Brief review on:

Filamentous foaming and bulking in activated sludge treatments: causes and mitigation actions

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June 2017
Abstract
Foaming and bulking phenomena in activated sludge systems are associated with the presence of a variety of filamentous bacteria. High amount of filamentous bacteria can affect the settleability of the sludge and the whole biological process. Specific and non-specific strategies can be applied to control and eliminate bulking and foaming. Wrong actions, such as changing operative condition without knowing the real cause of bulking and foaming, should be avoided. In this technical report, the most common operating problems in activated sludge systems and their control strategies and methods are discussed.

1. Introduction
The activated sludge process is a widely applied treatment technique to remove biodegradable pollutants. It is a common aerobic treatment which reduces the amount of organic matter from wastewater by using a variety of microorganisms (Pal et al., 2014). These microorganisms include many species of virus, bacteria, protozoa, fungi, metazoan and algae. In this complex, bacteria are usually about 95% of the total microbial population (Jenkins et al., 1993). Under normal conditions in the activated sludge, bacteria occur either individually, in small chains or clumps. Under adverse conditions however, bacteria that grow in filaments begin to form longer chains called filamentous bacteria. When the filaments are present in too great numbers, the sludge flocs are bound together by the filaments in a network structure (Madoni et al., 2000). Filaments can become dominant in the wastewater treatment system due to a variety of conditions, and in that case the activated sludge processes suffer from biological sludge bulking or foaming (Martins et al., 2004). Sludge bulking is a common problem in activated sludge processes (Krhutkova et al., 2002). It is a condition in which, due the overabundance of filamentous organisms, the sludge becomes very light, experiences a volume increase, and will not settle. The filamentous bulking effects are: high Sludge Volume Index (SVI), low solid concentration in the return and waste sludge and hydraulic overloading of solids handling systems (EPA, 1987). Sludge foaming is a condition in which various kinds of foam appear on the surface of the aeration and clarification tanks. A more troublesome foam, heavy and brown, can accumulate on the surface of the aeration tank during normal operation, migrate to the clarification tank, and be discharged with the effluent (EPA, 1987).

Filamentous bulking and foaming can be controlled by various specific and nonspecific strategies. Specific control strategies are preferable as they are selective and preventive methods which have as objective the growth of floc-forming bacteria structures, whereas nonspecific methods tend to provide only temporary solutions (Noutsopoulos et al., 2006). In this technical report, the most common operating problems in activated sludge systems and their control strategies and methods are discussed, as well as typical wrong remediation procedures.

2. Filamentous organisms
Filamentous bacteria are generally present in the activated sludge system. Filamentous bacteria are characterized by their long, thread-like shape. By the systematic observation of several samples from different activated sludge treatment plants, 29 different filamentous bacteria, grouped in three clusters, have been identified (Eikelboom, 1975). As a matter of fact, filaments can aid in the settling of the sludge by creating a backbone for floc-forming bacteria to attach to. It is only when they are present in excessive amounts that they can cause operating problems. An excessive concentration of filaments extending from the floc into the bulk fluid can cause bulking. Some filaments can also cause foaming upon aeration. The foam caused by filamentous bacteria can be very stable and compact.
over the water surface. The following figures show typical foaming and bulking filaments and their effect in the wastewater plants.

### Typical foaming-forming bacteria

<table>
<thead>
<tr>
<th>M. parvicella</th>
<th>Nocardia</th>
<th>Type 1863</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="source1.jpg" alt="Image" /></td>
<td><img src="source2.jpg" alt="Image" /></td>
<td><img src="source3.jpg" alt="Image" /></td>
</tr>
</tbody>
</table>

**Effect**

![Image](source4.jpg)

Source: [1]  
Source: [2]  
Source: [3]

### Typical bulking bacteria

<table>
<thead>
<tr>
<th>Thiothrix</th>
<th>Nostocoida linitcola II</th>
<th>Type 0092</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="source5.jpg" alt="Image" /></td>
<td><img src="source6.jpg" alt="Image" /></td>
<td><img src="source7.jpg" alt="Image" /></td>
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</tbody>
</table>

**Effect**

![Image](source8.jpg)

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Source: [6]  
Source: [7]  
Source: [8]
3. Causes of filamentous bulking and foaming

Foaming and bulking problems in activated sludge systems are associated with the presence of a variety of filamentous bacteria. Filamentous bulking may occur when the sedimentation zone of the secondary settling tank is full of poorly compacted sludge. When such a spontaneous escape of biomass from the system is observed, it is usually too late for remedial actions. If the bulking is not severe, and if the sludge blanket is far enough under the water surface in the secondary settling tank, the effluent is crystal clear because all micro-flocs are enmeshed and trapped in the filamentous network (Wanner, 1994). Filamentous bulking is thus a typical problem of poor activated sludge compaction which results in:

- Low return and waste activated sludge concentrations;
- Difficult in maintaining the required activated sludge concentration in reaction basins;
- Poor sludge dewaterability in sludge-handling operations;
- Hydraulic overloading of sludge-handling facilities.

Different conditions which can promote the growth of filamentous bacteria are listed in Table 1.

<table>
<thead>
<tr>
<th>Enabling conditions</th>
<th>Indicative filament types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low DO concentration</td>
<td>Type 1701</td>
</tr>
<tr>
<td>Low F/M</td>
<td>Type 0041</td>
</tr>
<tr>
<td>Septicity</td>
<td>Thiothrix I and II</td>
</tr>
<tr>
<td></td>
<td>Nostocoida limicola I,II,III</td>
</tr>
<tr>
<td>Grease and Oil</td>
<td>Nocardia spp.</td>
</tr>
<tr>
<td></td>
<td>Microthrix parvicella</td>
</tr>
<tr>
<td></td>
<td>Type 1863</td>
</tr>
<tr>
<td>Nutrient Deficit</td>
<td>Type 021N</td>
</tr>
<tr>
<td></td>
<td>Thiothrix I and II</td>
</tr>
<tr>
<td></td>
<td>Nostocoida limicola III</td>
</tr>
<tr>
<td>Low pH</td>
<td>Fungi</td>
</tr>
</tbody>
</table>

Table 1: Causes of Filament growth in Activated Sludge (Richard, 2003).

The wastewater containing slowly biodegradable organic material like lipids, proteins, and fats, being preferred by filamentous microorganisms, are responsible for foaming (Jenkins et al., 1993).

Biological foaming by foam-forming filamentous microorganisms is a complex of physical-chemical and biochemical processes leading to the stabilization of a three-phase system, air-water-microbial cells. The stabilization of biological foams results from the following features of foam-forming filaments (Wanner, 1994):

- Foam-forming filamentous microorganisms produce extracellular materials like lipids, protein and carbohydrates;
- Contrary to other filaments and floc-formers, the cell walls of foam-forming microorganisms are strongly hydrophobic.

The foaming organisms can attach to the hydrophobic substrates of fats, oils and greases and use to grow by consuming them as a food source.
A brief list of activated sludge foam types and their causes is given in Table 2. The use of microscopic examination can readily diagnose most of these, particularly when filaments are involved.

<table>
<thead>
<tr>
<th>Foam Description</th>
<th>Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. White, frothy, billowing foam</td>
<td>Once common due to nonbiodegradable detergents</td>
</tr>
<tr>
<td>2. Pumice-like, grey foam</td>
<td>Excessive fines recycle from other processes</td>
</tr>
<tr>
<td>3. Thick sludge blanket on the clarifier</td>
<td>denitrification</td>
</tr>
<tr>
<td>4. Thick, pasty or slimy, greyish foam (only industrial system)</td>
<td>Nutrient-deficit foam</td>
</tr>
<tr>
<td>5. Thick, brown, stable foam enriched in filaments</td>
<td>Caused by Nocardia, Microthix or Type 1863</td>
</tr>
</tbody>
</table>

Table 2: Description and causes of Activated Sludge Foam (Richard, 2003).

The formation of stable foam in the aeration basins of activated sludge plants can create a wide range of operational problems (Warren, 1994):

- Foam generated during aeration may escape from aeration basins and cause aesthetic problems and danger for operators;
- The foam penetrates from the aeration basin to the secondary settling tank, increasing the concentration of suspended solids and the value of BODs in the secondary effluent.

**4. Sequential Anaerobic-Aerobic Systems**
The typical “wrong actions” taken when the foam exceeds in the aeration basin and the secondary settling are discussed below:

- Identification of the filamentous bacteria causing foaming/bulking only in the mixed liquor.
  This is one of the **worst actions usually taken** when the aeration basin and the secondary settling are completely covered by foam. The foam is not caused only by *Nocardia* but there are several filamentous bacteria that cause foaming/bulking. No corrective actions should be taken without a microscopic foam investigation. It is possible that the abundance of filamentous bacteria in the foam is different than the one observed in the mixed liquor.

- Identification of filamentous bacteria using only the conventional method.
  In some cases, it could be enough to use the conventional classification method proposed by Eikelboom (1975), while in other cases a methanogenic analysis and FISH technique would be needful.

- Do not identify in the first instance which filamentous bacteria are causing foaming/bulking.
  If the operators do not identify the filamentous bacteria, it will be impossible to implement any corrective actions.

- Change operational conditions without considering the biological inertia of the system.
Changes in operation conditions simultaneously, such as: modification of sludge age, organic load and oxygen concentration is not the best strategy. The biological system needs time to adapt itself to the new configurations.

- Change operational conditions when the effluent meets the discharge limits. When foaming/bulking problems are present in the plant, meanwhile the effluent meets the discharge limits in terms of parameters concentration, and knowing that the problems do not increase, the best choice is to do not do anything.

5. Practical control strategies and methods

Maintenance of optimum levels of filamentous microorganisms in activated sludge is necessary to ensure efficient settling. In any case, proper treatment plant design is the best means of preventing the excessive growth of filamentous microorganisms that cause bulking or foaming. On the other hand, sludge bulking must be corrected by adjustments in operations or by addition of chemicals.

5.1 Bulking control

A good general approach to controlling bulking problems is:

- Identify the filamentous microorganisms causing the bulking;
- Verify the dissolved oxygen concentration;
- Check if the management of the preliminary treatment is adequate;
- Check if the concentration of MLSS is suitable;
- Make sure that the mixing in the aeration basins is good;
- Determine the probable cause of bulking;
- Verify the operational process conditions.

To control sludge bulking there are two strategies that can be followed, non-specific and specific methods.

Non-specific methods consisting in chemicals addition are reported below:

- Chlorination.
  Widely used in the USA, but limited in Europe due the potential formation of by-products, such as halogenated organic compound. The goal of chlorination is to expose the activated sludge to sufficient chlorine in order to damage the filaments extending from the floc surface while leaving organisms within the floc largely untouched. Chlorine may be added at three points of the system: directly into the aeration tank, at the outlet point where the mixed liquor is withdrawn from the aeration tank or into the return activated sludge stream (RAS). It is well known that Polyaluminum chloride (PAX) is one of the most efficient coagulants. With the reduction of foaming potential, PAX addition also helps improve the settling properties of activated sludge. The microscopic analysis of sludge samples proved that after PAX addition, flocs appeared more compact and dense (Mamais et al., 2011). Chlorination must be used only when the target value of SVI is regularly exceeded. Microscopic examination of the activated sludge during chlorination is recommended to control chlorine application. The application of chlorine should be stopped when about 70% of the cells are damaged or missing a filament.
• Hydrogen peroxide.
The use of hydrogen peroxide (H₂O₂) has been proven effective when dosed to the RAS line. It attacks the sheath of the filamentous microorganisms, destroying their shape. It is possible that as H₂O₂ kills filamentous microorganisms, it also releases oxygen. If bulking was a result of low DO, this could provide additional operational improvements.

Non-specific methods do not remove the causes of the excessive growth of filamentous microorganisms and their effect is only transient (Martins et al., 2004). On the other hand, specific methods are preventive methods that have as goal to favor the growth of floc-forming bacteria structures at the expense of filamentous bacteria structures (Martins et al., 2004). These methods allow a permanent control of bulking in activated sludge systems. These methods are discussed below:

• Use of a selector.
A selector is defined as the initial part of a biological reactor where RAS and influent wastes are mixed before the aeration basin to strengthen the floc-forming bacteria against the filamentous microorganisms. Selectors were quickly installed in full-scale activated sludge systems and are still the most applied engineering tool for the prevention of sludge bulking phenomena. The selector could be aerobic, anoxic or anaerobic.

• Mean cell residence time (MCRT).
MCRT is a parameter that describes the average time in days that microorganisms stay in the activated sludge process (Pal et al., 2014). It was demonstrated that the reduction of sludge age (between 8 and 10 days) is an efficient method to suppress M. parvicella growth (Noutsopoulos et al., 2006). On the other hand, for Nocardia control, the sludge age should be reduced to 3 days (Jankins at al., 1993).

• Control of DO concentration.
Low aeration in basins (therefore low DO) leads to bulking by several types of filaments: S. natans, type 1701, and H. hydrossis. The DO concentration in the bulk solution around the flocs has to be high enough to maintain an aerobic floc interior. Since oxygen moves into the floc by diffusion, its bulk concentration needs to be high enough to reach the floc center before becoming deleted. A bulk solution of 4.0 mg/L or more has been needed to prevent these filaments in some industrial wastewater systems operated at high F/M values of 0.5 (Richard, 2003).

• Reduce septicity in the collection system.
Septicity is the term used to describe the condition where the wastewater becomes anaerobic and anaerobic bacteria ferment organic matter to organic acids. Septicity can occur ahead of the plant or in the collection system such as lift stations. Influent wastewater septicity can be treated by pre-aeration, chemical oxidation or chemical precipitation (Richard, 2003).

• Change in F/M conditions.
Low F/M conditions, usually below an F/M of 0.15, can cause the growth of different filaments, such as type 0041, type 0675, type 1851 and type 0803. Control of low F/M
bulking can be achieved by reducing the aeration basin MLSS concentration. Lowering the MLSS concentration may not be suitable for many plants, as this may cause the loss of nitrification and increase the waste sludge production. Any change in the operation which effectively increases the substrate concentration available for the activated sludge and introduces batch or plug-flow characteristics to the aeration basin will help against low F/L bulking (Richard, 2003).

5.2 Foaming control
Several different types of foam have been observed in activated sludge treatment systems (Table 2). Some are normal and harmless, while others are symptoms of operational problems and need to be controlled. When considering foam problems, the question must be asked, “Is the amount of foam that exists a problem?”.

Following the classification reported in Table 2, the possible corrective actions are listed below.

1. White, frothy, billowing foam:
   White billowy foam is caused by high concentrations of surfactants such as detergents. This foam can accumulate on the aeration tank and can even be blown around by the wind. The solution is usually applying oxidative pressure by increasing the solids retention time in the aerobic reactor.

2. Pumice-like, grey foam:
   This foam is usually due to solids returned from sludge processing. It may be due poor solids capture from a belt sludge press or form digester supernatant return that contains excess solids. The key to improvement of this condition is to improve the solids capture in the sludge processing scheme.

3. Thick sludge blanket on the clarifier:
   Denitrification processes in the secondary clarifier is the most probable cause of this type of foaming. To remedy this situation, an increase in sludge wasting rates by no more than 10% per day, will help reduce or eliminate the degree of nitrification. Waste sludge rates should be maintained to keep the process within proper MCRT and F/M ratios.

4. Thick, pasty or slimy, greyish foam:
   A thick, greyish slimy foam, caused by nutrient deficit. It is often related to a slime bulking condition. The solution usually involves addition of the limiting nutrient, such as nitrogen and phosphorus.

5. Thick, brown, stable foam rich in filaments:
   Sample analysis of sludge from systems containing heavy brown foam has revealed large numbers of the filamentous microorganism *Nocardia* and *M. parvicella*. The causes of *Nocardia* and *M. parvicella* growth in activated sludge are not well understood, however, researchers have found correlations between high *Nocardia* and *M. parvicella* counts and various sludge parameters. These include high sludge age, oil and grease in the wastewater, low F/M ratio and high SS concentrations. Control of *Nocardia* and *M. parvicella* foaming is difficult. Chemical antifoaming agents have not proven to be generally effective, probably because they act on chemical surfactants and not on a solids-stabilized foam. Many plants reduce aeration in order to control foaming, but process
performance may suffer if oxygen becomes limiting. Physical control of foam is most widely practiced using enlarged surface scum traps and water sprays. Foam should be removed entirely from the system and not recycled back into the plant. A reduction in the grease and oil contents of the wastewater is needed. These filaments are usually controlled by a reduction of the system sludge age, septicity and DO concentration. It is to be noted that increasing the DO concentration causes more foam formation, due to the physical action of the additional air present. Many operators reduce aeration when foaming occurs to reduce the foam, but this only causes more filament growth in the long term (Richard, 2003).

6. Conclusions
The main conclusions of this brief review are the following:

• Foaming and bulking caused by filamentous microorganism are often present in wastewater treatment plants;
• Generally, the right amount of filaments improves sludge settleability;
• Even if foam is present in the aeration basin and secondary clarifier surface, the quality of the effluent could reach the normative limits, nevertheless, this is always a risk factor;
• Different operational conditions can cause foaming and bulking;
• In order to apply corrective actions it is necessary to conduct a previous deep investigation about the filaments responsible of foaming and bulking phenomena;
• It is essential to know the current process conditions of the wastewater treatment plant;
• Non-specific methods such as chlorination are often used to quickly stop a bulking problem, however the best approach is to assess the specific methods suitable for the problem that is occurring, because non-specific methods do not provide a long-term solution. For example, if there is an imbalance of the nutrient substance, the problem will persist and come back as soon as the corrective method is removed;
• Specifically, for the textile sector, when bulking is present, chlorine is dosed in the sludge return at a rate of up 12 g of chorine per ton of dry sludge.

References