

Wastewater Treatment: Understanding the Activated Sludge Process

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The activated sludge process is used to treat waste streams that are high in organics and biodegradable compounds. Here are some principles of design and operation.

The activated sludge process (Figure 1) uses a mass of microorganisms (usually bacteria) to aerobically treat wastewater. Organic contaminants in the wastewater provide the carbon and energy required to encourage microbial growth and reproduction; nitrogen and phosphorous are sometimes added to promote this growth. The wastewater is thoroughly mixed with air in an aeration tank, and the organic matter is converted into microbial cell tissue and carbon dioxide.

The microbial mass together with the wastewater is referred to as a mixed liquor. After a specified time in the aeration tank, the mixed liquor passes into a settling tank, or clarifier, where the biomass, or sludge, settles by gravity from the treated wastewater. This continuous process produces an effluent that may be treated further or discharged directly to a publicly owned treatment works (POTW).

The activated sludge process was developed in the early 1900s for the treatment of domestic wastewaters, and it has since been adapted for removing biodegradable organics from industrial wastewaters. Today, it is widely employed in the treatment of both municipal and industrial wastewaters.

Applicability – chemicals, concentrations, facilities

Activated sludge treatment is suitable for use at facilities that have organic chemical waste. These may include municipal sewage-treatment plants, oil refineries, pulp and paper mills, food processing plants, and chemical manufacturing facilities.

When properly designed, the activated sludge process provides good treatment for wastes containing biodegradable compounds. It is generally used to treat biodegradable organic wastewaters of moderate (10–1,000 ppm) to high (>1,000

ppm) strength. Performance varies depending on the specific chemicals present and their concentrations, as shown in Table 1. The results in Table 1 are based on laboratory-scale testing and should be considered only as guidelines for developing pilot-scale and full-scale studies.

Activated sludge treatment is not intended to remove metals or dissolved or suspended solids. A rather high concentration (>100 ppm) of organics is needed to maintain proper operation. Low-strength industrial effluent and moderate-strength domestic wastewater may be combined for treatment to achieve the required concentration. Wastewater containing a wide variety of biodegradable organics can be treated by the activated sludge process, as long as the concentration is in the

Table 1. The performance of activated sludge treatment varies with the type of chemicals in the waste being treated.

Chemical Type Treated	Typical Feed Concentration, ppm	Typical Removal
Phenolics (aromatic –OH)	100 to 1,000	>99%
Polynuclear Aromatic Hydrocarbons (PAHs)	0.01 to 1	>95%
Oil and Grease	10 to 100	40 to 92%
Total Organic Carbon (TOC)	500 to 3,000	>90%
Ammonia (–N)	10 to 1,000	>95%
Cyanide, Thiocyanide	1 to 1,000	40 to 98%
Metals (arsenic, mercury, zinc)	0.5	Settles with sludge
Benzene, Toluene, Xylene (BTX)	5 to 1,000	>99%

hundreds of parts per million.

Many remediation sites require the treatment of groundwater, surface water, or landfill leachate with very low organic concentrations, typically less than 10 ppm. This is not high enough to sustain the biological mass needed, and such streams are more appropriately treated by ozone, ultraviolet light, trickling filters, and/or API separators. Some plants combine groundwater, boiler blowdown and stormwater runoff with process wastewater and feed the combined stream to an activated sludge treatment facility.

The process

Before it enters the aeration basin, raw wastewater (influent) is normally pretreated to remove easily settled solids or other suspended matter, such as oil. Raising the pH will slightly solidify iron and zinc (if present). A steam or air stripper can remove ammonia, phenol, and any light ends, while a filter removes heavy particulates. Because substantial changes in the incoming water characteristics will cause a process upset, an equalization tank is sometimes included in the pretreatment system to achieve the required design inlet conditions, such as a certain flowrate or chemical concentration.

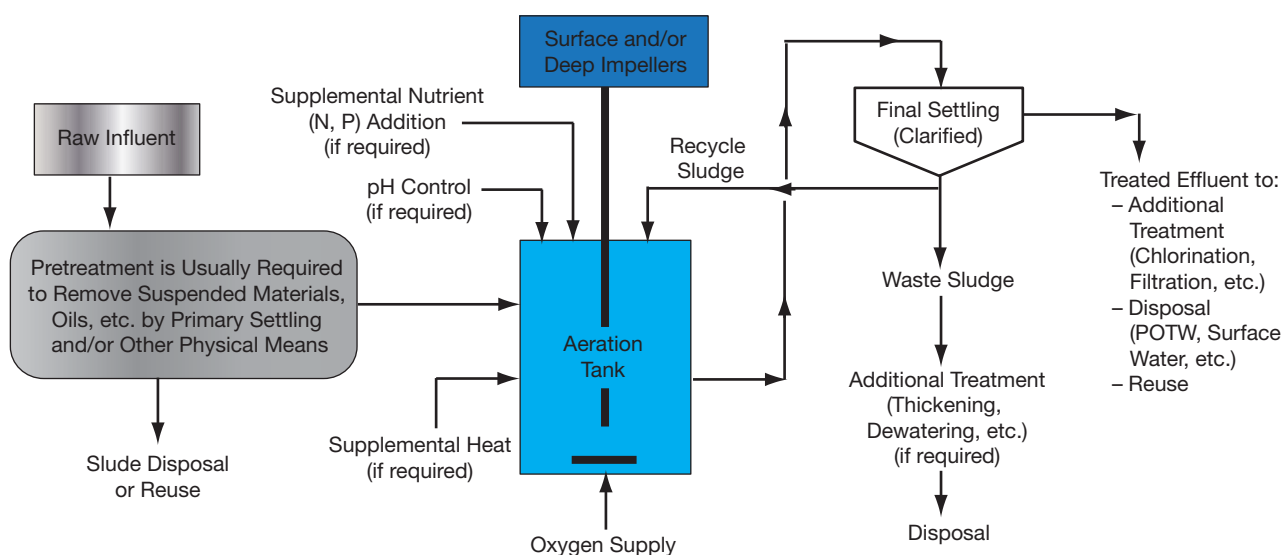
The pretreated influent is pumped into the aeration tank (or basin), where it is combined with the microorganisms. In order to maintain the bacterial mass in the aeration basin, aerators perform two important functions: they keep the liquid and sludge agitated, and they promote the transfer of oxygen into the wastewater. The aerators run continuously and are strategically positioned to keep the mixed liquor in suspension throughout and avoid the formation of dead zones. Foam gen-

erated by the aerators can be contained by anti-foam sprays.

The pH of the incoming wastewater or mixed liquor must be steadily controlled for proper microorganism growth. A neutral pH is maintained by adding a caustic or acid, usually 25% by weight in solution. Supplemental nutrients in the form of nitrogen (urea) and phosphorus (phosphoric acid) are added on an as-needed basis, such as when the raw wastewater is an insufficient source of required nutrients.

In colder climates, supplemental heat is required to maintain an acceptable temperature range for the microorganisms. Indirect heat is added to the base of the aeration basin via a steam bayonet or a gas-fired heater. Some plants save energy by first preheating the influent with a hot process stream (e.g., distillation column bottoms) in a heat exchanger.

After spending a specified amount of time in the aeration basin, water overflows into a clarifier, where the microbial solids settle by gravity and are separated from the treated water. The clarifier consists of a tank with a center feed well, which promotes even dispersion. The settled sludge is raked from the quiescent zone at the bottom of the clarifier with mechanical scrapers. A portion of the biomass is recycled back to the aeration basin to maintain the desired concentration of organisms in the basin. The remaining sludge is pumped from the system, typically by a motor-driven centrifugal pump equipped with a flowmeter, for final disposal. Floating materials that collect at the surface of the liquid in the clarifier are collectively referred to as scum. A skimmer constantly moves the scum toward a collection trough that drops it into a receiver for later removal. Both the sludge scraper and the scum skimmer are connected to a common



▲ **Figure 1.** Conventional activated sludge systems process raw influent in the aeration tank before sending it to the clarifier for settling.

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drive shaft powered by a small motor.

Clean water travels to the outside edge of the clarifier and is discharged under a baffle and over a notched weir that extends around the periphery. The concentration of total suspended solids (TSS) in the effluent discharge is low, 10–100 ppm. This water may go to a POTW, be discharged as surface water in accordance with a National Pollutant Discharge Elimination System (NPDES) permit, or receive tertiary treatment such as by activated carbon adsorption.

Wasted sludge from the bottom of the clarifier is thickened, typically in a vacuum filter press, prior to its ultimate disposal. The degree of wasting determines the solids retention time (SRT) of the system. At a low wasting rate, the SRT would be relatively high — *i.e.*, the solids remain in the system longer.

System design

Table 2 lists key design parameters that are determined by lab tests and past experiences.

The first design methods were formulated based on the retention time of the wastewater in the aeration basin. Generally, short hydraulic retention times (HRT) were chosen for weak (dilute) wastewaters and long HRTs were chosen for

strong (concentrated) wastewaters. HRT (measured in days) is defined as the aeration tank volume (V , gal) divided by the discharge rate (Q , gal/d):

$$HRT = V/Q \quad (1)$$

Typical HRTs range from 1–5 d for municipal waste to 1–10 d for industrial waste.

Around 1970, other design parameters were developed using fundamental scientific concepts, such as mass balance and microbial growth kinetics. Although design equations ultimately serve as the primary basis for the design of an activated sludge system, pilot plant and/or laboratory tests are essential for developing the design criteria. The resulting design reflects the reaction rates, settling rates, solids retention time, and oxygen requirements for a particular type of wastewater. The rate equations somewhat resemble those used by chemical engineers to describe reactor kinetics, suggesting that an aeration tank may be envisioned as a biological “reactor.”

The solids retention time is an important design factor and provides a theoretical indication of how long the microorganisms remain in the aeration tank. Since these microorganisms normally reproduce more quickly than they die, some activated sludge must be removed, or blown down, via a recycle line. Blowdown, also called sludge wasting, should be carried out daily to maintain the proper SRT. Without such wasting, the mass of sludge could build up in the settling tank (clarifier) until solids overflow into the effluent.

The SRT (in days) is a function of the aeration tank volume (V , gal), the sludge wasting rate (w , gal/d), and the concentrations of suspended solids in the mixed liquor in the aeration tank ($MLTSS$, g/L) and in the recycle line ($MLTSS_r$, g/L):

$$SRT = (V \times MLTSS) / (w \times MLTSS_r) \quad (2)$$

SRTs for municipal wastewater treatment range from

Table 2. Typical characteristics of wastewater can be addressed in the design process by examining these variables.

Wastewater Characterization	Design Variables
Flowrate	Hydraulic Retention Time (HRT)
Water Quality	Solids Retention Time (SRT)
Toxic or Inhibitory Compounds	Recycle Ratio (r)
	Optimization of HRT, SRT and r
	Oxygen Requirements
	Bacterial Growth and Decay Factors
	Sludge Settling Factors

Table 3. When upsets occur, follow these suggested guidelines.

Problem	Probable Cause	Remedy
Low or high pH in the aeration basin	Extremely high or low pH in influent	Add alkali or acid to the aeration tank
	No biological activity	Reduce high concentrations of phenols and oils, or add phosphorous or dissolved oxygen to the aeration tank
Low dissolved O ₂ (DO) concentration in the aeration tank	Influent feed rate is too high or has slug of organics	Reduce feed until DO concentration goes above 1.0 mg/L
	Concentration of total suspended solids in the mixed liquor (MLTSS) is too high	Lower SRT by wasting more sludge
High total suspended solids (TSS) concentration in POTW	Presence of unwanted bacteria	Increase DO or reduce influent organics by reducing feed flowrate
	Clarifier is overloaded	Determine whether the recycle ratio and feed rates are properly set

5 to 20 d, whereas SRTs for industrial waste range from 20 to 1,000 d.

Another important design factor is the recycle ratio, r :

$$r = q/Q \quad (3)$$

where q is the recycled sludge flowrate (gal/d) and Q is the influent wastewater flowrate (gal/d). Recycle ratios are generally 0.5–3.0 for both municipal and industrial wastewater treatment plants.

HRT, *SRT* and r are interrelated and are the most important design variables. Combined with sludge settling characteristics, they determine the size of the aeration basin, sludge settling tank, and related pumps. The recycle ratio also affects the size of the clarifier.

Other important factors that determine the final design include the bacterial growth coefficient (Y) and the decay coefficient (b), each of which may be determined through laboratory treatability testing. The bacterial growth coefficient is defined as the mass of bacteria produced per mass of chemical consumed, and it has a value between 0.1 and 0.5. The b coefficient indicates the decay rate of the bacterial organisms. Typical values range between 0.01 and 0.05 d⁻¹. The decay rate does not have as much influence on wastewater treatment system design as the bacterial growth rate.

Operating conditions

Operation of an activated sludge process relies on maintaining an acceptable environment for microbial activity through routine monitoring and preventive maintenance, and on the ability to survive any process upsets. The following performance considerations may be relevant daily, weekly or monthly.

Effluent. Limits on effluent water quality are determined by the state or local environmental agency. The NPDES permit generally specifies the allowable discharge flowrate, pH, total organic carbon (TOC, mg/L), and TSS (mg/L).

Influent. To ensure smooth operations and avoid upsets, the plant should maintain the influent flowrate, temperature, pH, and concentrations of TOC, TSS, oil and grease, and phenol (which can cause microbial shock) within specified ranges. Values that exceed design limits indicate that pretreatment modifications are necessary. For example, excess oil and grease in the incoming water may indicate that the API separator polymer-addition step needs to be modified.

Mixed liquor in the aeration tank. The aeration tank must maintain the proper environment for microbial activity. The pH should be between 6.5 and 7.5, the temperature between 15°C and 30°C, the dissolved oxygen (DO) concentration above 2.0 mg/L, and nitrogen and phosphorous at the necessary levels. Aeration tanks have pH and DO monitors to automatically record these data. The aeration tank should also be

routinely checked for mixed liquor volatile suspended solids (MLVSS, mg/L) to ensure that an adequate concentration of organisms is present.

Final thoughts

It is important to understand that most of the design considerations discussed here are site-specific. This requires the collection of samples from the wastewater to be treated, as well as performing lab analysis and onsite testing to determine the relevant parameters for designing an activated sludge system.

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