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Case Report

State-of-the-Art in Managing Sludge Settling Problems for Some Treatment Plants in the United States

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Abstract: Foaming and bulking in secondary mixed liquor particularly in activated sludge waste water treatment plants is a growing problem. The efficiency of secondary waste water treatment is critically dependent on the separation of the supernatant liquids from the sludge. Bulking and foaming primarily make it very difficult or impossible to achieve effective separation, thus reducing the treatment efficiency. The study is part of an ongoing effort by practitioners to understand and quantify the extent of the problems of foaming and bulking. The study presents a survey of some waste water plants in the northwest United States, and the results of statistical analysis in search of linkages between operating characteristics and settling problems.

Keywords: Activated Sludge, Foaming, Bulking, Secondary Treatment, Settling, Flocs

1. Introduction

Activated sludge systems are widely used in biological treatment of wastewater worldwide. Under the National Pollution Discharge Elimination System (NPDES) of the Clean Water Act, [1], wastewater treatment plants were required to reduce effluent levels of biochemical oxygen demand (BOD) and suspended solids (SS) below 30 mg/L, the so-called the "30-30" rule. When properly designed and operated, the activated sludge system of secondary wastewater treatment allows the attainment of the so-called "30-30" rule. Although several variations of the system are in use, the basics are; aeration of the wastewater followed by settling to separate the solids created by biological growth from the clean water. The efficiency of the system is critically dependent on the separation of liquids from solids. With the proliferation of the activated systems world-wide solids separation problems increased in wastewater treatment plants. All indications are that it is a growing problem as reported by several sources, e.g. [2]. Common settling problems associated with solid-liquid separation include excessive growth of algae and bacteria and bulking of solids in the bioreactor preceding settling. Other reported problems are excessive foaming resulting in difficult to manage solids and other nuisances.

In a critical review of bulking in activated sludge plants, [3], noted that despite extensive work in bulking and associated problems in the past two decades, they occur worldwide with no comprehensive solution in sight. Collectively, the settling problems result in significant reduction in the efficiency of BOD and suspended solids removal in secondary treated wastewater.

The purpose of this paper is to present a survey of treatment plants in the Pacific Northwest States of Washington, Oregon and Idaho. The survey measures the extent of the problem, and ways practioners have successfully controlled problems associated with bulking and foaming. Although others e.g., Jenkins and Richard [4], Jenkins et al. [5], identified six variations of settling problems associated with the activated sludge processes as; dispersed growth, non-filamentous bulking, pin flocs, filamentous bulking, blanket rising, and foaming. Settling problems associated with activated sludge systems are identified as either bulking or foaming.

2. Previous Work

Beginning in the early eighties, many investigators made concerted efforts on understanding and treating bulking, and foaming in activated sludge systems. One of the earliest surveys in the literature was conducted by Blackbeard et al. [6] for activated sludge plants in the Republic of South Africa. Their survey concluded that bulking and foaming were quite widespread and severe in South African plants. They identified several groups of filamentous organisms responsible for bulking and foaming. Madoni et al. [7] surveyed one hundred and sixty seven plants in Italy. Eighty four had foaming problems, eighty one with bulking problems, and fifty five were affected by both. The survey results indicated that the use of contact zone technique and/or addition of chemicals such as oxidants and coagulants were promising approaches to control.

Elliott [8] in a pulp and paper publication surveyed sludge bulking in several Canadian pulp and paper mills. He concluded that septicity, low dissolved oxygen, food to micro-organism ratio (F/M ratio), nutrient availability, and the presence of oil were causes of bulking in the majority of the plants surveyed. The survey indicated that many of the plants experienced more than one settling issue and found no link between prevalence of bulking and mill type. It also indicated that about fifty percent of the mills used hypochlorite for temporary control of settling problems. Seviour et al. ([9] surveyed activated sludge plants in Australia and examined foaming in mixed liquor. They concluded that there was weak relationship between filamentous community composition and plant operating parameters, and that Norcadia species were dominant organisms in foams. Blackall et al. [10] reported that only eight percent of the forty six surveyed plants had no foaming problems, and most of those were under loaded. The study concluded that foaming was dependent on plant operation parameters such as sludge age and mixed liquor, rather than plant design. Furthermore, the survey identified several Norcadia species present in foams.

In a survey of eight activated sludge plants in the Czech Republic with advanced nutrients removal, Krhutková et al. [11] found a relationship between foaming and sludge settling problems. Wanner et al. [12] surveyed national plants in the Czech Republic and concluded that the problem was widespread, and also isolated M. *parcivella* as the dominant filamentous organism in mixed liquor of plant experiencing settling problems. They concluded that the effect of filamentous organisms in sludge separation may be overestimated. As the preceding literature survey shows, the causes of settling problems are varied and not well understood. At this time, there is no agreement among practitioners on the causes and particularly, the solutions to sludge foaming, bulking and other related sludge settling problems.

3. The Survey

Survey questions were mailed to fifty randomly selected major municipal wastewater treatment plants in the States of Washington (Gig Harbor, Edmonds, Puyallup, Yelm, Olympia, Anacortes, Pasco, Seattle, Burlington, Soap Lake, Vancouver, Ridgefield, and Tacoma), Idaho (Boise, Lampa, Post Falls, and Moscow) and Oregon North Bend, Albany, St. Helens, Medford, and Salem). One of the returned survey indicated no city of location. The survey was limited to plants operating the activated sludge biological treatment systems of all variations. The surveyed plants include ones operating conventional, complete mix, pure oxygen, extended aeration, and sequenced batch reactor systems [13].

Information sought in the survey included plant location, type, operational characteristics, and the presence and type of settling problems affecting the plant, such as bulking, and foaming. Twenty four plants completed the survey. As Table 1 shows, the survey reported detailed plant operating characteristics such as; biochemical oxygen demand (BOD_i), sludge volume index (SVIM), mixed liquor suspended solids (MLSSM), minimum and maximum flows (Q_{min}, Q_{max}). Also shown in the table is a summary of descriptive statistical parameters including mean, median, standard deviation, standard error, range, minimum, maximum, and skewness coefficients of the variables.

The last item on the questionnaire provided the opportunity for additional comments. Table 2 indicates that the majority of the responding plants (79%) experienced settling problems such as filamentous foaming, non-filamentous foaming, and filamentous bulking. Many treatment plants experience multiple problems with settling of secondary sludge.

Chemical control measures such as addition of chlorine compounds, hydrogen peroxide, ozone, metal salts, and polyelectrolytes were preferred by the majority of plants in the control of foaming and bulking (Table 3). Furthermore, chlorine and chlorine compounds were by far the most popular group of chemicals (Table 4). Foam skimming, water sprays, operational control and treatment selectors were also used to control some problems. The operational controls identified in the survey included dissolved oxygen manipulation, nutrient removal and control of septicity in the mixed liquor. Several of the surveyed plants, employed multiple control schemes such as combining chemical addition with process control. The use of multiple methods as a means of controlling settling issues in treatment plants is corroborated by other studies such as Eikelboom and Grovenstein [14]), Eikelboom and Geurkink [15]; Demel and Moebius [16]); Andreasen et al. [17]; Juang [18]; and Yang et al. [19]

Table 1. *Basic Descriptive Statistics of surveyed plants.*

	Qmin (mgd)	Qmax (mgd)	BOD_i (mg/L)	MLSS (mg/L)	SVI (g/ml)
N	24	24	24	24	24
Mean	7.41	35.91	202.13	2819.56	179.59
Median	2	10	201	2750	152.5
Mode	0.2	20	175	2000	250
Std. Deviation	14.93	65.95	88.23	958.18	89.12
Skewness	3.66	3.243	-0.17	0.19	1.69
Std. Error	0.48	0.481	0.481	0.48	0.49
Range	70	299.94	337	4650	357
Minimum	0	0.06	33	600	93
Maximum	70	300	370	5250	450

Table 2. *Plant Settling Problems by Type and Season.*

Plant	Foaming	Bulking	Season
1	Yes	No	Summer
2	Yes	No	Winter
3	Yes	No	Spring
4	Yes	No	All year
5	Yes	No	All year
6	Yes	No	All year
7	Yes	No	All year
8	No	No	All year
9	No	No	All year
10	No	Yes	All year
11	No	Yes	Winter
12	No	Yes	All year
13	No	No	All year
14	No	Yes	Winter
15	No	Yes	All year
16	No	Yes	All year
17	No	Yes	All year
18	Yes	Yes	Spring
19	Yes	Yes	Winter
20	Yes	Yes	Winter
21	Yes	Yes	All year
22	Yes	Yes	All year
23	Yes	Yes	All year
24	No	Yes	All year

Table 3. *Summary of Methods used by Treatment Plants to control of Foaming and Bulking.*

Plant	Settling problems	Operational control	Chemical addition	Foam skimming	Water sprays
1	Yes	No	No	Yes	Yes
2	Yes	No	Yes	No	No
3	Yes	No	Yes	No	Yes
4	Yes	No	No	Yes	Yes
5	Yes	No	Yes	Yes	No
6	Yes	No	Yes	Yes	No
7	No	No	No	No	Yes
8	No	No	No	No	No
9	No	No	No	No	No
10	Yes	Yes	Yes	No	No
11	Yes	Yes	Yes	No	Yes
12	Yes	Yes	Yes	No	Yes
13	No	No	Yes	No	No
14	Yes	Yes	No	No	No
15	Yes	No	Yes	No	Yes
16	Yes	No	Yes	No	No
17	Yes	No	Yes	No	No
18	Yes	Yes	No	Yes	No
19	Yes	No	Yes	No	No
20	Yes	Yes	Yes	Yes	No
21	Yes	Yes	Yes	No	No
22	Yes	No	Yes	Yes	Yes
23	Yes	No	Yes	No	No
24	No	Yes	No	No	Yes

Table 4. *Typical Chemicals used by Plants for control of Bulking and foaming.*

Chemical addition	Chlorine compounds	Other chemicals
NA		
	YES	
NA		
NA		
		YES
	YES	
NA		
NA		
NA		
		YES
		YES
NA		
		YES
	YES	
NA		
NA		
	YES	
		YES
	YES	
		YES
	YES	
NA		
	YES	

4. Statistical Inferences

Before statistical inferences could be made, the survey data was examined for conformity to the standard Gaussian (Normal) distribution by obtaining a frequency plots using the software SPSS [20]. As the results show (Figures 1, 2, 3, 4, 5) with the exception of the variables Qmin, and Qmax, the variables the Normal distribution. A secondary purpose of the survey was to examine if plant operating parameters such as BOD_i, SVIM, MLSSM Q_{min}, and Q_{max} could be statistically correlated with the settling problems of foaming and bulking denoted by “PRBN”. For that purpose, non-parametric Spearman’s pairwise correlations coefficients were computed for pairs of variables. As the results as shown in Table 4 no significant correlations among the pairs at the 95% level of significant. The closest to significance was obtained for the (Q_{min}, Q_{max}) pair, followed by (BOD_i, MLSSM) pair (87.4%), and then (Q_{min}, PRBN) pair (77.3%) pair. Significant correlation between Qmax and Q min is of little value in this case.

To further examine the data for any linkages between settling problems and plant operating parameters, the data was examined using “Discriminant Analysis”. Discriminant analysis is a statistical technique used as a predictive tool to determine if a given individual, (such as a treatment plant) is likely to be a member of a given group (have settling problems, PRBN) based on one or more parameters. In other words can it be inferred that settling and foaming problems are associated with operating parameters of minimum flow (Q_{min}), maximum flow (Q_{max}), Sludge Volume Index (SVI), and Mixed Liquor Suspended Solids (MLSSM)? For this purpose the variable "PRBN" is assigned two possible values, "Yes" and "No" indicating the presence and absence of settling issues, respectively. The results of the Discriminant analysis are shown in Table 5 and Fig. 6. They indicate that although a majority of surveyed plants (sixty four percent) can classified as having a settling problem or lack a problem based on the variables Q_{max}, Q_{min}, MLSSM, SVIM, and BOD_i. However, this result is very preliminary and additional studies with a larger samples will be required before generalized conclusions can be drawn. If in the future the inference can be categorically made, it will help plant operators predict the possible onset of settling problems based on operating parameters.

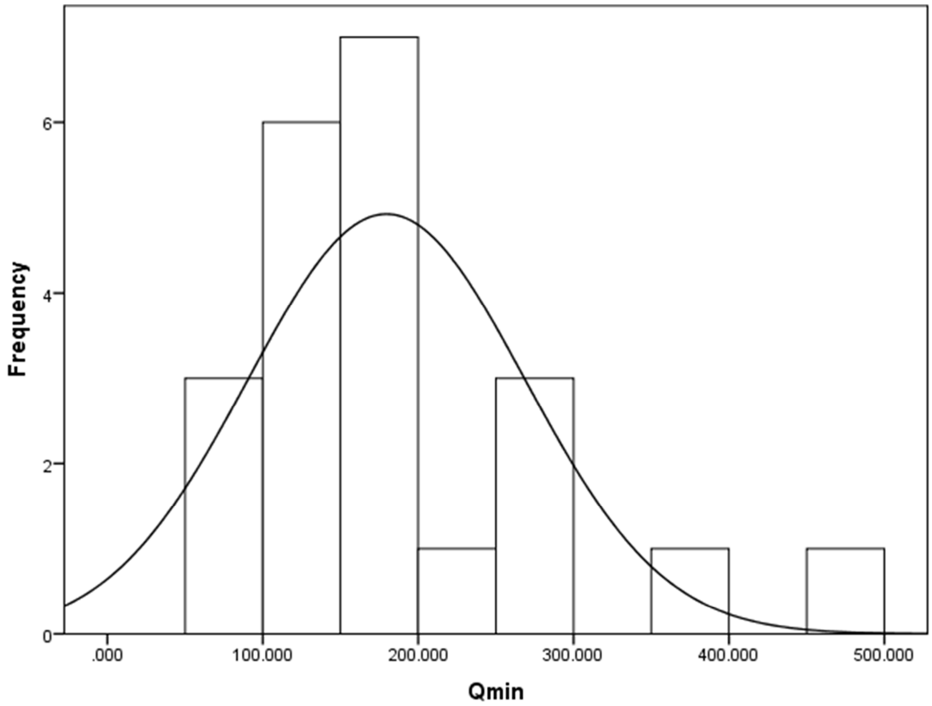

Fig. 1. *Frequency diagram for Qmin.*

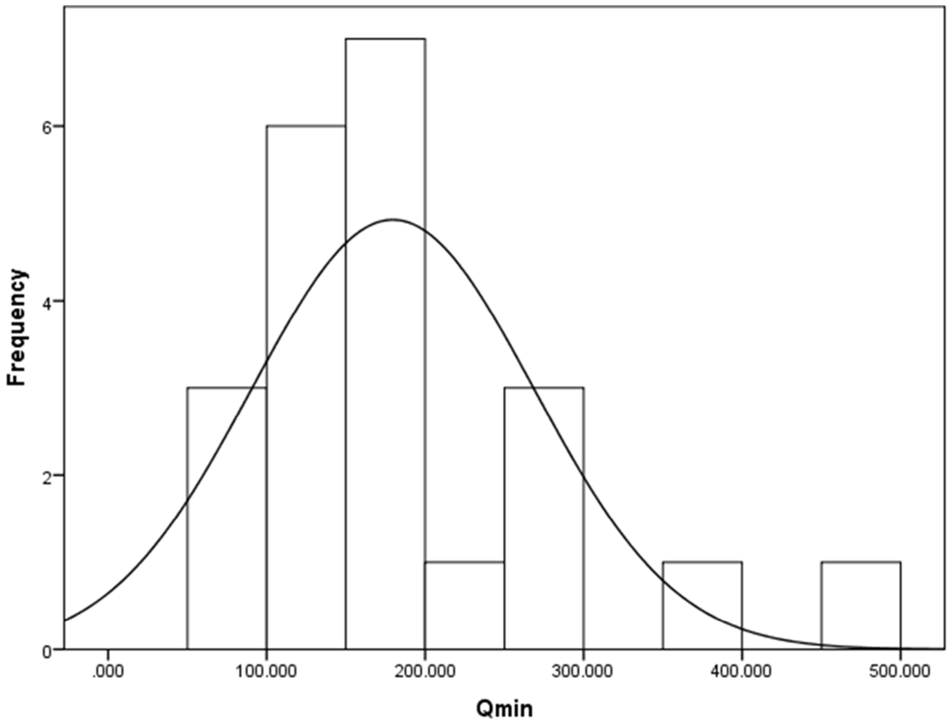

Fig. 2. *Frequency diagram for Qmax.*

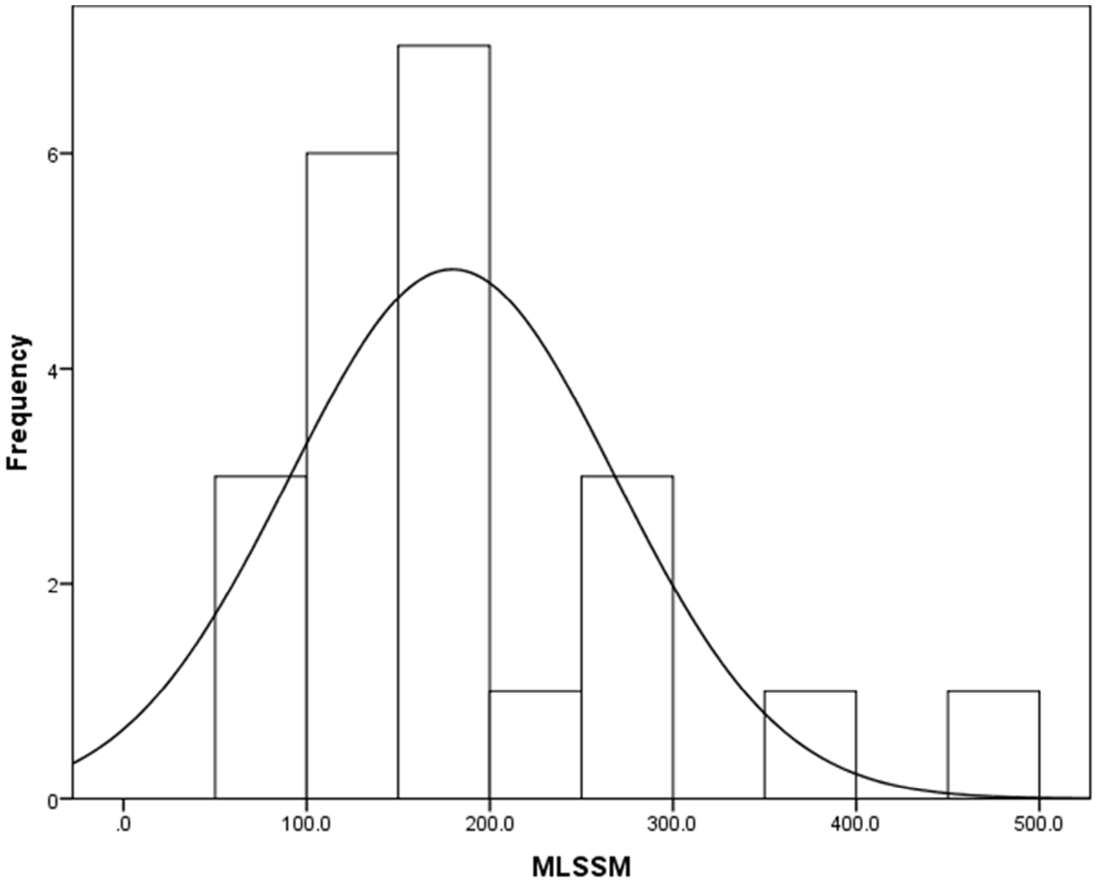

Fig. 3. *Frequency diagram for MLSSM.*

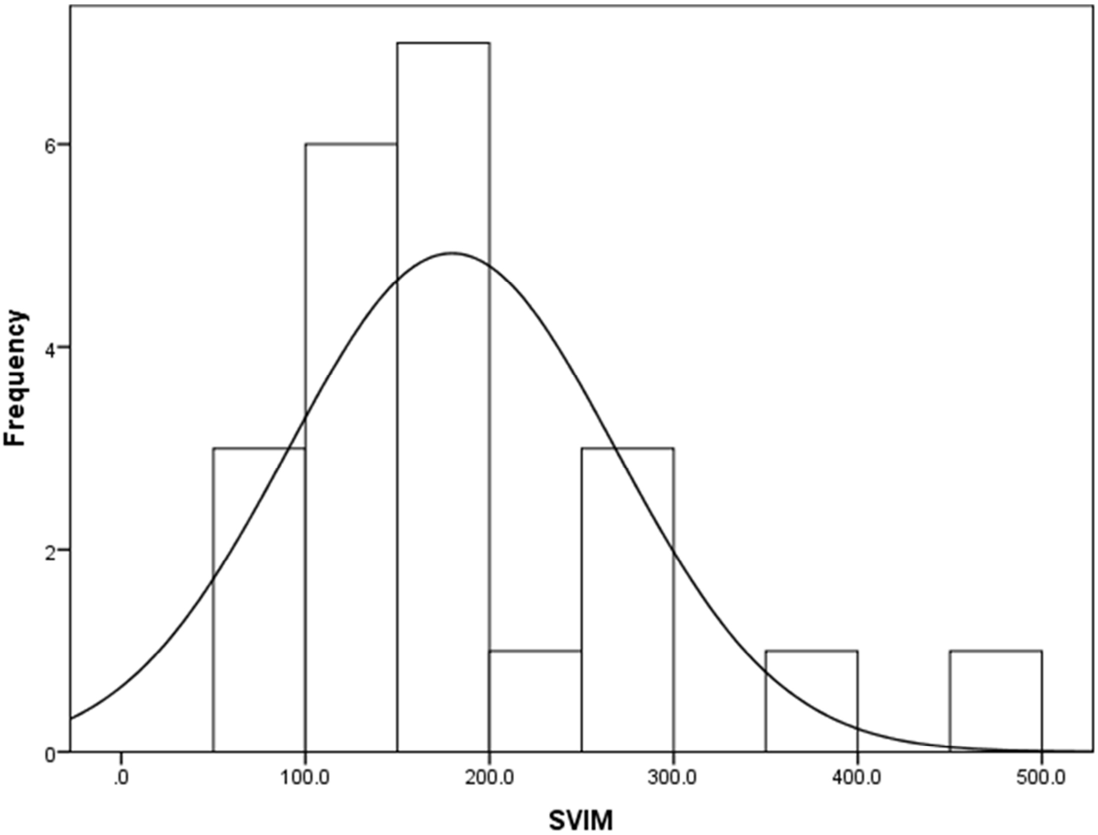

Fig. 4. *Frequency diagram for SVIM.*

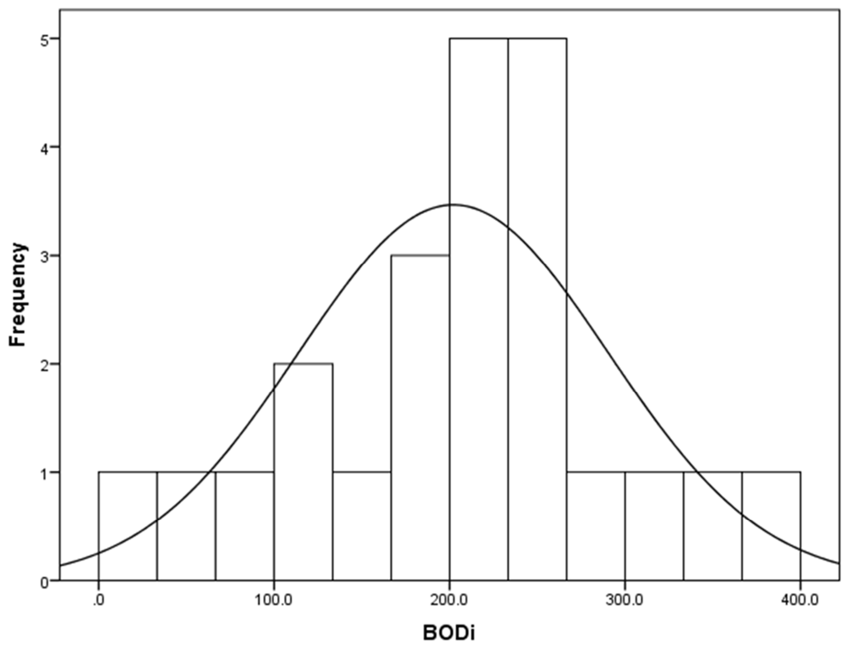

Fig. 5. *Frequency diagram for BOD_i.*

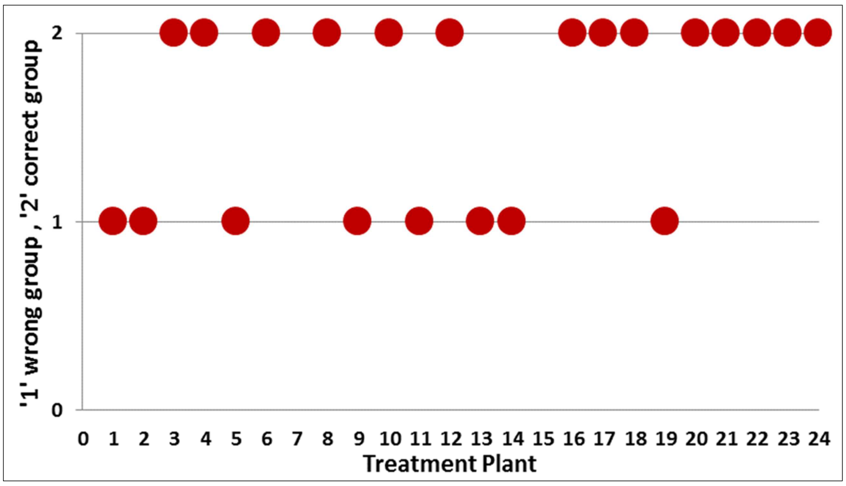

Fig. 6. *Graphical representation of discriminant analysis.*

Table 5. *Pearson's correlation coefficients for variable pairs.*

		Qmin	Qmax	BODi	MLSSM	SVIM	PRBN
	Pearson Correlation	1	.953	-.053	-.236	.360	-.064
Qmin	Sig. (2-tailed)		.000	.811	.290	.108	.773
	N	23	23	23	22	21	23
	Pearson Correlation	.953**	1	-.120	-.217	.296	-.074
Qmax	Sig. (2-tailed)	.000		.585	.333	.193	.736
	N	23	23	23	22	21	23
	Pearson Correlation	-.053	-.120	1	-.036	-.133	-.185
BOD_i	Sig. (2-tailed)	.811	.585		.874	.564	.397
	N	23	23	23	22	21	23
	Pearson Correlation	-.236	-.217	-.036	1	-.420	.101
MLSSM	Sig. (2-tailed)	.290	.333	.874		.052	.648
	N	22	22	22	23	22	23
	Pearson Correlation	.360	.296	-.133	-.420	1	-.152
SVIM	Sig. (2-tailed)	.108	.193	.564	.052		.499
	N	21	21	21	22	22	22
	Pearson Correlation	-.064	-.074	-.185	.101	-.152	1
PRBN	Sig. (2-tailed)	.773	.736	.397	.648	.499	
	N	23	23	23	23	22	24

The data appears to support the earlier findings by others that most wastewater treatment plants employing the activated sludge treatment systems are increasingly experiencing sludge settling problems such as bulking and foaming. The frequencies of the settling problems vary from one plant to another, ranging from occurrences of several times a year, to year round. Generally, plant size and wastewater flow rates do not appear to be a factors, nor does the variation of activated sludge treatment systems in use.

For the control of settling problems, a majority of wastewater treatment plant operators in the survey used chemicals (Table 4). The chemicals commonly used to control bulking and foaming are chlorine and chlorine compounds, ferric sulfate, ozone, ferric chloride, and hydrogen peroxide. System and operational modifications such as selectors, control of mixed liquor concentrations, dissolved oxygen reductions, and nutrient balance were preferred by others. In several of the surveyed cases, plant operators used both chemicals and system and operational modifications to control foaming and bulking control. Anti-foaming agents, foam skimming, and water sprays were methods of choice for controlling excessive foaming, as reported in the survey.

5. Conclusions

Foaming and bulking in secondary sludge appear to be widespread in treatment plants in the states of Washington, Idaho and Oregon. Almost 80% of the plants surveyed experienced bulking or foaming. There appears to be no discernible patterns in the timing or frequency of occurrences. Plants in the survey experienced settling issues in the summer and winter months or year round. Statistical analysis of the data from the surveyed treatment plants indicated no significant relationship between plant operational parameters and bulking or foaming, although there appears to be preliminary indications of a linkage. Foaming and bulking appear to be complex and may involve intrinsic biological issues of species succession, abundance of nutrients and dissolved oxygen, and septicity of mixed liquor, involving several phyla of bacteria [21], [22]. Effective control of activated sludge plant problems of foaming, and bulking, as reported by the survey, included chemicals addition, and operational controls using methods such as dissolved oxygen manipulation, mechanical removal and water spraying. Many plants in the survey plant operators combined several control techniques for effectiveness.

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