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Municipal Wastewater and Sludge Treatment

At municipal wastewater treatment plants in the United States, raw municipal wastewater undergoes preliminary, primary, secondary, and in some cases, additional treatment to yield treated effluent and a concentrated stream of solids in liquid, called sludge. The sludge is treated as required for utilization or disposal, and additional treatment of effluent may be needed to accommodate specific water reuse opportunities.

The practice of municipal wastewater treatment evolved primarily to accommodate dis-charge of treated effluent to surface waters, not to facilitate use of effluent on crops (see Chapter 2). Because municipal wastewater treatment techniques are well established in the United States and because effluent from some municipal wastewater treatment facilities is discharged both to surface water and used to irrigate agricultural land, secondary or higher levels of wastewater treatment typically precede wastewater reuse in agriculture in the United States.

The relationship of municipal wastewater and sludge treatment to crop production is shown schematically in Figure 3.1. As illustrated, reuse of wastewater for food crop production or in other reuse applications, such as ground water recharge or urban landscape irrigation, typically occurs after secondary wastewater treatment and may necessitate additional treatment. Treatment to produce reclaimed water often adds coagulation, filtration, and disinfection to secondary treatment. Figure 3.1 also illustrates the origin and treatment of municipal wastewater sludges applied to cropland. Following treatment, sludges may be disposed of (for example, in a landfill) or used for food crop production or in other applications (such as silviculture and nonfood crop agriculture).

This chapter briefly reviews typical amounts and properties of treated effluent and sludge, then examines processes used in conventional wastewater treatment (defined as preliminary, primary, and secondary treatment), processes intended specifically to accommodate wastewater application to crops, and typical sludge treatment processes.

QUANTITY AND QUALITY OF MUNICIPAL WASTEWATER EFFLUENT AND SLUDGE

Municipal wastewater represents the spent water supply of communities. In 1990, aver-

FIGURE 3.1 Following conventional wastewater treatment (preliminary, primary, and secondary), municipal wastewater is discharged to surface waters or reused, or before discharge to surface waters (not illustrated). Additional treatment may be needed before reuse. Sludge from wastewater treatment processes are treated and then disposed or reused in crop production or other applications.

age per capita usage from public water supply systems in the United States was 184 gallons (700 liters) per day (Solley et al., 1993). In arid areas, municipal wastewater production is typically less than the amount withdrawn for water supply, but in some areas, wastewater flow exceeds the water supply because of infiltration and inflow (e.g. stormwater) into wastewater collection systems. Using 85 percent of water use as an estimate of typical wastewater production (Henry and Heinke, 1989), a city of 200,000 people would produce an average of about 31,000,000 gal/day (about 117,000 m^3/day) of raw wastewater. The amount of treated wastewater effluent extracted is not appreciably diminished from the original quantity of raw wastewater particularly if sludge is dewatered, as is common.

The quality of treated effluent from secondary wastewater treatment plants in the United States must comply with the federal regulation of a monthly average of 30 milligrams per liter of biochemical oxygen demand or BOD (a measure of the amount of biodegradable organic material remaining in the treated wastewater) and 30 mg/liter of suspended solids (particles removable by filtration). Typical concentrations of other constituents in wastewater treatment plant effluent are summarized in Chapter 2. More detailed information on typical effluent quality is presented in sections of this report where potential effects of individual constituents are considered. For example, Chapter 5 includes information on the types and quantities of pathogens typically found in various wastewater treatment plant effluents.

The volume of municipal wastewater sludge produced by wastewater treatment facilities is an elusive quantity because it varies as a result of typical sludge treatment (see "Volume Reduction Processes" later in this chapter). Since the mass of dry solids is conserved during most treatment processes, dry weight is a more useful basis for expressing the amount of sludge from municipal wastewater treatment. Typical primary and secondary wastewater treatment produces a total of about 1.95 lbs (0.94 kg) of dry solids per 1,000 gal (3.78 m^3) of wastewater treated (Metcalf and Eddy, 1991). Chemical addition to sludges during conditioning and stabilization processes (see later sections of this chapter) can appreciably increase the mass of solids in sludges. Biological stabilization acts to reduce the mass of suspended solids through oxidation of some of the volatile organic solids in sludges. For example, if sludge contains 80 percent volatile suspended solids and 50 percent of them are destroyed through oxidation, the stabilized mass of sludge solids would be reduced to 60 percent of the initial mass.

Typical solids contents of sludges at various stages of treatment are summarized in this chapter. Typical ranges of other common constituents in sludges are summarized in Chapter 2. As with wastewater effluents, more detailed information about specific sludge constituents is found in sections of the report where the potential effects of those constituents are discussed.

CONVENTIONAL WASTEWATER TREATMENT PROCESSES

Municipal wastewater treatment typically comprises preliminary treatment, primary treat-ment, and secondary treatment. Secondary treatment is the United States national standard for effluent discharged to surface waters. A higher degree of treatment, termed here "advanced" or "tertiary" treatment, may be required at specific locations to protect health or environmental quality. In this report, conventional municipal wastewater treatment is considered to include screening, grit removal, primary sedimentation, and biological treatment because it is the most common method (Figure 3.2). Elaboration on these terse descriptions may be found in sources such as Henry and Heinke (1989) and Metcalf and Eddy (1991).

Preliminary Wastewater Treatment

Preliminary wastewater treatment ordinarily includes screening and grit removal. Waste-water screening removes coarse solids such as rags that would interfere with mechanical equipment. Grit removal separates heavy, inorganic, sandlike solids that would settle in chan-nels and interfere with treatment processes.

FIGURE 3.2 Municipal wastewater is conventionally subjected to preliminary, primary, and secondary treatment in the United States. Additional tertiary or advanced treatment may be justified by local conditions. Processes typically involved in each stage of treatment are shown. Preliminary treatment effects minimal change in wastewater quality. Primary treatment typically removes about one-third of the BOD and one-half of the suspended solids in domestic wastewaters. Combined primary and secondary treatment is required to achieve 85 percent reduction in both BOD and suspended solids concentration to meet the regulatory definition of secondary treatment.

Preliminary treatment serves to prepare wastewater for subsequent treatment, but it ef-fects little change in wastewater quality. The residues from preliminary wastewater treatment, screenings and grit, are not ordinarily incorporated with sludges, and they are not considered further in this report.

Primary Wastewater Treatment

Primary wastewater treatment usually involves gravity sedimentation of screened, degritted wastewater to remove settleable solids; slightly more than one-half of the suspended solids ordinarily are removed. BOD in the form of solids removable by sedimentation (typically about one-third of total BOD) is also removed. At one time during the evolution of domestic wastewater treatment in the United States, facilities only practiced primary wastewater treatment and the primary effluent was commonly discharged to surface waters offering appreciable dilution. Now, primary treatment is used as an economical means for removing some contaminants prior to secondary treatment. The residue from primary treatment is a con-centrated suspension of particles in water called "primary sludge."

Although the goal of primary wastewater treatment is to separate readily-removable suspended solids and BOD, wastewater constituents that exist as settleable solids or are sorbed to settleable wastewater solids may also be removed. Thus, primary treatment effects some reduction in the effluent concentration of nutrients, pathogenic organisms, trace elements, and potentially toxic organic compounds. The constituents that are removed are contained in primary sludge.

Secondary Wastewater Treatment

Secondary municipal wastewater treatment is almost always accomplished by using a biological treatment process. Microorganisms in suspension (in the "activated sludge" process), attached to media (in a "trickling filter" or one of its variations), or in ponds or other processes are used to remove biodegradable organic material. Part of the organic material is oxidized by the microorganisms to produce carbon dioxide and other end products, and the remainder provides the energy and materials needed to support the microorganism community. The mi-croorganisms biologically flocculate to form settleable particles, and, following biological treat-ment, this excess biomass is separated in sedimentation tanks as a concentrated suspension called "secondary sludge" (also known as "biological sludge," "waste activated sludge," or "trickling filter humus").

Wastewater constituents can become associated with secondary sludge as a result of microbial assimilation, by sorption onto settleable solids, or by incorporation into agglomerate particles formed as a result of bioflocculation. Some of the wastewater constituents that are incidentally associated with the biomass from secondary treatment processes include pathogens, trace elements, and organic compounds.

Tertiary or Advanced Wastewater Treatment

Tertiary treatment is used at municipal wastewater treatment plants when receiving water conditions or other uses require higher quality effluent than that produced by secondary wastewater treatment. Disinfection for control of pathogenic microorganisms and viruses is the most common type of tertiary treatment. The concentrations of suspended solids and associated BOD in treated effluent can be reduced by filtration, sometimes with the aid of a coagulant. Adsorption, ordinarily on activated carbon, can be used to remove some persistent organic compounds and trace elements. The concentration of ammonia in secondary effluent can be reduced by nitrification. Tertiary treatment to remove nitrogen and phosphorus, so as to mini-mize nutrient enrichment of surface waters, is common; nitrogen is usually removed by nitrification followed by denitrification, and phosphorus is removed by microbial uptake or chemical precipitation. Not all tertiary treatment processes follow secondary treatment, as was shown schematically in Figure 3.1; nutrient removal, for example, can be achieved by design and operational variations to primary and secondary treatment processes. The residues from tertiary treatment typically become incorporated with sludges from primary and secondary treatment.

There are many variations to these treatment practices. For instance, secondary treatment is rarely achieved using physical and chemical processes rather than biological treatment. Primary treatment is sometimes eliminated. Long-term retention in lagoons is sometimes sub-stituted for both primary and secondary treatment.

TREATMENT TO FACILITATE CROP IRRIGATION WITH RECLAIMED WATER

The degree of wastewater treatment required prior to using wastewater effluent for crop production depends on the crop, local conditions, and state regulations. In considering specific applications of reclaimed wastewater for crop production, tradeoffs may exist between degree of wastewater treatment needed and agricultural practices.

Special treatment to allow agricultural use of treated effluents is not always considered necessary by states that regulate the practice (see Chapter 7); effluents from conventional primary and secondary wastewater treatment are used. Indeed, historically, untreated raw wastewater has been used, but the practice is not found in the United States and is not con-sidered herein.

In identifying appropriate wastewater treatment for crop application, it is appropriate to consider protection of health and environmental quality, water quality requirements of crops, and requirements of the irrigation water storage and delivery system (such as avoiding odors and clogging) (EPA, 1981; Water Pollution Control Federation, 1983). As a practical matter, the extent of wastewater treatment required prior to food crop application ordinarily is established by health and environmental quality considerations. Disinfection and suspended solids removal are the processes most frequently used to further improve conventional wastewater treatment plant effluents for use on crops.

Disinfection of treated effluent is most often accomplished by chlorination. Chlorine is an economical disinfectant, but it reacts with organic material in wastewater effluent to form chlorinated organic compounds that are of potential concern with potable reuse of reclaimed wastewater, but not with irrigation (see Chapter 6). Alternatives to chlorine as a wastewater disinfecting agent include ozone and ultraviolet light. The latter two processes do not provide a residual disinfectant as required by some state regulations for applying treated wastewater to food crops (EPA, 1992).

Additionally, suspended solids are sometimes removed from conventional wastewater treatment plant effluent prior to using the effluent in agriculture. Removal of suspended solids aids in control of pathogenic organisms and viruses by making disinfection more effective. Suspended solid removal minimizes deposition of solids on top of soils, and reduces clogging of some irrigation water delivery systems. Further reduction of suspended solids in effluent is typically achieved by adding a coagulating chemical, settling, and filtering through granular media (Faller and Ryder, 1991; Kuo, et al., 1994).

Treatment technology to produce any degree of wastewater quality perceived to be necessary for food crop production is available; however, treatment costs escalate with incre-mental water quality improvements. Additionally, residue (sludge) management problems accompany some processes (such as those using membranes) that might be used to improve treated wastewater quality beyond the current norms. Situations exist today in which water quality discharge requirements, the crop value and water scarcity justify the higher degrees of wastewater treatment before application to food crops.

SLUDGE TREATMENT PROCESSES

Primary and secondary sludges may be expected to contain settleable materials from raw wastewater and the products of microbial synthesis. Other materials are also removed from wastewaters and incorporated into primary and secondary sludges, however. The large surface area of particles incorporated into sludges provides sites for adsorption of constituents from the liquid phase. Nondegraded organic compounds in solution may partition into the organic fraction of the particles. Bioflocculation may incorporate colloidal particles that otherwise would not be removed by sedimentation into settleable particles. These and other mechanisms result in selective enrichment of wastewater constituents in sludge. Additionally, wastewater sludges are mostly water and, hence, wastewater constituents remaining in the liquid phase also are in-cluded in sludges.

Because primary and secondary sludges have different properties, advantage is sometimes sought by treating them separately. As an illustration, secondary sludge thickens better using the dissolved air flotation process (see following section) than by gravity thickening, and it is sometimes thickened separately from primary sludge. The two sludges almost invariably are combined prior to the end of the treatment, and, for purposes of discussing the ultimate util-ization of treated sludge, they are not further distinguished.

A wide variety of sludge treatment processes are used to reduce sludge volume and alter sludge properties prior to disposal or use of the treated product. The nature of these processes is summarized in the sections that follow. Additional details may be found in sources such as Dick (1972), Vesilind (1979), and EPA (1977), and Metcalf and Eddy (1991).

Sludge treatment is considered herein to comprise engineered processes for altering sludge quality prior to disposal or reclamation. When sludge is applied to land, inactivation of remaining pathogenic organisms and viruses continues, biological stabilization of residual organic material progresses, and biologically-mediated and abiotic chemical transformations occur.

Volume Reduction Processes

Biological sludge, as produced from secondary wastewater treatment processes, often has a suspended solids content of less than one percent by weight; that is, each kg of activated sludge solids is accompanied by more than 99 kg of water. Primary sludges are more con-centrated, but marginally so; typical combined primary and secondary sludge might contain about 3 percent solids by weight. Because of the voluminous nature of sludges, processes categorized here as "thickening," "dewatering," "conditioning," and "drying" (listed in order of decreasing frequency of application) are common in sludge management. Removal of water from sludges improves efficiency of subsequent treatment processes, reduces storage volume, and decreases transportation costs.

Thickening

Sludge thickening produces a concentrated product that essentially retains the properties of a liquid. Gravity thickening, or concentration by simple sedimentation, is the thickening process most commonly applied to municipal sludges. The product of gravity sludge thickening often contains 5 to 6 percent solid material by weight. Alternatives to gravity thickening include flotation thickening (in which a gas is incorporated with sludge solids, causing them to float), as well as the use of gravity drainage belts, perforated rotating drums, and centrifuges.

Dewatering

Sludge dewatering processes produce material with the properties of a solid, even though the dewatered sludge is still mostly water. Dewatered sludge can be transported in a dump truck, whereas a tank truck is required to transport thickened sludge. Dewatering may be accomplished on sand drying beds and, occasionally, in lagoons, where gravity drainage and evaporation removes moisture. More often, larger municipal installations use mechanical means for dewatering sludge. Mechanical sludge dewatering equipment includes filter presses, belt filter presses, vacuum filters, and centrifuges. The solids content of mechanically dewatered sludge typically ranges from 20 to 45 percent solids by weight; most processes produce con-centrations of solids at the lower end of that range.

Conditioning

Sludge conditioning processes do not, in and of themselves, reduce the water content of sludge. Conditioning alters the physical properties of sludge solids to facilitate the release of water in dewatering processes. Indeed, the mechanical dewatering techniques discussed in the previous paragraph would not be economical without prior sludge conditioning. Chemical and, less frequently, physical techniques are used to condition sludge. Chemical conditioning most commonly involves adding synthetic organic polyelectrolytes (or "polymers") to sludge prior to dewatering. Inorganic chemicals (most commonly, ferric chloride and lime in the United States) can also be used. Inorganic chemical conditioning dosages are large, and increase the mass of the solid phase of sludge. Physical conditioning techniques include heat treatment and freeze-thaw treatment.

Drying

If circumstances justify removal of water beyond that achievable by dewatering processes, drying is needed. Thermal drying with direct or indirect dryers is used to achieve near-complete removal of water from sludges. Solar drying is feasible in some locations. Partial drying also results from heat produced in biochemical reactions during composting and from other chemical reactions described in the stabilization processes below.

Stabilization Processes

The purpose of sludge stabilization is to minimize subsequent complications due to biodegradation of organic compounds. Stabilization is usually accomplished by biological or chemical treatment processes, as described below.

The vector attraction reduction provisions of the Part 503 Sludge Rule (EPA, 1993a) concern stabilization processes. Vectors, such as flies, are organisms that might be attracted to un-stabilized sludge and are capable of transmitting infectious diseases. Stabilization process performance requirements are specified in the Part 503 Sludge Rule for both biological and chemical stabilization. When sewage sludge is applied to agricultural land, vector attraction reduction requirements can also be satisfied by injecting sludge below the surface or incor-porating sludge into the soil.

Stabilization can also be achieved by drying sludge adequately to impede microbial activity.

Obviously, sludge combustion, too, accomplishes the stabilization objective. Many stabilization processes can also cause appreciable inactivation of pathogenic organisms and viruses. Inactivation of pathogens in sludges is considered separately in a subsequent section.

Biological Stabilization

In biological stabilization processes, the organic content of sludges is reduced by bio-logical degradation in controlled, engineered processes. Most commonly, domestic wastewater sludge is biologically stabilized as a liquid in anaerobic digesters from which methane gas is a byproduct. Liquid sludge can also be biologically stabilized in aerobic digesters to which oxy-gen (or air) must be added. Composting is a process that biologically stabilizes dewatered sludge. Composting is ordinarily an aerobic process, and an amendment such as wood chips or sawdust must be added to improve friability in order to promote aeration. Composting takes place at thermophilic temperatures (often, about 55°C) because of heat released by biochemical transformations. Aerobic digesters can be made to operate thermophilically using heat from the same source. Anaerobic digesters can operate at thermophilic temperatures by burning methane produced from the process, but they typically operate at mesophilic temperatures (at about 35°C) in the United States.

Chemical Stabilization

Chemical stabilization of sludges is aimed not at reducing the quantity of biodegradable organic matter, but at creating conditions that inhibit microorganisms in order to retard the degradation of organic materials and prevent odors. The most common chemical stabilization procedure is to raise the pH of sludge using lime or other alkaline material, such as cement kiln dust. Sludge can be chemically stabilized in liquid or dewatered forms. When dewatered sludge is used, the exothermic reaction of lime with water causes heating which helps destroy pathogens and evaporate water.

Inactivation of Pathogenic Organisms and Viruses

Many of the processes for drying and stabilizing sludges can be designed and operated to achieve appreciable inactivation of pathogenic agents, including bacteria, parasites, and viruses. Alternatively, sludge treatment processes specifically intended to control pathogenic organisms and viruses can be used. Processes specifically intended for inactivating pathogens include irradiation and pasteurization; these processes currently are not widely used in the United States.

In the Part 503 Sludge Rule, (EPA, 1993a) the pathogenic quality of sludge is controlled by categorization of sludges as either "Class A" (safe for direct contact) or "Class B" (crop and site restrictions required), according to criteria for the density of indicator and pathogenic organisms and by specification of process performance. The Part 503 Sludge Rule identifies specific processes with regard to their capability for pathogen destruction. Processes that can be used to reach the Class B category are identified by EPA as "Processes to Significantly Reduce Pathogens." These including aerobic digestion, air drying, anaerobic digestion, com-posting, and lime stabilization, or any combination of processes that can reduce fecal coliform less than 2,000,000 colony forming units per gram of total dry solids. EPA identifies more effective processes that can be used to reach the Class A category called "Processes to Further Reduce Pathogens." These Class A processes include composting at higher, controlled temp-eratures, heat drying, heat treatment, thermophilic aerobic digestion, beta ray irradiation, gamma ray irradiation, and pasteurization as well as high-level alkaline treatment and other processes that can be demonstrated to reduce pathogens to below detectable levels. Human health concerns about pathogenic organisms and viruses in sludge are considered in more detail in Chapter 5, and regulations to control infectious disease transmission from the use of sludge in crop production are discussed in Chapter 7.

Other Sludge Treatment Processes

A wide variety of processes are used to treat sludges. Those briefly discussed in this section ordinarily are less relevant to sludge management schemes directed towards food crop production than are the processes previously discussed.

Solidification/Immobilization

Solidification/immobilization processes involve the conversion of sludge to a solid material with load-bearing capacity and the incorporation of contaminants in the solid phase so as to minimize their migration. The technology for solidifying and immobilizing waste or-iginated in the nuclear waste industry, and although it has been widely applied in attempts to control hazardous waste, it is less commonly applied to municipal sludges.

Metal Stripping and Toxic Organic Destruction

Research has been conducted on selective removal of trace metals from municipal sludges and destruction of toxic organic compounds in sludges. These processes are not commonly used and were not considered in this report. Control of trace elements and toxic organic compounds in sludges is more appropriately managed by the regulation of wastewater at its sources.

Combustion

Combustion destroys organic compounds in municipal sludges and leaves an inorganic dry ash. Rarely, sludge combustion is carried out in the liquid phase under high pressure, pro-ducing an ash in liquid suspension.

Because most of the organic material in sludge has beneficial attributes in agricultural systems, the combustion process is inappropriate when sludges are to be applied to cropland. Accordingly, combustion is not considered further in this report.

Ultimate Sludge Utilization or Disposal

Options for ultimate use or disposal of municipal wastewater sludges are quite restricted. The Clean Water Act and the Ocean Dumping Ban Act eliminated all but land-based options for ultimate use or disposal of municipal wastewater treatment sludges. Any attempt to extract and recycle materials from sludges is unrealistic due to the highly heterogeneous nature of municipal wastewater sludge. With the exception of sludge ash used in building materials, municipal wastewater sludges currently are land-applied for beneficial uses or disposed of on the land.

Beneficial uses of treated municipal wastewater sludges on land include agriculture and silviculture uses; application to parks, golf courses, and public lands; use in reclaiming low quality or spoiled lands; and use as landfill cover or fill material. Disposal on land includes landfilling and permanent storage of dewatered sludge or sludge incinerator ash in lagoons or piles.

Integrated Sludge Management Schemes

The large number of alternatives for accomplishing of the many objectives of sludge treatment lead to many variations in municipal sludge management schemes. When sludge is applied to agricultural land, the extent of water removal during its treatment is a major factor influencing cost and process selection. It is not necessary to remove water from sludge prior to land application—indeed, the water may be beneficial to crops. Sludge dewatering is justified when its cost is offset by savings in transportation costs. Optimization of sludge treatment process integration by Dick, et al. (1982) illustrated that lengthy transport may be cheaper than sludge dewatering. Sludge drying, which is more expensive than sludge dewatering, allows further reduction in transport costs, and also enables sludge to be stored and packaged.

Figures 3.3a, b, and c illustrate sludge management schemes for agricultural application of liquid, dewatered, and dried municipal sludges, respectively. Liquid sludge discharge to agricultural land, as illustrated in Figure 3.3a, is the simplest scheme, but substantial liquid storage capacity might be needed if land application sites are unavailable for extended periods. Agricultural application of dewatered sludge, as illustrated in Figure 3.3b, requires more ex-pensive and extensive processing, but could be compatible with other disposal and use options that may be used in addition to agricultural use. Inclusion of drying in the sludge process-flow as diagramed in Figure 3.3c is ordinarily the most costly of the three options. Storage to accommodate agricultural demand is easiest when sludge is dried, and dried sludge can also be adapted to other disposal and use options.

Integration of sludge treatment processes for use on agricultural land also requires consideration of the effects of the treatment processes on sludge quality. For example, de-watering, composting, or alkaline treatment can be expected to reduce the amount of nitrogen in sludge that is available to plants. This would require on increase in the areal rate of sludge solids applied to satisfy the plant nitrogen demand, and would, in turn, increase the rate at which trace metals and toxic organic chemicals associated with the sludge solids were applied to soil.

INDUSTRIAL WASTEWATER PRETREATMENT

Pretreatment of industrial wastewaters is a means to manage toxic contaminants in treated wastewater effluents and sludge residuals. It is defined as "the removal of toxic materials at the industrial plant before the wastewater is released to the municipal sewer" (National Research Council, 1977). Because industrial activity is a substantial source of toxic chemicals in sludge and reclaimed wastewater in populated metropolitan areas, pretreatment programs have been effective in reducing the concentrations of most heavy metals in wastewater (refer back to Tables 2.3, 2.4, 2.5, and 2.6). They are grouped in four Priority Pollutant categories: Section 307 of the Clean Water Act regulates 127 hazardous compounds, (1) 14 heavy metals and cyanide, (2) 28 volatile organic compounds, (3) 58 semi-volatile organic compounds and (4) 25 pesticides and polychlorinated biphenyls (PCBs) (40 CFR 123.21 (1986)).

Fate of Toxic Chemicals During Secondary Wastewater Treatment

As will be discussed below, most of the priority pollutants in wastewater accumulate in sludge during the wastewater treatment process (Lue-Hing et al., 1992).

Heavy Metals

Investigations of heavy metal partitioning in secondary wastewater treatment plants include both surveys of operating POTWs (Mytelka et al., 1973; Oliver and Cosgrove, 1974; EPA, 1982) and more controlled pilot-plant studies (Petrasek and Kugelman, 1983; Patterson and Kodukula, 1984; Hannah et al., 1986). Researchers have focused on seven heavy metals:

cadmium, chromium, copper, lead, mercury, nickel, and zinc. These heavy metals are par-titioned onto sludges both in primary wastewater treatment such as sedimentation, and in biological secondary treatment processes such as like activated sludge. From 5 to 50 percent of these metals were found to have been removed from wastewater and concentrated into primary sludge. Removal of heavy metals in secondary biological sludges was greater: 15 to 80 percent. Combining the findings of a number of studies (Lue-Hing et al., 1992; Cheng et al., 1975; Neufield et al., 1975), the removal of heavy metals from wastewater into secondary sludge is reported to be (in declining order): mercury, copper, lead, chromium, cadmium, zinc, and nickel.

Cyanide

In a study of 40 selected POTWs, removal of cyanide from untreated sewage was found to vary between 7 and 98 percent (Lue-Hing, et al., 1992). This wide removal range is somewhat deceptive. The minimum removal was associated with a very low influent cyanide concentration, 0.003 mg/liter. The maximum reported influent wastewater concentration, 7.58 mg/liter, was associated with higher removals. Many researchers have verified that cyanide is relatively biodegradable by aerobic (Knowles and Bunch, 1986) and anaerobic (Fallon, 1992) metabolic pathways. Richards and Shieh (1989) found that cyanide was removed from waste-water by activated sludge in concentrations of up to 100 mg/liter. It is likely then that small amounts of cyanide from industrial discharge into sewers are destroyed during secondary treatment and are not concentrated into sludge (Lordi et al., 1980).

Toxic Organic Chemicals: Volatile and Semivolatile Organic Compounds, Pesticides and PCBs

There are 111 organic priority pollutants, which constitute the majority percent of the hazardous chemicals regulated in wastewater. Unlike heavy metals, which are concentrated in sludge, many organic priority pollutants are removed from wastewater by a variety of mech-anisms: volatilization during secondary treatment aeration, sedimentation and sorption onto both primary and secondary sludges, and biodegradation (Hannah et al., 1986; Petrasek et al., 1983; Kincannon et al., 1983; Tabak et al., 1981). Seven of the organic priority pollutants were found in over 50 percent of samples of treated wastewater effluent from 40 POTWs in the United States: 1,1,1-trichloroethane (52 percent), chloroform (82 percent), methylene chloride (86 percent), bis (2-ethylhexyl) phthalate (84 percent) and di-n-butyl phthalate (52 percent) (EPA, 1982).

Hannah et al. (1986) and Petrasek et al. (1983) conducted activated sludge pilot-plant studies on 21 and 22 organic priority pollutants, respectively. Reported removals ranged from 18 to 99 percent; the investigators found that over 90 percent of the majority of the organic chemicals were removed by the activated sludge process. Volatile organic priority pollutants were not concentrated into either primary or secondary sludge; however, semivolatile organic priority pollutants did accumulate in primary and secondary sludges, with concentration factors ranging from 5 to 200. High concentration factors were associated with higher molecular weight polyaromatic hydrocarbons and phthalate compounds.

Pretreatment

As discussed above, toxic heavy metals and those organic priority pollutants which are not biodegraded or volatilized are concentrated in wastewater sludge. The National Research Council (1977) reported that pretreatment has the potential to alleviate problems of sludge disposal due to heavy metals and toxic organic compounds. In a study of operating POTWs in Chicago, Illinois and in a pilot study at a POTW in Buffalo, New York where significant amounts of industrial wastewater discharge were received, it was found that industrial pre-treatment programs reduced toxic heavy metal concentrations by a range of 50 to over 90 per-cent (Zenz, et al., 1975; EPA, 1977).

Pretreatment Goals

The General Pretreatment Regulations of the Clean Water Act (40 CFR 403 (1978)) establishes limits on industrial discharges of hazardous pollutants to municipal sewers in order to:

· prevent the introduction of pollutants which will interfere with the performance of the POTW treatment processes for wastewater and sludge;

· prevent the pass-through of toxic pollutants into surface waters receiving discharges of treated wastewater effluent; and

· enhance opportunities to recycle treated municipal wastewater and sludge (EPA, 1993b)

Pretreatment Implementation

The pretreatment regulations identify strategies for setting numerical standards on industrial dischargers to POTWs. First, 34 categories of industries have been identified as po-tential sources of priority pollutants in wastewater, and standards have been set for 29 of these categorical dischargers based on the best available technology. Second, discharge standards that prohibit hazardous pollutants enable POTWs to increase the scope of their pretreatment reg-ulation to include all nondomestic users of municipal sewers, in addition to the categorical dischargers. Finally, the local POTW can set more stringent limits based on its specific re-quirements, and these also are federally enforceable. (Lue-Hing et al., 1992; Outwater, 1994).

More recently, the third goal of pretreatment, to enhance POTWs' ability to beneficially use sludge and reclaim wastewater, has been added to the regulation of industrial wastewater. Because heavy metals and many toxic organic chemicals accumulate in sludge, it is necessary to control not only the end-of-the-pipe concentration of hazardous compounds with standards, but to limit the total mass loading of pollutants that are concentrated in sludge (Outwater, 1994). For example, it has been reported that protection of sludge quality has caused a POTW in Georgia to set heavy metal discharge levels two orders of magnitude below categorical pre-treatment limits for these compounds (Ford et al., 1994).

SUMMARY

Conventional municipal wastewater treatment processes were developed to produce effluents suitable for discharge to surface waters. The processes are intended primarily to remove BOD and suspended solids, but wastewater constituents associated with particles are also removed. Thus, substantial removal of trace contaminants may occur in conventional treatment even though the treatment processes were not designed for trace metal or toxic chemical re-moval.

When required by receiving water conditions or effluent reuse practices, advanced, or tertiary, wastewater treatment processes may be used in addition to conventional municipal wastewater treatment processes. Destruction of pathogenic organisms and increased removal of suspended solids or nutrients are some of the goals of tertiary treatment.

With the exception of compounds biologically degraded or volatilized during wastewater treatment, substances removed from wastewaters are contained in the residues, or sludges, produced. A wide variety of sludge treatment processes are used to prepare municipal wastewater treatment sludges for use or disposal. The objectives of most municipal sludge treatment processes are to reduce the water content of sludges, to avoid complications from decomposition of the biologically degradable fraction of sludges, and to reduce the levels of pathogenic organisms in sludges.

Economically viable technology for selective removal of trace elements and toxic organic compounds from sludges does not exist. Amounts of these constituents in municipal sludges can currently be controlled only by regulating the quality of wastewater entering municipal waste-water collection systems. Industrial wastewater pretreatment programs have been demonstrated to substantially improve the quality of sludge from municipal wastewater treatment. Mod-ification of industrial processes, control of corrosivity of water in water supply systems, and changes in the formulation of disposable consumer products are other measures needed to control wastewater and, hence, sludge quality.

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FIGURE 3.3 Sludge Management Schemes