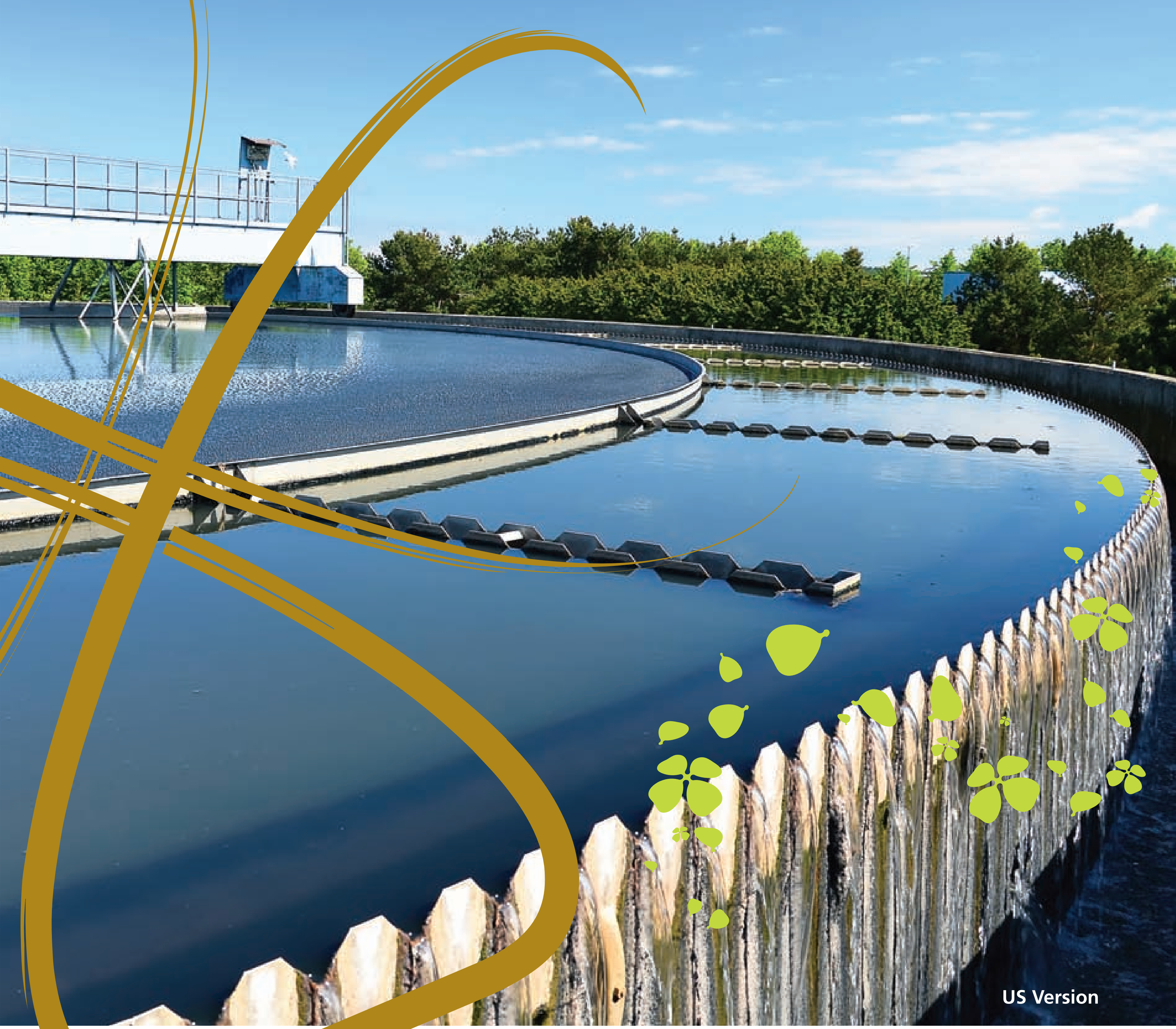

Reference Guide to
Activated Sludge

Wastewater Solutions

novozymes®
Rethink Tomorrow

Activated sludge

Activated sludge systems are the most common aerobic systems. They produce an activated mass of microorganisms (sludge) capable of aerobically degrading a waste. The contact between the microorganism mass (sludge or biomass) and the wastewater takes place in an aeration basin similar to the one shown in Figure 1. The aeration basin contents are referred to as mixed liquor. After treatment in the aeration basin, the mixed liquor is then conveyed to a clarifier where the biological solids are separated from the liquid by gravity settling. A portion of the biomass is recycled to the aeration basin with the remainder wasted. The wastage is necessary to maintain a steady concentration of the biomass within the aeration basin.

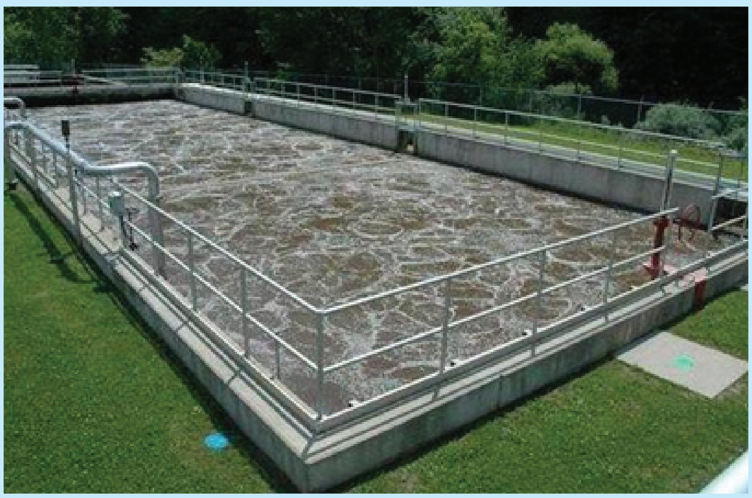

Figure 1. Activated sludge aeration basin with submerged aeration.

Abbreviations

BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
TOC	Total organic carbon
DO	Dissolved oxygen
SOUR	Specific oxygen uptake rate
SV_{30}	Sludge volume time at 30 min.
SVI	Sludge volume index
TSS	Total suspended solids
MLSS	Mixed liquor suspended solids
mg/L	Milligrams per liter
MCRT	Mean cell residence time
F/M	Food to Microorganism ratio
Q_{RAS}	Return activated sludge flow
Q_{WAS}	Waste activated sludge flow
Q_{INF}	Influent plant flow
mgd	Million gallons per day
gpm	Gallons per minute
VSS	Volatile suspended solids
F	Mass loading of BOD per day
M	Mass of MLSS under aeration and in secondary clarifier

Aeration

Air can be supplied to the aeration basin by either diffused (subsurface) or mechanical (surface) aeration. Diffused aeration is located on the bottom of the basin as shown in Figure 2, while mechanical aeration is supplied by a mixer on the surface, either mounted on a structure or floating, as shown in Figure 3.

Figure 2. Diffused aeration system

Figure 3. Fixed mounted surface aerators with a clarifier

Clarification

Gravity separation of the biomass from the liquid portion of the mixed liquor is accomplished in a clarifier. A circular clarifier is shown adjacent to the aeration basin in Figure 3. Typically, the mixed liquor will enter the clarifier from the center. The clarified effluent flows over a weir located near the circumference of the clarifier as shown in Figure 4. The settled sludge is raked to the bottom's center where it is either removed from the system or returned to the aeration basin. Some secondary clarifiers may be equipped with a skimmer mechanism, which is used to remove any floating sludge.

Figure 4. Clarifier weir overflow with scum baffle.

Operational parameters

There are three basic flow patterns that can be applied within an activated sludge aeration basin. One is a plug flow. In a plug flow reactor, the fluid passes through the tank and is discharged at the other end. The retention time is the time it takes for the flow to travel the length of the reactor. A complete mix reactor completely disperses the flow throughout the tank immediately upon entering. The contents of the reactor are essentially the same throughout the tank. The third type is the batch reactor. Flow is not continuous in a batch reactor, but the flow enters the tank where it is mixed and treated prior to discharge.

Two key operational parameters in an activated sludge reactor are dissolved oxygen and temperature. Oxygen is necessary for the biological reaction to occur. The dissolved oxygen (DO) within an aeration tank should be maintained between 1 and 2 mg O_2/L. This can be easily measured with a DO probe. Oxygen solubility in water at ambient temperature will be approximately 8 mg O_2/L. If the DO is close to the solubility, it could be an indicator that bioactivity is low. If the DO is not detected, the system could be anoxic. Temperature is also a critical factor for the biological activity. Mesophilic bacteria, which make up the majority population in soil and water, have an optimum operating temperature in the range of 30 to 45°C (86° to 110°F). Typical operating parameters for the standard activated sludge processes are provided in Table 1.

Activated sludge process characteristics and parameters								
Process	**Application**	**Flow model**	**BOD removal, %**	**Hydraulic Retention Time, hr**	**Sludge age, days**	**Food to Microorganism Ratio, lb BOD/ lb MLVSS-day**	**MLSS, mg/L**	**Sludge Recycle Ratio ($Q_{RAS}/Q_{INF}+Q_{RAS}$)**
Conventional	Low-strength domestic wastes	Plug	85-95	4-8	5-15	0.2-0.4	1,500-3,000	0.25-0.5
Complete-mix	General application	Complete mix	85-95	3-5	5-15	0.2-0.6	3,000-6,000	0.25-1.0
Step-aeration	General application	Plug	85-95	3-5	5-15	0.2-0.4	2,000-3,500	0.25-0.75
Contact stabilization	Expansion of existing systems, package plants	Plug	80-90	Stage 1: 0.5-1.0 Stage 2: 3-6	5-15	0.2-0.6	Stage 1: 1,000-3,000 Stage 2: 4,000-10,000	Stage 1: 0.25-1.0
Extended aeration	Small communities, package plants, low sludge waste	Complete mix	75-95	18-36	20-30	0.05-0.15	3,000-6,000	0.75-1.5
High rate aeration	General application	Complete mix	75-95	0.5-2	5-10	0.4-1.5	4,000-10,000	1.0-5.0
Pure oxygen	General application where limited volume available	Complete mix	85-95	1-3	8-20	0.25-1.0	6,000-8,000	0.25-0.5
Q_{RAS} = Sludge return flow $Q_{INF}+Q_{RAS}$ = Total flow								

Table 1. Operational characteristics and parameters for activated sludge processes

Other versions of activated sludge systems

There are a number of modifications to the activated sludge process. These all have the aeration tank as the main reator.

Oxidation ditch

An oxidation ditch is a type of plug flow basin configuration. Rather than a rectangular basin, the oxidation ditch is more of an oval or "race track" configuration as shown in Figure 5. Otherwise, it operates as a conventional, step aeration or contact stabilization process.

Figure 5. Oxidation ditch

Membrane Biological Reactor

Membrane biological reactors (MBR) operate under the same principles as conventional activated sludge, however, instead of a clarifier, the system has a membrane filter; typically microfiltration or ultrafiltration to separate. The filters are typically either hollow-fiber or flat-sheet configuration. A schematic of an MBR system is provided in Figure 6. The membrane filtration can either be located within the aeration tank or in a separate vessel. There are a number of benefits to the MBR:

Exceptional effluent quality – As the biomass is completely retained, the effluent solids concentrations are <1 mg/L. With membrane filtration, the water is prepared for recycle/reuse without further filtration.

Small footprint – Using a membrane instead of a clarifier, it can take up less land area. Since there is no need for gravity settling, the sludge MLSS concentration can be higher (~8000 mg/L), which, in turn, allows a smaller tank to achieve the proper F/M ratio.

Modular system – Membrane systems are of a modular construction, making it an easier and more flexible configuration.

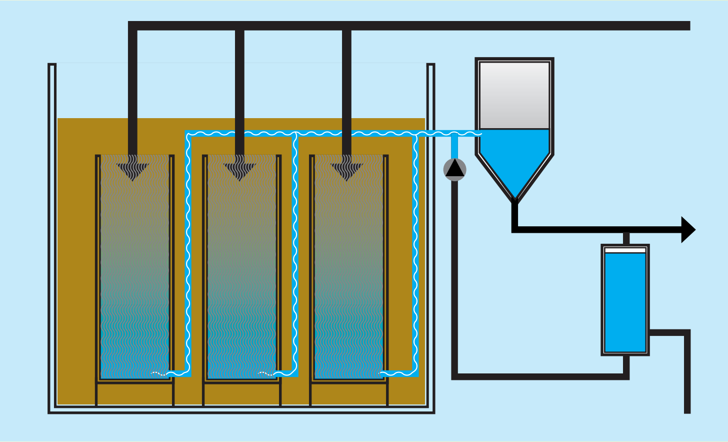

Figure 6. MBR configuration

Flexible and reliable operation – The system can operate in a wide range of sludge retention times (sludge age) and with a variable MLSS concentration. As sludge settling is not an issue, the presence of filaments in the sludge does not necessarily present a problem.

Sequencing, or sequential, batch reactor (SBR)

An SBR system has both the aeration and clarification combined in one vessel. Typically, these are installed as a minimum of two vessels in parallel that operate in an alternating mode so that flow is not interrupted. The sequence of operation within the reactor is shown in Figure 7.

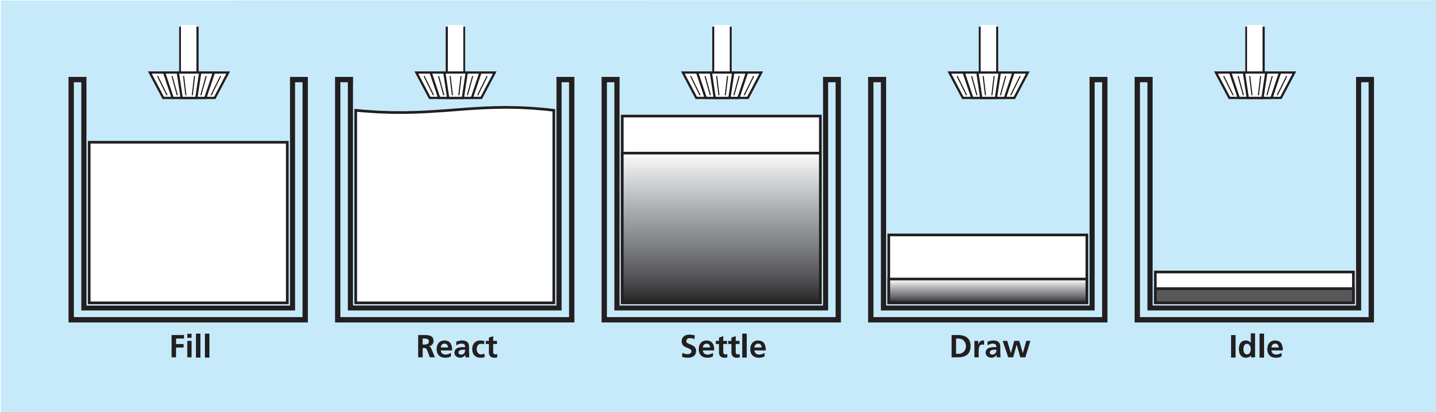

Figure 7. Sequencing batch reactor

Because these reactors have multiple cycles, there is some flexibility in the operation. With a longer sludge age, nitrification, the conversion of ammonia to nitrate, can be enhanced. Subsequently, due to the potential for an anoxic environment after the reaction stage is completed, denitrification can occur in the same vessel.

Opportunities for bioaugmentation in aerobic systems

There are numerous opportunities for the use of bioaugmentation in aerobic systems. These include:

- Cold weather tolerance
- Organic compound removal including hydrocarbons, phenols, surfactants, and FOG
- Reseeding for filament control
- Plant start-ups
- Removal of recalcitrants or “hard” COD
- Enhancement or recovery of nitrification
- Hydrogen sulfide control

Common formulas

Plant loading

This is the formula for BOD or plant loading in pounds. The concentration of BOD in mg/l times the plant flow in mgd times the weight of one gallon of water equals pounds of BOD.

$$\text{mg/L} \times \text{mgd} \times 8.34 = \text{lbs/day}$$

MLSS in the aeration tank

This is for calculating MLSS in an aeration tank. Concentration of MLSS times the volume of the aeraton tank in million gallons (mg) times 8.34 equals pounds of MLSS.

$$\text{MLSS mg/L} \times \text{Aeration Volume (MG)} \times 8.34 = \text{lbs of MLSS}$$

F/M Ratio

This is the formula for the ratio of food to microorganisms.

$$\frac{\text{lbs BOD}}{\text{lbs MLSS}} \text{ or } \times \text{ lbs MLSS} = \frac{\text{lbs BOD}}{\text{Ratio}}$$

MLSS

This is the formula for finding mg/l of MLSS, when the required MLSS in pounds is known.

$$\text{mg/l MLSS} = \frac{\text{lbs MLSS}}{\text{Aeration Volume (MG)} \times 8.34}$$

BOD removal

This is the formula for calculating the percentage of BOD removed.

$$\frac{\text{lbs BOD removed}}{\text{lbs BOD in}} \times 100$$

Total return sludge rate

This formula is based on utilizing MLSS concentration and taking into account the settleability factor.

$$Q_{RAS} = \frac{\frac{Q \times M}{1{,}000{,}000}}{\text{SVI}} - M$$

Detention time

This is the formula for calculating detention time.

$$\frac{\text{tank volume} \times 24 \text{ hrs.}}{\text{plant flow}} = \text{Detention time}$$

Rate of flow

This is the formula to find the rate of flow in gpm when weight in lbs and concentration in percent are known. (Based on a 24-hour day. K = 120.)

$$\frac{\text{weight in lbs}}{\text{K} \times \text{conc. in \%}} = \text{gpm Where: K=120}$$

$$\text{or} \quad \text{gpm} \times \text{K} \times \text{concentration} = \text{pounds}$$

$$\text{or} \quad \text{concentration in \%} = \frac{\text{lbs}}{\text{gpm} \times \text{K}}$$

Proportionality

This proportionality equation can be used to solve for an unknown flow volume or a concentration.

$$V_1 \times S_1 = V_2 \times S_2$$

V_1 = flow in S_1 = conc. in
V_2 = flow out S_2 = conc. out

To solve for V_2 rearrage the basic formula

$$V_2 = \frac{V_1 \times S_1}{S_2}$$

Solids balance

To obtain a solids balance around an aerator, this formula–based on flow and concentration–can be applied.

$$(Q_{INF} + Q_{RAS}) \text{ MLSS mg/L} = Q_{RAS} \times \text{RAS mg/L}$$

Return sludge rate

This is the formula to find return sludge flow when concentrations and plant flow are known.

$$Q_{RAS} \text{ conc.} = \frac{\frac{\text{MLSS (mg/L)}}{\text{RAS (mg/L)}} \times Q_{INF\ (MGD)}}{1 - \frac{\text{MLSS (mg/L)}}{\text{RAS (mg/L)}}}$$

Glossary

Absorption
A condition in which something takes in another substance.

Activated Sludge
The organisms, accumulated food materials and waste products from the aerobic process of wastewater treatment.

Adsorption
The process by which molecules of a substance, such as a gas or a liquid, collect on the surface of another substance.

Aerobic
The presence of oxygen in an aquatic environment.

Alkalinity
A measure of the capacity of a solution to neutralize a strong acid. Usually measured as CaCO3 (mg/L) in wastewater.

Anaerobic
The absence of a common electron acceptor such as oxygen, nitrate or sulfate in an aquatic environment.

Anoxic
Environment where nitrate is used as the electron acceptor with no free oxygen present.

AOB
Ammonia oxidizing bacteria. A group of microorganisms that are capable of converting ammonia into nitrite as the first of two steps in nitrification.

Autotrophic
Organisms that can use inorganic materials for life processes in the presence of oxygen.

BOD
Biochemical oxygen demand. A measure of the strength of a wastewater by measuring the amount of oxygen consumed by microorganisms as they break down the organic matter under controlled conditions of time (typically 5 days) and temperature (20 °C).

BNR
Biological nutrient removal. A process used for nitrogen and phosphorus removal in wastewater treatment systems.

Bulking Sludge
Sludge with poor settling characteristics.

Cellular respiration
The metabolic process by which an organism obtains energy by reacting oxygen with glucose to give water, carbon dioxide and ATP (energy). (Not the same as respiration.)

COD
Chemical oxygen demand. An indirect measure of the strength of a wastewater by oxidizing the organic compounds to carbon dioxide in the presence of a strong oxidizer in acidic conditions under heat.

Colloidal
A substance microscopically dispersed evenly throughout another substance.

Conversion
The expression of a quantity in alternative units or something that is changed from one use, function, or purpose to another.

Dissolved Oxygen (DO)
The concentration of oxygen that is dissolved in an aquatic environment. Usually expressed as mg/L O_2.

DOUR
Dissolved oxygen uptake rate. A measurement that indicates biological activity of microbes in the wastewater treatment process by monitoring dissolved oxygen uptake over time.

Endogenous
Biological and ecological processes including endogenous respiration/cell maintenance, cell decay, predation on bacteria by higher microorganisms and cell lysis due to adverse environmental conditions.

Endogenous respiration
Biological growth when organisms oxidize their own cellular mass.

Enzyme
Proteins that catalyze biochemical and chemical reactions. Enzymes are non-living.

Filamentous Bacteria
Bacteria that form long sheaths to gain a competitive advantage over floc forming bacteria in the presence of adverse conditions such as low F:M or septicity.

Floc
An group of microorganisms that adhere tightly together and consume BOD in an activated sludge aeration basin.

F/M Ratio
Food to mass ratio. A process control calculation used to evaluate the amount of BOD or COD available per pound of MLVSS.

Heterotroph
Organisms that break down organic material as a food source in the presence of oxygen.

Hydraulic Retention Time (HRT)
The measure of time that a drop of water remains in the activated sludge process.

Log Growth
The phase of growth where bacterial populations are categorized by cell doubling.

Lysing
The breaking down of a bacterial cell, often by viral, enzymatic, or osmotic mechanisms that compromise its integrity.

MCRT
Mean cell retention time. The average amount of time a MLSS particle is retained in the activated sludge process.

Microexam
A microscopic evaluation of an activated sludge sample to determine plant performance, assess floc quality, identify filaments and enumerate higher life forms.

Microorganisms
Microscopic unicellular organisms, fungi, and bacteria.

Mixed Liquor
The combination of return activated sludge and wastewater influent which flows into the aeration basin.

MLSS
Mixed liquor suspended solids. The suspended solids concentration of the mixed liquor.

MLVSS
Mixed liquor volatile suspended solids. The volatile portion of the suspended solids concentration of the mixed liquor. This is commonly used to represent the biological fraction of the activated sludge.

NOB
Nitrite oxidizing bacteria. A group of microorganisms capable of converting nitrite into nitrate as the last of the two major steps in nitrification.

Organic Matter (OM)
Matter that contains carbon usually from once living organisms or is the product of decay.

ORP
Oxidation reduction potential. A measure of the oxidation potential of wastewater that is usually expressed in mV.

Oxidation
The addition of oxygen or the removal of hydrogen from a molecule.

PAO
Polyphosphate accumulating organisms. Organisms that are responsible for luxury phosphorus uptake in anaerobic zones of a treatment system.

Particulate
A minute separate particle, as of a granular substance or powder.

pH
A measure of hydrogen ion activity.

RAS
Return activated sludge. The solids returned from the secondary clarifier to the head of the aeration basin.

Respiration
The transport of oxygen into cell. (Not the same as cellular respiration.)

Soluble
A substance that is able to be dissolved in a solvent, most commonly water.

TKN
Total Kjeldahl nitrogen. The sum of the organic and ammonia nitrogen.

TN
Total nitrogen. The sum of the organic nitrogen, ammonia nitrogen, nitrate and nitrite.

TSS
Total suspended solids. All particles suspended in wastewater which will not pass through a filter.

SRT
Sludge retention time. The average amount of time a MLSS particle is retained in the activated sludge process. Same as MCRT.

SV30
Settled volume 30 minutes. The volume in mL/L or percentage occupied by an activated sludge sample after 30 minutes of settling time.

SVI
Sludge volume index. A process control calculation used to evaluate the settling quality of an activated sludge sample by taking into account the 30 minute settling volume and MLSS concentration.

Synthesis
The combination of two or more substances to form something new.

VSS
Volatile suspended solids. The volatile portion of the particles suspended in wastewater which will not pass through a filter. Indicates a measure of the amount of biological verses inert material in the activated sludge process.

WAS
Waste activated sludge. The sludge that is removed or wasted from the activated sludge process.

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