefit this spinning period should be followed by skimming of the supernatant liquid down to the liquid sludge interface. Depending on their clarity, the skimmings may be (a) added to the overflow and included in its analysis or (b) recycled back to become part of the feed to the nest cycle.

503.2.5 The third important factor to be determined during the test procedure is the solids content of the unloaded solids centrate. This may vary through the depth of the cake so for maximum accuracy the entire batch of unloaded cake should be quartered repeatedly until reduced to a sample of appropriate size. Grab sampling, as from a conveyor belt, is a less accurate method.

503.2.6 The fourth important factor to be determined during the test procedure is the net capacity of the centrifuge. This may be determined by:

a. When skimmings are added to overflow-
   1) Outage from feed tank during the feeding portion of the cycle divided by total cycle time.
   2) Feed rate multiplied by feed time divided by total cycle time.

b. When skimmings are recycled back to feed-
   1) Net outage from the feed tank during a complete cycle divided by total cycle time.
   2) Feed rate multiplied by feed time less volume of recycled skimmings, the net volume divided by total cycle time.

503.2.7 It is recommended that the results from a minimum of three complete cycles, not taken sequentially, should be used as a performance test.

503.3 Cyclic Centrifugal Filters

503.3.1 Cyclic centrifugal filters are normally operated at constant feed flow rate during the feeding phase of the cycle. During this period, and depending on the design of the centrifuge, some of the solid phase may pass to the filtrate:

a. By passage through the filter medium.
b. By splashing of the feed over the lip ring.
c. By pick up of solids from a previous

unloading.

503.3.2 The analysis of the filtrate for suspended solids content may be an important part of the test procedure. Generally this is only possible by sampling the filtrate receiver. For accuracy the filtrate should be well agitated and held at the same temperature as that of the feed. The sample should be maintained at the feed temperature during the analysis to avoid distortion of results by changes in solubility.

503.3.3 Generally the capacity of a centrifugal filter is reported in terms of units of mass of solids discharge per unit time either on an as is or a dry basis.

503.3.4 When practical the unit load of solids discharged should be weighed and sampled. The capacity is the weight of the discharge load divided by the time of the complete cycle corrected for the volatile content of the solids if the reporting is to be made on a dry basis. Under constant conditions three cycles should be adequate for a performance test with the results to be averaged.

503.3.5 When it is not possible or is impractical to weigh the unit load of discharged solids, other means of evaluating capacity are necessary. Some suggested alternatives are:

a. Outage from a feed tank of known composition corrected for loss of solids to filtrate.

b. Weight of dried solids per unit time when centrifuge and final drier are close coupled, In this case the test should be of sufficient duration to dampen out irregularities in the flow and hold up in the system.

c. Melting the product solids and measuring their volume per load or per unit length of time may be feasible in certain systems.

Under these conditions the test should be of sufficient duration to insure the desired accuracy in the measurement.

503.4 Liquid/Liquid Separators

503.4.1 Liquid/Liquid separators are normally operated at constant feed flow rate.

503.4.2 This flow rate may be measured by any of the conventional means previously discussed such as:

a. Outage from the feed tank over a measured time interval.

b. Combined additions to the tanks receiving the separated flows over a measured time interval.

c. Calibrated flow meters of the variable orifice, fixed orifice, Venturi types, etc.

503.4.3 In the event a particulate solid phase is present, cyclic operation will be necessary with a time interval for removing the accumulated solids. In this case the net flow rate becomes:

Feed Rate x Feed Time ÷ Total Cycle Time

503.4.4 When solids removal is manual, such as on systems containing only a small proportion of suspended solids, the separation should be monitored by taking a minimum of five sets of samples at equal intervals during the feeding phase of the cycle. The degree of separation, or clarification, is the numerical average of the analyses of these samples, or of a single analysis of a mixture of these samples.

503.4.5 Tests on centrifuges that discharge the solids, either under time cycle control or as a result of solids accumulation to a predetermined degree, while rotating at constant speed, may be conducted in a manner similar to 503.4.4. If the interval between solids discharges is short, it may be preferable to accumulate the separated phases from a single cycle in appropriate receivers and sample these. Feed samples should be taken at regular intervals to insure that the feed concentration is constant or to monitor changes in it.

503.5 Nozzle Discharge Centrifuges

503.5.1 Continuous liquid/liquid separators discharge some or all of the suspended solids through periperal nozzles with a portion of the separated heavy liquid phase. If periodic manual cleaning is required, the gross capacity must be adjusted to give the net capacity. Sampling of the feed and of the separated liquid should be conducted at appropriate regular intervals during the course of a complete cycle. Samples of uniform size may be combined for a single analysis but more information will be gained by analyzing the individual samples and using the results to monitor the effect of changes in feed composition and changes in effluent composition due to the accumulation of solids in the bowl.

503.5.2 Any of the tests on liquid/liquid separators should be of sufficient duration to monitor at least three, preferably nonsequential, cycles.

503.5.3 Peripheral nozzle discharge clarifier centrifuges, with or without recycle of a portion of the underflow, are used to concentrate small particulate solids, such as yeast, starch and corn gluten, and to classify solids by particle size and density such as corn starch (discharged with the underflow) from gluten (discharged with the overflow). These are normally operated at constant feed flow rate and the underflow concentration is controlled by varying the recycle rate. When this feature is not available the underflow concentration is controlled within somewhat narrower limits by returning a portion of the underflow back to the feed to increase its concentration, or by varying the feed rate. In centrifuges operated with an internal recycle (recognized by the absence of an external recycle pump), measurement of the recycle flow is impractical. In this case the recycle rate may be determined by calculation.

503.5.4 The feed rate may be measured by:

a. Outage from the feed tank over a measured time interval,

b. Combined addition to the tanks receiving the overflow and the net underflow over a measured time span, or

c. Calibrated flow meter of the variable orifice, fixed orifice, Venturi type, etc.

503.5.5 The recycle rate may be measured by a calibrated flow meter of the variable orifice, fixed orifice, Venturi type, etc. or it may be calculated with minimal error.

503.5.6 The overflow rate and the net underflow rate may be measured by the respective addition to tanks receiving then over a measured time span. Flow meters should not be used in the underflow draw-off line and only in the overflow line when the centrifuge is equipped with a centripetal overflow pick up device.

503.5.7 It is preferable to measure both the flow rate and the insoluble solids content of the feed, the overflow and the net underflow (nozzle discharge less recycle) at each sampling interval.

503.5.8 In the event that this is not possible, one or two missing values can be calculated from the equations:

$$Q_f^* = Q_o + Q_u \text{ (net)}$$

$$Q_f C_f = Q_o C_o + Q_{u(net)} C_u$$

*When Q is determined on a volumetric basis, C should be determined and used on a weight per unit volume basis.

503.5.9 Runs on separations of this type are usually of extended duration, frequently a week or longer, being interrupted for cleaning the rotor when several nozzles have plugged, for sanitary reasons or for scheduled plant shut-downs. The intervals between samplings should be agreed to prior to the start of the test and may range from hourly to once or twice a shift depending on the constancy of the feed with respect to composition, rate and temperature.

600.0 COMPUTATION OF RESULTS

601.0 *Analytical Methods*

In the following sections typical methods are presented for translating test data into the information needed to analyze the centrifuge performance. The analytical methods necessary to accomplish this may be perfectly straight forward, such as drying to constant weight at 105°C or filtering out, drying and weighing insoluble solids, or considerably more complex depending on the system being centrifuged. In any event the analytical and other procedures to be employed should be established in advance of the tests and should become part of the test record.

601.1 Intervals Between Cleaning

601.1.1 The determination of the optimum interval between cleanings of *batch centrifuges,* or of *continuous centrifuges* subject to the gradual accumulation of undischarged solids, or of *batch or continuous centrifugal filters* subject to scaling or other blinding of the filter medium is best determined by carefully monitoring a single cycle and repeating this monitoring when indicated by a change in performance. Cleaning is required when the product analysis is below a preset value or when the average analysis of the total product discharged is below the preset value.

601.1.2 The interval between cleanings for sanitary resons is usually established by normal plant operating procedures.

601.2 Selection of Data

601.2.1 On the completion of the test, the log and the several analyses, together with pertinent charts from recording instruments should be examined for obvious errors.

601.2.2 Data selected for use in computations relating to continuous centrifuges of either the filtration or sedimentation type should be representative of stable operation for a period of time previously established. A minimum period of one hour is suggested

601.2.3 During this period feed rate, feed composition and feed temperature should be as required to obtain results within the desired limits of accuracy.

602.0 *Data Requirements*

602.1 Data Required for Continuous Centrifuges

The information obtained should include, but not necessarily be limited to:

602.1.1 Feed temperature, volumetric flow rate, density, content of suspended solids (and of second liquid phase if present) and particle size distribution of suspended solids.

602.1.2 If the cake is to be washed or rinsed, the concentration of the mother liquor soluble component that is to be removed or reduced by rinsing the cake.

602.1.3 If applicable, rinse or wash liquid temperature, volumetric flow rate, density and composition.

602.1.4 Discharged liquid centrate (or centrates if centrifuge is operated as a liquid/liquid separator): flow rate, density, composition with respect to content of solids or unremoved second liquid phase and volatile content.

602.1.5 Discharged solids centrate: gross gravimetric flow rate, mother liquor content, or content of volatile component of mother liquor.

602.1.6 Particle size distribution of the discharged solids.

602.1.7 If the cake has been washed, its content of the mother liquor soluble component that is to be reduced is also required.

602.2 Data Required for Batch Centrifugal Filters

Data selected for use in computations relating to batch centrifugal filters should be representative of stable operations for a period of time or a number of cycles (minimum of three is suggested).

602.2.1 In addition to the required information covered in Paragraphs 602.1.1 through 602.1.7 the record should include the time for each phase of the operating cycle, which may be summed up as the total time per operating cycle, and the volume of screen wash liquid necessary per cycle to maintain the porosity of the filter medium

602.2.2 A typical operating cycle would include some or all of the following component phases:

a. Accelerate to loading speed.
b. Feed, charge or load.
c. Accelerate to full speed.
d. Wash or purge cake.
e. Repeat wash as required.
f. "Dry" spin.
g. Decelerate to unloading speed.
h. Unload.
i. Rinse filter medium.

Some condensation of the above phases may be possible as screen rinsing during a. and cake washing during c. Additionally, phases a., c. and g. do not apply to constant speed batch centrifugal filters.

602.2.3 Capacity may be measured as the unit load of solids (calculated on a dry or mother liquor free basis) discharge multiplied by the number of cycles per unit length of time or as the total weight of solids discharged (calculated on a dry or mother liquor free basis) per unit lenth of time.

602.2.4 When cleaning of the centrifuge is required, as for a change in feed stock to avoid cross contamination or for sanitary reasons, the cleaning procedure and the methods for checking its efficacy should be established by the participants in advance of the test and become part of the test record.

602.2.5 Since time spent in cleaning represents unusable production time, it may properly be added pro rata to the gross cycle time to arrive at the net capacity of the centrifuge.

602.3 Data Requirements for Batch Sedimentation Centrifuges.

Data selected for use in computations relating to batch sedimentation centrifuges should be representative of stable operation for a period of time or a number of cycles (minimum of three is suggested). In general, such centrifuges are fed at constant flow rate during the feeding portion of the cycle.

602.3.1 The major classifications include:

a. Tubular and disc clarifiers and separators with intermittent manual removal of accumulated solids after stopping and disassembly of the rotor.
b. Disc clarifiers and separators of the desludging type with manually or automatically controlled discharge of solids while the bowl is rotating at full speed. Feed may or may not be continued during the desludging phase of the cycle depending on the application.
c. Solid wall "basket" centrifuges of either the variable speed (vertical axis) type or constant speed (horizontal axis) type.

602.3.2 During the period of the test feed flow rate, composition and temperature should be as required to obtain results within the desired limits of accuracy.

602.3.3 Capacity may be reported as gross flow rate during the feeding portion of the cycle, particularly for classification 602.3.1 a., or as net flow rate (Gross Flow Rate times Feed Time divided by Total Cycle Time), the latter being preferable for classifications 602.3.1 b. and 602.3.1 c.

602.3.4 Since there will almost certainly be a reduction in clarification or separation effectiveness as solids accumulate in the rotor, sufficient feed and centrate samples should be taken at uniform intervals of time during the cycle to properly monitor this fall off.

602.3.5 These samples should be analyzed individually during the first several cycles to determine the point at which manual cleaning or discharge of solids from the rotor is required. After that the analysis of composited samples is adequate.

602.3.6 Batch classification centrifuges may be equipped with a skimming device to remove supernatant liquid from the rotor, after feeding has been completed, in order to maximize the concentration of the solids that are to be discharged. Such skimmings are normally recycled back to the feed tank and their volume should be considered in the calculation of net capacity.

602.4 Data Required for Continuous Nozzle Discharge Centrifuges

Data selected for use in computations relating to continuous nozzle discharge clarifiers or separators should be representative of stable operation for the test period.

602.4.1 During the period of the test feed flow rate, composition and temperature should be as required to obtain results with the desired limits of accuracy.

602.4.2 The analysis of samples taken when one or more of the peripheral discharge nozzles has plugged should not be considered in the computations.

602.4.3 Samples of the feed, overflow (or overflows in the case of liquid/liquid separators) and underflow should be taken at regular intervals of time during the test.

602.4.4 These may be analyzed separately to monitor a possible trend or equal volumes of such samples may be combined before analysis to be reported as shift or daily averages.

602.4.5 Concurrently, measurements should be made of the flow rate of the feed, the overflow (or overflows in the case of liquid/liquid separators) and the gross and net (gross minus recycle) underflow.

602.5 Typical Computations

Typical computations from selected data are included in the Appendix Section 800.

700.0 INTERPRETATION OF RESULTS

701.0 *Test Data*

It should include the following information:

a. Description of centrifuge and auxiliary equipment.
b. Operating conditions.
c. Feed characteristics.
d. Liquid centrate characteristics.
e. Separated solids centrate characteristics.
f. Power consumption.

Most of these data are important to provide a history of what has been done so the test can be repeated and to monitor possible deterioration in performance.

702.0 *Test Results*

Test results may be interpreted and performance evaluated in accordance with the following characteristics:

702.1 Capacity may be expressed as volumetric or mass feed flow rate; or mass rate of solids discharged corrected to zero volatile content or to some other volatile content.

702.2 Proportion of insoluble solids not captured is the ratio of the dry basis insoluble solids content of the effluent or filtrate to the dry basis insoluble content of the feed for a prescribe period of time. Proportion of solids captured is one minus this ratio, usually expressed as a percentage.

702.3 Discharged solids solvent, moisture or other volatile content is the loss by evaporation to constant weight, under conditions compatible with the material being processed, reported as a percentage of the weight of the sample (as discharged basis).

702.3.1 As an alternative, in some situations the solvent content may have to be determined by a more complex procedure.

702.3.2 In situations where the mother liquor content of the discharged solids, rather than just their volatile content, is a consideration, the solvent content shall be corrected by the proportional amount of solute it is know to contain at the feed temperature.

702.4 Rinse or wash efficiency is the reduction in the solute content of the discharged solids by a specified ratio of rinse rate to dry basis solids discharged. The usual reference point is the solute content of the discharged solids during a period when no rinse is applied.

702.5 Liquid/liquid separation effectiveness is determined by analyzing each of the separated liquids for its content of the other, either volumetrically or gravimetrically, as agreed to by the participants.

702.6 A number of special analytical procedures to evaluate centrifuge performance may also be required on specific applications. Covering these in specific terms is beyond the scope of these Procedures.

703.0 *Frequent Causes of Poor Performance*

703.1 Not complying with supplier's installation recommendations.

703.2 Centrifuge is not level.

703.3 Centrifuge supporting structure lacks sufficient strength, mass and rigidity to control vibration.

703.4 Connecting piping and duct work lacks sufficient flexibility to accomodate centrifuge vibration.

703.5 Centrifuge and/or auxiliaries are rotating in wrong direction.

703.6 Centrifuge is not rotating at design speed (RPM).

703.7 Centrifuge drive motor lacks sufficient power to accelerate rotor to operating speed or to maintain desired speed during operation under load.

703.8 Centrifuge feed pump lacks sufficient capacity to deliver design flow at required pressure.

703.9 Liquid centrate pump becomes vapor bound.

703.10 Liquid centrate piping is improperly sized and/or sloped to provide for vapor disengagement in the piping.

703.11 Solids centrate is accumulating in the centrifuge solids discharge area preventing free discharge of succeeding centrate solids.

703.12 Feed rate control permits wide variation in instantaneous feed rate.

703.13 Rinse (if required) is not being properly distributed over surface of cake.

800.0 APPENDIX

801.0 *Glossary*

- C_f - feed concentrations (suspended solids by weight)
- C_o - overflow concentration (suspended solids by weight)
- C_u - underflow concentration (suspended solids by weight)
- g - gravitational acceleration (9.81 m/s^2), (32.17 ft/s^2)
- G - ratio, $\omega^2 r/g$
- hr - hour
- IS - insoluble solids, (suspended solids)
- kg - kilogram
- m - meter
- m^3 - cubic meter
- min - minute (time)

mm	-	millimeter	RCF	-	relative centrifugal force, $\omega^2 r/g$ (same as G)
M_f	-	feed rate gravimetric	RPM	-	revolutions per minute
M_o	-	overflow rate, gravimetric	sec	-	second (time)
M_u	-	underflow rate, gravimetric	TS		total solids
Q_f	-	feed rate, volumetric	vol/vol	-	volumetric ratio
Q_o	-	overflow rate, volumetric	wt/wt	-	gravimetric ratio
Q_u	-	underflow rate, volumetric			
r	-	radius	ω	-	angular velocity of rotation (radians/sec)

802.0 *Typical Calculations for Selected Applications*

802.1 Continuous Sedimentation Centrifuge

Application: Concentration of Waste Activated Sludge

Feed Rate	36 m^3/hr (158.5 gpm)
Feed Temperature	20°C (68°F)
Feed Concentration	1.4% TS
Underflow Rate	Unknown
Underflow Concentration	7.1% TS
Overflow Rate	Unknown
Overflow Concentration	0.15% TS

$36 = Q_u + Q_o$

$36 \times 1.4 = 7.1\ Q_u + 0.15\ Q_o$

$36 \times 1.4 = 7.1\ (36 - Q_o) + 0.15\ Q_o$

$50.4 = 255.6 + 7.1\ Q_o + 0.15\ Q_o = 255.6 - 6.95\ Q_o$

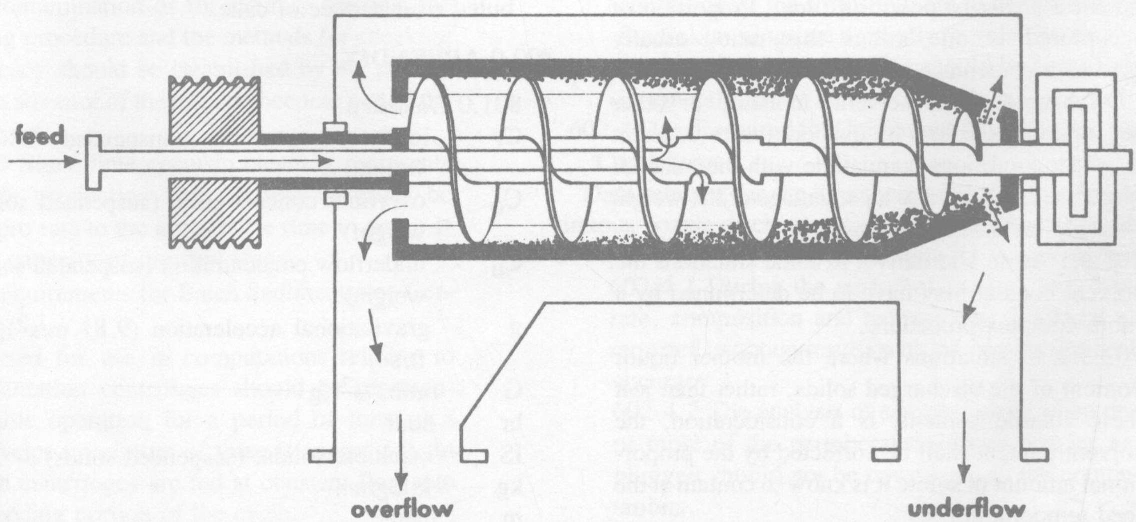
$6.95\ Q_o = 255.6 - 50.4 = 205.2$

$Q_o = 29.525$

$Q_u = 6.475$

Recovery of Suspended Solids = $(6.475 \times 7.1) \div (36 \times 1.4) \times 100 = 91.21\%$

Loss of Suspended Solids (to overflow) = $(29.525 \times 0.15) \div (36 \times 1.4) \times 100 = 8.79\%$



802.1 Continuous Sedimentation Centrifuge