2.4 Tertiary Treatment

2.4.1 Chemical

Tertiary treatment consists of removing suspended and dissolved solids from the wastewater using chemical processes. In these processes, chemicals are added to the wastewater to increase settling and coagulation. Solid masses known as floc are formed from the addition of coagulating chemicals. Slow stirring of coagulated wastewater aggregates the destabilized particles and forms rapidly settling floc (Reynolds and Richards, 1996). Bacteria and other organisms are used to assimilate the dissolved and nonsettable organic material in biological processes (Kerri, 1994). These organisms can be either aerobic (utilizing oxygen) or anaerobic (no oxygen) in nature.

It is important to realize that there are two separate waste streams of a plant, the wastewater and the biosolids. This report focuses on the production and handling of the biosolids and does not go into detail for the effluent water portion.

3.0 SOLIDS HANDLING PROCESSES

With regard to the handling of biosolids, there are almost as many ways and process sequences as there are plants. In this section, the main processes will be briefly outlined and explained. Figure 1 shows the possible flow paths that can be taken in the solids handling processes. Different facilities may choose to skip steps while others may incorporate all of them. The solids produced during various stages of cleansing are classified differently. Primary sludge consists mainly of organic solids, grit, and inorganic fines. Primary sludge is typically pumped to a downstream process for additional thickening, stabilizing, conditioning and dewatering; disposal or reuse then follows (ASCE & WEF, 1992).

Secondary sludge is biological sludge produced by treatment processes such as activated sludge, trickling filters, and rotating biological contactors. Although many variations are possible, all secondary sludges result from aerobic biological treatments. Secondary sludges are typically more difficult to thicken or dewater than primary sludges and chemical sludges (ASCE & WEF, 1992). Chemical sludges result from the addition of various chemical used to improve suspended solids removal or to precipitate phosphorus. Generally, the addition of lime improves the thickening and dewatering while additions of iron and aluminum salts can improve water removal (ASCE & WEF, 1992).

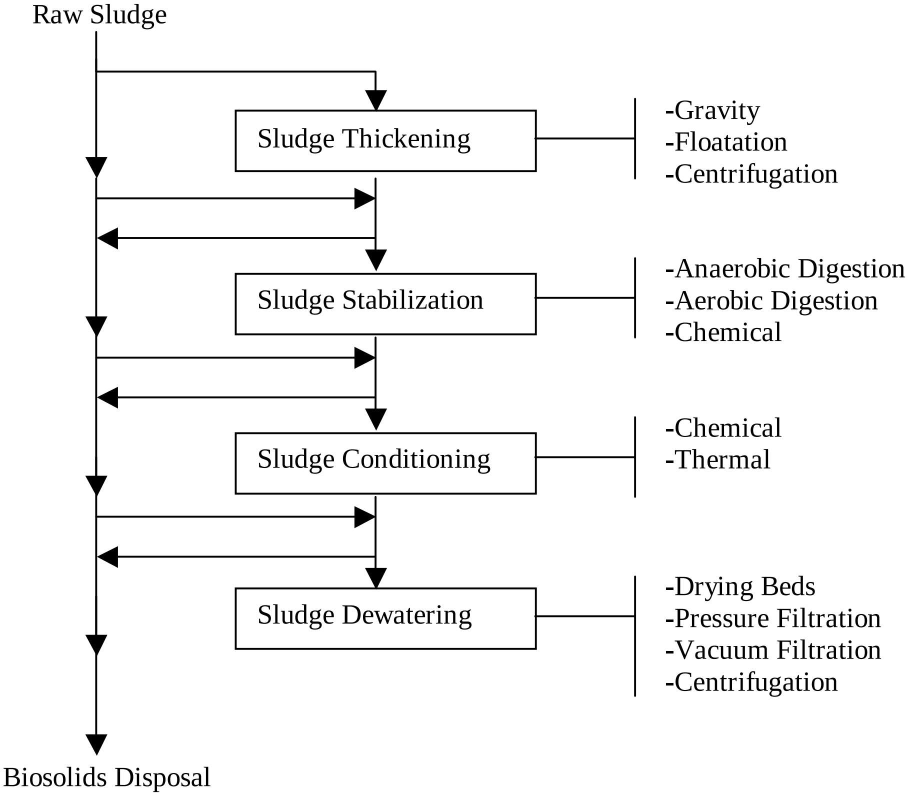

Figure 1. Flowchart for sludge treatment showing possible flow paths (Adapted from Federation, 1977).

3.1 Sludge Thickening

For the solids generated during chemical and biological processes in secondary and tertiary treatments, concentration or thickening is usually the first step. The primary function of sludge thickening is to reduce the water content and sludge volume (Kerri, 1994). There are three main sludge-thickening processes: gravity thickening, flotation, and centrifugation. Table 4 presents typical concentrations for thickening processes.

Table 4. Typical solids concentrations for sludge thickening processes.[a]

Operation	Solids Concentration (%)	
	Range	Typical
Gravity Thickeners		
Primary sludge only	4-10	6
Primary and waste activated	2-6	4
Floatation Thickeners		
With chemicals	3-6	4
Without chemicals	3-6	4
Centrifuge Thickeners		
With chemicals	4-8	5
Without chemicals	3-6	4

[a] Adapted from Metcalf and Eddy (1991).

3.1.1 Gravity

As the name indicates, gravity is used to separate the liquids from the solids. Sludge is pumped into a circular tank, similar to circular clarifiers, where solids and liquids are separated by settling. In some processes, rakes are utilized within the tank to stir and break up the sludge enhancing the release of water. This water is then returned to the headworks of the facility where it can undergo the treatment process again. Gravity thickeners usually thicken sludge to about twice the original solids content, thus decreasing the volume of fresh sludge to about half the original volume. Gravity thickeners are employed principally for thickening of primary sludges, lime sludges, combinations of primary and activated sludges, and to a lesser degree, activated sludge only (ASCE & WEF, 1992; Reynolds and Richards, 1996).

3.1.2 Dissolved Air Floatation

A second method of thickening sludge is by dissolved air flotation (DAF). Flotation separates solids from the liquid phase by attaching air bubbles to particles of suspended solids (Kerri, 1994). A variety of polymers can be added to help the flocculation of solids particles suspended in the wastewater. Organic polymers used for sludge thickening and dewatering are long chain, water soluble, synthetic organic chemicals. Polyacrylamide, a non-ionic compound, is the most widely used polymer (ASCE & WEF, 1992). The aggregate or thickened sludge floats to the surface of the tank and is removed by surface skimmers. DAF thickening is commonly used for waste activated, aerobically digested, contact stabilized, modified activated, or extended aeration sludges without primary settling. DAF is generally not used for primary sludges and trickling filter sludges because gravity settling of sludges that settle readily is more economical than DAF (ASCE & WEF, 1992).

3.1.3 Centrifugation

Centrifugation is a third method of sludge thickening. Sludge is fed at a constant feed rate into a rotating bowl and the solids are separated from the liquid by the centrifugal forces created by the rotating bowl. The solids are compacted to the bowl wall and the liquid and fine solids exit the unit through the effluent line (Kerri, 1994). An internal screw conveyor removes the dewatered sludge out one end of the bowl while water leaves the other end (Figure 2). The effluent water is usually pumped back to the headworks of the plant while the solids are discharged from the centrifuge. The goal of centrifugal thickening is to obtain a solids concentration of approximately 20%.

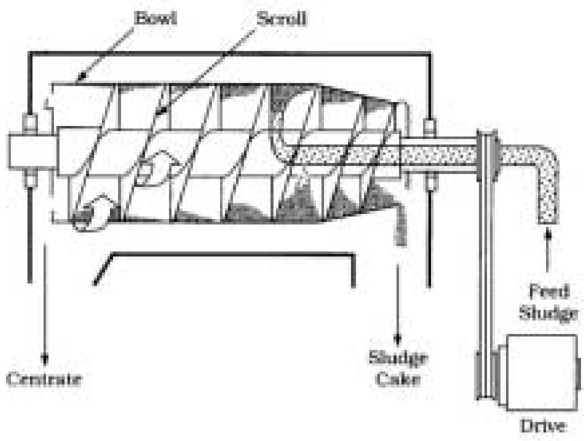

Figure 2. Continuous countercurrent solid-bowl centrifuge (Adapted from Reynolds and Richards, 1996).

Centrifuges are commonly used for thickening waste activated sludge and other biological sludges from secondary wastewater treatment and are occasionally used to reduce the volume of stabilized sludges to minimize the transportation component of ultimate disposal methods. Primary sludge is better suited to settling by gravity than centrifugal thickening because of its settleability and tendency to contain abrasive material that is detrimental to a centrifuge (ASCE & WEF, 1992).

3.2 Sludge Stabilization

After the solids from the secondary treatment are thickened they are often stabilized. The purpose of sludge stabilization is to reduce and convert the odor-causing portion of the biosolids, volatile organics, to an innocuous end product, preventing the breeding of insects upon disposal and reducing the pathogenic bacteria content (Kerri, 1994). There are several types of sludge stabilization: 1) anaerobic digestion, 2) aerobic digestion, 3) composting, 4) chemical stabilization and other combinations of these processes. The most widely used is anaerobic digestion.

3.2.1 Anaerobic Digestion

Anaerobic digestion is a complex biochemical process in which several groups of anaerobic and facultative organisms break down organic matter (Kerri, 1994). Sludge from primary and secondary treatment is pumped to the digester tank where it is held at a controlled temperature for a predetermined time. Biosolids are continuously mixed using mechanical or gas mixing devices that aid in uniform temperature control and assimilation of the "food" with the digestive organisms present. During anaerobic digestion, gases such as methane and carbon dioxide are produced by the organisms as they consume the organic matter in the sludge. These gases, especially methane, can lower operational costs when used to operate facility engines and/or to maintain temperatures of various operations within the system. The resulting biosolids are considered stabilized because of the low volatile organic content that produces relatively little odor. Table 5 presents the advantages and disadvantages of anaerobic digestion.

Table 5. Anaerobic digestion advantages and disadvantages.[a]

Advantages	Disadvantages
-Production of energy as methane	-High operator monitoring required to maintain parameters
-Reduction of 30-50% sludge volume	-High operating cost due to temperature management
-The protection of sludge generally free from objectionable odors when fully digested	-Complete volatile solids destruction does not occur
-High rate of pathogen destruction particularly with the thermophilic process	-Possible problems resulting from explosive gas production from aerobically digested sludge

[a] Adapted from ASCE & WEF (1992).

3.2.2 Aerobic Digestion

Aerobic digestion, like anaerobic digestion, stabilizes raw or partially oxidized sludge so it can be either treated in further processes or disposed. This process is used most commonly in plants with design capacities less than 5 MGD, although other processes are also used in small plants (ASCE & WEF, 1992). Sludge is brought into a large tank where it is aerated for an extended period of time. When primary sludge is mixed with waste activated sludge or trickling filter humus and the combination is aerobically digested, there will be both oxidation of the organic matter in the primary sludge and endogenous oxidation of the cell mass produced from the biological oxidation and from the activated sludge or filter humus. Thickened sludge withdrawn from aerobic digester settling basins ranges in concentration from 2-3% solids (ASCE & WPCF, 1977; Reynolds and Richards, 1996). Table 6 presents aerobic digestion advantages and disadvantages.

Table 6. Aerobic digestion advantages and disadvantages.[a]

Advantages	Disadvantages
-Relatively inoffensive & biologically stable product	-High Power costs associated with aeration
-Low capital cost	-Reduced cold weather efficiency
-Comparatively simple, safe operational control	-Mixed results achieved in mechanically dewatering aerobically digested sludge
-Comparatively low odor potential	
-Production of nonexplosive gas	-Nonproduction of methane gas from which can be recovered (as in anaerobic digestion)
-A relatively clean recycle stream	

[a] Adapted from ASCE & WEF (1992)

3.2.3 Composting

Composting is used as a stand-alone form of stabilization in some facilities. A detailed description of composting is discussed in the Current Biosolids Management Practices section.

3.2.4 Chemical Stabilization

Chemical stabilization, another method of sludge stabilization, is not often practiced. The major disadvantage to chemical stabilization is the cost required for large amounts of chemicals needed for the process. The two types of chemicals used for stabilization are lime and chlorine. The goal of lime stabilization is to add sufficient quantities of lime to the sludge to raise the pH to about 11.5 to 12.0. To achieve this pH, a dosage of approximately 200 to 220 pounds of lime per ton for primary solids and 400 to 800 pounds of lime per ton for waste activated sludge are added (Kerri, 1994). Unlike other stabilization processes that reduce solids content, lime stabilization actually increases the total amount of solids that ultimately have to be disposed, thus increasing disposal costs. Chlorine stabilization is accomplished by adding sufficient quantities of chlorine to the sludge to kill pathogenic and nonpathogenic organisms. Dosages to achieve disinfection are generally 100 to 300 lbs. of chlorine per ton of sludge solids (Kerri, 1994).

3.3 Sludge Conditioning

After stabilization, the sludge is ready to be conditioned. The purpose of conditioning is to pretreat the sludge to improve the efficiency of thickening and the removal of water in ensuing treatment processes and for ultimate use or disposal. Raw primary sludge is much easier to condition than digested or biological sludge. Biological sludges from high rate processes are the most difficult to condition (ASCE & WEF, 1992; Kerri, 1994). Chemical and thermal are the two types of conditioning that are discussed in this section.

3.3.1 Chemical

Inorganic chemical conditioning is associated principally with vacuum filters and pressure filter presses. The most common practice is to use chemicals such as ferric chloride alone or in combination with lime. The addition of these chemicals to the sludge reduces electrostatic repelling forces and allows the solids to coagulate and flocculate into a heavier mass. Chemical conditioning also results in the discharge of cell bound water, reducing the volume of sludge to be handled (Kerri, 1994). The optimum ferric chloride and lime dosages for sludge conditioning depend on the sludge characteristics. In general, ferric chloride dosage ranges from 2-10% of solids and lime ranges from 5-40%, both based on dry solids (ASCE & WEF, 1992).

3.3.2 Thermal

Thermal conditioning subjects the sludge particles to heat at elevated pressures to enhance the dewatering without the additional chemicals. In thermal conditioning, the application of heat disintegrates the cell walls of microorganisms contained in biological sludges, releasing bound water from the sludge particles (ASCE & WEF, 1992). The heat treatment results in coagulation of solids, decomposition of large quantities of the cell mass, and a reduction of water affinity of sludge solids (Metcalf & Eddy, 1972). The resulting biosolids are now prepared for the next process without the need for chemical additions.

3.4 Sludge Dewatering

After stabilization and conditioning, the sludge is often referred to as biosolids and is ready for dewatering. The purpose of dewatering is to reduce biosolids moisture and volume to a degree that will allow for economical disposal (Kerri, 1994). Table 7 presents the three common methods for dewatering biosolids: pressure filtration, vacuum filtration, and centrifugation.

Table 7. Typical solids concentrations for sludge dewatering processes.[a]

Operation	Solids Concentration (%)	
	Range	Typical
Vacuum Filtration		
With chemicals	15-30	20
Belt Filter Press Filtration		
With chemicals	15-30	22
Filter Press		
With chemicals	20-50	36
Centrifuge Dewatering		
With chemicals	10-35	22
Without chemicals	10-30	18

[a] Adapted form Metcalf and Eddy (1991).

3.4.1 Drying Beds

A commonly used dewatering method is drying beds. Drying beds are usually 20 to 30 ft wide, are 25 to 125 ft long, and consist of a 6-10 inch coarse sand layer above a 6-12 inch graded gravel layer (Figure 5) (Reynolds and Richards, 1996). Biosolids are applied to the bed in a 8-12 in layer so the water can evaporate and drain through the biosolids mass and supporting gravel/sand structure into the underlying drainage system (Metcalf & Eddy, 1991). Drained water is returned to the facility headworks for further treatment. Drying times vary with weather conditions and percent solid contents of the biosolids. The biosolids are left on the drying beds vary from two days to two months. Removal of the dried biosolids (30-50% solids) in a "liftable state" varies with both individual judgment and final disposal means (Eckenfelder, 1980).

3.4.2 Pressure Filtration

Pressure filtration, usually performed by a gravity belt filter press, occurs when sludge is pumped between plates or belts that force water to be excreted. Gravity belt filter presses are particularly suitable for the thickening and dewatering of waste activated sludge before further processing and for thickening digested sludges as a volume reduction measure before transportation for ultimate disposal (ASCE & WEF, 1992). Water removed is returned to the facilities headworks for further treatment. The sludge or cake solid that exits the press now has a solids content between 14-20%, depending on the pressure applied and the length of application (Figure 3).

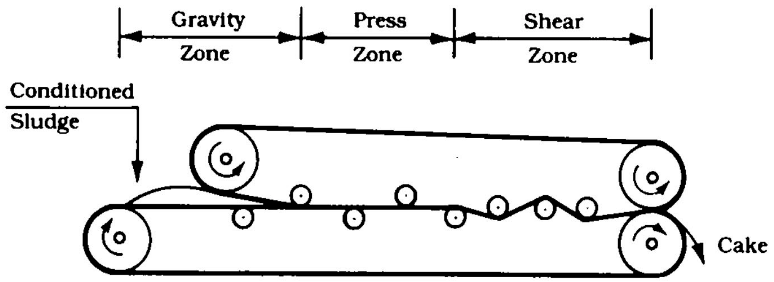

Figure 3. Belt filter press (Adapted from Reynolds and Richards, 1996).

3.4.3 Vacuum Filtration

Vacuum filtration is an effective means of removing large volumes of water from sludge that in some cases has been conditioned with ferric chloride and lime. In a vacuum-filter operation, a large rotary drum passes through a continuously stirred slurry tank in which the solids are retained on the drum surface under applied vacuum (Eckenfelder, 1980). Figure 4 is a diagram of a belt type rotary vacuum filter system. The drum surface, which is only partially submerged in the solids tank, is covered with a filter media such as cloth, wire mesh, synthetic fibers or coil springs that allows water to pass through, trapping the solids on the filter. These trapped solids form a sludge mat on the drum surface and are removed. The filter media is then washed in preparation for repeating the process. Vacuum filtration is a continuous process that can reduce the sludge to 30% solids (Metcalf & Eddy, 1972). Table 8 shows the potential dry solids of sludge cake that result from various treatment processes.

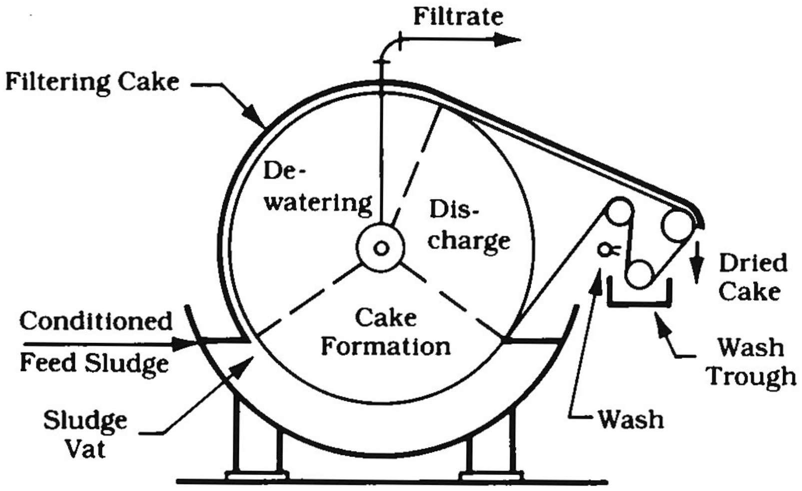

Figure 4. Belt rotary vacuum filter (Adapted from Reynolds and Richards, 1996).

Table 8. Vacuum filter performance for processing municipal sludges conditioned by ferric chloride and lime.[a]

Type of Sludge	Solids Loading ($lb/hr-ft^2$)	Percent Solids Cake
Fresh primary	6-8	25-38
Fresh primary and waste activated sludge	4-5	16-25
Fresh primary and waste activated sludge (pure oxygen)	5-6	20-28
Fresh primary and trickling filter humus	4-6	20-30
Digested primary (anaerobic)	5-8	25-32
Digested primary and waste activated sludge (anaerobic)	4-5	14-22

[a] Adapted from The EPA, Sludge Treatment and Disposal, FPA Process Design Manual Washington, D.C., 1979.

3.4.4 Centrifugation

Sludge centrifugation for dewatering purposes is the same as for the sludge thickening process. The sludge is fed into a rotating solid bowl centrifuge where it is centrifuged and collected on the inner wall of the bowl. The percentage of dry solids in the sludge cake removed range from 10-30%, depending on the previous processes used before dewatering (Reynolds and Richards 1996).

Once the treatment is performed to produce the end products of effluent water and biosolids, the specific question of "What to do with it now?" arises. The water effluent is usually treated with chlorine or UV light as a final disinfection step before being returned to the receiving

waters or applied to agricultural land. The nature of the conditioned biosolids poses greater disposals concerns than that of the water.