Have You Tried "Off-On" Aeration Yet?

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One of the myths of operating the Activated Sludge process is that you need to maintain a constant level of dissolved oxygen in the aeration basin (Miklos). This simply is not true. In fact there are numerous benefits of operating activated sludge in an "off" then "on" cycle of aeration (Schuyler). The benefits occur when nitrified mixed liquor is forced or allowed to denitrify. Benefits include: energy savings, improved effluent quality, recycle of oxygen and alkalinity, improved filament control, and improved solids separation and dewatering. Drawbacks of the practice would occur in plants where diffusers are incompatible with the "off" cycle or in non-nitrifying plants, where "off" time may result in low dissolved oxygen problems. The practice is not suitable for all locations, but many operators find that with an understanding of the biological process they can manipulate their facility to achieve improved operations and significant energy savings.

The Biology

In most aeration basins two major groups of organisms are at work. The heterotrophs remove BOD while the autotrophs remove ammonia. More specifically the autotrophs in sewage treatment are nitrifying organisms, which use ammonia as their source of energy and carbonate or bicarbonate in the water as a carbon source for their own growth. During nitrification, ammonia in the sewage is oxidized into nitrite then nitrate (a low energy form of nitrogen) by the nitrifying bacteria. This is a rather expensive process in several ways. In order to nitrify, a plant's mixed liquor suspended solids must be maintained at a higher level than required for BOD removal. Each pound of ammonia removed requires the addition of 4.33 pounds of oxygen and consumes 7.14 pounds of alkalinity. The air is generally provided through mechanical aerators using electric motors. The alkalinity in the incoming wastewater is usually sufficient to provide what is necessary, but in some cases additional alkalinity must be added using a variety of chemical sources such as lime, soda ash, bicarbonate of soda, and sodium hydroxide. Where a plant is designed to denitrify or forced to by turning the aeration "off", 65% of the oxygen and 50% of the alkalinity needed to remove ammonia is recycled back into the system. This effectively reduces the cost of removing ammonia.

During the time the air is "off", free oxygen levels fall to zero and the BOD oxidizing bacteria will begin looking for another oxygen source. If they have no free dissolved oxygen, their next favorite source of oxygen is nitrate. These facultative heterotrophic bacteria simply adjust their metabolism and continue oxidizing BOD using nitrate as a source of oxygen effectively using that oxygen a second time. The first time to remove ammonia and the second time to remove BOD. The removal of the oxygen from the nitrate molecule releases nitrogen gas which can make settled sludge very light and sometimes float to the surface. When this occurs in the clarifier, it is called clarifier clumping. If there are large amounts of clumps, they can foul the effluent with unwanted solids. But if the clumping occurs in the aerator, there is no risk of effluent fouling. Depending upon conditions, the nitrogen may form gas bubbles which can be seen rising to the surface.

To force denitrification to occur three conditions are needed. First an anoxic environment where there is little dissolved oxygen but where nitrate is present. Second there must be BOD present. The amounts of BOD and the type of BOD will determine the speed of the reactions. Finally there must be heterotrophic bacteria to oxidize the BOD using the nitrate.

As the BOD oxidizing bacteria use the nitrate oxygen, alkalinity is returned to the water. This alkalinity can then be reused in the ammonia removal process. Denitrifying results in oxygen being used twice and alkalinity being recycled for use again. The cost savings from denitrifying result from the electricity saved and in some cases the reduction or elimination of a purchased alkalinity source.

Other Benefits

In addition to reducing the cost of treatment, denitrification produces other benefits. A denitrified biomass settles better, and the variation of oxygen levels puts selective pressure against low D.O. filaments. Low Dissolved Filaments prefer conditions of continuous low dissolved oxygen, that is a level of under 0.5 mg/L day in and day out. They will not thrive where oxygen is higher or where it is 0.0mg/L, or where it is changing from high to low. Because an aerobic digester is an extension of the aeration process, similar cycles can be used in their operation. Cycling the aeration in the aerobic digester also produces similar results including improved dewatering of the sludge or biosolids.

Digesters receive only waste sludge and little food in the form of BOD so they would be classified as operating in endogenous respiration. During aeration times the heterotrophic bacteria consume what little food is available, and their stored energy then begin to die and consume each other. Some ammonia is produced during this oxidation of organic matter. The ammonia is then further oxidized to nitrate. Because endogenous oxidation occurs more slowly than the oxidation in the aeration basin where there is adequate BOD for food, less oxygen is needed in a digester unit. With this slow rate of respiration or metabolism occurring in the digester, cycle times will need to be longer than in an aeration basin.

Total Nitrogen Limits

As permit limits become stricter, some Tennessee wastewater plants are finding Total Nitrogen limits being added to their NPDES permits. Total Nitrogen is the sum of Total Kjeldahl Nitrogen (TKN, includes organic nitrogen and ammonia nitrogen) plus Nitrite and Nitrate nitrogen. If we look at the fate of each of these parameters we find that organic nitrogen is the fraction of nitrogen within the organic solids, so when Total Suspended Solids (TSS) is low, organic nitrogen is low. Ammonia should be low if nitrification is complete. Nitrite creation is an intermediate step in the nitrification process and is rarely an effluent problem. This leaves nitrate as the parameter of concern when faced with Total Nitrogen limits. In order to respond to these new parameters, plant designs are changing to include denitrification basins. These are usually small basins where raw sewage, return activated sludge, and some mixed liquor are mixed but not aerated to create the anoxic environment. In this zero oxygen environment the bugs in the RAS consume BOD from sewage using nitrate as an oxygen source. Other methods of removing nitrate include the use of aeration basins with non-aerated mixing cycles, another way is to recycle to primary clarifiers, and then the simple "off-on" aeration cycles. For very low effluent nitrate limits (less than 5.0mg/L) a post aeration anoxic zone with methanol feed may be needed. This is an effective method but does require the purchase of methanol and the monitoring of an additional process. Where new tankage or new plants aren't practical, operators may find that "off-on" aeration may be all that is necessary to meet the new limits. Generally Tennessee limits for nitrate are no lower than 10.0 mg/L.

Setting Cycles

In an ideal situation the mixed liquor is aerated until the ammonia is removed then the aeration is stopped until the nitrate is removed. The length of these cycles can be determined by monitoring ammonia and nitrate, but there are simpler, though more indirect methods. The "off" time can be estimated using an oxygen and nitrate mass balance and the mixed liquor oxygen uptake rate. The oxygen level plus the product of the nitrate level times 2.88, divided by the oxygen uptake rate will give an approximate time to denitrify. One mg/L nitrate equals 2.88 mg/L oxygen for the denitrification process. Other ways include on-line or manual measurements using oxidation-reduction potential (ORP), pH, or alkalinity. The way I see most operators establishing cycle duration is simple trial and error based upon their experience with the facility and the available equipment. The availability of timers is an important element in establishing cycles.

Examples of "Off-On" Aeration

Plant #1

Complete mix with forced air aeration, clarification, chlorination, post air.
Two "off" cycles/ Day 1-5 p.m. and 1-6 a.m.
Total off time nine hours per day

Effluent values,	Jan-June 2002	June 2004
BOD	2.0 mg/L	~3.0 mg/l
TSS	5.0 mg/L	~1.0 mg/L
Ammonia	0.35 mg/L	<0.2 mg/L
Nitrate	<5.0 mg/L	~5.0 mg/L

Benefits, nine hours electricity per day, improved effluent, operator pride of accomplishment. Off cycle ORP may get as low as –200mV with no odor problems.

Plant #2

Complete mix aeration with forced air aeration, clarification, chlorination, sand filters.

Basic cycle, 3 hours "Off" 3 hours "On"

Effluent	2001	2004
BOD	<5.0 mg/L	~1-2 mg/L
TSS	<5.0mg/L,	~1-2mg/L
Ammonia	<1.0 mg/L	~0.3mg/L
Nitrate		1-4 mg/L

Benefits, 12 hours per day electrical savings, elimination of purchased alkalinity additions, and part of comprehensive cost savings program by operators.

Plant #3

Oxidation Ditch, clarifier, chlorination.
Three hours "0ff" five hours "On"
Effluent, BOD 2.0 mg/L
TSS 5.0 mg/L
No ammonia limit.

Benefits, nine hours per day electrical savings, pH depression stopped, improved effluent.

Plant #4

Aerobic Digester

Process goal: To reduce sludge nitrate to allow for continued land application at high levels. With increasing sludge nitrate levels agronomic loading rates were dropping which requiring additional land for biosolids disposal. In this case land which was not available.

Cycles: 8 hr "on" 16 hr "off"

Sludge nitrate levels reduced from 4,000-7,000mg/L range to 100-1,000 mg/L range.

Cautions

There can be negatives with any process change. Plan any "off-on" program carefully; think through the entire plant process before making dramatic changes. Monitor the process carefully.

Ceramic aeration diffusers do not handle the "off-on" cycle. Other types of diffusers may not either. If in doubt, check with the manufacturer for their specific recommendations.

Whenever large motors are started, the cost of "starting" must be considered. The start load as well as the demand should be considered. Many small plants do not have demand meters, but most large electric meters are equipped with a way of measuring the demand. Your electrical supplier or TVA should be able to assist you with this information.

Whenever the aeration is "off", the biomass will settle unless there is mixing available. Though the process proceeds without mixing, as in each of the three examples, the clear water above the biomass blanket will receive little nitrate removal, but through several cycles per day much of the nitrate will be removed. A preferred situation though not mandatory is to have non-aerated mixing. A popular plant design that operates in a cycle mode is the Sequencing Batch Reactor (SBR). These are characterized with excellent effluent and low incidences of filament outbreaks. While the SBR is in the settle and decant mode, the aeration is "off" and there is no mixing; a situation which promotes denitrification without adverse effects to the plant effluent.

A word of caution about odors is in order. The heterotrophic organisms within the wastewater plant are very adaptive. If there is no oxygen they will use nitrate; and if they use all the available nitrate, their next favorite source of oxygen is sulfate (SO_4). When they strip the oxygen from the sulfate, molecule sulfur is left. This sulfur is attached to a hydrogen atom to form hydrogen sulfide (H_2S). All water contains sulfate, and we even add it during drinking water treatment in the form of alum (aluminum sulfate). When the air is off, there is odor potential so be cautious. Monitor the process. Generally maintaining an ORP above –50mV is recommended but in the examples cited ORP values of -100mV to -200mV have been recorded without odors. Producing noticeable amounts of Hydrogen Sulfide depends upon many variables. Important ones include the length of time sulfate reduction conditions are present, the capacity of the water to maintain that H_2S in a dissolved state, and chemical and physical factors which influence the release of the gas into the atmosphere.

Various strategies can work to denitrify an aeration basin. Much depends upon the style of aeration, availability of timers or operators schedules, and wastewater flow patterns. The benefits of denitrifying can be reached through process manipulation even in facilities not specifically designed for biological nitrogen removal. By understanding how nitrification and denitrification works, plant operators can make adjustments to their operations that will improve plant performance and save money. Others have been successful; it's a matter of understanding the biology, adjusting the plant and then monitoring the process. Take the challenge, make better effluent, save some money, try "off-on" aeration.

References

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