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Project Summary

Effect of Aeration Basin Configuration on Bulking at Low Organic Loading

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Five series of experiments were carried out in laboratory-scale activated sludge systems (10.5 to 80 L) to investigate the effect of aeration basin configuration on possible causes and cures of bulking at low food/micro-organism ratios (F/M). Continuous-flow, laboratory-scale activated sludge units were operated on domestic sewage from the City of Richmond, California at low F/M. In continuous-flow, stirred-tank reactors (CSTR) (at the F/M range of 0.05 to 0.25g COD removed/g of total mixed liquor volatile suspended solids (TMLVSS) per day), bulking did not occur with a weak sewage feed (BOD_5 = 139 mg/L) and a total mixed liquor suspended solids (TMLSS) of 1.5 g/L. Supplementation of sewage by blending with raw sludge produced a stronger sewage (BOD_5 = 315 mg/L), which caused TMLSS to increase to 3.5 g/L. Bulking occurred in CSTR units and in 2-, 4-, 8-, and 16-compartment units. An aeration basin with an initial compartment of 1/32 of aeration basin volume prevented but did not cure bulking. An aeration basin with the initial compartments 1/74 of the total aeration basin volume prevented and cured bulking. Anoxia in an aeration basin with two initial compartments each 1/64 of total aeration basin volume did not help to cure bulking. The Sludge Volume Index (SVI) of sludges at low F/M (0.3 to 0.35 g COD removed/g TMLVSS per day) and high TMLSS (3.5 g/L) is related to conditions in the initial compartment rather than to those in the remainder of the aeration basin. Initial compartment COD, F/M, and size are important; floc loading, dispersion number, and total number of aeration compartments are not.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, Ohio, to announce key findings of the research project which is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Filamentous bulking in activated sludge occurs under certain conditions characterized by the presence of excessive length — greater than 10 km/g suspended solids (SS) — of various types of filamentous organisms extending from the activated sludge floc Bulking has many causes, and they can often be determined by the types of filamentous organisms present For example, *Sphae-rotil-us natans* and types 1701, 021N, and 1863 are characteristic of plants with aeration basin dissolved oxygen (DO) too low for the applied organic load; *Microthrix parvicella* and types 0041, 0092, 0581, and 1851 are associated with plants having a low food/microorganism ratio or low F/M. The remedy for low-DO sludge bulking is to increase aeration basin oxygenation capacity or lower the F/M. Direct remedy of low F/M bulking usually is not possible because low F/M may be required for nitrification, for designer preference, or for lower than anticipated wastewater flows or wastewaters with significantly lower BOD_5 concentrations than expected.

Previous work suggests that the growth of filamentous organisms at low F/M is suppressed in systems that either have a low degree of longitudinal mixing ("plug flow") or are provided with an initial compartment for a short detention time during which the wastewater feed and return activated sludge are mixed.

The mechanism of filamentous organism suppression is not clear Suggestions include lower filamentous organism growth rate compared with flock formers at high substrate levels, inability of filamentous organisms to store substrate for later use in growth, and lower substrate utilization rate of filamentous organisms compared with flock formers. The term "biosorption" has recently been used by Eikelboom to lump all of these factors with physical incorporation of particulate and soluble substrates in the floc He proposes that filamentous organisms growth in activated sludges with high biosorption capacity can be suppressed by use of high initial floc-loading values (mg COD/g MLVSS)

Five series of experiments were conducted in laboratory-scale activated sludge systems ranging from 10 5 to 80 L to investigate the effect of aeration basin configuration on possible causes and cures of bulking at low F/M values.

Materials and Methods

The experiments were conducted in laboratory-scale activated sludge systems with acrylic plastic aeration basins that ranged in size from 10 5 L for the continuous-flow, stirred tank reactor (CSTR) to 80 L for various compartmentalized aeration basin units. Mixing was by paddles with a mean velocity gradient of 85 sec^{-1}. Mixing intensity was increased only 10% when house air was used for aeration Dissolved oxygen (DO) in the CSTR control units and in up to five of the initial compartments of the other basin configurations was controlled by a feedback system consisting of a galvanic oxygen electrode, DO analyzer, and a recorder-controller that operated a solenoid valve on the air or O_2 supply line. A control range of approximately -0 and +2 mg/L relative to the desired minimum DO was achieved.

All wastewater used in the experiments was domestic sewage from the City of Richmond, California.

Secondary clarifiers were inverted Erlenmeyer flasks with their bottoms cut off, and in some cases with an acrylic plastic cylinder attached. Bronze or nichrome wires, bent to conform to the conical portion of the inner clarifier walls, related at 1 rpm to aid thickened sludge flow to the recycle lines. Both influent sewage and return sludge were dosed into the aeration basin by peristaltic pumps. The ratio of return sludge (RAS) flow rate to influent flow rate was 1 0. Sludge was wasted directly from the aeration basin. The systems were operated at ambient temperature, which varied between 18 and 24°C.

The systems were characterized by (1) the ratio of the total volume of the aeration basin to that of the initial aeration basin compartment (V_T/V_I), and (2) by the dispersion number, which was determined from Rodamine B slug addition tracer studies on the aeration basin without the secondary clarifier or return sludge stream. The F/M ratio was calculated as

$$F/M = \frac{\text{Total COD in (g/day)} - \text{Soluble COD out (g/day)}}{\text{TMLVSS (g)}}$$

where COD in = COD of feed
COD out = COD of effluent
TMLVSS = total mixed liquor volatile suspended solids, or aeration basin volatile suspended solids (VSS) + clarifier VSS

Results

In the first of the five series of experiments, CSTR aeration basins (Figure 1a) were operated at several steady states in the F/M range of 0.05 to 0.25 g COD removed/g TMLVSS per day. Experiments commenced with *nonbulking sludge No bulking occurred* at any of the F/M ratios tested; neither was a bulking sludge producd when the settled sewage feed was made stale (septic) by storage at room temperature for 2 5 days. (Two other researchers had suggested that stale sewage could promote the growth of filamentous organisms). In these experiments, the rather weak Richmond settled sewage (BOD_5 = 139 mg/L, COD = 300 mg/L, TSS = 75 mg/L) was the feedstock. Because of the weak feed, TMLSS levels ranged from 1.0 to 1.7 g/L.

Previous work on bulking at low F/M by other investigators has been conducted with stronger *influent wastes, and* thus higher MLSS concentrations occurred at an equivalent F/M. Another researcher observed that a continuously fed, one-compartment activated sludge system produced bulking sludge at a MLSS of 4 g/L, but not at 1 g/L. Because of this, the strength of the Richmond settled sewage feed was increased by blending it with raw sludge settled from the same sewage in the primary clarifier. A comparative analysis showed that the BOD_5 of the supplemented feed increased to 315 mg/L and the COD to 750 mg/L. But the BOD_5/COD ratio and the soluble percentages of BOD_5 and COD remained similar to the previous feed All subsequent experiments were conducted with supplemented sewage

The second series of experiments was conducted largely at an F/M of 0.15 to 0.2 g COD removed/g TMLVSS per day and a TMLSS of 3.0 to 3.5 g/L. Two *parallel* CSTR *aeration basin systems* were operated (Figure 1a). One received stale supplemented sewage, and the other was fed with fresh supplemented sewage. When the experiment began with a nonbulking sludge (SVI $\leq$ 100 ml/g), bulking (SVI $\geq$ 150 ml/g) occurred after 35 days in both systems when TMLSS concentration reached 3.0 g/L. Thereafter, the two activated sludge systems were operated on fresh, supplemented sewage feed. System 1 was designated at this time as the CSTR control, and system 2 was operated at steady-state, with the aeration basin being divided progressively into 2, 4, 8, and then 16 equal-sized compartments. Sewage feed and RAS always entered the first compartment Compartmentalization to 16 equal-sized compartments did not improve sludge settleability over the control CSTR

The third series of experiments employed a CSTR control (Figure 1a) and an aeration basin with 16 equal-sized compartments (Figure 1e). Both units were operated at steady-state F/M values in the ranges of 0.15 to 0.20, 0.20 to 0.25, 0.35 to 0.45, 0.50 to 0.60, 0.60 to 0.80, 0.90 to 1.15, and 1.15 to 1.40 g COD removed/g TMLVSS per day. For the F/M values of 0.15 to 0.20, 0.20 to 0.25, 0.35 to 0.45, and 0.50 to 0.60, bulking activated sludge was initially used. For the F/M values 0.60 to 0.80, 0 90 to 1 15, and 1.15 to 1.40, the control and 16-compartment unit were started with nonbulking sludge from a laboratory batch system. Though sludge in the 16-compartment unit bulked somewhat later than that in the CSTR control, bulking was not prevented at any of these F/M ranges by aeration basins with 16 equal-sized compartments. The conclusion was that bulking could not be cured at the lower F/M values by use of an aeration basin with 16 equal-sized compartments.

Because the 16 compartment aeration basin did not prevent or cure bulking at any of the F/M values tested in the third series of experiments; it was decided to return to an F/M value of 0.30 g COD removed/g TMLVSS per day and to examine the effect of using initial compartments smaller than 1/16 of the total aeration basin volume. The first eight compartments were reduced in size to the desired fraction of the total aeration basin volume; the last eight compartments were sized so that the total aeration basin volume was 56 to 58 L. This type of system is referred to as a selector configuration. A CSTR control was run in parallel at all times. All units were operated at an F/M of 0.3 g COD removed/g TMLVSS per day TMLSS was kept at 3.0 to 3.5 g/L and the fresh, supplemented sewage was used as the feed

A selector configuration of eight compartments, each 1/32 of the total aeration basin volume (Figure 1f), prevented bulking, whereas the CSTR control bulked. At this point (day 26), the test unit aeration basin was changed back to 16 equal-sized compartments (Figure 1e), and the control CSTR unit was restarted with nonbulking sludge. Again the CSTR bulked. The unit with 16 equal-sized compartments also bulked, but less rapidly than the CSTR control.

The system with 16 equal-sized aeration basin compartments (Figure 1e) was returned to a selector configuration, with the first eight compartments each 1/32 of the total aeration basin volume (Figure 1f). This selector configuration, which had previously *prevented* the bulking of a nonbulking sludge, did not *cure* an already-bulking sludge The SVI's of the selector and control units fluctuated widely, but these were similar to each other.

At this point, a plan was made to change the selector configuration so that the first two compartments were 1/64 of the total aeration basin volume, the following six compartments were 1/32 of the total aeration basin volume, and the last eight compartments were equal size at 1/10 of the total volume to

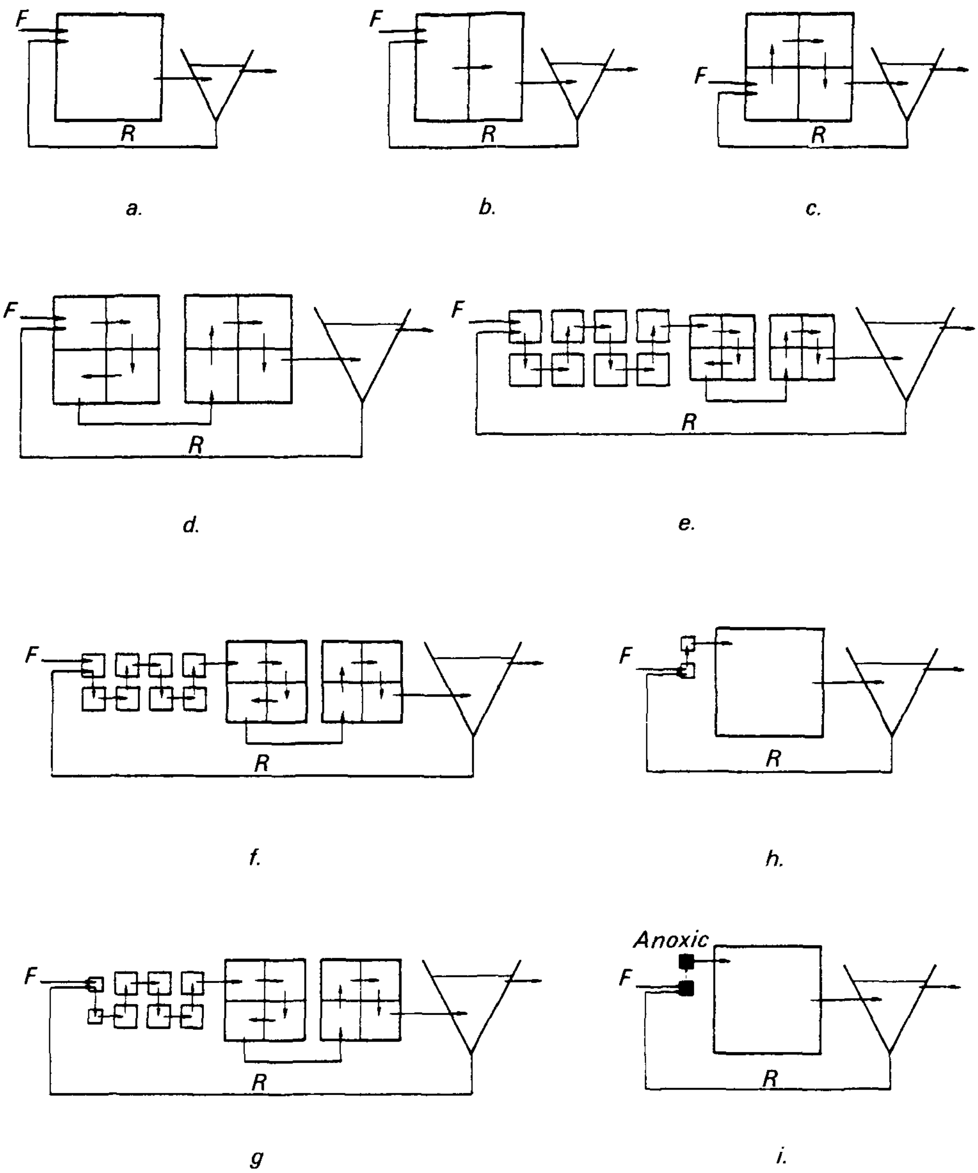

Figure 1. *Aeration basin configurations used. Values of V_T/V_i are given in parentheses.*

a. CSTR system (1); for CSTR control, 10.5-L aeration basin; for 1-compartment system, 40-L aeration basin.
b. 40-L aeration basin, 2 compartments (2).
c. 40-L aeration basin, 4 compartments (4).
d. 80-L aeration basin, 8 compartments (8).
e. 56-L aeration basin, 16 equal-sized compartments (16).
f. 58-L aeration basin, 16 compartments (32); first 8 are each equal to 1/32 of total aeration basin volumes, and the next 8 are equal in size.
g. 58-L aeration basin, 16 compartments (74); first 2 are each equal to 1/74, the next 6 are each equal to 1/32 of total aeration basin volume, and the last 8 are equal in size.
h. 42-L aeration basin, 3 compartments (64); first 2 are each equal to 1/64 and the following compartment is equal to 62/64 of total aeration basin volume.
i. 42-L aeration basin, 3 compartment (64); same as h, but the 2 initial compartments are anoxic.

give a total aeration basin volume of 58 L (Figure 1g). But a measurement error caused the first two compartments to be 1/74 of the total aeration basin volume. Starting with a bulking sludge, this selector configuration rapidly reduced SVI, and the CSTR continued to bulk (at maximum SVI)

The unit with the selector configuration containing nonbulking sludge was converted to an aeration basin with 16 equal-sized compartments (Figure 1e) The control CSTR was then restarted with nonbulking sludge. Both units bulked as they did previously at this configuration. Again, the control CSTR bulked somewhat more rapidly than did the unit with the 16 equal-sized compartments.

Because the 16 compartment unit with two initial compartments equal to 1/74 of the total aeration basin volume was successful in both preventing and curing bulking, it was decided to determine whether the same results could be obtained when the two initial selectors were followed by a single large CSTR rather than 14 more compartments. A decision was also made to determine whether any advantage existed in creating anoxia (no aeration) in the first two compartments

To achieve these goals, three reactor trains were set up int he fifth series of experiments· A control CSTR (Figure 1a) and two three-compartment aeration basins, each with two initial compartments 1/64 of the total aeration basin volume and a third that was 62/64 of the total aeration basin volume (Figures 1h and 1i). In one of the three-compartment units, the two initial selector compartments were covered and stirred. The freeboard volume was purged with N_2 gas to create anoxia.

The unit with two 1/64-volume aerated selectors reduced the SVI slowly and erratically to final values of 173 ml/g (at 2.5 g TSS/L) and 150 ml/g (at 1 5 g TSS/L). The final SVI value in the CSTR control and the unit with two 1/64-volume anoxic selectors were the maximum values possible (i.e., 400 ml/g at 2.5 g TSS/L, and 667 ml/g at 1.5 g TSS/L). Though the final SVI value in the aerated selector would still classify this sludge as bulking, these values were significantly lower than in either the control or anoxic selector systems. Table 1 summarizes average operating data and initial and final SVI values for all experiments that used selector configurations.

Conclusions

1. Bulking at low F/M (0.05 to 0.25 g COD removed/g TMLVSS per day) did not occur when CSTR activated sludge systems were fed fresh or stale domestic wastewater and the TMLSS was in the range of 1.0 to 1.7 g/L.
2. Bulking did occur when supplemented, settled wastewater was fed to CSTR activated sludge systems at an F/M in the range of 0.15 to 0.2 g COD removed/g TMLVSS per day.
3 The conditions existing in the zone of initial mixing of activated sludge and wastewater are important in determining whether or not filamentous bulking occurs at low F/M. The degree of longitudinal mixing (as measured by the dispersion number) and the soluble COD gradient throughout the reactor do not appear to be important for bulking at low F/M.
4 The F/M in the initial aeration basin compartment was found to be consistently related to the final SVI, whereas the floc loading defined by Eikelboom in 1981 (Eikelboom, D.H., Biosorption and Prevention of Bulking Sludge by Means of High Floc Loading. Paper 3, Water Research Centre Conference, Cambridge, England, 1981) did not show such a relationship.
5 An aeration basin configuration consisting of 16 compartments, the first eight of which are 1/32 of the total aeration basin volume, will prevent low F/M filamentous bulking from occurring in a nonbulking sludge, but this configuration will not cure low F/M filamentous bulking in an already-bulking sludge.
6. An aeration basin configuration consisting of 16 compartments (compartments 1 and 2 equal to 1/74 of the total aeration basin volume, compartments 3 through 8 equal to 1/32 of the total volume, and compartments 9 through 16 equal to 1/10 of the total volume)

Table 1. *Operating Data Summary for Experiments Employing Selector Configurations*

Parameters	Units	Control CSTR	16-Compartment Aeration Basins: A	B	C	D	E	Two Selectors × CSTR: Aerobic	Anaerobic
$V_T V_I$		1.0	32	16	32	74	16	64	64
Operation period	day	216	26	33	42	23	35	56	56
F/M	g COD removed / g TMLVSS, day	0.31	.31	0.30	0.30	0.31	0.31	0.31	0.31
TMLSS	g/L	3.0	3.2	3.4	3.4	3.3	3.4	3.2	2.7
Average hydraulic detention time	hr	19	17	18	19	20	21	21	22
MCRT	day	15	14	15	14	12	13	12	14
Sewage strength	mg COD/L	720	620	660	720	745	790	830	830
$SVI_{2.5}$									
Initial	mL/g	96	98	78	373	389	46	400*	400*
Final	mL/g	400*	70	373	376	50	387	173	392
Initial Compartment F/M	g COD removed / g MLVSS, day	0.32	9.0	5.0	8.0	22.0	5.0	21.0	20.0
Soluble COD	mg/L	33	63	43	53	87	48	75	183

*Maximum SVI value at 2.5 g SS/L.

will both prevent and cure low F/M bulking. A system consisting of two initial basins each 1/74 of the total basin volume followed by a large CSTR with the remaining 72/74 of the volume should work as well. The initial mixing zones for control of low F/M bulking should apparently be aerated; anoxic initial compartments did not show any decrease in bulking.

7. Critical values for initial compartment parameters to control low F/M bulking for this waste are: soluble COD $\geq$ 80 mg/L and F/M in the first reactor $\geq$ 20 g COD removed/g MLVSS per day. Further work is needed to generalize these values and to account for the effects of variables such as waste characteristics, recycle ratio, and MLSS concentration.

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***Ronald F. Lewis** is the EPA Project Officer (see below).*

The complete report, entitled "Effect of Aeration Basin Configuration on Bulking at Low Organic Loading," (Order No. PB 82-234 287; Cost: $7.50, subject to change) will be available only from:

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