Wastewater Treatment Best Practices

Minnesota Water Sustainability Framework
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Wastewater treatment refers to the treatment of sewage and water used by residences, business, and industry to a sufficient level that it can be safely returned to the environment. It is important to treat wastewater to remove bacteria, pathogens, organic matter and chemical pollutants that can harm human health, deplete natural oxygen levels in receiving waters, and pose risks to animals and wildlife. Wastewater discharge quality is regulated by the US EPA and MPCA under the Clean Water Act through the National Pollutant Discharge Elimination System (NPDES). Wastewater treatment plants (WWTP) are issued permits for allowable discharges of solids, oxygen (as biological oxygen demand, or BOD), bacteria, nutrients, and other regulated pollutants on a plant-by-plant basis, depending on their receiving waters.

Conventional Treatment. Wastewater undergoes multistage treatment involving the removal of physical, biological, and chemical contaminants. After debris removal, the first stage is primary treatment, which removes solids by settling. Secondary treatment is a biological treatment stage to remove dissolved organic matter from wastewater. Sewage microorganisms are cultivated and added to the wastewater, and the organic matter serves as their food supply. The microorganisms absorb nutrients and organic matter as they grow. There are three approaches used for secondary treatment, and they include fixed film, suspended film and lagoon systems. Fixed film treatment grows microorganisms as a film on a solid substrate (such as rocks), and technologies include trickling filters, rotating biological contactors, and sand filters. Suspended film systems grow the bacteria in suspension, and they settle out as sludge which is removed, treated, and disposed of. Suspended film systems can be operated in a smaller space than fixed-film systems that treat the same amount of water. However, fixed-film systems are more able to cope with drastic changes in the amount of biological material and can provide higher removal rates for organic material and suspended solids than suspended growth systems. Activated sludge, extended aeration, and sequential batch reactor systems are all examples of suspended film systems. Lagoon systems are shallow basins which hold the wastewater for several months to allow for the natural degradation of nutrients and organic matter by naturally occurring bacteria. This approach is usually used by smaller plants (< 1 million gallons/day).

Constructed wetlands are being used more frequently, and, depending on design, can act as a primary, secondary and sometimes tertiary treatment. However, design is critical to their performance, more so than for other systems, and they are subject to space limitation.

Membrane bioreactors (MBR) are also used for secondary treatment, and combine activated sludge treatment with the use of a membrane to separate solids from liquid. This approach can overcome poor settling of sludge in conventional activated sludge systems. It allows for very effective removal of both soluble and particulate biodegradable materials at higher loading rates. This increases sludge retention times, usually exceeding 15 days, and ensures complete nitrification (the biological conversion of ammonia to nitrate) even in extremely cold weather.

The cost of building and operating an MBR is usually higher than conventional wastewater treatment plants, and the membranes can be fouled over time. This technology is becoming more common, and life-cycle costs have been steadily decreasing. The small footprints of MBR systems, and the high quality effluent produced, make them particularly useful for water reuse applications. They are typically used for small-to-medium systems (<10 million gallons/day)

Tertiary Treatment. The minimal level of wastewater treatment that is universally required is secondary. However, tertiary treatment of wastewater is often required to further remove contaminants to a sufficient degree to protect receiving waters, and may be mandated for certain plant permits. Tertiary treatment can consist of an extension of secondary biological treatment for additional nutrient removal, or advanced treatments to remove other contaminants.

Phosphorus can be removed by chemical precipitation with alum, ferric chloride, or lime. Phosphorus also can be reduced by enhanced biological phosphorus removal. Specific microorganisms can be selectively enriched and accumulate the phosphorus during their growth, and can be removed and the resulting sludge used as fertilizer. This approach is considered highly effective and cost-efficient. It has been used successfully on the Metro WWTP.

Nitrogen removal involves oxidizing ammonia (the form of nitrogen found in wastewater) to nitrate (nitrification) in a two-step aerobic process, and then reducing the nitrate to nitrogen gas (denitrification) under anoxic conditions. All steps are facilitated by selectively enriched bacteria. The resulting nitrogen gas is harmless and is released to the atmosphere. Sand filters, lagoons, and constructed wetlands can all be used to reduce nitrogen, but a well-designed activated sludge process can do the job the most easily and effectively. Denitrification is often accomplished with mixed slurry reactors, in fixed bed reactors, or denitrification filters. The process is very sensitive to temperature, available organic carbon, sludge age, retention time, and pH. In summary, modern WWTPs can effectively accomplish nitrogen removal when biological nitrification/denitrification is a part of the activated sludge process.

Advanced Treatments and their Efficacy for CEC Removal. A range of new technologies have been developed to remove additional contaminants, including contaminants of emerging concern (CECs; see Part III, Issue C). For wastewater that is discharged to pristine waterways, or is being re-used for other purposes, a higher level of treatment may be needed. The following sections discuss treatments for the removal of certain classes of CECs, including endocrine disrupting compounds (EDCs) and pharmaceuticals and personal care products (PPCPs). It should be noted that most of these contaminants are not regulated because there is insufficient data to conduct a human health risk assessment. However, in many instances around the country and internationally, there is clear evidence of impacts of these contaminants in wastewater discharge on fish in receiving waters.

Activated Sludge. Activated sludge processes have been shown to remove >77% and >90% of the natural estrogen compounds estrone (estrone) and estradiol (estradiol) across all biological field treatment types. Natural estrogens have been noted to make up a majority of wastewater effluent estrogenicity in many studies. Another study reports that activated sludge can consistently remove >85% of estradiol, estriol, and ethynyl estradiol (synthetic estrogen used for birth control pills), while estrone is more variable. Natural estrogens tend to be low on the sorption spectrum, and thus most of their removal is due to biodegradation, not simple sorption, although estrogenic activity is still expected in sludge. Maximum removal of natural estrogens is obtained in aerobic conditions; in anaerobic conditions, some compounds are more persistent (e.g., estrone degradation decreases by a factor of 3-5; ethynyl estradiol is only degraded under aerobic conditions, while estradiol is oxidized at similarly high rates across all redox conditions). Estradiol removal efficiencies in a Canadian study of 16 WWTPs found estradiol removal rates of 40-99%, estrone removal rates from net production of 98%, with nitrification being correlated with successful estrone and estradiol removal. Estradiol is also noted to require similar conditions as those that result in nitrification. In general, removal of estrogenic activity is highly variable during conventional secondary treatment.

Natural steroid estrogens degrade slowly (in order of rapidity: estrone>estradiol>ethynyl estradiol, with complete removal of ethynyl estradiol taking up to a few days). Overall, some estradiol and estrone are expected to persist following conventional activated sludge treatment, with relatively lower estradiol persistence (<10%). Cited studies show estradiol removal rates of 70%, 87%, 88%; estrone rates of 74% and 61%; estriol rates of 80-95%; and ethynyl estradiol rates of 30-85%. Assessment of natural estrogen removal is complicated by the possibility that these compounds are being transformed among their different chemical forms inside the WWTP. A full scale mass balance showed that total estrogenic potential was reduced from 58-70ng/L to 6ng/L in one WWTP using conventional activated sludge treatment. Another study reported 50-66% total estrogenic potential reduction in conventional activated sludge treatment, with 5-10% of the total estrogenic potential partitioning to sludge.

WWTPs using activated sludge with nitrification/denitrification processes have been shown to have increased removal of PPCPs, EDCs, and nitrate compared to WWTPs without nitrification/denitrification. Many studies have confirmed that approximately >90% of estrone, estradiol, and ethynyl estradiol will be removed from activated sludge treatment plants with nitrification/denitrification. Sludge age (same as solids retention time), hydraulic retention time, temperature, nitrification/denitrification, and phosphate elimination are thought to be factors affecting removal rates of contaminants in activated sludge systems.

Regarding synthetic EDCs and PPCPs, alkylphenols (nonionic detergent surfactant additives and their stable breakdown products; they can constitute up to 5-10% of dissolved organic carbon in WWTP influent) are less water soluble and tend to accumulate more in sludge than the natural estrogens. They tend to persist in anaerobic sludge environments, although subsequent land spreading may result in >90% degradation in 1-3 months. Additionally, nonylphenol has been detected in surface water that receives WWTP effluent in the 0.1-14μg/L range, indicating that not all NP is bound to sludge; significant portions leave in effluent.

In a study of 5 conventional activated sludge WWTPs, 85-99% of nonylphenol and 38-99% bis-phenol A (BPA) were removed. Alkylphenols and phthalates concentrated in sludges. Nonylphenol has shown indications of being degradable by conventional activated sludge similarly to other major wastewater organic compounds (60-88% removal rate), although widely varying ranges have been reported. Again, where nitrification occurs, removal of nonylphenol tends to be enhanced. Additionally, production of estrogenic byproducts is reduced in aerobic vs. anaerobic sludges.

In one published study, 95% of Ibuprofen was removed, in agreement with other literature stating that ibuprofen, although widely present, can be readily eliminated. “Low” eliminations of Atenolol, Solatol, Trimethoprim, Azithromycin, Erythromycin, macrolide antimicrobials, and “variable” eliminations of sulfamethoxazole and Ketoprofen have been reported in WWTPs using activated sludge. Note that although conventional WWTP can achieve high removal efficiencies, this treatment does not eliminate trace PPCP contamination in surface waters, as removal rates vary greatly due to local conditions and the nature of the contaminant.

Linear alkylbenzene sulfonates (LAS) are used in the production of anionic surfactants; they are readily biodegraded in conventional WWTP settings (~80% biodegradation, with total removal 95-99.5%).

Phthalate plasticizers and brominated flame retardants tend to partition to sludge in the WWTP process.

In summary, overall removal rates of EDCs and PPCPs in conventional WWTPs with activated sludge vary strongly, and elimination is often incomplete. The more polar the molecule, the more likely it is to remain soluble in effluent. Activated sludge processes can result in high EDC removal, but are not likely to achieve concentrations below maximum allowable levels for some estrogens, alkyphenols, or BPA.

<u>Reverse Osmosis.</u> Reverse osmosis removes ionic salts and other molecules by selective filtration. It appears to be a viable treatment for removal of most EDCs/PPCPs in drinking water, except for neutral low molecular weight compounds. Reverse osmosis achieved >90% removal of natural steroid hormones in one study. A combination of reverse osmosis with nanofiltration can result in very efficient PPCP removal, including a wide range of pesticides, alkyl phthalates, and estrogens. Reverse osmosis and nanofiltration foul quickly in the treatment of wastewater, making them prohibitively expensive.

<u>Granulated Activated Carbon (GAC).</u> Water is passed through a bed of activated carbon granules that adsorb contaminants. GAC has been shown to be very effective at removing many pharmaceuticals, except for clofibric acid. Competition with organic matter in WWTP effluent for sorption sites can reduce EDC and PPCP removal rates. EDC and PPCP removal depends on the solubility of the compounds – more soluble, polar compounds are not removed efficiently. Powdered activated carbon has greater efficiencies of removal for some pharmaceuticals, but is typically used in episodically to treat a specific situation.

<u>Ultrafiltration/Nanofiltration.</u> Water is forced through semipermeable membranes that filter out very small particulates (ultrafiltration) and dissolved molecules (nanofiltration). A study of 52 EDC/PPCPs in modeled and natural waters found that nanofiltration exceeded ultrafiltration in EDC/PPCP removal. Nanotfiltration removal efficiencies were between 44-93%, except for naproxen (0% removal), while ultrafiltration removal was typically less than 40%.

Nanofiltration retains these compounds on the membrane both through hydrophobic adsorption and size exclusion, while ultrafiltration retention is typically due to hydrophobic adsorption. However, these systems foul quickly when used on wastewater systems, and are reserved for use in drinking water treatment. These techniques are also highly effective for the removal of pathogens.

Ozonation and other Advanced Oxidation Processes. Water is treated with ozone or other reagents to produce strong oxidizing agents that react and breakdown contaminants. Ozonation has been, in some cases, very effective at removal of pharmaceuticals—diclofenac and carbamazepine (>90%), bezafibrate (50%) – but clofibric acid was stable even at high ozone doses. Ethynyl estradiol and estradiol are expected to be completely transformed; nonylphenols have also been effectively removed. Pairing ozonation with UV or H_2O_2 (peroxide, such as is done in advanced oxidation processes) may be required to achieve the most effective transformation of pollutants. For instance, ozonation alone did not remove clofibric acid, but when pairing O_3 with H_2O_2, improved removal of clofibric acid and other compounds was achieved. This and other advanced oxidation processes are effective for drinking water treatment, but the high levels of organic matter in wastewater use up the oxidizers make them inefficient and yield limited results. Advanced oxidation systems are also effective at removing pathogens. One hypothetical option would be to apply these methods to highly treated wastewater after biological treatments to reduce the dissolved organic matter as much as possible. However, there are no examples of the commercial use of advanced oxidation for wastewater treatment.

Conclusion. Many advanced treatment technologies, especially combinations of them, are efficient at removing EDCs and PPCPs from drinking water. The high organic carbon content of wastewater, however, greater lowers their effectiveness and increases their costs, and thus greatly limits these treatments from being used by WWTPs. Currently there are no well-accepted or established treatment technologies for effectively removing EDCs and PPCPs from wastewater.

Resources

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