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Revision Memo

12/01 Minor corrections and modifications made.

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SCOPE

This section contains design considerations, recommended process design procedures, and mechanical design details for equipment to thicken sludge by gravity settling. The Talmadge & Fitch method in prior editions is replaced with a combination of Yoshioka and Talmadge & Fitch methods. For further information on their implementation, the Environmental Water and Waste Section of EMRE/EETD/ESCMD should be contacted. This Design Practice only presents design procedures for "Thickening." For design procedures of a secondary clarifier refer to the Clarification section of **DP XIX-A5.**

REFERENCES

DESIGN PRACTICES

Section XIX-A2 Flotation Units

Section XIX-A5 Biological Treatment of Wastewater

Section XX-A Guidelines and Considerations for Managing Solid and Liquid Wastes

EMRE WATER AND WASTEWATER DESIGN GUIDE (TMEE 080)

DG 11-6-3 Chemical Feeders for Wastewater Treating

OTHER REFERENCES

1. Altemoeller, P. H. and Goodrich, Jr., R. R., *Guidelines for Sizing Gravity Thickeners - Wastewater Treatment Sludge Applications*, ER&E Report No. EE.24E.89 (Please note that some of the numerical values in this report were not found to be representative; hence, they should be used with caution and should be confirmed for a particular situation).
2. Eckenfelder Jr., W. W., Patoczka, J. A., and Watkin, T., *Wastewater Treatment*, Chemical Engineering (September 2, 1985).
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4. Talmadge, W. P., and Fitch, E. B., *Industrial and Engineering Chemistry*, **47**, 38-41 (1955).
5. Water Pollution Control Federation, *Sludge Thickening - Manual of Practice No. FD-1* (1980).
6. Yoshioka, N., et al, *Continuous Thickening of Homogenous Flocculated Slurries*, Chem. Eng. (Jap.), **21**, 66 (1957).

DEFINITIONS

Bridge - A superstructure built over a thickener to support the rakes and drive mechanism and a walkway to the center of the unit.

Bridging - A self-supporting sludge structure, such as a matrix of agglomerated sludge particles, sometimes formed by a relatively concentrated sludge, which prevents the further settlement of the supported particles.

Clarification - A gravity settling process to produce a clear liquid overflow by the removal of suspended solids from the liquid.

Feed Solids - The dry weight of suspended solids in the influent to a thickener.

Limiting Sludge Concentration - The sludge concentration for which the ability of the thickener to transmit solids downward is a minimum. The limiting sludge concentration is usually between the feed concentration and the underflow concentration.

Liquor - The liquid portion of the sludge or the liquid removed from the sludge during the concentration process. The term liquor is usually used to designate the liquid when other phases are present or the liquid derived from a mixed phase.

Mass Loading - Synonymous with **solids flux**.

Operating Torque - The normal torque on the main shaft when it and the other thickener components are in normal operation (design feed flow rate, design feed solids concentration, design underflow rate, design underflow solids concentration, and underflow pumps discharging to the normal sludge facilities). The operating torque is designated in units of lb · ft or N · m.

Overflow Rate - The liquid flowing from the top of the thickener or other basin per unit time per unit area, expressed as gpm/ft^2 or m^3/hr · m^2.

Picket Rake - Vertical slats installed on a slowly rotating mechanism to aid thickening. The increased settling rates often obtained by the use of pickets appear to be due to the opening of additional channels for liquor to flow to the solid-liquor interface.

Rakes - Slowly moving mechanical blades on the bottom of a thickener, which push the settled, thickened sludge to the outlet location.

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DEFINITIONS (Cont)

Sludge - The accumulated semi-liquid suspension of settled solids deposited in tanks or basins from raw or treated wastewaters.

Sludge Blanket - The level of settled sludge carried in a thickener or clarifier, expressed in ft or m.

Sludge Volume Ratio - The quotient of the volume of the sludge blanket held in the thickener divided by the daily volume of sludge removed from the thickener. This ratio is equivalent to the number of days the sludge is held in the sludge blanket.

Slurry - A suspension of solids in a liquid.

Solids Flux - The downward flow of solids in the thickener per unit time per unit of thickener area, expressed as lb/day · ft^2 or kg/day · m^2. Solids flux at any point in the thickener is the product of the local slurry concentration and total subsidence rate.

Thickened Sludge - Sludge that has been concentrated in solids content by gravity settling or air flotation.

Thickener - A gravity sedimentation basin or tank used to increase the solids concentration of a slurry. Thickeners are usually circular and equipped with a slowly-rotating raking mechanism to convey the thickened sludge to a discharge location. Normally overflow clarity is not of primary concern in thickeners, and their design is controlled by the necessity to settle all of the incoming solids to the underflow and reach the desired underflow concentration.

Underflow - The stream removed from the bottom of a thickener or clarifier.

Underflow Concentration - The solids content of the sludge thickened and removed from the bottom of a sludge thickener or clarifier, expressed as weight percent solids.

Unit Area - A term sometimes used to designate thickener size requirements for a slurry. Unit area, the reciprocal of mass loading, is the area required to settle a unit weight of dry solids per 24 hours with a steady feed. Typical unit for the unit area is ft^2/lb · day or m^2/kg · day.

Wall Effect - The influence of the walls of a column on the behavior of the contents of the column. The wall effect in small diameter batch settling tests can cause the result to be inaccurate for the design of a full size thickener.

Zone Settling - The type of settling that typically occurs with concentrated slurries such as activated sludge and other water treatment sludges. The particles in the sludge aggregate, forming a mass that settles as a blanket, with a distinct interface between the settling sludge and the clarified effluent.

BACKGROUND

DESCRIPTION

A gravity sludge thickener, as shown in **Figure 1,** is a device used to increase the concentration of solids in a liquid-borne slurry. It is a settling tank, usually circular in shape. The influent goes to a feedpipe in the center of the thickener. The solids settle to the bottom and the clarified effluent overflows a peripheral weir, called a “launder", at the top. Most thickeners have a shallow conical bottom, fitted with slowly-moving rotating rake arms to work the thickened sludge to the central underflow discharge. A plow attached to the center of the rake prevents plugging of the center discharge sump or cone.

The rakes also break up bridges, which the settled particles may form, and thereby improve settling. Sometimes, gently rotating, vertical “picket fence" agitators are also provided to aid settling. Pickets increase the flocculation of sludge particles and allow “trapped" water to escape from the sludge blanket. The rake assembly is usually operated by a centrally located power unit; the vertical shaft carrying the rake is surrounded by a trough or annulus, sometimes moving with it, serving as a feedwell.

The overflow from the thickener is normally sent to the influent of the wastewater treating plant, to the influent of the API separator, to a clarifier, or to other sedimentation tankage.

While a thickener can be operated either as a batch unit or as a continuous unit, the continuous thickener is more widely used.

USES AND EFFECTS OF THICKENERS

Most of the wastewater treating operations result in solids which required disposal. In most cases these solids are removed from the treating units as relatively dilute slurries called sludge. Subsequent treatment of these sludge streams in a thickener increases the solids concentration and reduces the volume of the sludge.

The concentration of the solids in the sludges removed from various wastewater treating units varies, depending upon the type of unit, the way the unit is operated, the contaminants in the wastewater, etc. Likewise, the concentration to which the sludge can be thickened and the tank area required to thicken it also vary. In general, biological waste solids, especially waste activated sludge, are the most dilute and the hardest to thicken.

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BACKGROUND (Cont)

Typically, activated sludge is wasted at a solids concentration of only around 1 wt%, and can be thickened to only about 5 to 6 wt%. While sludge thickened to 5 to 6 wt% still contains a considerable quantity of water, the thickening step is usually justified since it reduces the sludge volume by 80% or so. The volume reduction reduces the size of downstream equipment, treating costs, and disposal costs.

The sludges from API separators, DAF units, and granular-media filter backwashes are generally more concentrated than waste activated sludge. They can be thickened to a higher concentration, and require less thickener area (see table on Page 7 for an example of concentrations for different types of sludges). Some other sludges (usually not from wastewater treating unit), e.g., lime sludge, catalytic cracking slurry, and coke slurry, are even easier to thicken, and with these slurries, underflow concentrations of 35 wt% are possible in equipment an order of magnitude smaller than that required for waste activated sludge. Sludges with good thickening characteristics can be blended with waste activated sludge to improve its settling rate.

Sometimes, it is necessary or desirable to reduce the volume of the sludge below that attainable by gravity thickening. Techniques that can be used for such additional consolidation include gravity belt filtration, centrifugation (see **Section XX-A**), vacuum filtration, air or steam drying, and incineration. Even when these other operations are used, it is usually economical first to reduce the sludge volume by gravity thickening to lessen the cost of the subsequent treating units. Prior thickening can reduce the required area of a filter, increase the dewatering rate in a continuous centrifuge and in an air-drying operation, and reduce the fuel requirements of an incinerator.

Thickeners provide some equalization and blending of the sludge. This smoothes the flow and improves the uniformity of the solids fed to downstream equipment. Thickners can also be designed to provide some minimal strorage capacity (one or two days).

For lighter than water or poor settling sludges, use of Dissolved Air Flotation (DAF) thickening may also be adequate. Refer to **Section XIX-A2,** *Flotation Units*, for DAF thickener design procedures.

GRAVITY THICKENING THEORY

The solids handling capacity of a continuous thickener is controlled, for the most part, by applied flow rate and underflow withdrawal rate. A slight reduction in the underflow concentration often causes a disproportionately large increase in solids throughput. Overloading is usually handled by increasing the underflow pump discharge rate at the expense of obtaining a slightly less concentrated sludge product.

The liquid handling capacity of a thickener may depend upon the finer solids materials in the feed and the required degree of overflow clarity. Increasing the finer solids concentration in the feed often causes an increase of the solids content in the effluent (imposing limitations on the thickener capabilities) unless a flocculating chemical is employed. Generally, thickener throughput is limited by the underflow concentration rather than by the overflow clarity. This is different from a clarifier where overflow clarity may be regulated.

The solids settling process is generally described in four types, as shown in **Figure 2A.**

Type 1: **DISCRETE SETTLING,** in which particles fall independently of each other. A mathematical development of the settling velocity is possible.

Type 2: **FLOCCULANT SETTLING,** in which particles coalesce and fall as combined clumps or flocculants. No strict mathematical solution of the settling velocity calculation is possible.

Type 3: **ZONE SETTLING,** in which the particles retard the settling of one another and fall at a rate which depends upon the local concentration of the particles.

Type 4: **COMPRESSION,** in which the particles are in intimate contact, and further subsidence is due to the weight of the solids squeezing out more water.

For the design of a thickener, various approaches exist. Most are based on Type 3 and Type 4 settling, but zone settling (Type 3) generally governs the design. Both mathematical and graphical methods exist for calculating the relationship between the settling velocity and the solids concentration. The Talmadge & Fitch and Yoshioka methods have been developed in graphical form for easy use.

The Talmadge & Fitch (T&F) method is based on the interface or mudline settling velocity of a sludge with one single initial concentration in a one-liter graduated cylinder. The batch settling curve (solid/liquid interface or mudline height versus time) from a laboratory test is then used graphically to find the compression point and to estimate thickener area (**Figure 2B**).

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BACKGROUND (Cont)

The Yoshioka (YOS) method involves estimating the total solids flux that can be applied to a thickener. The total solids flux consists of two components: settlement of the sludge by gravity and the bulk solids movement due to the removal of thickened sludge at the bottom of the thickener. The rate of gravity settling can be determined from a batch settling test. The rate of the bulk movement depends upon the rate at which solids are removed from the bottom of the basin. Also, the thickened solids underflow concentration depends upon the rate of solid removal. The total mass loading or solids flux of solids concentration, G_i, in the thickener is:

$$G_i = B\left[(c_i\ v_i) + (c_i\ u)\right] \qquad \text{Eq. (1)}$$

where: G_i = Total solids settling flux, lb/ft^2 · day (kg/m^2·hr)
B = Conversion factor = 1440 min/day for Customary units or 1 for Metric units
c_i = Concentration of solids at any location i during settling (location is usually taken at underflow), lb of solids/ft^3 (kg of solids/m^3)
v_i = Gravity settling velocity at the underflow concentration c_i, ft/min (m/hr)
u = Bulk downward velocity, ft/min (m/hr) = surface area / underflow withdrawal rate

The total flux is used to control the entire thickening process and must be below a limiting value for effective thickening. This limiting flux value determines the required area.

The most important difference between the T&F and Yoshioka methods is that the T&F procedure is based on settling **velocity** while the Yoshioka theory is based on settling **flux** of the sludge. The T&F method describes the settling rate of a sludge layer as a linear mathematical function of the solids concentration in the settling zone. However, for highly compressible sludges a linear function is not valid. Therefore, the T&F method results in a larger thickener area than required for wastewater sludges.

Gravity thickener sizing cannot be reliably estimated by only one method due to variability in obtaining sludge sedimentation characteristics. Even when the Yoshioka and T&F methods are applied on the same batch settling data, the resulting thickener sizes can vary over a large range. A review of current methodology suggests that a combination of the Talmadge & Fitch and Yoshioka methods is best suited for wastewater sludge applications. The thickener area can be bracketed by using the Yoshioka and Talmadge & Fitch methods, and then the required area can be estimated from the average of the areas developed using these methods adjusted for any conservatism. Many vendors may use Wilhelm & Naide (W&N) method which seems to yield a thickener diameter much less than the suggested methods. Care should be exercised when considering a vendor's design method.

DESIGN CONSIDERATIONS

SLUDGE QUALITIES

Sludges vary greatly in composition and properties. Sludges made up of solids with a high density such as, lime, grit, cat cracking catalyst, etc., settle rapidly, whereas sludges that are light, flocculant, or hydrophilic (capable of taking up water), such as waste activated sludge, resist thickening, i.e., settle slowly.

The sludges derived from petrochemical wastewater treatment plants are oily. In addition, they are compressible, so they decrease in volume as the depth of sludge increases.

FEED-SOLIDS CONCENTRATION

Thickener performance, i.e., underflow concentration, is set by the horizontal area, solids loading, and underflow rate. For a given thickener area, solids loading and underflow rate, the feed concentration as such will not have a significant impact on underflow concentration. However, variations in feed-solids concentration without offsetting variations in feed volumetric flow rate will affect underflow concentration because of the resulting variation in solids loading.

OVERFLOW CLARITY

The design of the thickener should keep the suspended solids concentration in the overflow at less than 100 ppm (mg/L), as determined by ASTM-D-1069. There are no design equations that ensure this criteria, rather, the design engineer should specify an overflow rate that should not be exceeded.

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DESIGN CONSIDERATIONS (Cont)

TEMPERATURE

Temperature does not have a pronounced effect on thickening over the temperature range normally encountered. Thermal currents and wall temperature gradients normally do not cause problems. However, the density and viscosity of the water vary with temperature. The thickener should be designed for the settling and compression rates at the lowest anticipated temperature.

FLEXIBILITY

The thickener should be provided with the necessary flexibility to perform satisfactorily over the range of flow rates, solids loadings, sludge characteristics, and temperatures it will encounter.

Flexibility items that should be provided include:

- Adequate sludge pumping capacity (a minimum of 150% of design underflow rate) so that solids removal is not a limitation.
- Continuous feed and underflow pumping (continuous blowdown).
- Ability to recycle sludge to the centerwell to prevent plugging when downstream equipment is shut down.
- Ability to pump sludge to a tank truck or withdraw sludge with a vacuum truck if this should be needed.

CHEMICAL AIDS

If the underflow is not as thick as desired, certain polyelectrolytes and coagulants may be added to potentially aid the thickening operation. The improvement might be a thicker underflow, a clearer overflow, or better sludge blanket control. The effect of a particular chemical and its economic implications are not predictable and must be determined by testing (see *Jar Test Procedure* in the **LABORATORY PROCEDURES** in this Design Practice). For types and concentration of chemical aids, refer to **DG 11-6-3.**

Reports from outside of ExxonMobil indicate that the addition of polyelectrolytes has in some cases improved overflow clarity, increased the allowable loading to the thickener, and/or allowed successful control of the sludge blanket height; but no increase in underflow solids concentration was observed. It appears that while polymer addition improves solids capture and reduces solids overflow, it may reduce the solids concentration in the underflow by entraining more water. Coagulating chemicals sometimes increase the capacity of a thickener by enhancing settling. When coagulating chemicals are used, a slow mixing flocculation chamber should be provided, either before or within the thickener. Coagulating chemicals also increase the total mass (pounds) of sludge to be handled.

EQUIPMENT DESIGN

Shape - Both circular and rectangular settling devices can be employed for sludge thickening. Circular units, however, have some advantages over rectangular units. The sludge is delivered continuously to the point of drawoff in a circular thickener, but only intermittently in a rectangular unit. It is also comparatively easy to maintain substantial sludge depth in the area of sludge withdrawal in a circular unit and avoid “rat holing" (the breakthrough of the sludge blanket); in a rectangular unit, it is more difficult to do this. For grassroots design of thickeners, a circular thickener is recommended, unless there is a plot space restriction.

Diameter - Circular thickeners vary from 10 to 100 ft (3 to 30 m) in diameter. Existing designs for ExxonMobil affiliates vary from about 20 to 85 ft (6 to 26 m) in diameter.

Depth - Thickeners are commonly 8 to 18 ft (2 to 5 m) deep. The concentration of the underflow solids increases with the depth (retention time) of the sludge layer, although the effect may vanish with sludge layers deeper than 3 ft (0.9 m). The side water depth (SWD) should be at least the sum of the following:

- Feedwell Immersion — 2 ft (0.6 m).
- Mass Subsidence — From 2 ft (0.6 m) for fast-settling to 6 ft (1.8 m) for slow-settling sludge.
- Sludge Holdup — As required to allow the required total sludge holdup time (usually 1 to 2 days). Sludge holdup time is calculated by dividing the total mass of solids in the influent by the mass of solids in the underflow per day.

Overflow clarity tends to improve with increasing thickener depth, although this is not indicated by settling theory, and laboratory data cannot accurately predict the effect of liquor depth on overflow clarity.

The sludge blanket should be deep enough to avoid dilution of the underflow. With too shallow a blanket, if the underflow pumping rate exceeds the rate at which sludge is conveyed to the drawoff, the blanket breaks, and short-circuiting and a less dense underflow results.

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DESIGN CONSIDERATIONS (Cont)

Area - Sufficient area must be provided so that feed solids can pass through all concentrations to the underflow concentration. A feed solids rate that results in a mass loading higher than design can result in solid carryover with the overflow.

See STANDARD PROCEDURES in the **DESIGN PROCEDURES** for the procedure to calculate the required area from settling data. Factors are applied to the thickener area calculated from settling data to account for short-circuiting, turbulence, etc. In most cases, the holdup requirements to accommodate downstream equipment outages result in a thickener diameter larger than the minimum required for settling and thickening.

See QUICK, ROUGH SIZING BASIS in the **DESIGN PROCEDURES** for guidance on the estimation of thickener area when data are not available. Generally thickeners for refinery wastewater sludges can be operated at mass loading of 4 to 8 $lb/day \cdot ft^2$ (19.5 to 39.0 $kg/day \cdot m^2$).

Bottom Slope - Bottom slopes are relatively steep, ranging from 1.5 to 3 in./ft (125 to 250 mm/m). The steep slope enhances transfer of solids to the central withdrawal area. It also reduces the tendency to produce dilute underflows as a result of the drawdown of a dilute suspension from a zone above the bottom of the discharge cone. Further, the steeper floors minimize the residence time of sludges in the tank and thus reduce biological degradation problems.

Freeboard - The freeboard should be 18 to 24 in. (455 to 610 mm) when the overflow is collected by weirs.

Feedwell - Feedwell design is left to the manufacturer. If large size debris can enter the thickener and plug the underflow outlet, a screen should be provided at the inlet or over the entire tank, depending upon the source of the debris.

Rakes and Drives - The system should be protected against torque overload with a combination of alarm, shutdown system, a rake-lifting device, and a shear pin. The rake-lifting device can be manual or automatic.

- **Manual Rake-Lifting Device -** A manual rake-lifting device should automatically shut off the raking mechanism in the event of torque overload. An operator can then manually lift the rakes out of the thickest sludge by some means such as a handwheel. A manual rake-lifting device is generally adequate for biological sludge thickeners.
- **Automatic Rake-Lifting Device -** On high torque, the entire rotating rake system should automatically lift 24 to 36 in. (610 to 915 mm) by means of a hydraulic screw jack. An alarm should be actuated when the rakes rise. An automatic rake-lifting device is the preferable type with heavy sludges.

The design of rake's arms and blades and the selection of rake speed and drive system are left to the manufacturer.

Pickets - Pickets, slow-moving, vertical, slat agitators, sometimes improve thickening. Their effect cannot be predicted, and scale-up of laboratory tests of the effects of pickets is uncertain. Qualitative laboratory or pilot plant observation, or experience, either by affiliates or by the manufacturer(s), is the best guide as to whether or not pickets should be provided.

APPURTENANCES

Feed Launder - Normally, thickener-feed enters the feedwell through a pipe, radial launder, or hollow center column.

Skimmer - If the sludge is oily, which is usual, provide a skimmer (similar to a Dissolved Air Flotation float skimmer) at the water surface. The skimming system should include a scum baffle, skimming blade, scum collecting box, and scum scraper. For circular units, the skimmer should be full size, nominally the size of the thickener radius.

Center Columns and Superstructures - Thickeners are generally provided with a center column or superstructure which supports the drive system, rakes, feed launder, and a walkway to the center to provide access for inspection and maintenance. The design of the center column or superstructure and its supports is left to the manufacturer, who may vary the design with the diameter of the tank. Center columns and beams are often used with small diameters; trusses with large diameters. The support for a superstructure can be either the tank wall or external columns of steel or concrete.

Cover - Thickeners have normally been uncovered, but they can be covered if this is necessary or desirable to prevent the release of vapor or odors or to retain heat.

Heating Coils - If the thickener will handle oily sludge, the tank can be provided with a heating coil to break emulsions. The oily sludge should be heated to about 130 to 150°F (54 to 66°C) to start breaking the emulsion. Gas blanketing is also possible.

SLUDGE SYSTEM

Underflow - For typical industrial application, the underflow pipe from the center cone can be encased in the concrete base of the thickener or be buried under the thickener.

The underflow pumps are generally located beside the tank.

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DESIGN CONSIDERATIONS (Cont)

Sludge Connections - A minimum of three sludge outlets (for example, spaced 120° apart on the cone) should be provided for underflow pumping. Rodding and back-flushing connections should be provided for the sludge outlet nozzles and the sludge pumps as shown in **Figure 3.** For heavy sludges a plow should be provided in the discharge cone to prevent plugging.

MATERIALS OF CONSTRUCTION

The selection of materials of construction is to be based on structural and economic considerations, which include the effect of possible corrosion and erosion on the useful life of the equipment. Thickeners are usually constructed of concrete, steel, or a combination of the two, and can be coated or lined. Submerged parts of thickeners should be fabricated of corrosion resistant materials or coated.

LABORATORY PROCEDURES

JAR TESTS

The jar test is used to evaluate coagulants and flocculants in water, wastewater, and sludge clarification and thickening applications. There is no “standard" jar test procedure. The general principle is to reproduce, as closely as possible, the existing or anticipated conditions of the sedimentation process. In effect, the operation of the thickener is attempted in a miniature scale.

Jar testing can determine the best chemical agents, their optimum dosages and the best order of chemical addition. If a polymer does not work in the jar test, it will not work in the system. If a polymer does work in the jar test, it probably will work in the system, but may not. For this reason, plant trials are necessary. If a polymer fails in the final trial, but works in the jar test, mechanical limitations are often the reason (mixing, feeding, retention time, shear, etc.). This should be anticipated before the plant trial is performed.

The jar test involves the following objectives:

1. Determine the types of coagulants or polyelectrolytes that will effectively thicken the sludge.
2. Establish effective concentration ranges of treatment chemicals/coagulants.
3. Establish optimum dosages of treatment chemicals/coagulants.
4. Establish order and time of addition for treatment chemicals/coagulants.
5. Estimate the treated effluent quality.
6. Estimate settling rate of flocs or precipitates.
7. Estimate the sludge volume (settleable solids) produced as a result of each treatment parameter variation.

Equipment Needed

1. A 4 or 6 place gang stirrer with RPM gauge.
2. 12-600 ml or 1000 ml beakers.
3. A stopwatch with sweep second hand.
4. A turbidimeter or Spec 20 to monitor final water quality.
5. A plastic pail of at least 5 gallon (or 20 liter) capacity.
6. Polyelectrolytes freshly diluted to proper application strength
7. Disposable syringes

Jar Test Procedure

1. Obtain a fresh sample of material to be treated in a clean bucket. Larger samples are better because more tests can be run without having to reset controls.

   The sample to be treated should contain everything normally found in the plant stream except the coagulants or flocculants. Efforts should be made to test at the same temperature as the plant system.
2. Add 500 ml or 1,000 ml of test water into the beakers and place the gang stirrer.

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