industrial wastewater applications of coagulants and flocculants

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abstract

Chemical additives are frequently used in the treatment of industrial wastewater, improving the efficiency of many treatment processes. This presentation gives an overview of the most important uses of the additives commonly called Coagulants and Flocculants. These are used in various solids separation processes, such as clarification and dewatering. The term coagulation is generally used to represent the destabilization of colloidal suspended solids, allowing them to be removed from surface water or wastewater. Stabilization, or resistance to separation, occurs due to the presence of repulsive charges and adsorbed contaminants that interfere with the agglomeration of colloidal particles. Coagulants destabilize particles by charge neutralization, and/or contaminant replacement. Flocculation is the agglomeration of colloidal particles and usually takes place after coagulation. Flocculants are typically large molecular weight polymers and work by forming bridges between the particles, increasing their effective diameter. Larger particles separate faster from the water. In dewatering operations, flocculants are used to form a uniform microstructure of ideally sized particles that optimize the removal of water from the sludge.

Applications discussed in this presentation are Clarification (primary and secondary), Flotation and Sludge Dewatering.

Effective use of these chemicals requires close attention to their handling and feed, as well as optimizing the location at which they are added. Mixing conditions are a particularly critical aspect of their use.

Keywords: Coagulant, Flocculant, Industrial, Wastewater, Polymers, Applications

introduction

Solids separation processes are widely used in water and wastewater treatment plants, being critical in the preparation of drinking water, industrial process water and in the pre-treatment of many types of wastewater.

Many industrial wastewaters contain significant quantities of suspended solids (TSS). These can be pulp fibers in paper manufacturing wastes, metal particulates from iron and steel processing operation, coke fines from power plants, oil and grease from food processing or oil and gas refining operations, or just clay particulates from plant runoff. Industrial wastewater treatment facilities therefore often include a solids removal step in 'primary treatment.' Solids separation processes are also used later in the wastewater treatment plant to separate and thicken biological solids at the secondary treatment step, to remove or polish residual TSS via filtration at the end of the plant, and to remove water from wet solids, or sludge.

In most cases these processes are made much more efficient with the use of chemical additives. These additives include oxidants, pH adjustment chemicals, coagulants, precipitants and flocculants. The benefits of these additives include both a higher-quality treated water, as well as a reduction in required equipment size. The use of chemical clarification aids goes back a very long time, with the use of aluminum salts being described by Pliny the Elder 2000 years ago.

In this paper the modern use of coagulants and flocculants will be described in primary clarification/sedimentation for the removal of total suspended solids, flotation for the removal of oil and grease, secondary clarification in the activated sludge process, and sludge dewatering.

chemistry of coagulation and flocculation

The chemical additives being described herein are commonly called coagulants and flocculants, or clarification aids, but definitions vary. In this paper the terms coagulation and flocculation are defined by reference to the model of colloidal suspended solids becoming stabilized in suspension, by the acquisition of a net charge, and/or by the adsorption of organic material.

In many waters, colloidal particles, including oil droplets and solids within wet sludges, become charged, commonly with a negative charge. This charge is developed due to a number of processes including surface reactions, lattice imperfections at the surface of the particle and the adsorption of compounds present in the water, such as humic acids. These charges cause the particles to electrostatically repel one another. In addition, adsorbed compounds can sterically block particles from coming together. Without these interfering forces, colloidal particles would tend to come together and form larger agglomerations, due to the attractive forces known as London-van der Waals forces.

With these charges and adsorbed compounds, the colloids are said to be "stabilized" in suspension. This is important because work by Stoke and others showed that the particle size was the key determinant of many solids separation processes. The velocity of sedimentation was shown to be proportional to the square of the particle diameter, as seen in Figure 1, and commonly known as Stokes' Law, which governs independent particle sedimentation due to gravity under non-turbulent settling conditions (Stokes, 1845).

$$V \ = \ \frac{g.(p_s - p).d^2}{C.\mu}$$

Figure 1: Stokes Law

Where V = velocity of particle settling, under laminar flow conditions; g = gravity constant; p_s = particle density; p = density of water; d = particle diameter; μ = absolute or dynamic viscosity of water; C = constant that depends on units used.

This equation shows that the biggest impact on separation speed is the particle diameter. Hence colloidal stabilization, keeping particles small, has a major impact on clarification and other solids separation processes. Far more time is required to separate small-diameter solids, which translates into larger space requirements and more expensive equipment.

In the context of industrial wastewater treatment, oil droplets act like particles and can be stabilized in suspension by emulsifying agents. Stokes Law applies to the flotation of oil droplets as well, but with the density of oil generally being less than that of water, the direction of movement is opposite – up instead of down.

Coagulation is defined as particle destabilization, or the removal of the interfering forces. This is commonly meant to mean neutralization of the net negative charge, but in the wider context, can also mean the displacement of emulsifying agents, or other sterically interfering compounds. Coagulants possess positive or cationic charge and thus can be used to neutralize the stabilizing negative charge on the particles. Figure 2 is a simplified depiction of this process. The process of destabilization of suspended colloids is more complex than this simple depiction of charge neutralization however, particularly when metal coagulants are used. Precipitation reactions, ionic effects and adsorption reactions are also involved.
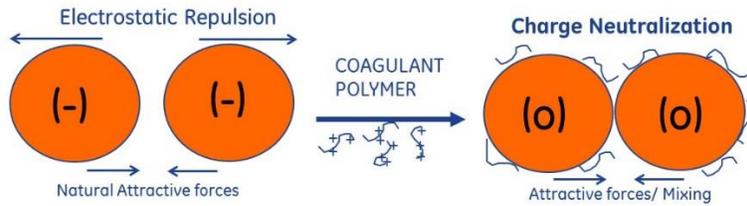
Figure 2: Coagulation by Charge Neutralization

Coagulant chemicals in use today can be grouped into four categories:

1) Traditional inorganic metal salts e.g. aluminum sulfate (alum), ferric chloride, ferric sulfate, lime

2) Polymerized aluminum products e.g. polyaluminum chlorides (PACl) of varying 'basicity,' or degree of hydroxide addition, aluminum content, net positive charge and molecular weight

3) Synthetic organic polymers (very high cationic charge), with a range of chemistries

4) Blends of inorganics/poly-inorganics and polymers

Each coagulant type has advantages and disadvantages and these can be summarized as shown in Table 1. In general, the higher the suspended solids of the water to be treated, the more cost-effective the use of synthetic organic polymers become. When sludge generation and handling costs are included, the polymers and PACl products generally provide a lower total cost of operation. In the vast majority of cases, coagulants are supplied as liquids, with the actives being completely soluble in water.

The two biggest differences in coagulant chemistry is impact of and on pH, and the generation of additional solids. In general, inorganics and low basicity poly-inorganics are the most impacted by pH (and impact pH the most), and also generate the most extra sludge. At the other extreme, organic polymer coagulants are the least affected by pH and generate the least additional solids.

Choice of coagulant is typically made by each user's assessment of cost-effectiveness. This can be carried out via full scale plant trials, or more commonly using bench testing. The most common bench test employed for coagulant (and flocculant) selection is the "Jar Test," where various products are dosed into 1000 ml samples of wastewater and mixed following a specific protocol, followed by settling and a measurement of the final supernatant quality (e.g. turbidity, or contaminant concentration).

Table 1: Comparison of Coagulant Types

Inorganics	Polymeric Coagulants
Lower $/lb	Add less sludge
Work for many waters	Sludge easier to dewater
Familiar chemistry	No extra caustic needed
Fast reaction	Wide effective pH range
Often best for color/TOC	No post-precipitation
	No addition of metals or anions downstream
	More cost-effective at higher TSS
	Lower instability, handling/safety issues

After colloidal particles and emulsified oil droplets have been destabilized, or coagulated, they can be brought together and 'agglomerated' into larger particles, that will separate faster (as per Stokes Law). This process is called Flocculation. Flocculation can occur naturally, due to London-van de Waals attractive forces and molecular bombardment, given enough time and mixing. In some situations, no additional chemistry is needed. In other situations, chemical flocculants are used to accelerate this agglomeration.

Flocculation can take place by a number of physico-chemical processes, depending on the type of chemical used. Traditional inorganic coagulants, such as alum and ferric salts, form voluminous precipitates with water alkalinity. These precipitates, mainly metal hydroxide and complex polymeric metal-OH species, also provide a flocculating action by entrapping the colloidal particles onto the precipitating metal hydroxides. Other types of precipitating coagulants, that also provide some flocculating action due to adsorptive processes, include derivatives of natural starch and tannin extracts.

Modern synthetic polymeric flocculants are commonly made by polymerizing acrylamide. These 'polyacrylamide' polymers can have very high molecular weights in the 2 to 20 million Dalton range. Their flocculating action is generally described as a 'bridging' action, as shown in Figure 3.
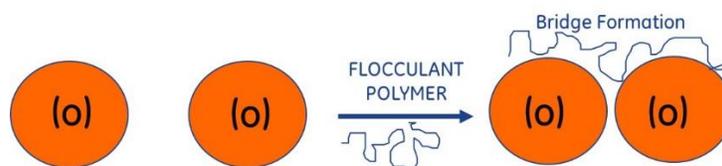

Figure 3: Flocculation using polymers

These synthetic polymers have become the main type of flocculant used, for a number of reasons: cost-effectiveness, wide pH range and minimal solids addition. They are available in a range of forms, charge and molecular weights.

1) Form:
- Powders (@80- 99% actives)
- Liquids (in water soluble form @2-10% actives)
- Emulsions in an oil carrier (@30-60% active) – the most popular form in industrial applications
- Dispersions in water (@15-25% active)

2) Charge:

Covering the spectrum from high negative (anionic), through non-ionic, to high positive charge (cationic).

3) Molecular Weight (MW): in the range of 2 to 20 million

The choice of flocculant form is typically made by a user based on ease of use, size of application, operator skill, feed equipment available and personal preference. The choice of charge and MW depends on pH and types of contaminants and solids present. This choice is usually made by Jar Testing, as with the coagulant selection. Cationic flocculants can sometimes work as dual-functionality products, also providing charge neutralization (coagulation) functionality.

application of coagulants and flocculants

The most critical application factors that have to be considered for the cost-effective use of coagulants and flocculants are:

1) Mixing energy and reaction time of the chemical and water to be treated

This is critical to the success of these chemicals. Coagulants thrive on high energy mixing, especially important in raw water clarification. In high solids wastewater solids separation applications, the energy required is less than in raw water, but is still an important factor to be optimized. Each combination of coagulant and wastewater requires a specific minimum amount of mixing energy and time. Flocculation, and thus flocculant chemicals, require far more gentle mixing energy, but more reaction time.

These two factors are often combined in designing mixing conditions, using parameters of Velocity Gradient, G (sec-1), and G x time (G.t). Some plants are designed with mixing tanks included and are described as fast or rapid mix, and slow mix, or flocculation tanks. Coagulation and precipitation chemistry are usually added to the fast mix tanks, whereas the flocculants are added to the slow mix tanks. Even if a flocculant is not being used, the slow mix tank will facilitate natural flocculation. Some clarifier designs incorporate extra solids contact, and/or flocculation zones, thereby reducing the need for these tanks.

In other wastewater plants, no specific mixing tanks are incorporated into the design, but the location of chemical injection is chosen carefully to achieve the required mixing in the pipework on the way to the clarifier (or other solids separation unit). Well-designed jar testing and pipe hydraulic analyses can be used to choose the best chemical dosage locations. Poor choice of chemical addition point is a common cause of reduced cost-effectiveness of both coagulants and flocculants.

2) Chemical Handling and Feed

Coagulant chemistries are mostly water-soluble liquids that require no special feed equipment, but several of the inorganics have handling issues that must be dealt with: extreme acidity, corrosivity and tendency to precipitate are some of the most common. Maintenance costs to keep chemicals pumping can be much higher than expected, if suppliers' recommendations are not scrupulously followed.

Flocculant polymers have to be stored carefully in both the powder and emulsion form and dissolution into the water phase requires special feed equipment or skilled operators. Deficiencies in this area are a common source of poor cost-effectiveness, if not complete failure of flocculant applications.

Coagulants are fed as neat products, or in any convenient dilution to obtain the target dosage. Flocculants in powder or emulsion form have to be carefully dissolved into a water solution with a pumpable viscosity. The emulsions have the additional requirement of needing to be 'inverted' from the oil phase into the water phase, and the initial dilution targeted should be in the range specified by the supplier. This initial dilution, or 'make-down' step that flocculants have to undergo is a critical application detail.

3) pH of the reaction

For traditional, non-polymerized inorganics, pH of the treated water is a critical parameter that controls the specific series of reactions that the metal goes through in the destabilization of colloids. Co-precipitation/adsorption processes for the removal of arsenic and selenium are also heavily affected by operating pH, as are heavy metal precipitation reactions. Choice of coagulants and flocculants can also be influenced by pH and so product selection testing should evaluate pH as a variable.

4) Temperature of the water

Although water temperature is not usually controlled it can significantly affect clarification in a variety of ways:

a) Speed of reactions

b) Floc formation

c) Optimum pH

d) Water viscosity and thus settling velocity. This can be significant during winter, with settling rates decreasing 30- 40%. If a clarifier is operating near capacity, this can result in reduced ability to treat water. Use of flocculants can often mitigate this problem.

Factors (a) to (c) mainly affect metal salt coagulants.

5) Wastewater variability and chemical demand – Dosage Control

Variation in contaminant loading (mass/time) will require changes in chemical dosage. Variation can be due to fluctuating wastewater flow, and/or changes in contaminant concentration. Ideally, the use of equalization tanks can minimize this issue. However, in most industrial plants equalization rarely solves this issue completely, because wastewater can be highly variable and equalization equipment is almost never designed for both concentration and flow variability. The most basic way to address flow variability is to pace the chemical feed to wastewater flow, to maintain a dosage (ppm) set point. This basic automation concept is still not widely practiced however.

More complicated than flow pacing is matching ppm set point to contaminant concentration variation. The existing best practice is routine jar testing by operational personnel. New online sensor based monitoring is being trialed by various parties, in both feedback and feedforward modes. Feedback mode is easier in that the performance parameter is typically TSS or Turbidity and they can be reliably measured at typical effluent quality levels. However, long lag times can make this approach insensitive and non-optimum. Feed forward control of dosage would theoretically be more responsive to water quality changes, but instrument fouling and multiple influencing parameters make this option difficult, and it has only been successful implemented in a few situations. Research is ongoing to improve reliability, accuracy and responsiveness of chemical feed automation.

6) Equipment-specific operating parameters

Will be discussed in each application below.

common industrial wastewater applications

1. primary clarification/sedimentation

When raw wastewater contains significant quantities of TSS, particularly solids that are heavier than water, sedimentation is often the first or second unit operation in the wastewater treatment plant. Some type of equalization tank is often the first step, incorporated to smooth flow and/or contaminant concentrations.

Where the wastewater TSS includes large particulates, the sedimentation step may be a simple tank or pit, with a relatively short retention time. In the steel industry, these are called 'scale pits,' and in the refining sector, these are often called 'API separators.' Larger particles are removed here, often without need for chemical treatment. Separation or gravity settling times are often in the order of minutes rather than hours. Rectangular, plug flow designs are common. These devices can remove particles with diameters above 100 um typically.

Where a significant fraction of colloidal TSS exists, however, more sophisticated clarification equipment and chemical treatment is required in order to produce larger agglomerations of particles, to allow removal in a practical retention time. Primary clarification is also used as a means of protecting the secondary, or biological, process from excessive loading, and/or potentially toxic contaminants, such as metals or oil. Primary clarification can sometimes also remove significant COD ahead of secondary treatment, reducing aeration costs and making the biological treatment process more efficient, especially where TSS is not readily bio-degradable.

Primary clarification can also be used to host precipitation reactions for removal of a range of soluble contaminants, as well as for removal of influent suspended solids. Examples include: phosphate, fluoride, heavy metals, arsenic and selenium. These reactions can require aluminum, ferric or calcium chemistry as the coagulant/

precipitant, together with pH adjustment and in some cases oxidation (e.g. Se). For heavy metal precipitation to very low levels, supplemental specialty precipitants are often also used.

Modern clarifiers designed for industrial wastewater treatment are typically circular, with the influent wastewater entering a small central stilling well, or "centerwell," and then flowing down and up to a peripheral effluent launder. Operational that often have to be addressed include periodic short-circuiting caused by excessive flow or temperature variability, or weir maintenance issues.

Coagulant and flocculant use in primary clarification is heavily dependent on the type of wastewater, and whether concomitant precipitation reactions are being carried out, as described above. For some types of wastewater, a flocculant alone might be all that is required, whereas for more complex applications a coagulant would also be required for colloid destabilization, and/or contaminant removal.

For optimum TSS removal from industrial wastewater, operational control would include:

- Wastewater flow, concentration and/or temperature equalization

- Using jar tests to obtain coagulant, and/or flocculant choices and dosage set-points (in ppm). In some cases, with high variability and inadequate equalization, this can involve daily jar tests. In general, inorganic contaminants, with higher pH, require anionic flocculants, whereas lower pH and organic contaminants require cationic flocculants.

- pH control (if needed)- this is preferably done upstream of the clarifier, under automation, so that coagulant and flocculation chemistry sees a constant pH

- Sludge removal control i.e. blowdown control. The objective is to keep a solids mass balance. The mass of solids being separated from the water each day has to be removed (blown down) from the clarifier each day on average. In wastewater clarifiers it is generally not necessary to keep high sludge beds. In fact, this can lead to anaerobic conditions developing, with production of gases that might cause offensive odors, or solids carryover. Thus, control of solids removal is a critical operational parameter.

- Flow pacing of chemical feed to maintain ppm set point under variable flow conditions. Other chemical feed automation schemes are used to adjust the ppm target, based on feedback (turbidity), or feedforward (TSS, streaming current), and each approach has advantages and disadvantages depending on the specific application. Wastewater applications can be more difficult to automate due to the variety of contaminants, and variability of both flow and contaminant concentration.

- Regular weir maintenance e.g. cleaning, levelling

Performance expectations from a primary clarifier treating industrial wastewater would be at least 65% TSS removal, with coagulant/flocculant treatment. Removals upwards of 80% have been seen.

2. gas flotation

The use of gas flotation to separate suspended material from industrial wastewater is common in the refinery and food processing sectors. This is due to the large fraction of TSS that is oil or grease. With much of the TSS having a density close to, or less than water, flotation is more cost-effective than sedimentation. Flotation works by attaching small gas bubbles to the suspended material, effectively reducing their density even further, thereby increasing the density difference with water, which is one of the drivers of solids separation (see Fig.1). The gas used can be air, more common in the food industry, or nitrogen, more common in the oil refining industry.

There are two general types of gas flotation devices, dissolved gas flotation (DGF) and induced gas flotation (IGF), although the dividing line is getting blurred with recent innovations in induced gas technology.

A common gas flotation process flow schematic is shown in Figure 4. Gas is typically injected into a pressurized recycle line, with or without a saturation tank, which then joins the influent wastewater, just before a pressure reducing valve, prior to entering the flotation unit. As the pressure falls to the operating pressure of the unit, the injected gas comes out of the water in the form of small bubbles that attach to the flocculated particles. In a

dissolved gas flotation unit (DGF, DAF), the bubbles are dissolved in a pressurized saturation tank, and they then come out of solution as very small bubbles, ca 10- 20 um. In a classic IGF unit, the induced gas bubbles are dispersed, not truly dissolved, and tend to be much bigger, closer to 100 um. Improvements in IGF designs have recently provided smaller bubble size. Smaller bubbles are able to attach to smaller floc better and so generally produce more efficient flotation.
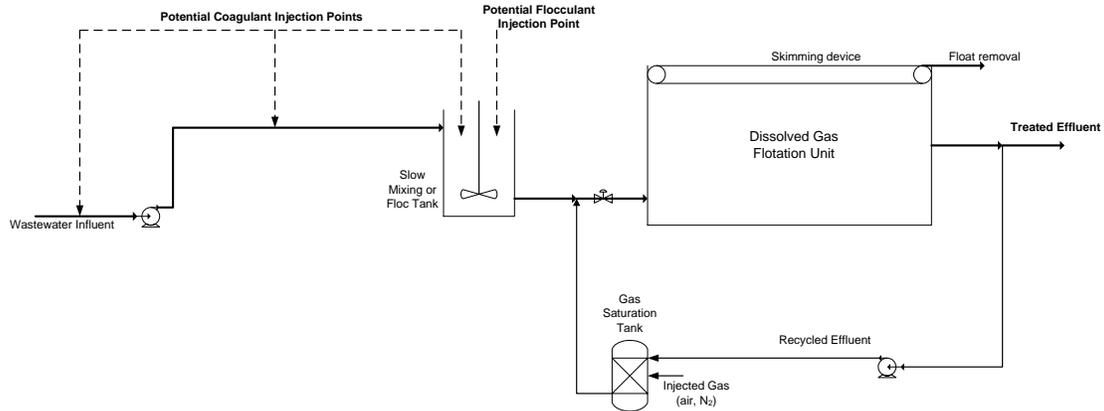

Figure 4: Dissolved Gas Flotation Unit

Coagulants and Flocculants have been found to be very useful in optimizing flotation units. There are two main ways that these chemicals assist flotation treatment of wastewater:

i. As described previously coagulants and flocculants destabilize individual small colloidal particles and expedite the formation of larger floc agglomerates. By providing a closer match between particle and bubble size, flotation efficiency and TSS removal is improved.

ii. Where oil and grease is a significant contaminant, emulsions often form. Emulsions are just another form of stabilized particles, where the particles are small droplets of oil. Coagulation can be used to displace or precipitate the emulsifying agents, allowing flocculation to take place. In this context, coagulation can be called 'emulsion breaking.'

In some DAF applications, flocculation tanks are incorporated just ahead of the flotation unit. A variable speed mixer can be used to further optimize floc formation and unit performance. This feature provides added flexibility, as coagulants and flocculants vary widely in their need for mixing and flotation units vary in what floc type and size works best.

Good operational control of Gas Flotation units, require many of the same controls and methods described above for clarification. In addition, the following are critical control parameters:

- Chemistry: With the variation in wastewater characteristics and flotation unit design, chemical flotation aids provide an extra set of levers in optimizing solids separation performance. Skilled use of chemistry is invaluable in maximizing operation. The coagulant choice and dosage is typically controlled by the wastewater characteristics and mixing available. However, similar wastewaters can require very different flocculants, depending on the specific flotation unit being used.

- Gas addition control. The demand for gas is relatively proportional to the solids loading. In a classic DAF, air addition is controlled by saturation tank pressure and recycle rate. With increased solids (including oil) loading, more air is required, and so a higher saturation tank pressure, and/or higher recycle rate can be used to deliver more air to the influent wastewater. Newer designs of flotation units utilize proprietary gas injection pumps, with their own set of operational adjustments. Monitoring air or nitrogen flow can be used as a check on gas addition rates for most of these units.

- Floated solids skimming control. Timely removal of the "float" is essential to prevent re-entrainment of removed solids back into the treated water. Each design has a different method of adjusting float removal (e.g. skimming speed, or duration, or water level). Balanced against this effluent water quality requirement is the need in many plants for drier sludge, to reduce handling costs. Typically, a longer float retention time means a drier float. Therefore, control of float removal can become a balancing act between two separate needs. If dry float is a strong economic driver, flocculant choices can be made to accomplish this, while producing good effluent quality. A dual-flocculant approach has been used to accomplish this in some food processing wastewater plants.

3. secondary clarification

In traditional activated sludge treatment plants, the clarifier is often the weak link in the system. Serving to separate the biomass solids from the treated wastewater, thicken the solids and then recycle the biomass back to the aeration basin, the secondary clarifier is a critical component of the process. In municipal sewage treatment plants, the biomass usually settles and thickens well. The bacteria self-flocculate, producing a bio-polymer to form floc. In many industrial activated sludge plants, however, the variability and characteristics of contaminant loads often leads to stressed and poor settling biomass. This can manifest itself in excessive floc carryover, and/or poor sludge thickening.

While operational adjustments, or process configuration changes, are being made to fix the underlying cause of these clarifier settleability issues, coagulants and flocculants can play a valuable role in maintaining compliance and keeping the activated sludge system under control.

Coagulants are the most cost-effective solution for pin floc carryover and turbid clarifier effluent. Shock loadings, inhibitory contaminants and excessive sludge age are three common causes of individual particle carryover. Biological floc is usually negatively charged and so coagulants are good clarification aids to help ameliorate this problem. One consideration in the use of coagulants for secondary clarifiers is whether to use products containing inorganics. Ideally these should be avoided in biological processes as they add inerts to the biomass, accumulating to a level determined by the dosage and sludge age. Inerts are unwelcome in biological treatment processes as they interfere with oxygen mass transfer and add additional mixing and pumping costs to the operation. In addition, they result in having to use a higher MLSS than otherwise necessary, which then puts a higher solids load on the clarifier. Organic coagulants are therefore preferred.

Flocculants are often the more cost-effective solution for moderate to severe settling and thickening problems in secondary clarifiers. Cationic flocculants are usually used, for the same reason that coagulants work well. If thickening problems are not severe, coagulants can often improve settling and thickening issues cost-effectively. Coagulants are easier to handle and feed and so if they work well enough they are the preferred solution. In severe filamentous bulking situations however, flocculant addition alone may not be enough to solve the problem and other control options may be necessary.

One challenge that both coagulants and flocculants can face in secondary clarifier applications is limited mixing between the aeration basin and the clarifier. Pipe runs are often short and chemical injection locations are limited. Finding a suitable injection location to provide adequate reaction time can be a challenge.

As with most applications of coagulants and flocculants, jar testing is used to select products and dosages. Note that the dosage obtained from the jar test has to be applied to the total flow to the clarifier (forward wastewater flow rate, plus recycle rate).

Performance is measured by effluent turbidity (or TSS), and/or sludge settleability (SVI). There are very few operational controls available strictly at a secondary clarifier, and even flow pacing is rarely used. The assumption being that flow at this point is normally relatively constant. Operational adjustments that do affect clarifier performance, and thus chemical demand, are mostly associated with the activated sludge system as a whole. These include all the usual factors that contribute to biomass health, e.g. aeration basin pH, D.O., temperature, nutrient addition, salinity, sludge age, F/M. A healthy sludge usually settles well.

4. sludge dewatering

Most wet solids thickening and virtually all dewatering applications benefit from sludge conditioning ahead of the thickening/dewatering device. Coagulants and flocculants are widely used in this application in many industries, as water removal at its essence is a solids separation process, affected by some of the same chemistry at the micro-structure level of the wet solids (sludge). Water release from sludge is affected by electrostatic forces of attraction and repulsion, in that floc size controls the flow of water through the sludge under gravity (thickeners, centrifuges), or under pressure (belt and plate presses). Untreated sludges comprise a wide range of floc size that is not optimum for water passage out of the sludge. Chemical conditioning produces a much more regular floc size that facilitates water passage. See a simplified depiction of this in Figure 5.

Hydrogen bonding also causes water to be held onto the floc at the micro-structure level, especially in biological sludges. Coagulation and flocculation can disrupt this chemical bonding, facilitating release of this 'bound' water.
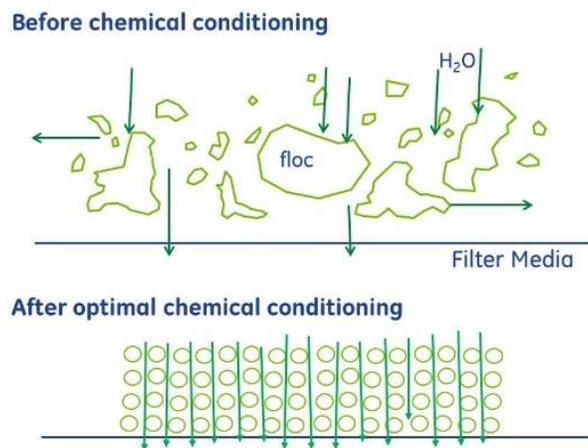

Figure 5: Impact of Sludge Conditioning

In most thickening and dewatering applications, flocculants alone are sufficient to provide the water release desired. In some applications, such as dewatering inorganic sludges in plate and frame presses, inorganic coagulants are used on their own. At times, in dewatering some difficult sludges (e.g. with high contamination), a combination approach using coagulant and flocculant is the most cost-effective approach, as coagulants provide more cationic charge at lower cost than flocculants.

Product selection methodologies varies somewhat in dewatering applications, ranging from bench tests to lab or pilot scale models of the equipment being used (belt filter press, centrifuge, vacuum filter, P&F press, etc).

Some of the more common bench scale tests are: Capillary Suction Time (CST), Buchner Funnel Free Gravity Drainage, Cylinder Settling and Filter Leaf test methods.

Chemical demand for optimal sludge conditioning depends on a wide range of factors, some of which are unknown and the correlation to dewaterability of most are not well defined. Table 2 shows some of the important variables affecting chemical demand.

Table 2: Factors affecting polymer demand in sludge conditioning applications

Factor	Effect
Feed Solids Concentration	Higher TSS better
Ratio of Primary to Secondary Sludge	Primary sludge usually easier to dewater
pH	Higher pH often requires more polymer
Oil & Grease	Increases demand
Charged Contaminants & Surfactants	Increases demand
Biological sludge 'quality'	Settleability, presence of filaments, EPS can all affect dewaterability
Sludge Age/Digestion	Long SRT can increase polymer demand

A successful and reliable dewatering application depends on how well these factors are controlled i.e. made less variable. The fewer variables an operator has to manually control, the more successful a unit operation is.

On the question of dosage, this is more complicated in sludge conditioning. In lower solids aqueous streams, dosage in ppm (mg/l) is often an adequate parameter for chemical control and costing, as it compensates for flow variation. However, it does not compensate for TSS variation, and manual (jar testing), or automatic (TSS measurements) methods are used for improved control. In sludge conditioning applications solids levels are much higher and changes can make a significant difference in chemical demand. Best Practice therefore, for dosage and cost measurement, is based on solids loading and not ppm. The parameter commonly used is pounds of polymer per ton of dry weight solids in the feed. An appropriate cost parameter is therefore $ per ton of solids.

Attempts to automate chemical feed have met with mixed results over the years. The Water Environment Research Foundation reviewed some of these techniques in 2001 (Gillette and Joslyn, 2001). There are commercial offerings available, but they are not widely used.

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