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Small Community Wastewater Issues Explained to the Public

Explaining the Activated Sludge Process

It is to everyone's advantage for a community to be able to treat its wastewater in the most economical way. The activated sludge process has the advantage of producing a high quality effluent for a reasonable operating and maintenance costs.

The activated sludge process uses microorganisms to feed on organic contaminants in wastewater, producing a high-quality effluent. The basic principle behind all activated sludge processes is that as microorganisms grow, they form particles that clump together. These particles (floc) are allowed to settle to the bottom of the tank, leaving a relatively clear liquid free of organic material and suspended solids.

Described simply, screened wastewater is mixed with varying amounts of recycled liquid containing a high proportion of organisms taken from a secondary clarifying tank, and it becomes a product called mixed liquor. This mixture is stirred and injected with large quantities of air, to provide oxygen and keep solids in suspension. After a period of time, mixed liquor flows to a clarifier where it is allowed to settle. A portion of the bacteria is removed as it settles, and the partially cleaned water flows on for further treatment. The resulting settled solids, the *activated sludge*, are returned to the first tank to begin the process again.

Initially developed in England in the early 1900s, the activated sludge process did not become widespread in the U.S. until the 1940s. Today a number of variations of the basic process have been developed. This issue of *Pipeline* includes descriptions of three of the most common variations: Extended aeration, sequencing batch reactors, and oxidation ditches. A glossary of terms can be found on page 2.

The activated sludge plant is the most popular biological treatment process for larger installations or

Activated sludge package plant at Mason Dixon Elementary School in Monongalia County, West Virginia.

Photo by Ed Winant

Glossary

Activated sludge – sludge particles produced in wastewater by the growth of organisms in aeration tanks. The term 'activated' comes from the fact that the particles teem with bacteria, fungi, and protozoa. Activated sludge is different from primary sludge in that the sludge particles contain many living organisms that can feed on the incoming wastewater.

Activated sludge process – a biological wastewater treatment process which speeds up waste decomposition. Activated sludge is added to wastewater, and the mixture is aerated and agitated. After a certain amount of time, the activated sludge is allowed to settle out by sedimentation and is disposed of (wasted) or reused (returned to the aeration tank)

Aerobic – a condition where oxygen is present

BOD – biological oxygen demand. Measure of oxygen organic material in the water requires.

Bulking – sludge that forms clouds in the secondary clarifiers when the sludge does not settle properly, usually caused by filamentous bacteria

F:M – food to microbe ratio

Floc – clumps of bacteria

Flocculation – agitating wastewater to induce the small, suspended particles to bunch together into heavier particles (floc) and settle out.

Loading - a quantity of material added to the process at one time

MLSS – mixed-liquor suspended solids

MLVSS – volatile mixed-liquor suspended solids

Mixed liquor – activated sludge mixed with raw wastewater

Package plant – pre-manufactured treatment facility small communities or individual properties use to treat wastewater

SRT – solids retention time

Sludge – the solids that settle out during the process

Supernatant – the liquid that is removed from settled sludge. It commonly refers to the liquid between the sludge on the bottom and the scum on the surface.

TSS – total suspended solids

Wasting – removing excess microorganisms from the system

small package plants being used today. These plants are capable of producing a high quality effluent for the price. Other advantages of the activated sludge process are the low construction cost and the relatively small land requirement.

The activated sludge process is widely used by large cities and communities where large volumes of wastewater must be highly treated economically. Activated sludge process plants are good choices too for isolated facilities, such as hospitals or hotels, cluster situations, subdivisions, and small communities.

The process

A basic activated sludge process consists of several interrelated components:

- An aeration tank where the biological reactions occur
- An aeration source that provides oxygen and mixing
- A tank, known as the clarifier, where the solids settle and are separated from treated wastewater
- A means of collecting the solids either to return them to the aeration tank, (return activated sludge [RAS]), or to remove them from the process (waste activated sludge [WAS]).

Aerobic bacteria thrive as they travel through the aeration tank. They multiply rapidly with sufficient food and oxygen. By the time the waste reaches the end of the tank (between four to eight hours), the bacteria has used most of the organic matter to produce new cells.

The organisms settle to the bottom of the clarifier tank, separating from the clearer water. This sludge is pumped back to the aeration tank where it is mixed with the incoming wastewater or removed from the system as excess, a process called wasting. The relatively clear liquid above the sludge, the supernatant, is sent on for further treatment as required. See Figure 1 on page 3.

Sludge characteristics

By analyzing the different characteristics of the activated sludge or the sludge quality, plant operators are able to monitor how effective the treatment plant's process is. Efficient operation is ensured by keeping accurate, up-to-date records; routinely evaluating operating and laboratory data; and troubleshooting, to solve problems before they become serious. A wide range of laboratory and visual and physical test methods are recommended. Principally, these include floc and settleability performance using a jar test, microscopic identification of the predominant types of bacteria, and analysis of various chemical parameters.

The treatment environment directly affects microorganisms. Changes in food, dissolved oxygen, temperature, pH, total dissolved solids, sludge age,

Safety considerations

- ✓ Practice careful personal cleanliness
- ✓ Require hard hats, boots, and gloves
- ✓ Ventilate all covered tanks
- ✓ Prohibit smoking around the plant
- ✓ Consider empty tanks as enclosed spaces and apply the proper entry procedures
- ✓ Keep all hatches closed and secured
- ✓ Keep tank areas well lighted
- ✓ Keep walkways clear to prevent falling
- ✓ Provide lockout protection for all electrical equipment, gates or valves when working in empty tanks

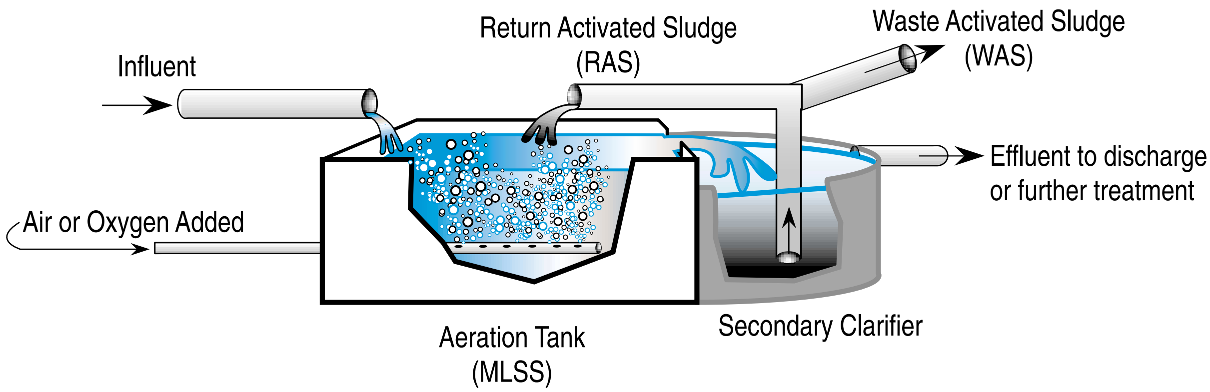


Figure 1 ***Typical Activated Sludge Process***

presence of toxins, and other factors create a dynamic environment for the treatment organisms. The operator can change the environment (the process) to encourage or discourage the growth of specific microorganisms. See the table below.

Problem / Effect

Problem	***Effect/observation***
Poor primary clarification	Plugging Standing water Odors Reduced efficiency
Hydraulic overload	High effluent TSS
Nitrification	High effluent TSS High chlorine demand Low pH
Nutrient shortage	Filamentous bacteria Rising sludge Pass through of soluble BOD
Organic overload	Pass through of soluble BOD Odors Low DO Poor effluent quality
Cold weather	Loss in removal efficiency Icing problems
Organic underload	High energy use Nitrification

Food (organic loading) regulates microorganism numbers, diversity, and species unless other factors limit it. It is important to maintain the proper ratio of food to microorganisms (F:M) to ensure optimum operation.

Activated sludge consists of a mixed community of microorganisms, approximately 95 percent bacteria and 5 percent higher organisms (protozoa, rotifers, and higher forms of invertebrates). Particular ones are considered indicator microorganisms that can be observed using inexpensive microscopes. Significant numbers of a particular species can indicate the condition of the process.

The most predominant microorganisms are aerobic bacteria, but there are also substantial populations of fungi and protozoa. Rotifers and nematodes are most frequently found in systems with long aeration periods.

Amoeboid forms, the flagellates, and the ciliates are the most common protozoans in a working sludge. Amoeboids predominate in 'young' sludges, such as at plant start-up or after an upset, such as a shock load (when a stronger than usual batch of influent comes into the plant). Typically, little or no sludge forms at this time.

Flagellates are free-swimmers and predominate in light mixed liquors during high food to microorganism conditions. Their presence usually indicates poor effluent quality.

Free-swimming ciliates predominate as the F:M ratio decreases. Stalked ciliates predominate when there is an abundance of bacteria. Effluent and sludge quality are typically best when these types of microorganisms predominate.

Filamentous bacteria can cause the sludge not to settle properly, a condition called bulking, which causes clouds of billowing sludge rather than settling. These bacteria flourish when the excess sludge is not removed at the proper rate. Filamentous sludge bulking is a common problem at small, extended aeration treatment plants.

Developing and maintaining good floc structure is critical for optimum system performance. A multiple jar test is a procedure used to evaluate the effectiveness of coagulants, optimum dosage for coagulation, concentration of the coagulant aid and the most effective order in which to add various chemicals. It consists of a multiple stirring apparatus with a variable-speed drive. Samples are held in one- or two-liter jars or beakers.

The activated sludge samples are mixed and agitated for varying lengths of time, and then allowed to settle. The nature and settling characteristics of the floc are noted, as well as the clarity of the supernatant.

Chemical testing reveals sludge conditions and can warn of impending process problems. Compliance with the plant's National Pollutant Discharge Elimination System (NPDES) permit requires specific chemical analyses. Alkalinity, solids (total, suspended and dissolved), biological oxygen demand, chemical oxygen demand, nitrogen and phosphorus are some of the parameters that plant operators must monitor.

Variations of the Activated Sludge Technology

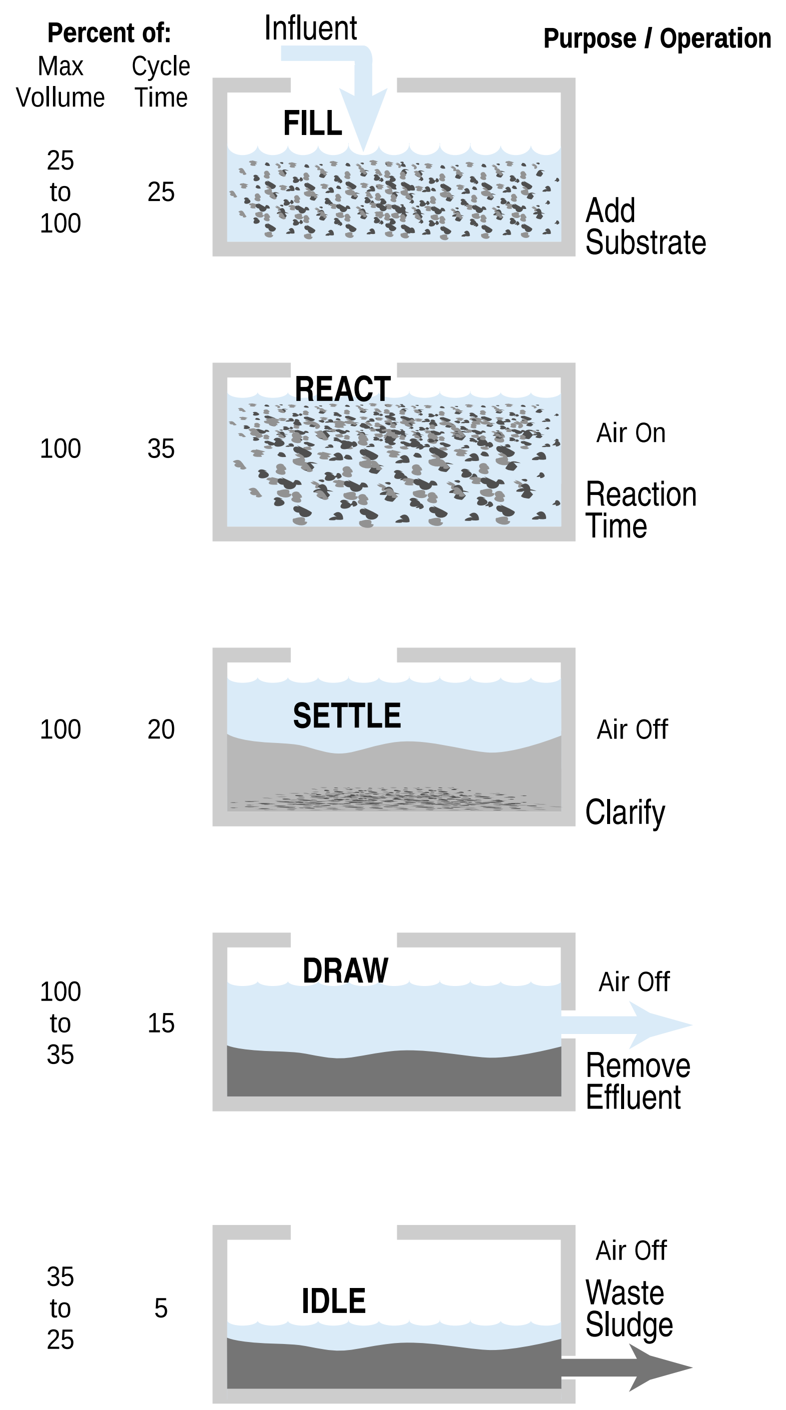
Package plants are pre-manufactured treatment facilities used to treat wastewater. Usually designed to treat flows between 10,000 and 250,000 gallons per day, these are good choices for areas with a limited number of people and small wastewater flows. These plants are options for small communities or in such isolated locations as trailer parks, highway rest areas, hospitals and prisons. Some of the most common types of package plants use biological aeration processes: extended aeration, sequencing batch reactors and oxidation ditches.

Extended aeration

The extended aeration process holds wastewater in an aeration tank for 18 hours or more and the organic wastes are removed under aerobic conditions. Air may be supplied by mechanical or diffused aeration. Mixing is by aeration or mechanical means.

This process operates at a high solids retention time (low F:M), resulting in a condition where nitrification may occur. The microorganisms compete for the remaining food. This highly competitive situation results in a highly treated effluent with low solids production.

The wastewater is screened to remove large suspended or floating solids before entering the aeration



Typical sequencing batch reactor operation for one cycle

Figure 2

chamber, where it is mixed, and oxygen is added. The solids settle out and are returned to the aeration chamber to mix with incoming wastewater. The clarified wastewater flows to a collection channel before being diverted to the disinfection system.

This is the process many package plants that schools, housing developments, and small communities use. Due to the light food to microorganism loading, extended aeration plants are considered one of the most stable wastewater treatment processes.

The extended aeration process can accept periodic (intermittent) loadings without upsetting the system. Extended aeration does not produce as much waste sludge as other processes; however, wasting still is necessary to maintain proper control of the process.

Sequencing batch reactors

The sequencing batch reactor (SBR) is considered a fill-and-draw activated sludge system. The processes of equalization, aeration, and clarification are all achieved in the same tank, unlike a conventional activated sludge system, in which the same processes are accomplished in separate tanks. Wastewater is added to the tank, treated to remove undesirable components, and then discharged.

SBR systems consist of five common steps carried out in sequence: (1) fill, (2) react (aeration), (3) settle (sedimentation/clarification), (4) draw (the effluent is decanted), and (5) idle. Sludge wasting usually occurs during the settling phase. The SBR acts as an equalization basin when filling with wastewater, enabling the system to tolerate peak flows or loads.

After passing through a screen to remove grit, the effluent enters a partially filled reactor. Once the reactor is full, it performs like a conventional activated sludge system without a continuous influent or effluent flow. Aeration and mixing are discontinued after the biological reactions are complete, the solids are allowed to settle, and the treated effluent (supernatant) is removed. Excess solids are removed at any time during the cycle. See Figure 2 on previous page.

SBRs are typically used where flowrates are five million gallons per day or less. Due to their relatively small footprints, they are useful in areas where available land is limited. In addition, it is easy to modify cycles within the system for nutrient removal if necessary. SBRs are also cost effective if treatment beyond biological treatment, such as filtration, is required. SBRs also offer a potential capital cost savings by eliminating the need for clarifiers.

SBRs require a sophisticated level of maintenance due to the timing units and controls. Depending upon the downstream processes, it may be necessary to equalize effluent after leaving the SBR.

Oxidation ditches

The oxidation ditch is an extremely effective variation of the activated sludge process, consisting of a ring or oval shaped channel equipped with mechanical aeration devices, such as brush rotors or disc aerators. See Figure 3 below.

Oxidation ditches typically operate in an extended aeration mode with long solids retention times (SRTs). Solids are maintained in suspension as the mixed liquor circulates around the ditch.

Preliminary treatment involves bar screens and grit removal. Secondary sedimentation tanks are used for most applications. Tertiary filters may be required after clarification and disinfection. Re-aeration may be necessary prior to final discharge.

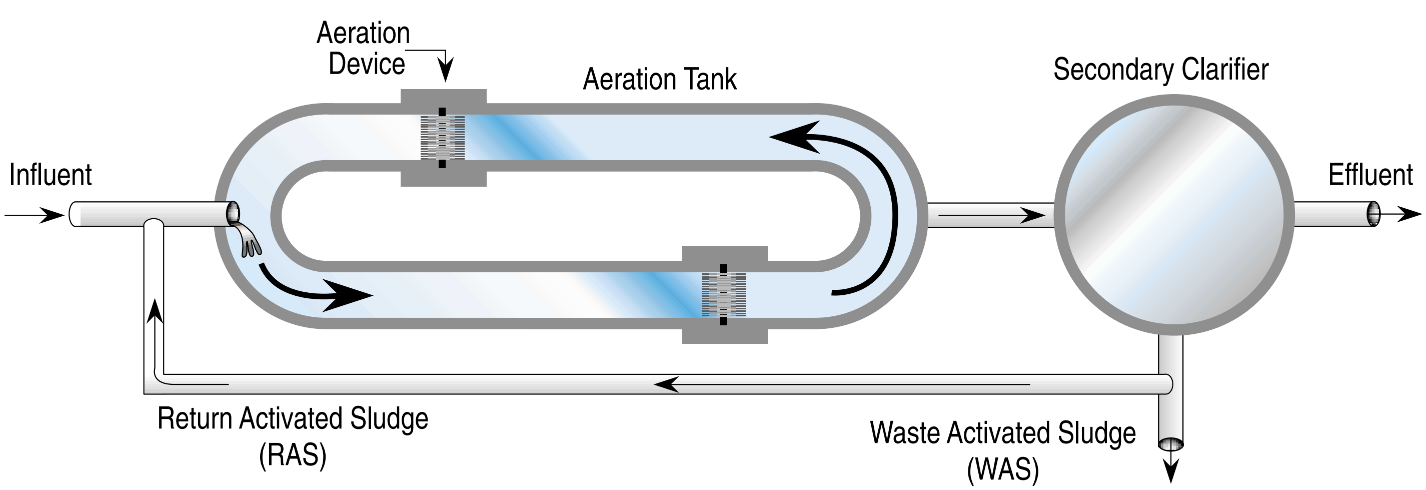


Figure 3 *Oxidation Ditch*

Oxidation ditch process plants can be designed to achieve specific objectives including nitrification, denitrification, and/or biological phosphorus removal. And due to the constant water level and continuous discharge, oxidation ditch technology is very reliable and does not cause an effluent surge common to other biological processes, such as SBRs.

Oxidation ditches are more energy efficient than other similar processes, so this technology can be a better choice for small communities and isolated institutions over conventional treatment plants. But oxidation ditches require a larger land area which sometimes limits their use in areas where land costs are high.

Comparisons of the advantages and disadvantages of extended aeration plants, SBRs, and oxidation ditches

Type	Advantages	Disadvantages
Extended aeration	Easy to operate Easy to install Odor free Small footprint Low sludge yield	Unable to achieve denitrification or phosphorus removal Limited flexibility in response to changing effluent requirements Large energy requirement
SBRs	Able to achieve nitrification, denitrification, and phosphorous removal Large operation flexibility Minimal sludge bulking Few operation and maintenance problems Able to be operated remotely	High energy consumption Difficult to adjust cycle times for small communities Frequent sludge disposal
Oxidation ditches	Moderate energy requirements Unaffected by weather Provides high quality effluent in terms of TSS, BOD, and ammonia Low sludge yields Capable of handling shock	Noisy and odiferous if not operated correctly Unable to treat toxic waste streams Relatively large footprint

Package plant servicing an apartment complex in rural West Virginia

Photo by Charles C. Metzgar

Aeration

An example of mechanical aeration, provided by rotary brushes, at an oxidation ditch in in Jane Lew, WV.

Aeration serves two important purposes: supplying the required oxygen to the organisms to grow and providing optimum contact between the dissolved and suspended organic matter and the microorganisms. The aeration system consumes approximately 50 to 65 percent of the net power demand for a typical activated sludge wastewater treatment plant, therefore the efficiency of different aeration systems is an important consideration. The time that the mixed liquor is aerated varies from as little as 30 minutes to as much as 36 hours depending upon the treatment process used. Aeration can be performed mechanically or by using a diffused system.

Mechanical aerators physically splash the wastewater into the atmosphere above the tank and create turbulence assuring effective wastewater mixing. Mechanical aerators include brushes, blades or propellers that introduce air from the atmosphere. Surface aerators float at the surface or are mounted on supports in or above the basin. Mechanical aerators tend to incur lower installation and maintenance costs.

A diffused air system introduces compressed air through a perforated membrane into the wastewater. Diffusers are classified by the physical characteristics of the equipment, or by the size of the air bubble. The choice of bubble size, diffuser type, and diffuser placement can have a great effect on the efficiency of the aeration process.

Porous (fine bubble) diffusers are attached to the bottom of the tank or positioned just below the surface. They are available in various shapes and sizes, such as discs, tubes, domes, and plates. Fine pore diffusers introduce air in the form of very small bubbles, maximizing the contact time the air bubbles have with the mixed liquor and encouraging mixing while at the same time, discouraging deposits on the tank bottom. These fine pore diffusers produce a high oxygen transfer efficiency, but they are susceptible to chemical or biological fouling and as a result, require routine cleaning.

Nonporous (course bubble) diffusers usually have fixed or valved orifices. Due to the larger bubble size, nonporous diffusers produce lower oxygen transfer efficiencies.

Other diffusion devices include jet aerators, which discharge a mix of air and liquid through a nozzle, and aspirator aerators that use a propeller on the end of a hollow shaft, creating a vacuum as the propeller draws air from the atmosphere and disperses it into the wastewater.

NSFC RESOURCES AVAILABLE

To order any of the following products, call the National Small Flows Clearinghouse (NSFC) at (800) 624-8301or (304) 293-4191, fax (304) 293-3161, e-mail nsfc_orders@nesc.wvu.edu, *or write NSFC, West Virginia University, PO Box 6064, Morgantown, WV 26506-6064. Be sure to request each item by number and title. A shipping and handling charge will apply.*

Related EPA Fact Sheets
These wastewater technology fact sheets can be read or downloaded from *www.epa.gov*.

Wastewater Technology Fact Sheet: Package Plants
EPA 832-F-00-016, September 2000 (# WWFSGN194. Cost is $2.40)

Wastewater Technology Fact Sheet: Fine Bubble Aeration
EPA 832-F-99-065, September 1999 (# WWFSGN187. Cost is $1.40)

Wastewater Technology Fact Sheet: Oxidation Ditches
EPA 832-F-00-013, September 2000 (# WWFSGN195. Cost is $1.20)

Wastewater Technology Fact Sheet: Sequencing Batch Reactors
EPA 932-F-99-073, September 1999 (# WWFSGN179. Cost is $1.80)

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