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Practical Control Methods for Activated Sludge Bulking and Foaming

Part 1

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In this first part of a two part article, the causes of filamentous bulking and practical control measures are presented. Physical and chemical control of filaments and the causes and control of activated sludge foaming will be presented in a following second part.

Introduction

The start of any problem solving has to involve microscopic examination of the activated sludge. This reveals whether the problem is, or is not, caused by filaments. If caused by filaments, identification of the causative filament(s) yields a direction or approach to take for a remedy.

As shown in Table 1, the causes for filament growth include low oxygen concentration, low F/M, septicity, nutrient deficiency, low pH and high grease and oil. Control methods, based on the specific type(s) of filaments causing the problem, follow.

Table 1..

Filament Types as Indicators of Conditions Causing Activated Sludge Bulking

Causative Condition (1)	Filament Types
Low Dissolved Oxygen (for the applied organic loading)	_S. natans_, type 1701 and _H. hydrossis._
Low Organic Loading Rate >(low F/M)	_M.parvicella_, _Nocardia_ spp., and types 0041, 0675, 1851 and 0803.
Septic Wastes / Sulfides(high organic acids)	_Thiothrix I_ and _II_, _Beggiatoa_ spp., _N. limicola II_*, and types 021N, 0092*, 0914*, 0581*, 0961* and 0411.
Nutrient Deficiency - N and/or P (industrial wastes only) nitrogen - phosphorus -	_Thiothrix I_ and _II_ and type 021N. _N. limicola III_
Low pH (<pH 6.0)	fungi.
High Grease/Oil	_Nocardia_ spp., _M. parvicella_ and type 1863

(1) Note that some filaments occur at several conditions. * These filaments occur at lower F/M at septic conditions.

Low Dissolved Oxygen Concentration

Low aeration basin dissolved oxygen (DO) concentration for the applied organic loading (F/M) leads to filamentous bulking by several filaments (see Table 1). The required aeration basin DO concentration to prevent "low DO bulking" is not a constant, rather, is a function of the F/M rate (see Palm et al. JWPCF 52: 2484, 1980). Simply, higher bulk DO is required to prevent the growth of these filaments as the F/M increases, due to faster oxygen use within the floc at higher F/M, oxygen depletion inside the floc, and the need to maintain aerobic conditions in the interior of the floc. A higher bulk DO concentration increases the diffusion of oxygen into the floc interiors.

In general, a bulk DO concentration of 2.0 mg/L is recommended for F/M values up to 0.5, typical of most domestic waste plants. This DO concentration should be maintained at the point of greatest oxygen demand in the system, for example, at the head-end of a plug-flow system (not the back-end).

Some industrial waste systems and high rate domestic plants operated at higher F/M may need higher DO values than 2.0 mg/L due to oxygen diffusion limitations. Type 1701 bulking has occurred in an oxygen activated sludge plant operated at high F/M at a DO concentration of 12-14 mg/L, which was cured by raising the DO to 20 mg/L. As a rule, always trust the microscopic observation of low DO filaments to indicate oxygen limitation rather than the aeration basin DO values.

Control of low DO bulking is by raising the aeration basin DO concentration and by raising the aeration basin MLSS concentration (decreasing the F/M). Note that this action is opposite to what intuition directs: to reduce the MLSS concentration, since less biomass needs less oxygen (wrong! -the F/M is increased at lower MLSS concentration and oxygen needs increase).

Filamentous bulking is common in completely-mixed, lower F/M systems. Here, a number of filaments can cause bulking (see Table 1) because they grow better than most activated sludge floc-forming bacteria at low aeration basin BOD concentration. Intermittently-fed and plug-flow systems are more resistant to this type of bulking.

Control of low F/M bulking is by reducing the aeration basin MLSS concentration and increasing the F/M (manipulating the "M" component). Lowering the MLSS concentration may not be suitable for many plants as this may cause the loss of nitrification and increase waste sludge production. Any change in operation that effectively increases the substrate concentration available to the activated sludge and introduces batch or plug-flow characteristics to the aeration basin, even on a short term basis, will help control low F/M bulking. These include: compartmentalization of aeration basins; fed-batch operation; intermittent feeding of wastes; and use of a selector. These latter methods do not reduce the MLSS concentration in the system.

A selector is a mixing basin or channel where RAS and influent wastes mix prior to the aeration basin. Selector design is empirical at this time.

Successful examples involve a 15-30 minute contact time of the RAS and influent waste; are aerated; and achieve at 70-80% removal of soluble BOD5 through the selector. Several newer designs are either operated anoxic (no free oxygen but nitrate present) or anaerobic, however, these are too new to state their general usefulness.

A selector can be too large or too small in size to properly function. The goal is to provide a short term, high substrate condition which favors certain floc-formers but which discourages filaments. These floc-formers appear to rapidly store BOD as cellular storage products in the selector, which they use later for growth in the main aeration basin (they pack their own "lunch bags" in the selector). If the selector is too large, the substrate concentration achieved may not be high enough to encourage these special floc-formers and discourage filaments. If too small, insufficient time may be available for substrate uptake and storage. Also, a selector that is too small may cause the floc-formers to shunt carbonaceous substrate to exocellular polymer which can increase the SVI of the sludge ("slime bulking") and pose problems in waste sludge dewatering. The best approach is to try several selector sizes, using a larger basin or channel with movable baffles or exit gates. Use of a variable wastewater bypass around the selector can achieve the same objective and allow the operator some control over the selector.

Selectors are specific tools to combat low F/M filaments and are not needed by all plants. Inappropriate selector use may made the problem worse (for example, where bulking is caused by low DO, nutrient deficiency or waste septicity).

Septicity

Influent wastewater septicity is usually indicated by odors (H2S or "rotten egg" smell) and a dark color to the wastewater, caused by precipitated ferric sulfide. Septic wastes contain elevated amounts of sulfides and low molecular weight organic acids (such as acetic and butyric acids), both of which encourage the growth of certain filaments (see Table 1). Observation of these filaments with intracellular sulfur granules is a tip-off of a septicity problem.

Septicity is more common in systems in warmer climates and in those with large wastewater collection systems that have lift stations and force mains. Waste septicity can be treated by preaeration (which releases odors), by chemical oxidation (chlorine, hydrogen peroxide or potassium permanganate), by chemical precipitation (ferric chloride), or use of sodium nitrate in the collection system as an "oxygen source".

Septicity can originate within plant processes. Common sources of septicity include equalization basins, primary and secondary clarifiers, and return streams from sludge processing. These can be tested for sulfide or organic acid concentration to determine whether they are a significant source of septicity. A sulfide concentration >1-2 mg/L and an organic acid concentration >100 mg/L favors filament growth. Sulfide can be tested for using one of the simple sulfide test kits available commercially (such as by HACH). Organic acids can be tested for using distillation and titration as per Standard Methods (the same test as for digesters).

Low Nutrients

Nitrogen and phosphorus can be growth limiting if not present in sufficient amounts in influent wastewater, a problem with industrial wastes and not domestic wastes. In general, a BOD5:N:P weight ratio in the wastewater of 100:5:1 is needed for complete BOD removal. Other nutrients such as iron or sulfur have been reported as limiting to activated sludge, but this is not common.

Signs of nutrient deficiency include: filamentous bulking (see Table 1); a viscous activated sludge which exhibits significant exopolysaccharide ("slime") when "stained" with India ink; and foam on the aeration basin which contains exopolysaccharide (which has surface active properties). One check for nutrient deficiency is to be sure that at least 1.0 mg/L total inorganic nitrogen (TIN = ammonia + nitrite + nitrate) and 0.5-1.0 mg/L ortho-phosphorus remains in the effluent at all times.

In systems treating mixed domestic and industrial wastes, only TIN and ortho-phosphorus should be used to calculate nutrient availability. Organically combined nitrogen and phosphorus (Kjeldahl nitrogen and total phosphorus) may not be hydrolyzed fast enough by the microorganisms in the activated sludge to keep pace with BOD use.

Low pH

The aeration basin pH should be maintained in the range 6.5 to 8.5. Low pH, <6.5, may cause the growth of fungi and fungal bulking. The aeration basin pH can be adjusted using caustic, lime or magnesium hydroxide.

Summary

Control methods for filamentous bulking are based on, first, confirmation that the problem is indeed caused by filaments (some are not) and, second, identification of the causative filament(s). This information leads to specific remedies that can be used, appropriate for the filament(s) involved.

Reference

Causes and Control of Activated Sludge Bulking and Foaming, Second Edition, D. Jenkins, M.G. Richard and G. Daigger, Lewis Publishers, Boca Raton, FL, 1993.

Part 2

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In this second part, physical and chemical filament control and the causes of activated sludge foaming and its control are presented.

Inert Material and Polymer Addition

There exist several methods of chemical addition to enhance activated sludge settling. Most used are synthetic, high molecular weight, cationic polymers alone or in combination with an anionic polymer that serve to overcome the physical effects of filaments on sludge settling. These are usually added to the MLSS as it leaves the aeration basin or to the secondary clarifier centerwell. Use of polymer does not significantly increase waste sludge production but can be quite expensive, up to $450. per million gallons treated. A polymer supply company should be consulted for selection of a polymer. Jar testing should be performed at your plant to determine the type of polymer needed and its dosage, which are quite plant specific.

In some instances, inorganic coagulants/precipitants such as lime or ferric chloride can be beneficial. These produce a voluminous precipitate that sweeps down the activated sludge, improving settling. Sludge production may be significantly increased if these are used. The weighting action of inert biological solids has also been used to aid sludge settling in activated sludge modifications such as the Hatfield or Kraus processes that recirculate anaerobic digester contents through the aeration basin. Clay and fiber addition have been used by some industries (e.g. papermills) to help sludge settling on a short-term basis.

Chlorination

Two toxicants, chlorine and hydrogen peroxide, have been used successfully to control filaments. Chlorine is the most widely used as it is relatively inexpensive and available on-site at most plants, and only this will be discussed here. Chlorination for bulking control is widespread, used by more than 50% of plants.

The goal of chlorination is to expose the activated sludge to sufficient chlorine to damage filaments extending from the floc surface while leaving organisms within the floc largely untouched. Filamentous and floc-forming bacteria do not appear to significantly differ in their chlorine susceptibility. Chlorine dosage is adjusted such that its concentration is lethal at the floc surface but is sublethal within the floc, due to chlorine consumption as it penetrates into the floc. This is analogous to "peeling an orange" and removing the filaments attached to its surface. Chlorination is not a cure-all for all activated sludge microbiological problems, as this will actually make problems worse if the problem is non-filamentous, e.g. slime bulking, zoogloeal bulking or poor floc development.

Chlorine can be applied from a chlorinator using chlorine gas feed or as a liquid hypochlorite. A separate chlorinator should be dedicated to bulking control and an independent rotameter and sampling point in this chlorine line is needed. The chlorine addition point is of most importance and should be at a point where the sludge is concentrated, raw wastes are at a minimum, and at a point of good mixing. Poor initial mixing results in the consumption of large amounts of chlorine without bulking control. Three common chlorine addition points are: (1) into the RAS stream at a point of turbulence (elbows in pipes; into the volute or discharge of RAS pumps; and into and below the liquid level in a riser tube of an airlift RAS pump); (2) directly into the final clarifier center well or feed channel; and (3) in an installed sidestream where the MLSS is pumped from and returned to the aeration basin. Chlorine addition to the RAS line(s) is the method of choice and most generally successful. Chlorine addition to the aeration basin does not work and only causes floc dispersion and system damage.

The two most important parameters are chlorine dosage and frequency of exposure of the activated sludge to chlorine. Chlorine dose is measured conveniently on the basis of sludge inventory in the plant (overall chlorine mass dose). Effective chlorine dosages usually are in the range 1-10 pounds chlorine/1000 pounds MLVSS inventory/day (2-4 should work). Chlorine dosage should be started low and increased until effective.

Most domestic waste plants can achieve a frequency of exposure of the activated sludge inventory to chlorine of three or greater times per day (the optimum) in the RAS line. The needed frequency is a function of the relative growth rates and efficiencies of kill of filamentous and floc-forming organisms. Success has been achieved at frequencies as low as one per day, however, not below this.

In plants with long aeration basin hydraulic residence times (usually industrial waste plants), the daily passage of solids through the RAS line is generally too low (<1/day) for successful bulking control using chlorine at this point. Here, most success has been achieved using multiple chlorine addition points such as the RAS line(s) and the final clarifier(s).

Chlorination controls filament extension from the floc surface and merely reduces the symptoms of bulking. Filaments will regrow rapidly, often with a vengeance, after termination of chlorination since the cause of the bulking has not been addressed.

Signs of overchlorination are a turbid (milky) effluent, a significant increase in effluent TSS, a loss of the higher life forms (protozoa), and a reduction in BOD removal. It is normal to see a small increase in effluent suspended solids and BOD5 when using chlorine for bulking control.

Microscopic examination of the activated sludge during chlorination is recommended to control chlorine application. Chlorine effects on filaments include, in order: a loss of intracellular sulfur granules (in those filaments that have these); cell deformity and cytoplasm shrinkage; and finally filament lysis. For filaments that don't have a sheath, the sludge SVI usually declines within a few days of chlorine use, if the dosage and frequency requirements are met. For sheathed filaments, the sheath is not destroyed by chlorine. Here, sludge settleability remains poor until the sheaths are washed out of the system by sludge wasting, which requires 1-2 sludge ages. Chlorine use for sheathed filaments should be stopped when mostly empty sheaths remain (60-80% of filaments) and not continued until the SVI falls, which can result in overchlorination.

Activated sludge foaming is caused mostly by two filaments: *Nocardia* spp. and *Microthrix parvicella* (there are other non-filament causes of foaming). Both of these filaments have three causes in combination: (1) high grease and oil; (2) longer sludge age; and (3) low oxygen conditions or septicity.

Nocardia appears to be favored at higher aeration basin temperature and *M. parvicella* at lower temperature. Antifoam chemicals are not effective to control this type of foam, due to the physical interlocking of the filaments in the foam. RAS chlorination is of limited use in *Nocardia* foam control, but is more useful for *M. parvicella*. This is because *Nocardia* is found mostly within the floc, and the higher chlorine dosages needed to get at *Nocardia* may destroy the activated sludge floc. For *Nocardia* foams, surface spraying of a 50 mg/L chlorine solution can be effective.

Both these filaments grow on grease and oil. Systems that lack primary clarification (the main grease and oil removal mechanism) appear to suffer more foaming problems. Communities with enforced grease and oil ordinances appear to suffer less from foaming problems. Also, treatment of septage, which contains substantial grease and oil, has been associated with foaming problems.

There is some relationship of foaming by these filaments and low oxygen concentration and septicity in the system. Septicity appears to cause the breakdown of grease and fat to organic acids, which specifically favor these filaments. Successful foam control may need control of septicity and low oxygen conditions.

The most used control method for foaming is to reduce the system MCRT. *M. parvicella* can usually be controlled by a MCRT reduction to between 8 and 10 days. *Nocardia* can often be controlled by MCRT reduction to <8 days, but this is variable and somewhat temperature dependent. Plants in warmer climates have had to reduce the MCRT to <3 days for *Nocardia* control.

Many foams reach problem levels because they are not removed and buildup on the surface of aeration basins and final clarifiers. Needed are enlarged surface scum traps and forceful water sprays to carry this material out of the aeration basin or the clarifier. Foam should be removed entirely from the system and not recycled back into the plant (for example, into the headworks). Foam disposal into aerobic or anaerobic digesters can result in foaming there, so this should be avoided.

Summary

Filamentous bulking and foaming problems require the identification of the causative filament(s). This information leads to specific remedies, appropriate for the filament(s) involved. Short term control methods are often used to quickly stop a bulking problem. However, the best approach is to investigate the long term control methods suitable for your plant to arrive at long-term, trouble free operation.

Reference

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