CHAPTER 4

SLUDGE CONDITIONING

Sludge conditioning is a process whereby sludge solids are treated with chemicals or various other means to prepare the sludge for dewatering processes, in other words, to improve dewatering characteristics of the sludge.

MECHANISMS TO CONDITION THE SLUDGE

There are two mechanisms involved in sludge conditioning:

1. Neutralization of charge (double layer theory)
2. Bridging of individual particles into a floc structure (polymer bridge formation)

1. Double Layer Theory

The double layer model is used to visualize the ionic environment in the vicinity of a charged colloid and explains how electrical repulsive forces occur. It is easier to understand this model as a sequence of steps that would take place around a single negative colloid if its neutralizing ions were suddenly stripped away. We first look at the effect of the colloid on the positive ions (often called counter-ions) in solution. Initially, attraction from the negative colloid causes some of the positive ions to form a firmly attached layer around the surface of the colloid; this layer of counter-ions is known as the Stern layer. Additional positive ions are still attracted by the negative colloid, but now they are repelled by the Stern layer as well as by other positive ions that are also trying to approach the colloid. This dynamic equilibrium results in the formation of a diffuse layer of counter-ions. They have a high concentration near the surface which gradually decreases with distance, until it reaches equilibrium with the counter-ion concentration in the solution. In a similar, but opposite, fashion there is a lack of negative ions in the neighborhood of the surface, because they are repelled by the negative colloid. Negative ions are called co-ions because they have the same charge as the colloid [1].

Their concentration will gradually increase with distance, as the repulsive forces of the colloid are screened out by the positive ions, until equilibrium is again reached. The diffuse layer can be visualized as a charged atmosphere surrounding the colloid. The charge density at any distance from the surface is equal to the difference in concentration of positive and negative ions at that point. Charge density is greatest near the colloid and gradually diminishes toward zero as the concentration of positive and negative ions merge together. The attached counter-ions in the Stern layer and the charged atmosphere in the diffuse layer are what we refer to as the double layer. The thickness of this layer depends upon the type and concentration of ions in solution [1].

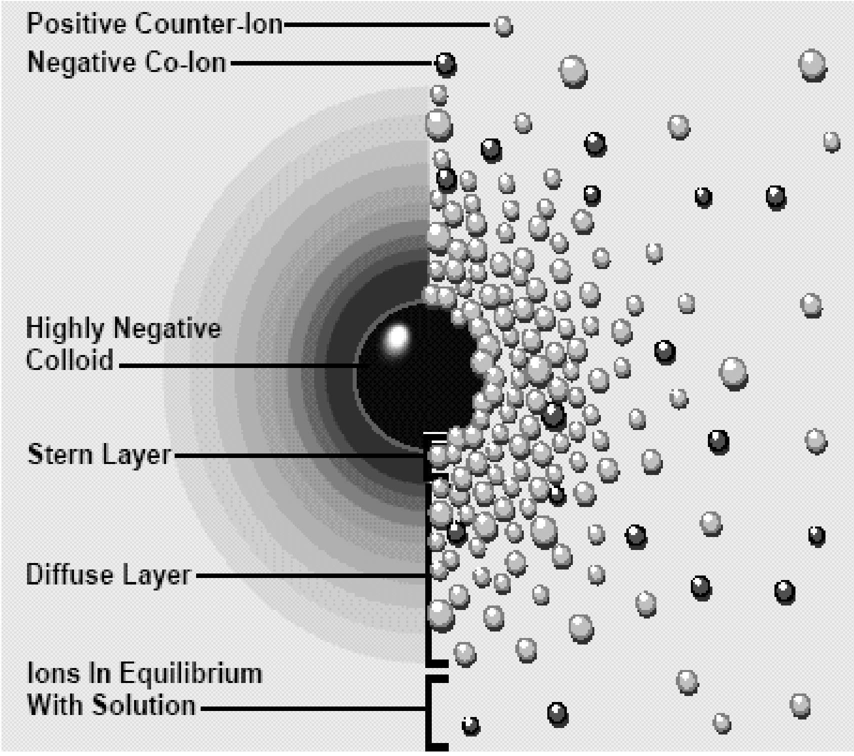

Figure 1. Visualization of the double layer theory [1].

Zeta Potential vs. Double Layer

Colloidal particles dispersed in a solution are electrically charged due to their ionic characteristics and dipolar attributes. Each particle dispersed in a solution is surrounded by oppositely charged ions called the fixed layer. Outside the fixed layer, there are varying compositions of ions of opposite polarities, forming a cloud-like area. This area is called the diffuse double layer, and the whole area is electrically neutral. When a voltage is applied to the solution in which particles are dispersed, particles are attracted to the electrode of the opposite polarity, accompanied by the fixed layer and part of the diffuse double layer, or internal side of the "sliding surface" [2].

Zeta potential is considered to be the electric potential of this inner area including this conceptual "sliding surface". **As this electric potential approaches zero, particles tend to aggregate [2]**.

The effect of zeta potential can be seen in Figure 2, 3 and 4. As the potential approaches to zero, particles (white dots) tend to get bigger and bigger because of the agglomeration. As the potential became smaller (approaching to negative high values), pin flocs or small flocs can be observed easily.

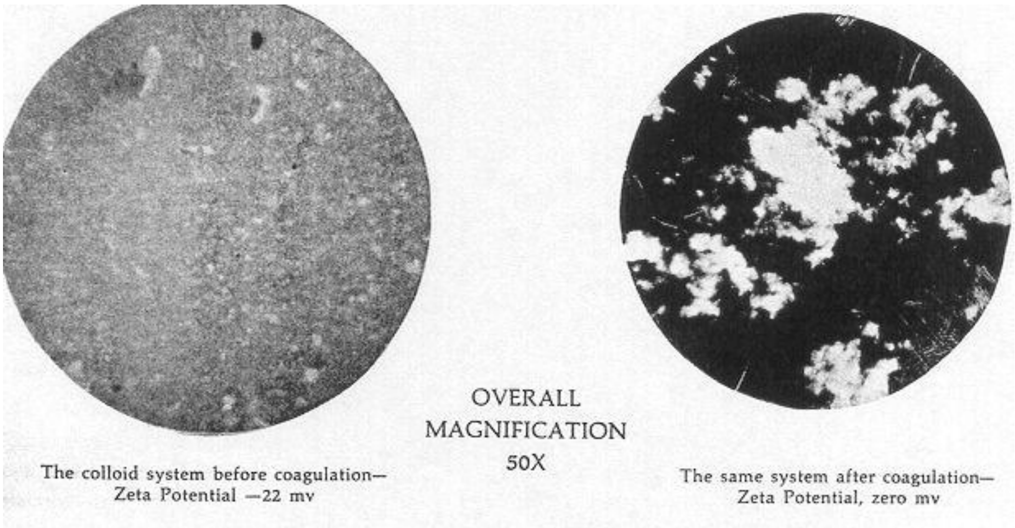

Figure 2. Effect of zeta potential [3].

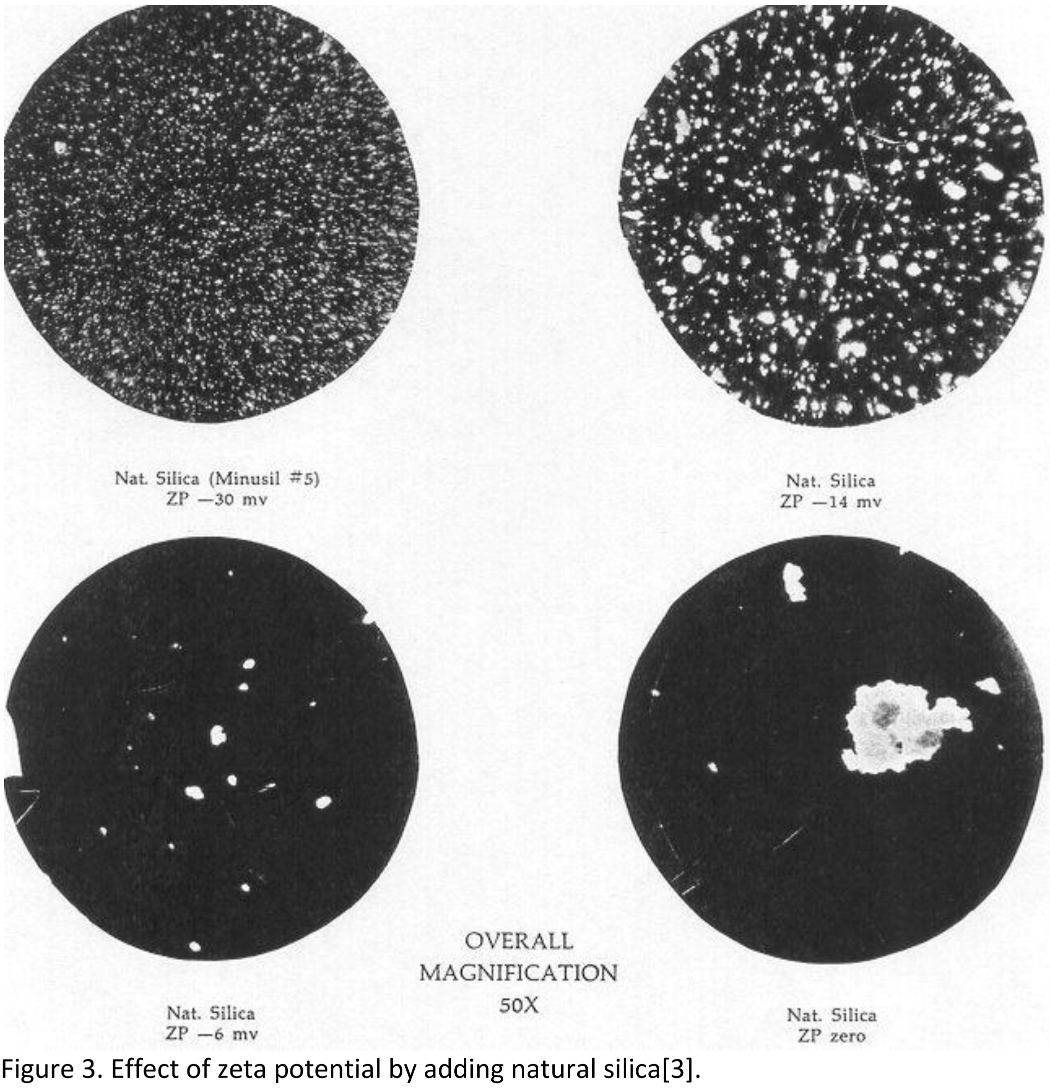

Figure 3. Effect of zeta potential by adding natural silica[3].

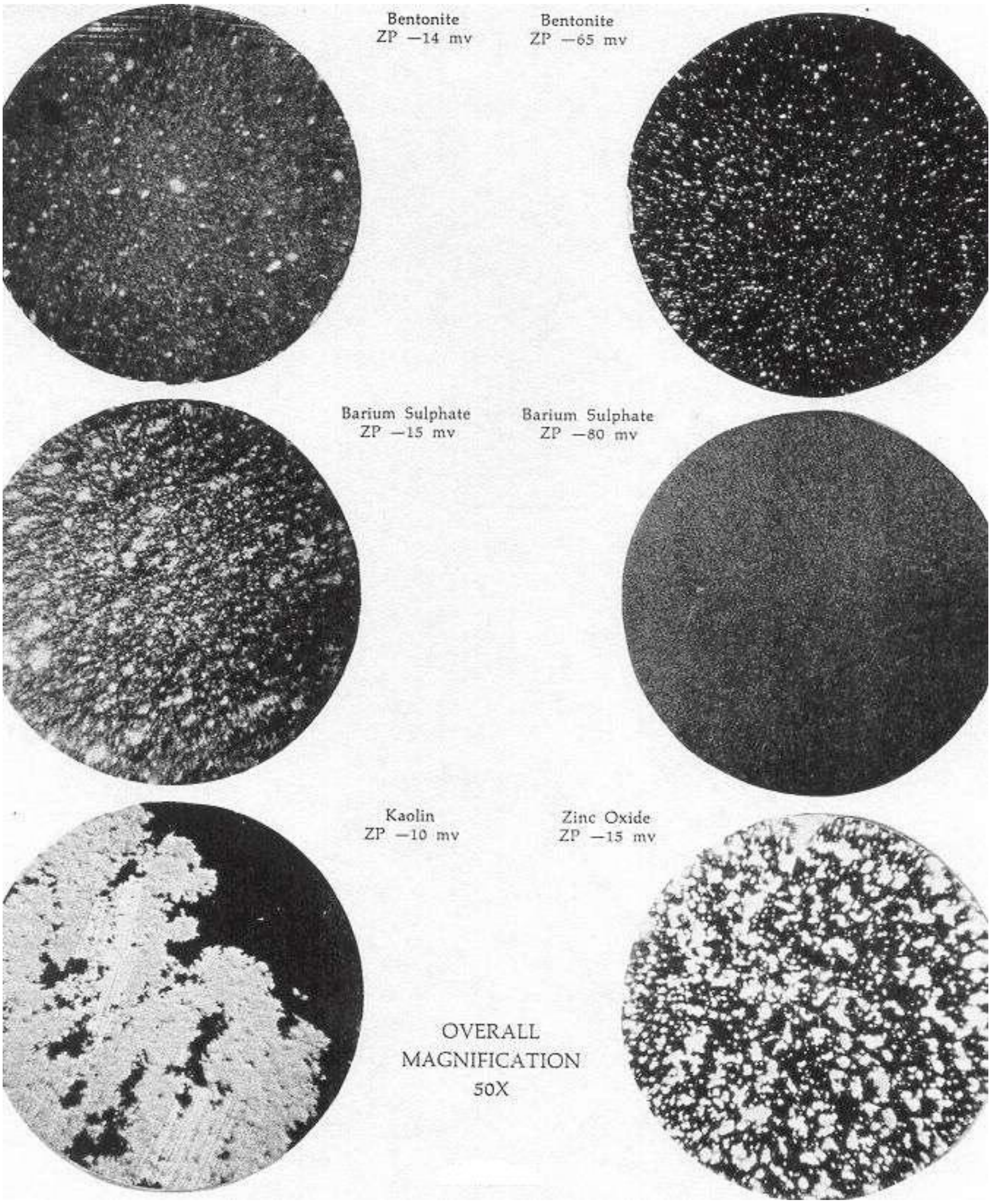

Figure 4. Effect of zeta potential by adding different coagulants[3].

2. Polymer Bridge Formation

Polymers that are anionic and non-ionic (usually anionic to a slight extent when placed in water) become attached at a number of adsorption sites to the surface of the particles found in the wastewater. A bridge is formed when two or more particles become adsorbed along the length of the polymer. The size of resulting three-dimensional particles grows until they can be removed easily by sedimentation. Where particle removal is to be achieved by the formation of the particle-polymer bridges, the initial mixing of the polymer and the wastewater containing the particles to be removed must be accomplished in a matter of seconds. Instantaneous initial mixing usually not required as the polymers are already formed, which is not the case with the polymers formed by metal salts [4]. Figure 5 shows the illustration of the polymer bridge formation.

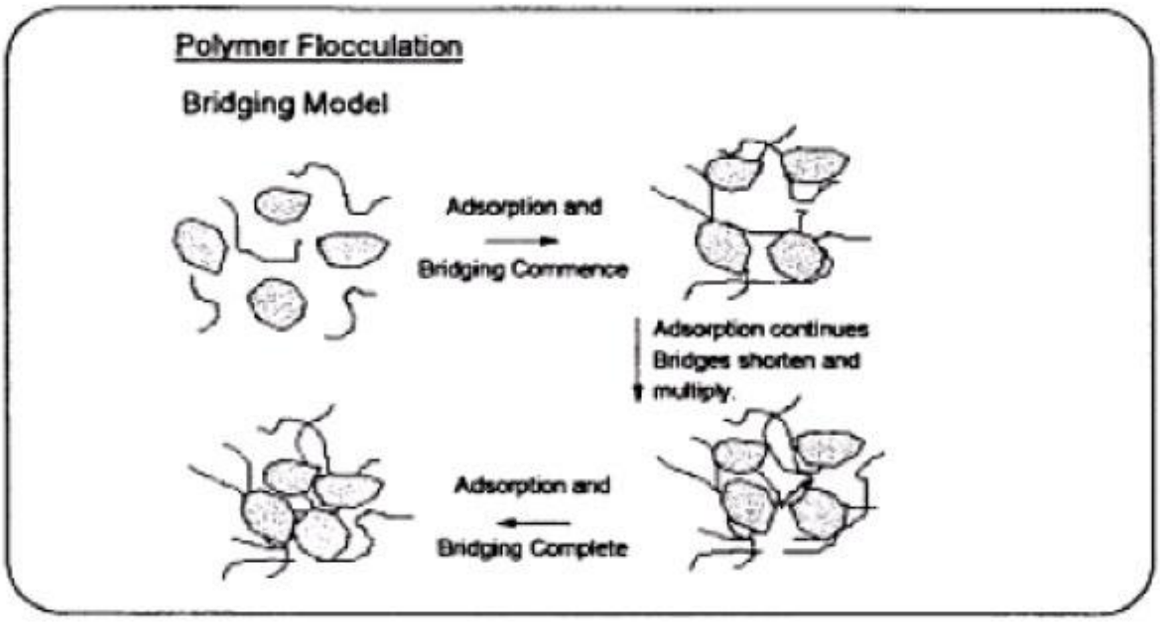

Figure 5. The illustration of the polymer bridge formation [5].

METHODS TO CONDITION THE SLUDGE

Sludge and biosolids are generally conditioned chemically. Other conditioning methods are heat treatment and freeze-thaw methods.

1. Chemical Conditioning

Chemical conditioning (sludge conditioning) prepares the sludge for better and more economical treatment with vacuum filters or centrifuges. Many chemicals have been used such as sulfuric acid, alum, chlorinated copperas, ferrous sulfate, and ferric chloride with or without lime, and others [6].

Chemical conditioning can reduce the 90 to 99% incoming moisture content to 65-85%, depending on the nature of the solids to be treated. Chemical conditioning results in coagulation of the solids and release of the absorbed water [4].

The local cost of the various chemicals is usually the determining factor. In recent years the price of ferric chloride has been reduced to a point where it is the one most commonly used [6].

The addition of the chemical to the sludge lowers or raises its pH value to a point where small particles coagulate into larger ones and the water in the sludge solids is given up most readily. There is no one pH value best for all sludges. Different sludges such as primary, various secondary and digested sludge and different sludges of the same type have different optimum pH values which must be determined for each sludge by trial and error. Tanks for dissolving acid salts, such as ferric chloride, are lined with rubber or other acid-proof material. Intimate mixing of sludge and coagulant is essential for proper conditioning. Feeders are also necessary for applying the chemicals needed for proper chemical conditioning [6].

The most frequently encountered conditioning practice is the use of ferric chloride either alone or in combination with lime. The use of polymers is rapidly gaining widespread acceptance. Although ferric chloride and lime are normally used in combination, it is not unusual for them to be applied individually. Lime alone is a fairly popular conditioner for raw primary sludge and ferric chloride alone has been used for conditioning activated sludges. Lime treatment to a pH of 10.4 or above has the added advantage of providing a significant degree (over 99 percent) of disinfection of the sludge [6].

Organic polymer coagulants, and coagulant aids have been developed in the past 20 years and are rapidly gaining acceptance for sludge conditioning. These polymers are of three basic types:

Anionic (negative charge): serve as coagulants aids to inorganic Aluminum and Iron coagulants by increasing the rate of flocculation, size, and toughness of particles.

Cationic (positive charge): serve as primary coagulants alone or in combination with inorganic coagulants such as aluminum sulfate.

Nonionic (equal amounts of positively and negatively charged groups in monomers): serve as coagulant aids in a manner similar to that of both anionic and cationic polymers.

The popularity of polymers is primarily due to their ease in handling, small storage space requirements, and their effectiveness. All of the inorganic coagulants are difficult to handle and their corrosive nature can cause maintenance problems in the storing, handling, and feeding systems in addition to the safety hazards inherent in their handling [6].

Factors Affecting Chemical Conditioning

Wastewater sludge consists of primary, secondary, and/or chemical solids with various organic and inorganic particles of mixed sizes. Depending on the sources, they have various internal water contents, degree of hydration, and surface chemistry. Sludge characteristics that affect thickening or dewatering and for which conditioning is employed include the following [7]:

- Source
- Solids concentration
- Particle size and distribution
- pH and alkalinity
- Surface charge and degree of hydration
- Other physical factors

Sources: Sources such as primary sludge, waste activated sludge, chemical sludge, and digested biosolids are good indicators of the source of conditioner doses required for thickening or dewatering. Based on published data about chemical conditioning requirements, primary sludge, as a general rule, requires lower doses than those required by biological sludge. Among the varieties of secondary biological sludge, attached growth sludge requires lower doses than does suspended growth biological sludge. Conditioning requirements for aerobically and anaerobically digested sludge generally are the same as for secondary digested biological sludge [7].

Solids Concentration: Municipal wastewater sludge contains a large number of colloidal and agglomerated particles, which have large specific surface areas. If the sludge has a low concentration of solids, these particles behave in a discrete manner with little interaction. In many applications, conditioning is the neutralization of the surface charge of sludge particles by the adsorption of oppositely charged organic polyelectrolyes or inorganic chemical complexes. With low interaction from the low concentration of solids, more coagulants are needed to overcome the surface charge. As the concentration of solids is increased, interaction increases. Therefore, on a mass of coagulant per mass of dry solids basis, the dosage can be reduced. For this reason, coagulant dose is usually expressed as a percentage of dry solids or as kilo-grams of coagulant per ton of dry solids. A higher suspended solids concentration produces effective conditioning over a wide range of dosage when organic polymers are used, which means that the higher the solids concentration, the less susceptible the process is to overdosing [7].

Particle Size and Distribution: Particle size is considered the single most important factor influencing the dewaterability of sludge. For the same concentration of solids in sludge, the greater the number of small particles, the greater the surface area/volume ratio. Increased surface area means greater hydration, higher chemical demand, and increased resistance to dewatering. One of the objectives of conditioning is to increase particle size by combining the small particles into large aggregates [7].

pH and Alkalinity: pH and alkalinity affect primarily the performance of inorganic conditioners. When added to water, inorganic conditioners reduce the water’s pH. Therefore, the dosage of inorganic conditioners such as iron or aluminum, and the alkalinity or buffering of the sludge, determine the pH of the conditioning process. The resulting pH, in turn, determines the pre-dominant coagulant species that will be present and the nature of the charged colloidal surface. The higher alkalinity of anaerobically digested biosolids is one of the reasons for the associated higher coagulant doses [7].

Surface Charge and Degree of Hydration: For the most part, sludge solids repel rather than attract one another. This repulsion may be due to hydration or electrical effects. With hydration, a layer of water binds to the surface of the solid. This provides a buffer that prevents close approach between solids. In addition, sludge solids are negatively charged and thus tend to be mutually repulsive. Conditioning is used to overcome these effects of hydration and electrical repulsion [7].

Physical Factors: Physical factors such as storage, pumping, mixing, and sludge treatment processes, including the types of thickening and dewatering devices to be used, also affect the thickening and dewatering characteristics of sludge. Sludge that has been stored for a long period of time requires more conditioning chemicals than fresh sludge does because of an increase in the degree of hydration and the fines content of the solids. Because of the fragile structure of sludge particles, some reduction in particle size typically results from the shear forces associated with the pumping process. Proper mixing and flocculation to evenly disperse the conditioning chemicals required also depend on the processing to which the sludge has been subjected and on the mechanics of thickening or dewatering process available [7].

2. Thermal Conditioning

There are two basic processes for thermal treatment of sludges. One, wet air oxidation, is the flameless oxidation of sludges at temperatures of 450 to 550°F and pressures of about 1200 psig. The other type, heat treatment, is similar but carried out at temperatures of 350 to 400°F and pressures of 150 to 300 psig. Wet air oxidation reduces the sludge to an ash and heat treatment improves the dewaterability of the sludge. The lower temperature and pressure heat treatment is more widely used than the oxidation process [6].

When the organic sludge is heated, heat causes water to escape from the sludge. Thermal treatment systems release water that is bound within the cell structure of the sludge and thereby improves the dewatering and thickening characteristics of the sludge. The oxidation process further reduces the sludge to ash by wet incineration (oxidation). Sludge is ground to a controlled particle size and pumped to a pressure of about 300 psi. Compressed air is added to the sludge (wet air oxidation only), the mixture is brought to a temperature of about 350°F by heat exchange with treated sludge and direct steam injection, and then is processed (cooked) in the reactor at the desired temperature and pressure. The hot treated sludge is cooled by heat exchange with the incoming sludge. The treated sludge is settled from the supernatant before the dewatering step. Gases released at the separation step are passed through a catalytic after-burner at 650 to 705°F or deodorized by other means. In some cases these gases have been returned through the diffused air system in the aeration basins for deodorization [6].

An advantage of thermal treatment is that a more readily dewaterable sludge is produced than with chemical conditioning. Dewatered sludge solids of 30 to 40 percent (as opposed to 15 to 20 percent with chemical conditioning) have been achieved with heat treated sludge at relatively high loading rates on the dewatering equipment (2 to 3 times the rates with chemical conditioning). The process also provides effective disinfection of the sludge.

Unfortunately, the heat treatment process ruptures the cell walls of biological organisms, releasing not only the water but some bound organic material. This returns to solution some organic material previously converted to particulate form and creates other fine particulate matter. The breakdown of the biological cells as a result of heat treatment converts these previously particulate cells back to water and fine solids. This aids the dewatering process, but creates a separate problem of treating this highly polluted liquid from the cells. Treatment of this water or liquor requires careful consideration in design of the plant because the organic content of the liquor can be extremely high [6].

3. Freeze-Thaw Conditioning

It is well-known fact that natural freezing of water and wastewater treatment plant residuals in cold climates enhances their dewatering characteristics. Freezing and thawing convert the jellylike consistency of the residuals to a granular-type that drains readily. Similar results have been achieved by the use of mechanical freeze/thaw equipment [4].

When sludge freezes, the free water begins to freeze first. As the free water binds by crystallization, it seeks more free water to bind and grow with while pushing the floc particles to the ice front. Once free water is frozen, the interstitial water is extracted by diffusion and added to the growing crystalline structure [4].

The initial concentration of solids in the sludge, the rate of freezing, and the duration of freezing conditions (curing time) are cited as important variables to consider in optimizing the freeze/thaw process.

To be effective, sludge has to be frozen for at least 30 minutes at temperatures of minus 10 to 20^0 C. After thawing and dewatering, dewatered sludge cake can range from 25 to 40% solids with a filtrate that is very low in TSS [4].

References:

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