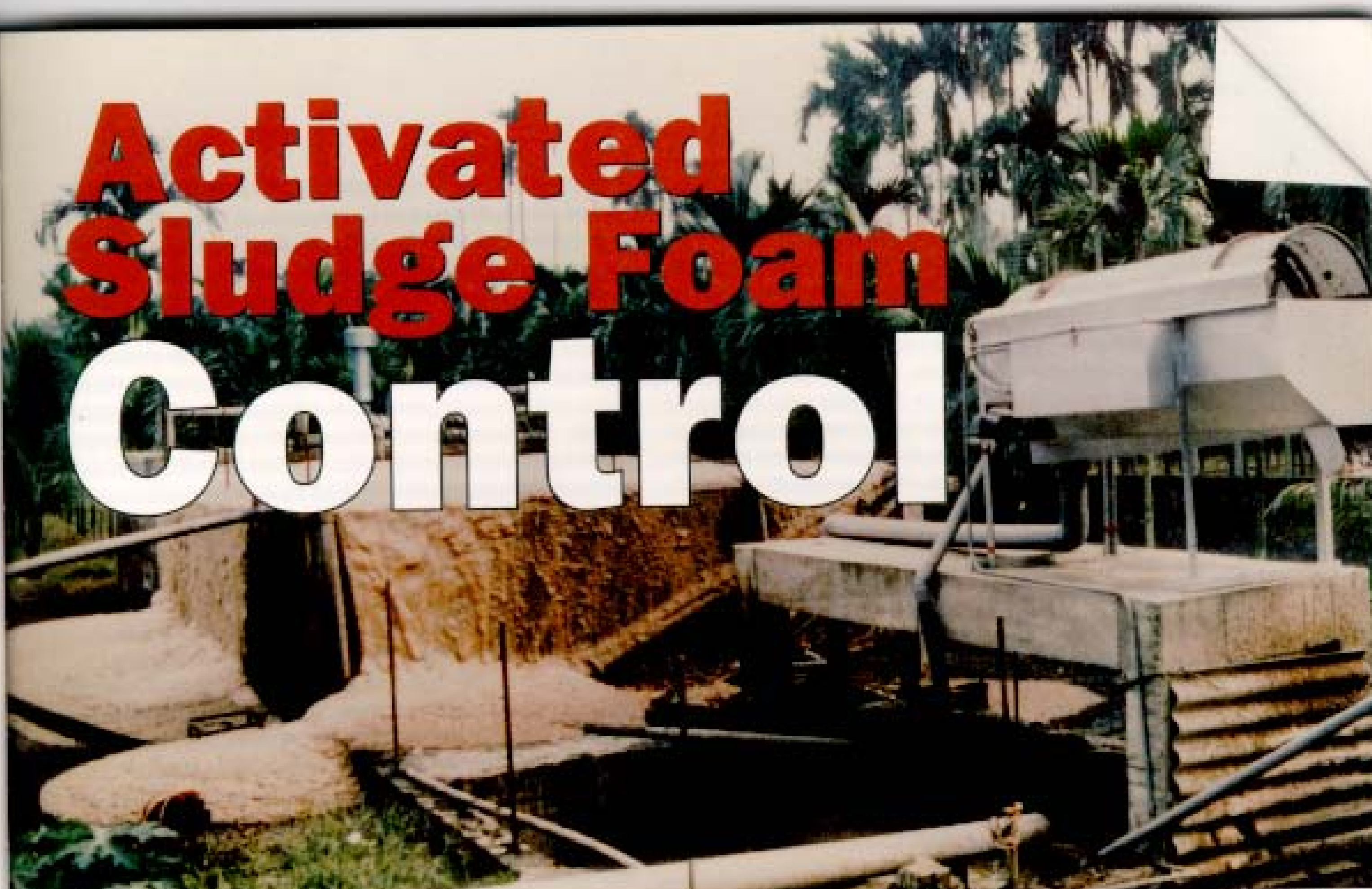
Activated Sludge Foam Control



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Foaming at an activated sludge plant.

Literature review finds little consensus, contradictory information for treatment plant operators facing foam problems caused by filamentous microorganisms

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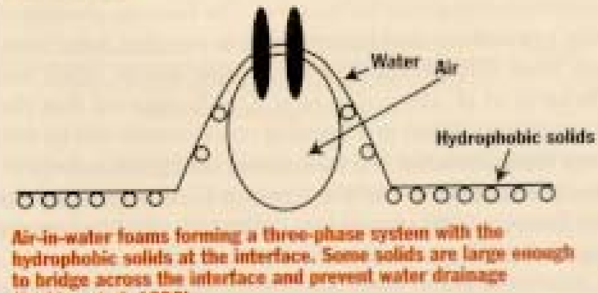
An extensive literature review revealed that little consensus exists on how best to control foaming in activated sludge treatment processes and that, in fact, information on the subject often is contradictory. The only things experts seem to agree on are that facility managers must understand what causes activated sludge foaming and that they need to quantify the intensity of foaming before choosing a particular control strategy.

Activated sludge foam is a dispersion of air in mixed liquor that forms a three-phase system with a clear liquid–air interface (see Figure 1, at right). The formation of foam in aeration basins and secondary clarifiers can be attributed to a number of causes, including the presence of such filamentous organisms as *Nocardia* spp., *Microthrix parvicella*, and Type 1863 (Jenkins et al. 1992; see Table 1, p. 19). Other causes include insufficient biomass during startup; slowly biodegradable surfactants, detergents, or oil and grease in industrial wastewater (nonbiological scum); and anoxic conditions in secondary clarifiers that cause settled sludge to rise with the nitrogen bubbles (rising sludge).

Activated sludge foaming caused by filamentous organisms often occurs when the microbes' hydrophobic cell surfaces form flocs that attach to air bubbles in the aeration basin. The abundance of branched hyphae in *Nocardia* spp. and the extended lengths of *M. parvicella* form a net that enables them to trap air bubbles and oil droplets. As these materials build up, a thick, brown viscous foam appears (Lemmer 1986). The foam produced by Type 1863 usually is whitish-grey in colour and collapses easily (Jenkins et al. 1992).

Foaming often disrupts the smooth operation of activated sludge plants and can even cause aeration basin overflows. In covered aeration basins, *Nocardia*-type foams can accumulate to such an extent that they hinder influent flow to the basin by lowering the hydraulic gradient. The effluent carries with it increased solids and increased biochemical oxygen demand. In hot climates, foam floating in the aeration basins putrefies rapidly and causes odours.

FIGURE 1



Air-in-water foams forming a three-phase system with the hydrophobic solids at the interface. Some solids are large enough to bridge across the interface and prevent water drainage (Jenkins et al. 1992)

FILAMENTOUS MICROORGANISMS

Microbiology. The filamentous microorganisms that cause foaming essentially are bacteria in the oxic organotrophic class, or "obligate aerobes." Many are classified as actinomycetes, which exhibit some metabolic and growth features similar to fungi (micromycetes) (Wanner 1994). They are able to use slowly degradable complex organic substrates, and their filaments form mycelia.

Among the actinomycetes is *Nocardia* spp., gram-positive, partially acid-fast and branched filamentous organisms. The filaments fragment into bacillary and coccoid elements, giving a pleomorphic appearance (Slack and Gerencser 1975). Jenkins et al. (1992) describe *Nocardia* spp. as irregularly bent, short filaments, 1.0 μm in diameter and 5 to 30 μm long, Neisser negative, and Neisser positive granules, with branched mycelium often observed. Their optimal temperature range for growth is 10°C to 50°C, with 37°C being ideal. Lemmer (1986) classifies *Nocardia* spp. as "former soil inhabitants" that are adapted better than their competitors to the condition of dryness and ultraviolet radiation prevailing in the floating foam fraction of activated sludge.

The other major foaming filamentous organism, *M. parvicella*, has been described by Jenkins et al. (1992) as irregularly coiled filaments, 0.6 to 0.8 μm in diameter and 50 to 200 μm in length, found in tangles in the floc or as loose "patches" in activated sludge.

Causes. Literature on the causes of foaming, particularly *Nocardia* foaming, is quite confusing (Pitt and Jenkins 1990) and often contradictory. To date, few detailed investigations into foaming have been performed (Pujol et al. 1991). Minnikin (1982) was the first to attribute the hydrophobic property of foaming-causing filamentous organisms to the presence of mycolic acid in their cell walls. Many authors assume that the presence of oil and grease in primary effluent is the main cause of foaming. Although the growth rate of *Nocardia* spp. is much faster on hydrophobic substrates, such as oil and Tween 90, than on hydrophilic substrates, such as glucose, this assumption has not yet been confirmed for all activated sludge plants, because foaming occurs even when primary effluent is totally free of oil and grease (Jenkins et al. 1992).

Ho and Jenkins (1991) demonstrated that poorly biodegradable surfactants increase the amount and stability of foam produced by *Nocardia* and that *Nocardia* foaming increases when foam-trapping devices are used in the aeration basin and secondary clarifiers. Blackall et al. (1991a) failed to obtain conclusive results correlating surface tension with foaming and say the theory that surfactants enhance actinomycete foaming may be incorrect. The foaming problem is even aggravated when trapped foam is recycled to the aeration basin through the return activated sludge (RAS) line (Richards et al. 1990). Cha et al. (1992) reported that the *Nocardia* population in a trapping configuration can be five times higher than that in a nontrapping configuration and that the optimum pH for *Nocardia* growth is 6.5. However, Hiraoka and Tsumura (1984) report that the growth rate for *Nocardia* at pH 6.5 is 66% of the growth rate at pH 7.0.

Khan et al. (1991) obtained results linking activated sludge foaming to the hydrophobicity of the sludge solids and concluded that the nature of surface chemistry (surface energy, surface charge, presence of biopolymers, etc.) is significant in determining the stability of the resulting foam. A study by Foot et al. (1993) into the structure of stable activated sludge foams using cryogenic electron microscopy and rheology revealed that activated sludge foams are air bubbles held in a dense matrix of filamentous microbes. Rheology measurements showed that foams have an appreciable viscosity that varies with the concentration of solids they contain. A significant difference was noted between the viscosities of foam and nonfoaming activated sludge that had been thickened to similar solids concentrations (Foot et al. 1993).

The commonly agreed upon cause of *Nocardia* growth and foaming is a low food-to-microorganism (F:M) ratio, or long mean cell residence time (MCRT), and higher temperatures. Pipes (1978) reports that an MCRT of 9 days or more at a temperature of at least 18°C is necessary for *Nocardia* to dominate the activated sludge. This has been supported by the findings of Pitt and Jenkins (1990), although Dhaliwal (1979) found no relation between *Nocardia* growth and MCRT.

Hiraoka and Tsumura (1984) report that fine bubbles are necessary to cause severe foaming problems. [About 0.44 mL of air or nitrogen is required to allow flotation of 1 mg of dry sludge (Lemmer 1986).] However, Sezgin and Karr (1986) report that some plants with coarse bubbles and mechanical aerators also experience foaming problems.

QUANTIFYING FOAMING INTENSITY

Vega-Rodriguez (1983) and Pitt and Jenkins (1990) have reported methods for rapid assessment of *Nocardia* populations by filament counting. This technique basically involves counting the number of branched Gram-positive filaments longer than 1 μm in a diluted sample of mixed liquor suspended solids (MLSS), with the count being expressed as the number of intersections per gram of volatile suspended solids.

Fujita et al. (1994) devised a method for enumerating *Nocardia amarae* in foaming activated sludge using n-octadecane as a carbon source. Mori et al. (1992) proposed an index, "foam production potential," to quantify foaming intensity. Foam production potential is defined as the amount of scum (by weight, expressed in milligrams) produced from 1 L of mixed liquor after 30 minutes. Foot et al. (1994) proposed three foaming coefficients — "stability," "foamability," and "production" — to describe the physical nature of activated sludge foams.

Pretorius and Laubscher (1987) proposed a Foam Index (FI) to quantify the intensity of foaming. Determining FI requires extensive diffused aeration of the mixed liquor until all potential scum floats. The FI is then expressed as the ratio (in percent) of the mass of purified scum recovered through selective flotation to the original suspended solids content of the mixed liquor.

Blackall et al. (1991a) proposed a qualitative method of rating foaming intensity based on selective flotation. This method is easier and faster and gives a qualitative measure of foaming intensity in terms of a foam rating between 0 and 7. The rating is calibrated according to the stability of the foam, with 0 indicating insignificant or no foam, and 7 representing dense, stable foam.

FOAM-CONTROL STRATEGIES

One of the most common foam control practices is to reduce MCRT — typically to less than 5 days — to washout *Nocardia*. This approach has been met with a good degree of success (Richards et al. 1990 and Pitt and Jenkins 1990). A survey conducted by Pitt and Jenkins found that activated sludge plants in the United States have about a 75% success rate in controlling foam by reducing MCRT. When the foam is recycled in the RAS line, the beneficial effects of reducing MCRT often are observed much later and at an MCRT much shorter than that at which foaming initially occurred (Gasser 1987). Therefore, when MCRT is manipulated to control foaming, the washout MCRT must be achieved for all activated sludge microorganisms.

Chlorinating MLSS or RAS also was found to be quite effective by Pitt and Jenkins (1990) and Pujol et al. (1991), who conducted an exhaustive survey of foam control methods used at activated sludge plants in France. Results of laboratory-scale toxicity tests conducted by Wong and Chung (1993) indicate that chlorination can successfully control *Nocardia* foaming in activated sludge. Their results show that treating RAS with 10 mg/L of hypochlorite for a shorter period (5 days) can control foam effectively without significantly affecting chemical oxygen demand removal or the sludge volume index (SVI).

Richards et al. (1990) report that selective foam wasting (SFW) is effective in eliminating *Nocardia*. In this approach, MCRT is first increased along with the aeration rate and temperature to enhance *Nocardia* growth. As *Nocardia* overflows from the aeration basins, it is collected in separate chambers and then wasted (not recycled through the RAS line). The *Nocardia* population can be completely eliminated at an MCRT of 20 days. The SFW approach is particularly useful where nitrification is necessary, although it contradicts past experience that high MCRT favours *Nocardia* growth. Jenkins et al. (1992) suggest that, in this case, wastewater contained an industrial waste with a slowly biodegradable surfactant that could only be degraded at a longer MCRT.

Pretorius and Laubscher (1987) suggest the use of selective flotation to control foaming. Cha et al. (1992) report that using aerobic selectors ahead of the aeration basin is effective in controlling *Nocardia* at an MCRT of 5 days, but not at an MCRT of 10 days or more. Anoxic selectors have been found to be effective in controlling *Nocardia* at an MCRT of more than 12 days in nitrifying activated sludges (Cha et al. 1992). However, the use of any kind of selector to control *Nocardia* foaming in a full-scale plant with foam trapping and recycle has not yet been assessed fully (Jenkins et al. 1992).

A contact zone technique has been found promising in some cases (Pujol et al. 1991). Creating periodic anoxic or low dissolved oxygen (DO) conditions in the aeration basin for a certain period every day also has been found to be effective in controlling *Nocardia* foaming (Gasser 1987).

Nowak et al. (1986) showed that the growth of foam-causing filamentous bacteria, such as Type 1863, *Nocardia amarae*, and *M. parvicella*, can be controlled by regulating the DO concentration and feed pattern. The growth rate for Type 1863 is stimulated at DO concentrations of less than 0.9 mg/L, while *Nocardia* and *M. Parvicella* predominate at low F:M ratios (Nowak et al. 1986). Franz and Matsche (1994) report that a bacteria-enzyme additive also prevents foaming at activated sludge plants.

Repositioning aerators for maximum, uniform turbulence can substantially reduce the extent of foaming on the surface (Blackall et al. 1991b). A recent report by Shao et al. (1997) suggests that the use of cationic polymers (originally used to control bulking) can be effective in controlling *Nocardia* foaming problems. Two hypotheses have been proposed to explain the possible reasons for the antifoaming characteristics of the polymer (Shao et al. 1997): The cationic polymer serves to eliminate the foam-stabilizing effect of any cationic surfactant by neutralization and the cationic polymer enhances coagulation of *Nocardia* filaments by incorporating them into the suspended activated sludge floc and reducing their tendency to float.

Table 2 shows the various control strategies in use and their success in combatting foaming.

TABLE 1

The Severity of Foaming Problems in Some Countries

	United States	South Africa	Australia	France
Percent of activated sludge plants affected	66%	40%	50%	20%
Dominant foaming organism	*Nocardia* spp.	*M. parvicella*	*M. parvicella*	*M. parvicella*

(WANNER 1994)

TABLE 2

The Success Rate of Common Control Strategies in Some Countries

Control strategy	United States	Australia	France
Lower mean cell residence time	73%	57%	—
Chlorination	58%	20%	66%
Water spraying	88%	28%	—
Antifoaming agents	20%	—	57%
Lower aeration	60%	33%	—
Use of selectors	—	—	73%

(WANNER 1994)

FOAM INDEX: A VERSATILE WAY TO QUANTIFY FOAMING

The FI, originally proposed by Pretorius and Laubscher (1987) as the Scum Index, is based on the principles of selective flotation — the natural tendency of foaming activated sludge filamentous microorganisms to float rather than settle.

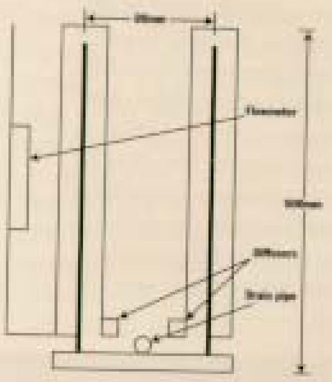
After complete selective flotation of the foaming elements as foam, the FI is expressed as

$$FI = \frac{\text{dry mass of purified foam recovered}}{\text{initial mass of suspended solids in the activated sludge sample}} \times 100\%$$

The FI technique for measuring foam intensity is fairly simple compared to other techniques. It also is reproducible at a plant site and allows for quick assessment of a foaming problem. In addition, the diffusers at the bottom of the apparatus simulate foaming conditions in the aeration tanks of activated sludge plants (see Figure 2, p. 20).

FIGURE 2

Setup for Foam Index Measurement



CONTROL STRATEGIES BASED ON THE FI

No universal quantitative index exists to measure foaming intensity, so developing and implementing practical approaches based on statistical and numerical analyses is difficult. Foam intensity indexes that have been used by researchers, including total extended filament length (TFEL), *Nocardia* filament count, and foam production potential, are of only theoretical interest because they are either time-consuming or offer plant managers little practical information in assessing foam problems.

The FI and its measurement, on the other hand, offer a fast, simple, and cheap technique for characterising foaming intensity at activated sludge plants. The process of selective flotation is what actually takes place in a full-scale aeration tank, so the FI is a more rational parameter that expresses the quantitative nature of selective flotation (foaming).

Once the parameter for quantifying the foaming is decided, analysing treatment data to assess a problem is simplified.

In an attempt to better understand the quantitative behaviour of foaming, data from a wastewater treatment plant can be analysed statistically and correlated against the FI. Major treatment parameters that affect the nature of foaming can be identified via the statistical technique for a nonkinetic model formulation.

The four essential phases of the statistical analysis are

- sampling analysis to measure FI (dependent variable);
- statistical screening to broadly identify potential foam-causing parameters;
- statistical modelling to form expression(s) that adequately depict the quantitative nature of foaming (known as the foaming function); and
- taking the statistical model as reference, performing feasible optimization analyses to control (minimize) the foaming function.

The plant-specific statistically significant model obtained in Step 3 would be of the form

FI = function { DO, pH, F:M, MCRT, ...}.

This model is known as the foaming function. Once the foaming function has been identified for a specific activated sludge plant, the problem of controlling foaming can be stated as a programming problem:

Minimize : foaming function,

Subject to : parameter constraints (range inequalities) and equalities.

Depending on the nature of the foaming function, the programming can be solved by some suitable algorithm (simplex algorithm if the foaming function is linear, or restricted search methods for nonlinear functions).

CONCLUSIONS

The literature review revealed the general inconsistencies that prevail regarding the control of activated sludge foaming and the need for a commonly agreed upon parameter that adequately defines the quantitative nature of foaming. The FI has been described as a versatile parameter that quantifies foaming intensity.

The FI is not being suggested as a universal solution to the foaming problem, but as a diagnostic tool to help plant managers derive a suitable control strategy to deal with foaming problems in their plants. A commonly agreed upon index also can make it easier for researchers throughout the world to compare the vast amount of treatment data available on foaming and for plant managers to conduct system-specific modelling analysis of the foaming phenomenon.

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REFERENCES

Blackall, L.L., A.E. Harbers, P.F. Greenfield, and A.C. Hayward (1991a), "Activated sludge foams: effects of environmental variables on organism growth and foam formation," *Environmental Technology*, Vol. 12, p. 241.

Blackall, L.L., A.E Harbers, P.F. Greenfield, and A.C. Hayward (1991b), "Foaming in activated sludge plants: a survey in Queensland, Australia, and an evaluation of some control strategies," *Water Research*, Vol. 25, No. 3, pp. 313–317.

Cha, D.K., D. Jenkins, W.P. Lewis, and W.H. Kido (1992), "Process control factors influencing *Nocardia* populations in activated sludge," *Water Environment Research*., Vol. 64, pp. 37– 43.

Dhaliwal, B.S (1979), "Nocardia amarae and activated sludge foaming," *Journal of the Water Pollution Control Federation*, Vol. 51, No. 2, pp. 344–350.

Foot, R.J., E. Kocianova, C.F. Forster, and A.J. Wilson (1993), "An examination into the structure of stable foams on activated sludge plants," *Journal of Chemical Technology and Biotechnology*, No. 56, p. 21.

Foot, R.J., E. Kocianova, and C.F. Forster (1994), "Systematic activated sludge bulking and foam control," *Water Science & Technology*, Vol. 29, No. 7, p. 213.

Franz, A. and N. Matsche (1994), "Investigation of a bacterial enzyme additive to prevent foaming in activated sludge plants," *Water Science and Technology*, Vol. 29, No. 7, p. 281.

Fujita, M., K. Iwahori, and H. Taki (1994), "A novel method of enumerating *Nocardia* amarae in foaming activated sludge," *Journal of Fermentation and Bioengineering*, Vol. 77, No. 6, p. 674.

Gasser, J. (1987), "Control of *Nocardia* scum in activated sludge by periodic anoxia," technical note, *Journal of the Water Pollution Control Federation*, Vol. 59, p. 914.

Hiraoka, M. and K. Tsumura (1984), "Suppression of actinomycete scum production — a case study at Senboku wastewater treatment plant, Japan," *Water Science & Technology*, Vol. 16, pp. 83–90.

Ho, C.F. and D. Jenkins (1991), "The effect of surfactants on *Nocardia* foaming in activated sludge," *Water Science & Technology*, Vol. 23, p. 879.

Jenkins, D., M. Richards, and G. Daigger, *Manual on the Causes and Control of Activated Sludge Bulking and Foaming*, 2nd Ed. Boca Raton, Fla., USA: Lewis Publishers, 1992.

Khan, A.R., E. Kocianova, and C.F. Forster (1991), "Activated sludge characteristics in relation to stable foam formation," *Journal of Chemical Technology and Biotechnology*, Vol. 52, p. 382.

Lemmer, H. (1986), "The ecology of scum-causing actinomycetes in sewage treatment plants," *Water Research*, Vol. 20, No. 4, pp. 761–763.

Minnikin, D.E. (1982), in (ed.) C. Ratledge and J. Stanford, *The Biology of the Mycobacteria*, Vol. 1. London: Academic Press, 1982, pp. 95–184.

Mori, T., K. Itokazu, Y. Ishikura, F. Mishina, Y. Sakai, and M. Koga (1992), "Evaluation of control strategies for actinomycete scum in full-scale treatment plants," *Water Science*, Vol. 25, No. 6, p. 231.

Nowak, G., Brown, and A. Yee (1986), "Effects of feed pattern and dissolved oxygen on growth of filamentous bacteria," *Journal of the Water Pollututiion Control Federation*, Vol. 58, No. 10, pp. 978–984.

Pitt, P. and D. Jenkins (1990), "Causes and control of *Nocardia* in activated sludge," *Journal of the Water Pollution Control Federation*, Vol. 62, pp. 143–150.

Pretorius, R.L. and C.J. Laubscher (1987), "Control of biological scum in activated sludge plants by means of selective flotation," *Water Science & Technology*, Vol. 19, pp. 1003–1011.

Pujol, R., P.H. Duchene, S. Schetrite, and J.P. Canler (1991), "Biological foams in activated sludge plants: characterization and situation," *Water Research*, Vol. 25, No. 11, pp. 1399–1404.

Richards, T., P. Nungesser, and C. Jones (1990), "Solution of *Nocardia* foaming problems," *Journal of the Water Pollution Control Federation*, Vol. 62, pp. 915–919.

Sezgin M. and P.R. Karr (1986), "Control of actinomycete scum in aeration basins and clarifiers," *Journal of the Water Pollution Control Federation*, Vol. 58, No. 10, pp. 972–977.

Shao, Y.J., M. Starr, K. Kaporis, S.H. Kim, and D. Jenkins (1997), "Polymer addition as a solution to *Nocardia* foaming problems," *Water Environment Research*, Vol. 69, pp. 25–27.

Slack, J.M. and M.A. Gerencser, *Actinomycetes, Filamentous Bacteria: Biology and Pathogenecity*. Minneapolis, Minn., USA: Burgess Publishing Co., 1975, p. 111.

Vega-Rodriguez, B.A. (1983), "Quantitative evaluation of *Nocardia* spp. presence in activated sludge," M.S. thesis, Department of Civil Engineering, University of California, Berkeley, USA.

Wanner, J., *Activated Sludge Bulking and Foaming Control*. Chicago, Ill., USA: Technomic Publishing Co., 1994.

Joint task force of the Water Environment Federation and American Society of Civil Engineers, *Design of Municipal Wastewater Treatment Plants*, Vol. 1., p. 5, Alexandria, Va., USA: Water Environment Federation, 1991.

Wong, P.K. and W.K. Chung (1993), "Control of bacterial foaming in activated sludge process by chlorination," *Journal of Environmental Science and Health*, Vol. A28, No. 8, pp. 1615–1628.