OXYGEN TRANSFER STUDIES AT THE MADISON METROPOLITAN SEWERAGE DISTRICT FACILITIES

by

William C. Boyle, Andrew Craven,
William Danley, and Michael Rieth
Department of Civil and Environmental Engineering
University of Wisconsin
Madison, Wisconsin 53706

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Project Officer

Richard C. Brenner
Water and Hazardous Waste Treatment Research Division
Risk Reduction Engineering Laboratory
Cincinnati, Ohio 45268

RISK REDUCTION ENGINEERING LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

Development of the information in this report has been funded in part by the U.S. Environmental Protection Agency under Cooperative Agreement No. CR812167 by the American Society of Civil Engineers. The report has been subjected to Agency peer and administrative review and approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

As part of these activities, an EPA cooperative agreement was awarded to the American Society of Civil Engineers (ASCE) in 1985 to evaluate the existing data base on fine pore diffused aeration systems in both clean and process waters, conduct field studies at a number of municipal wastewater treatment facilities employing fine pore aeration, and prepare a comprehensive design manual on the subject. This manual, entitled "Design Manual - Fine Pore Aeration Systems," was completed in September 1989 and is available through EPA's Center for Environmental Research Information, Cincinnati, Ohio 45268 (EPA Report No. EPA/625-1-89/023). The field studies, carried out as contracts under the ASCE cooperative agreement, were designed to produce reliable information on the performance and operational requirements of fine pore devices under process conditions. These studies resulted in 16 separate contractor reports and provided critical input to the design manual. This report summarizes the results of one of the 16 field studies.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

PREFACE

In 1985, the U.S. Environmental Protection Agency funded Cooperative Research Agreement CR812167 with the American Society of Civil Engineers to evaluate the existing data base on fine pore diffused aeration systems in both clean and process waters, conduct field studies at a number of municipal wastewater treatment facilities employing fine pore diffused aeration, and prepare a comprehensive design manual on the subject. This manual, entitled "Design Manual - Fine Pore Aeration Systems," was published in September 1989 (EPA Report No. EPA/725/1-89/023) and is available from the EPA Center for Environmental Research Information, Cincinnati, OH 45268.

As part of this project, contracts were awarded under the cooperative research agreement to conduct 16 field studies to provide technical input to the Design Manual. Each of these field studies resulted in a contractor report. In addition to quality assurance/quality control (QA/QC) data that may be included in these reports, comprehensive QA/QC information is contained in the Design Manual. A listing of these reports is presented below. All of the reports are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 (Telephone: 703-487-4650).

1. "Fine Pore Diffuser System Evaluation for the Green Bay Metropolitan Sewerage District" (EPA/600/R-94/093) by J.J. Marx

2. "Oxygen Transfer Efficiency Surveys at the Jones Island Treatment Plants, 1985-1988" (EPA/600/R-94/094) by R. Warriner

3. "Fine Pore Diffuser Fouling: The Los Angeles Studies" (EPA/600/R-94/095) by M.K. Stenstrom and G. Masutani

4. "Oxygen Transfer Studies at the Madison Metropolitan Sewerage District Facilities" (EPA/600/R-94/096) by W.C. Boyle, A. Craven, W. Danley, and M. Rieth

5. "Long Term Performance Characteristics of Fine Pore Ceramic Diffusers at Monroe, Wisconsin" (EPA/600/R-94/097) by D.T. Redmon, L. Ewing, H. Melcer, and G.V. Ellefson

6. "Case History of Fine Pore Diffuser Retrofit at Ridgewood, New Jersey" (EPA/600/R-94/098) by J.A. Mueller and P.D. Saurer

7. "Oxygen Transfer Efficiency Surveys at the South Shore Wastewater Treatment Plant, 1985-1987" (EPA/600/R-94/099) by R. Warriner

8. "Fine Pore Diffuser Case History for Frankenmuth, Michigan" (EPA/600/R-94/100) by T.A. Allbaugh and S.J. Kang

9. "Off-gas Analysis Results and Fine Pore Retrofit Information for Glastonbury, Connecticut" (EPA/600/R-94/101) by R.G. Gilbert and R.C. Sullivan

10. "Off-Gas Analysis Results and Fine Pore Retrofit Case History for Hartford, Connecticut" (EPA/600/R-94/105) by R.G. Gilbert and R.C. Sullivan

11. "The Measurement and Control of Fouling in Fine Pore Diffuser Systems" (EPA/600/R-94/102) by E.L. Barnhart and M. Collins

12. "Fouling of Fine Pore Diffused Aerators: An Interplant Comparison" (EPA/600/R-94/103) by C.R. Baillod and K. Hopkins

13. "Case History Report on Milwaukee Ceramic Plate Aeration Facilities" (EPA/600/R-94/106) by L.A. Ernest

14. "Survey and Evaluation of Porous Polyethylene Media Fine Bubble Tube and Disk Aerators" (EPA/600/R-94/104) by D.H. Houck

15. "Investigations into Biofouling Phenomena in Fine Pore Aeration Devices" (EPA/600/R-94/107) by W. Jansen, J.W. Costerton, and H. Melcer

16. "Characterization of Clean and Fouled Perforated Membrane Diffusers" (EPA/600/R-94/108) by Ewing Engineering Co.

ABSTRACT

Field studies at the Madison Metropolitan Sewerage District facilities were conducted over a 3-year period to obtain long-term data on the performance of fine pore aeration equipment in municipal wastewater. The studies were conducted on several basins in the East Plant containing ceramic domes installed in 1977 and two sets of first-pass basins in the West Plant with newly installed ceramic discs.

The performance of the domes was excellent even after 10 years of service. This conclusion was based on measured oxygen transfer efficiencies by off-gas analysis, alpha calculations, and diffuser characterization. Reasons for excellent performance included routine maintenance of the diffusers and the use of high quality ceramic diffusers and hardware. There was evidence presented in this plant that operation at high SRTs (low F/M loadings), which produced complete nitrification, resulted in higher αSOTE values than operation at low SRTs. Studies on the impact of diffuser cleaning and hydraulic flow patterns on performance were also reported.

The ceramic discs in the West Plant were monitored for 800 days. In this period of time, no perceptible decrease in diffuser performance was observed based on αSOTE measurements. The mean first-pass αSOTE values over 800 days was about 11.5%. The mean-weighted αSOTE for all three passes ranged from 12.1 to 15.3%. The West Plant aeration system was operated at high SRT values in order to achieve complete nitrification. As seen in the East Plant, there was some evidence of improved aeration performance (αSOTE) with increased SRT. Brief evaluations of diffusers in these low loaded basins suggested that fouling was not a problem in this plant.

This report was submitted in partial fulfillment of Cooperative Agreement No. CR812167 by the American Society of Civil Engineers under subcontract to the University of Wisconsin under the partial sponsorship of the U.S. Environmental Protection Agency. The work reported herein was conducted over the period of 1985-1987.

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ACKNOWLEDGEMENTS

The authors of this report wish to acknowledge the gracious support of Steve Reusser and Paul Nehm of the Madison Metropolitan Sewerage District. The generous support of the U.S. EPA in funding the work is also gratefully acknowledged. Finally, David Redmon and Lloyd Ewing of Ewing Engineering Company and Gerry Wren of Sanitaire are also thanked for their technical input and review during the project.

INTRODUCTION

The demand for more energy efficient wastewater treatment processes has resulted in the application of fine pore diffuser systems in new and upgraded treatment facilities. As a part of this new technology, a better understanding of the long-term performance of these systems and the maintenance requirements needed to attain these high efficiencies must be delineated.

In the spring 1985, the U.S. EPA funded a cooperative research agreement with the American Society of Civil Engineers in order to develop an in-depth data base on fine pore aeration. One of the plants selected for this study was the Madison, Wisconsin, Metropolitan Sewerage District (MMSD) facility. Madison installed one of the first contemporary ceramic fine pore aeration systems in the U.S. in 1977.

The initial objectives of the study at Madison were to obtain long-term data on the performance of fine pore aeration in domestic wastewater to evaluate the rate of fouling, if any, and the consequences thereof as well as the effectiveness of several diffuser cleaning methods with respect to oxygen transfer efficiency and pressure loss. An additional objective was to collect laboratory data on the fouling characteristics of ceramic fine pore diffusers from a number of municipal wastewater treatment facilities and to evaluate the impact of selected diffuser cleaning methods on these characteristics.

The Madison treatment facility consists of a number of activated sludge process additions since its initial construction in 1934. The field aeration studies were conducted in both the older aeration tanks, equipped with Norton fine pore domes in 1977 (the East Plant), and the new aeration tanks, equipped with Sanitaire fine pore discs and started up in 1985 (the West Plant). Selected parallel aeration tanks in the West Plant were equipped with acid gas cleaning equipment so that comparisons could be made between different scheduled applications of acid gas and also between in situ acid gas cleaning and other process interruptive techniques. However, as early as September 1985, it was determined that the Madison municipal wastewater did not generate a serious diffuser fouling problem. As a result, those studies to investigate the effects of diffuser cleaning at this plant were deemphasized. Instead, studies were introduced to evaluate the effects of plant operation on fine pore oxygen transfer efficiency.

This report presents the results of this study in two parts. Part I evaluates the long-term performance of the fine pore domes in the East Plant. Part II presents the results of two years of performance of fine pore discs in the West Plant.

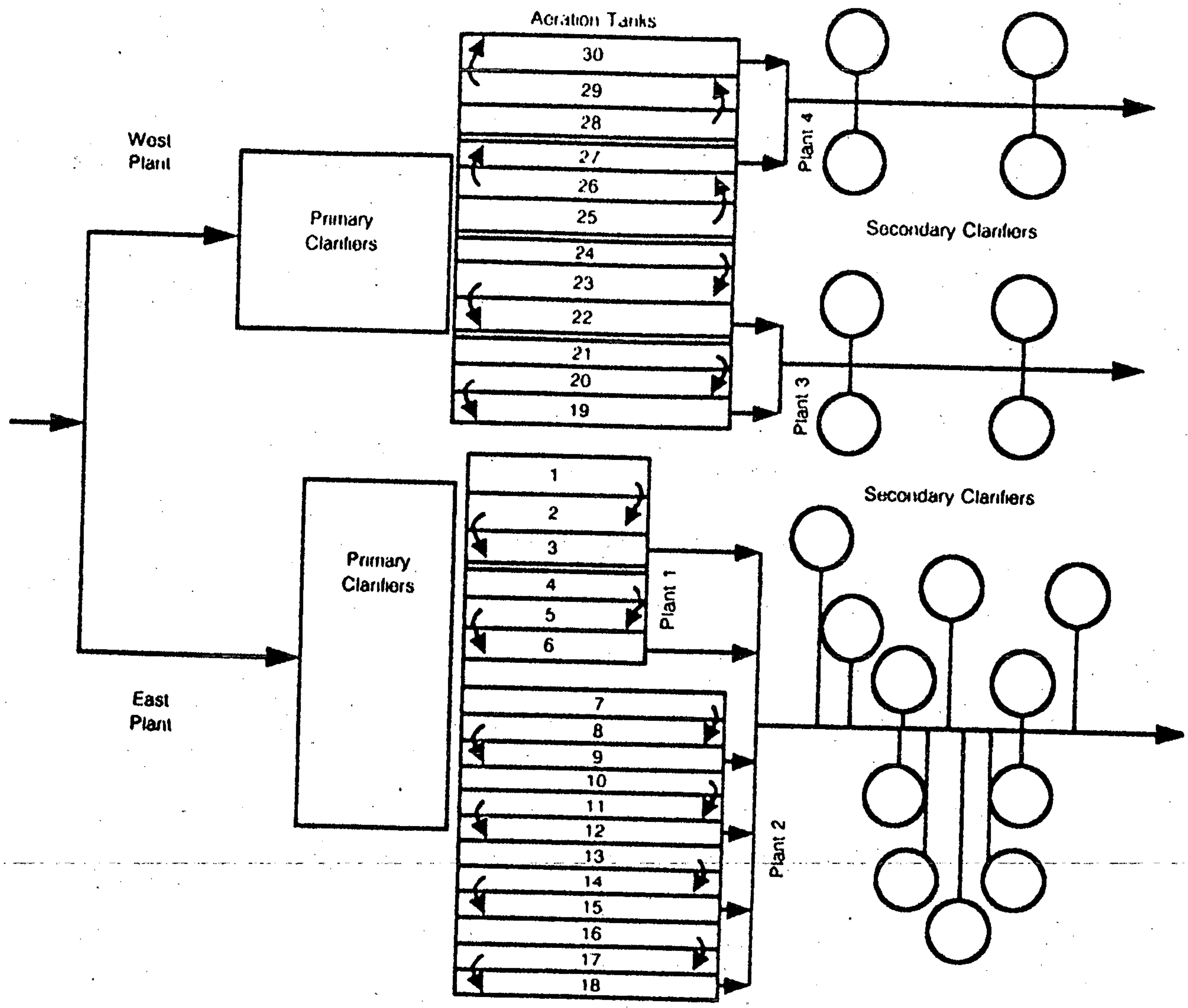
FACILITIES

The MMSD wastewater treatment facility, located on the south side of Madison, serves the cities of Madison, Monona, Middleton, and Fitchburg, six villages and portions of several townships within Dane County. The present average flow is approximately 38 MGD; the design flow is 50 MGD.

Figure 1 presents a plan view of the facility. Raw wastewater is brought to this treatment plant through 113 miles of interceptor sewers and force mains with the help of 84 pumping stations. Degritted wastewater is subsequently split between an East and a West Plant where it is settled prior to activated sludge treatment. The plant is currently operated to nitrify ammonia as a single-stage process. Secondary effluent receives ultraviolet irradiation prior to being pumped back into the Yahara River wastershed downstream of the chain of lakes in the Madison area.

This study was conducted in the aeration tanks in both the East and West Plant. The East Plant consisted of Plants 1 and 2 (Tanks 1-18), the West Plant was made up of Plants 3 and 4 (Tanks 19-30). Oxygen transfer tests were performed in Aeration Tanks 1-6 (domes) and 19 through 30 (discs). Details related to the aeration tanks, the aeration equipment, and test points are found in the appropriate chapters to follow.

Figure 1. Plan View, Madison Metropolitan Sewerage District Plant.



EXPERIMENTAL METHODS

Experimental Design

Both field and laboratory studies were conducted at this site. In the field studies, oxygen transfer efficiency was monitored by the off-gas method. In the East Plant, off-gas analyses were performed in all three passes of the three-pass aeration tanks on a given test day. These analyses were used to provide information on the long-term performance of one of the early dome installations. In the West Plant, off-gas analyses were performed primarily in the four parallel first passes (Tanks 21, 24, 25, and 28) of four sets of three-pass aeration tanks. Usually two tanks were tested on a given day. Occasionally, all three passes of a given set of tanks were analyzed. These analyses were used to provide information on the day-to-day variation in oxygen transfer for a new disc installation over a two-year period. Additionally, the effects of process operation on oxygen transfer efficiency were studied.

Laboratory analyses were performed on diffusers from the MMSD plant as well as those from other municipal treatment plants to determine the effect of fouling. Laboratory tests included dynamic wet pressure (DWP), bubble release vacuum (BRV), flow profile, and foulant analysis. In addition to these tests, a number of diffusers were also cleaned after being characterized using selected cleaning procedures including high pressure hosing, steam cleaning, acid-gas cleaning, and the Milwaukee Method. Changes in properties of these diffusers were then monitored.

Off-Gas Testing

Off-gas analyses were performed using a Ewing off-gas analyzer. A description of the theory of off-gas testing may be found in Redmon et al. (1). Details of the apparatus, techniques for measurement, and calculations of field standard oxygen transfer efficiency (αSOTE) can be found in Appendix A. A typical printout for a test is presented in Figure 2.

Two types of hood design were used in these studies. The fiberglass hood (Figure 3) was used for testing Aeration Tanks 1-6 in the East Plant. The hood measured 26 inches in width with a 31 square foot capture area and an underside airspace volume of 10 to 15 cubic feet. Floatation was provided by two 6-inch sealed PVC pipes which ran along the underside of the hood. Under its own buoyancy, the hood normally extended to about 6 inches below the mixed liquor surface. The ends of the hood were tapered to provide capture of off-gas under the Y-walls.

Tank to tank movement of the fiberglass hood was difficult due to its weight. To reduce the time of a test run, a number of plywood hoods were constructed for use in the West Plant tests (Figure 3). The 4 foot by 8 foot plywood hoods provided 32 square feet of capture area and an underside airspace volume of 8 to 10 cubic feet. Two inch thick Styrofoam was glued to the underside of the hood to provide stability. Marine varnish was

Figure 2. Computer Printout - Off-gas Data.

Summary Data Sheet

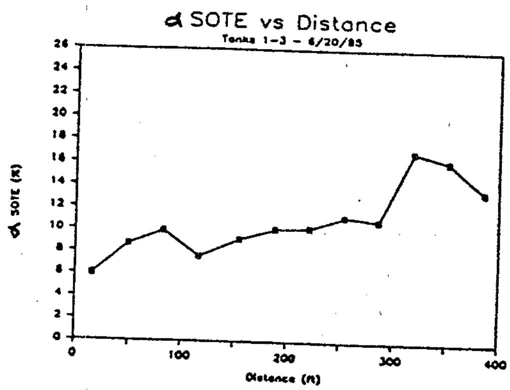
Test Site: Madison
Nine Springs
Tank # 1 - 3
Date: 6/20/85
Aeration System: Norton Domes
Ctemp: 9.17
Beta: 0.99
C*inf(20) Value: 10.60
Source: Ewing Engineering
C*inf(fld) Value: 10.33
Source: Calculated
Roto temp: 31.11
Tank Volume (MG/Tank (3 tank pass)) 0.47
Submergence(ft): 15.0
Sludge Age(days): 8.9
MLSS(mg/l): 1362
TDS(mg/l): <1000
Primary Effluent BOD: 141
Loading(lb/1000cuft/day): 29.3
Liquid Flow Rate During Test:
Wastewater(MG): 4.70
Recirculation(MG): 3.67
Total(MG): 8.37
Estimated Ret. Time(hr): 4.04
Applied Air Rate: NA cfm
Local Barometer: 29.22
Comments: 4 points per tank. 12 points total in the three tank pass.

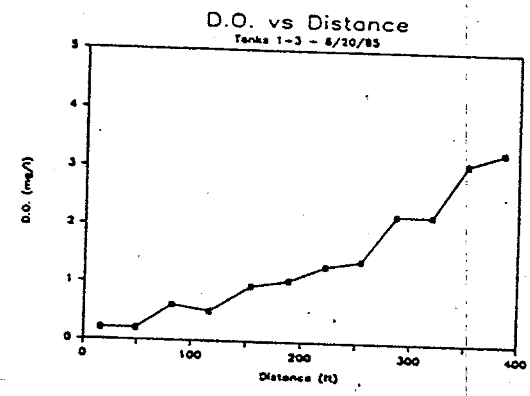
Overall Flux Rate scfm/sf	OTEf (mean)	OTEsp20 (mean)	α SOTE (mean)	SOTEdw	Clean SOTE dec
				0.0598	
				0.0870	
				0.0992	
				0.0761	
0.2625	8.59%	0.0097	10.19%	0.0917	
				0.1011	
				0.1024	
				0.1126	
				0.1095	
				0.1706	
				0.1625	
				0.1362	

Total Air Flow (calculated): 2023.16 scfm

Clock Time	Station	Mole Fraction CO2 (FCO2)	Sensor Output Off-Gas mv MOG	Sensor Output Ref Air mv MR	Mixed Liquor Temp. deg C	DO mg/l C
1420	1-1	0.5	916	965	19.75	0.20
1436	1-2	0.9	892	965	-	0.20
1451	1-3	1.0	884	964	-	0.60
1503	1-4	1.0	901	965	-	0.50
1540	2-5	1.3	890	965	-	0.95
1600	2-6	1.1	886	965	-	1.05
1615	2-7	1.1	887	965	-	1.30
1631	2-8	1.0	881	964	-	1.40
1713	3-9	1.2	885	961	-	2.20
1732	3-10	1.1	848	960	-	2.20
1745	3-11	1.2	863	960	-	3.10
1007	3-12	1.1	880	960	-	3.30

Deficit mg/l C*inf(f) - C	Roto 1 Float Height	Roto 2 Float Height	Field OTE(tf) dec	Specific OTEsp20 dec	Off-Gas Flux Rate scfm/sf
10.13	0	110	0.0575	0.0057	0.3736
10.13	0	100	0.0836	0.0083	0.3441
9.73	0	90	0.0915	0.0095	0.3147
9.83	0	101	0.0709	0.0073	0.3471
9.38	0	77	0.0815	0.0087	0.2765
9.28	0	72	0.0889	0.0096	0.2619
9.03	0	63	0.0876	0.0098	0.2355
8.93	0	56	0.0953	0.0107	0.2150
8.13	0	62	0.0843	0.0104	0.2326
8.13	211	0	0.1314	0.0163	0.1680
7.23	0	50	0.1113	0.0155	0.1975
7.03	250	0	0.0907	0.0130	0.1824





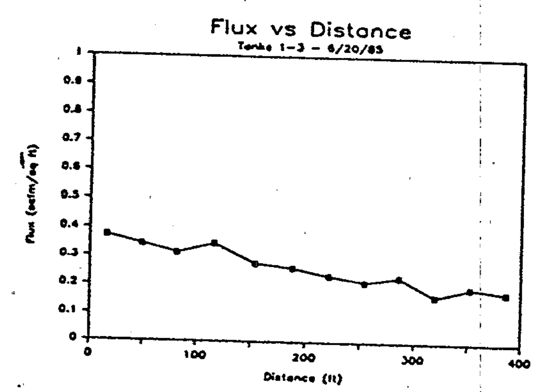


Figure 3a. Off-gas Hood - Fiberglass.

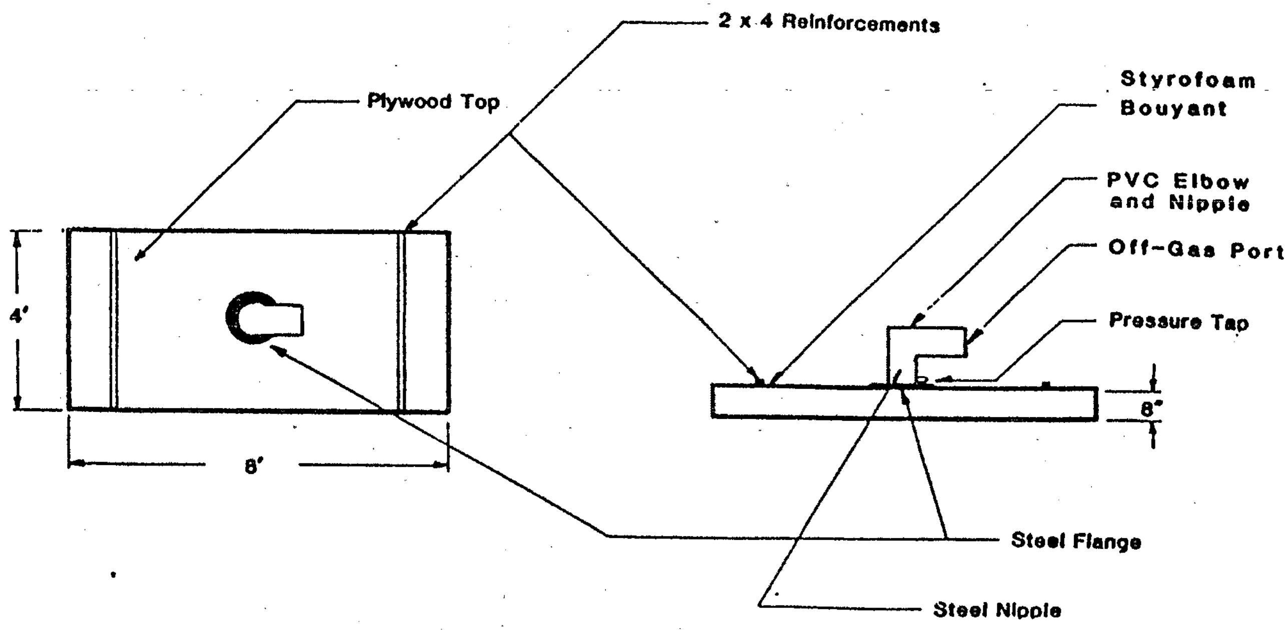
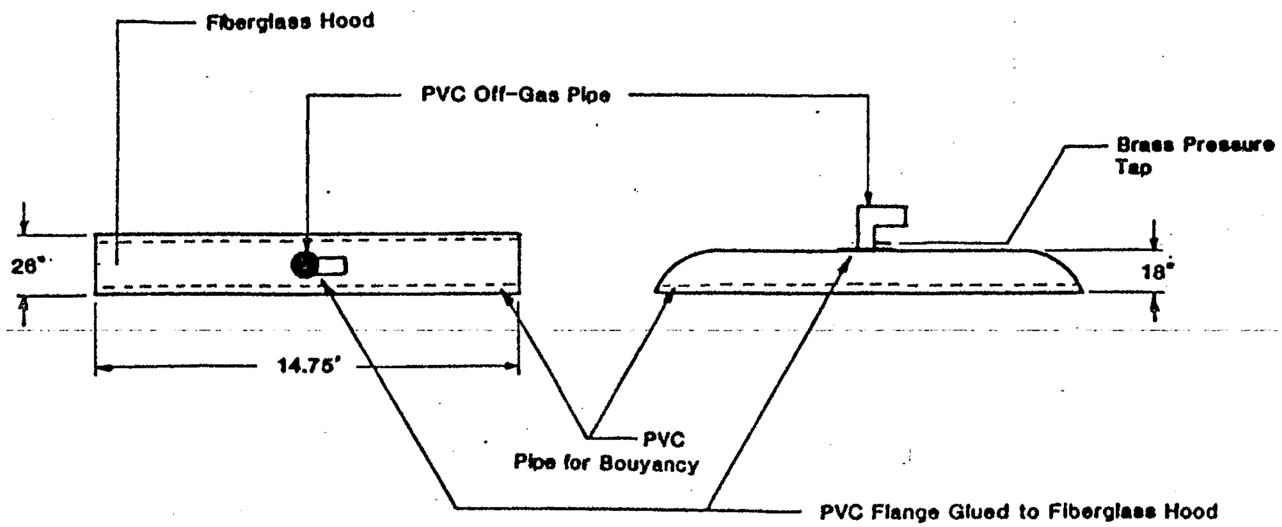


Figure 3b. Off-gas Hood - Plywood.



used to seal the plywood hood. Ullage on the underside of the hood varied from 3 to 4 inches. This was not sufficient on days when significant Nocardia foam developed. New hood designs now provide more freeboard, 8 to 10 inches, to avoid foaming problems.

Off-gas was pulled by vacuum through a 1.5 inch diameter vacuum hose. A pressure tap was located on the exit gas elbow fitting to assist the operator in proper throttling of off-gas exit rate. Normally excellent gas flow was obtained by insuring a positive hood pressure of 0.1 to 0.3 inches water (gauge). Negative pressures exceeding 1.5 inches water (gauge) could cause leaks of ambient air into the off-gas stream.

Laboratory Diffuser Characterization

Diffusers were characterized by dynamic wet pressure (DWP), bubble release vacuum (BRV), flow profile, and foulant analysis. Details of these test procedures appear in Appendix B.

Other Methods

Plant operation data were supplied by the MMSD and were gathered in their laboratory following procedures outlined in Standard Methods (2).

A test header consisting of four Sanitaire discs was installed in Aeration Tank 21 as a part of the ASCE/EPA Cooperative Research Agreement. Similar headers were installed in other plants and served to provide comparative data on the relative fouling properties of each plant's wastewater. A separate report on this interplant fouling study was written by Baillod (3).

Results of the off-gas measurements were reported as αSOTE. The value of αSOTE is the field oxygen transfer efficiency corrected to 20°C, 1 atmosphere pressure at a DO of 0 mg/L. The value of alpha (α) in this term is the "apparent" alpha accounting for both the wastewater mediated effects on transfer and the fouling effects on transfer. No effort was made in this research to differentiate between these two effects.

RESULTS AND DISCUSSION - EAST PLANT

Facilities

The East Plant at MMSD actually consists of two different sets of aeration tanks and clarifiers referred to as Plant 1 and Plant 2 (Figure 4). This study was conducted in Plant 1 with Aeration Tanks 1-6. These tanks were part of the original activated sludge system built in 1934. Initially these tanks were equipped with Walker Sparjers in a spiral roll configuration. In 1977, the MMSD determined that Aeration Tanks 1-6 would be equipped with "new" Norton dome diffusers in a full floor coverage. This decision was based on a review of 1973-74 plant operating data which revealed a field oxygen transfer efficiency (OTE) with the Sparjers of approximately 5.7%. It was estimated that the new domes would raise the efficiency to about 11%.

Each aeration tank consisted of three folded basins, each pass being 135 ft long. The diffusers were tapered in accordance with estimated oxygen uptake requirements along the aeration tank. Figure 5 presents a layout of the three tanks and Table 1 describes the physical characteristics of these six tanks. Figure 6 presents a detailed showing of the diffuser assembly. It should be noted that brass orifice bolts, brass washers, and integrally molded brass inserts were used to fasten the domes on the support pipe.

The two sets of three aeration basins were designed to operate in several modes: plug flow, step aeration with feed points at the head end of each of the three basins in series, or contact stabilization where the first tank of the series served as the reaeration basin.

Plant Operation and Diffuser Maintenance

Table 2 presents information on a selected number of operational parameters for Plant 1 from start-up in October 1977 through December 1987. Table 3 presents the yearly average raw wastewater (primary influent) characteristics over that same period.

Aeration Tanks 1-6 were placed on-line in October 1977. At that time, these two sets of tanks were operated as a "contact-stabilization" process with Basins 1 and 4 serving as the reaeration units and primary effluent was fed in a step aeration mode to Basins 2, 3, 5, and 6. Over the next two years, the system performed well with occasional partial nitrification occurring during the warmer months. Low SRTs (2-4 days) and high F/Ms (0.2-0.3) reflected the operation strategy of that time.

In September 1979, the basins were converted to step feed. Primary effluent was fed to the head end of all six basins. At that same time, raw BOD concentrations began to increase significantly (Table 3). For example, the average primary effluent BOD between October 1977 and September 1979 was 141 mg/L ($\sigma = 17$). Between October 1979 and August 1980, that average increased to 191 mg/L ($\sigma = 17$). This increase was believed to have been due primarily to whey discharges from dairies within the district. Sometime in the fall of 1980, those discharges were discontinued. Operating personnel noted a

Figure 4. Aeration Tank Layout - Plants 1 and 2.

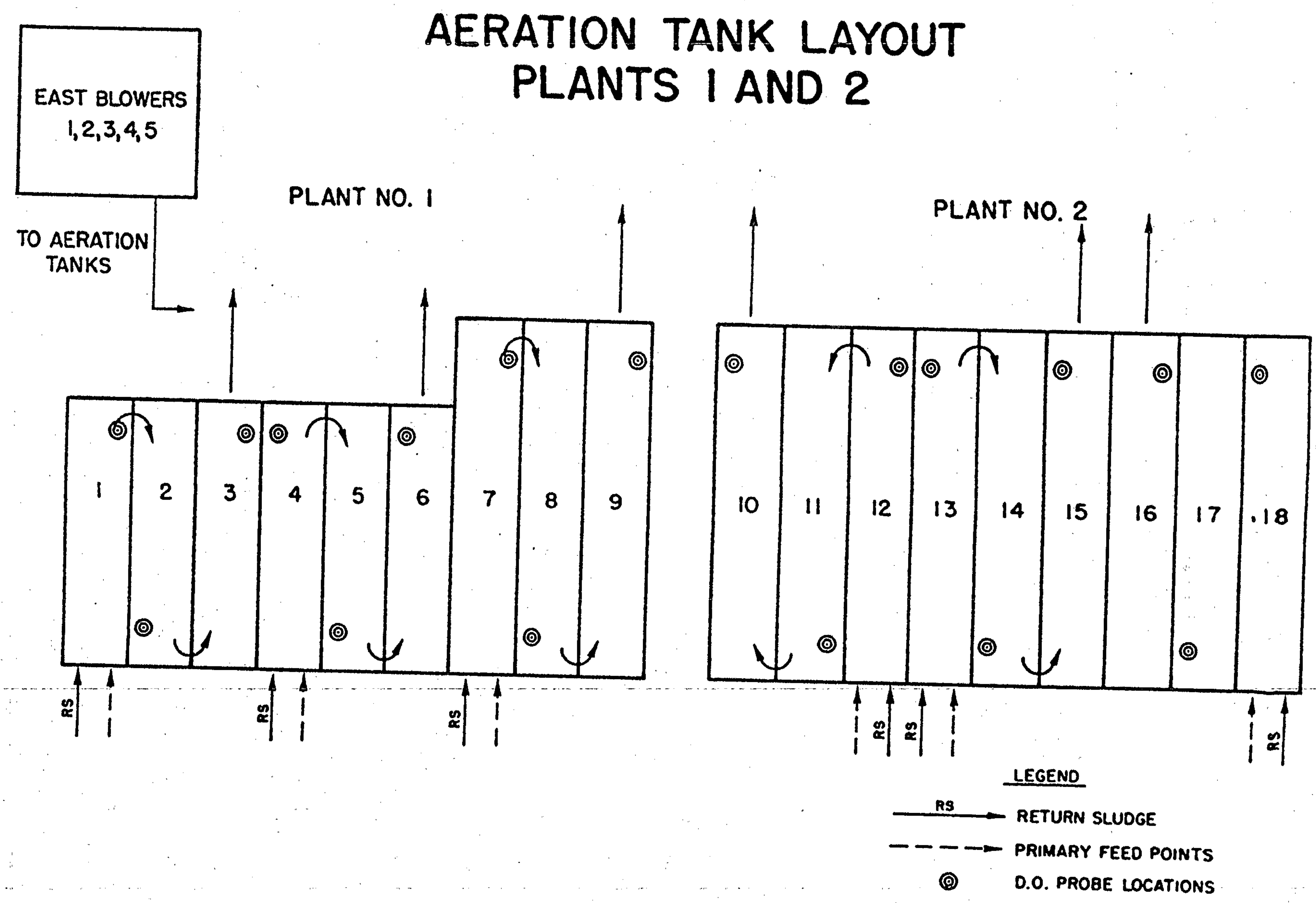


Figure 5. Aeration Tanks 1-6 - Typical.

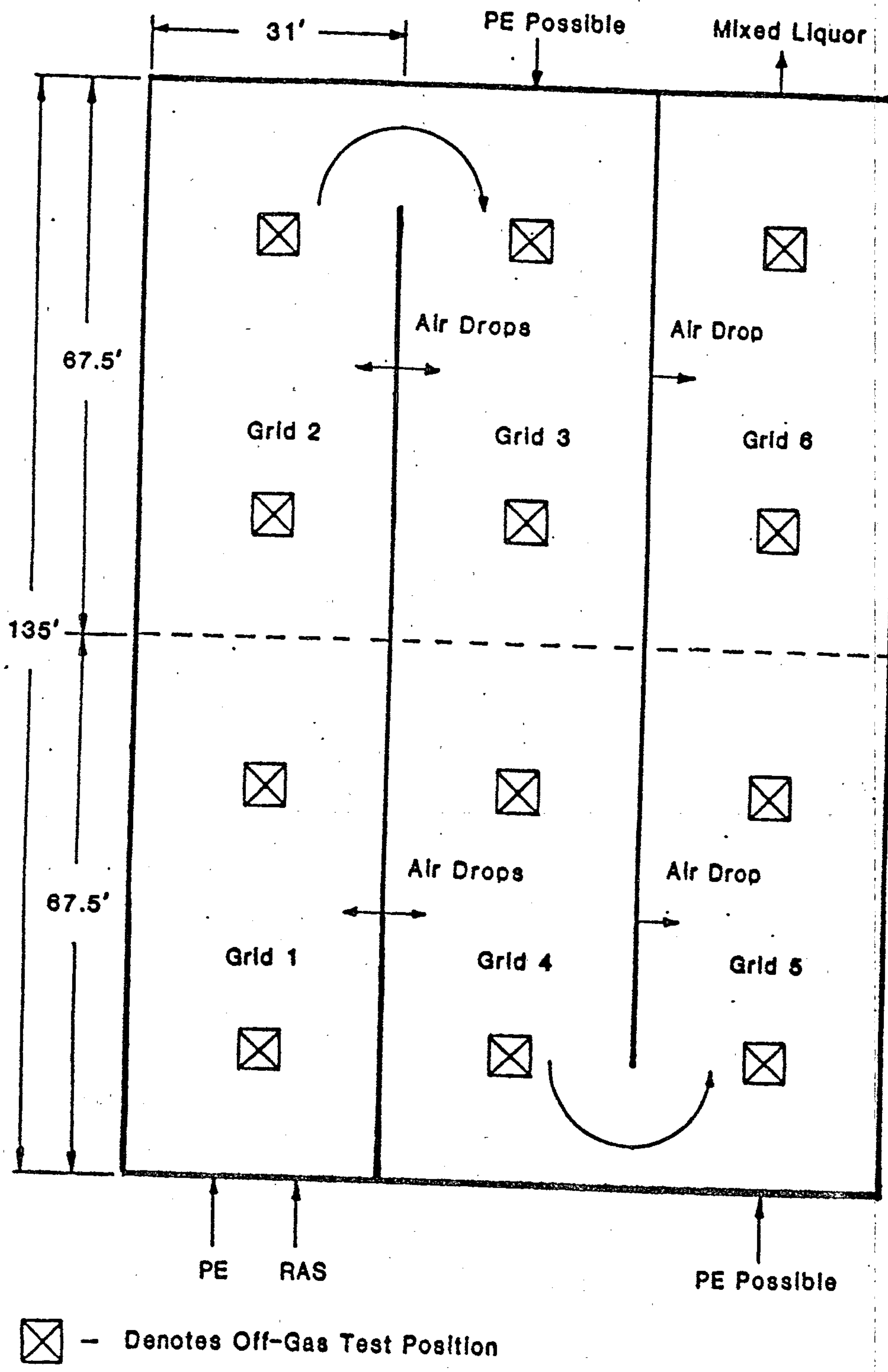


TABLE 1
AERATION TANKS 1-6 - NORTON DOMES

Tank Dimensions:	31' (center/center) x 135' x 15.5' (WxLxD)
Liquid Surface:	~23' x 135'
Grid Surface:	24' x 67.5' (2 grids per tank)
Max Y-wall Width:	29.5'
Tank Volume:	460,000 gallons
Diffuser Grids:	Norton domes in full floor coverage
Diffuser Submergence:	15'

Note: The above data is for individual tanks, while the data below is for the entire three-pass system

Diffuser Grid	No. of Diffusers	Diffuser Density	Tank No.
1	834	11%	1, 4
2	709	9%	1, 4
3	505	7%	2, 5
4	410	5%	2, 5
5	392	5%	3, 6
6	332	4%	3, 6

Diffuser Density = total projected diffuser surface area/grid surface area

Figure 6. Norton Dome Assembly.

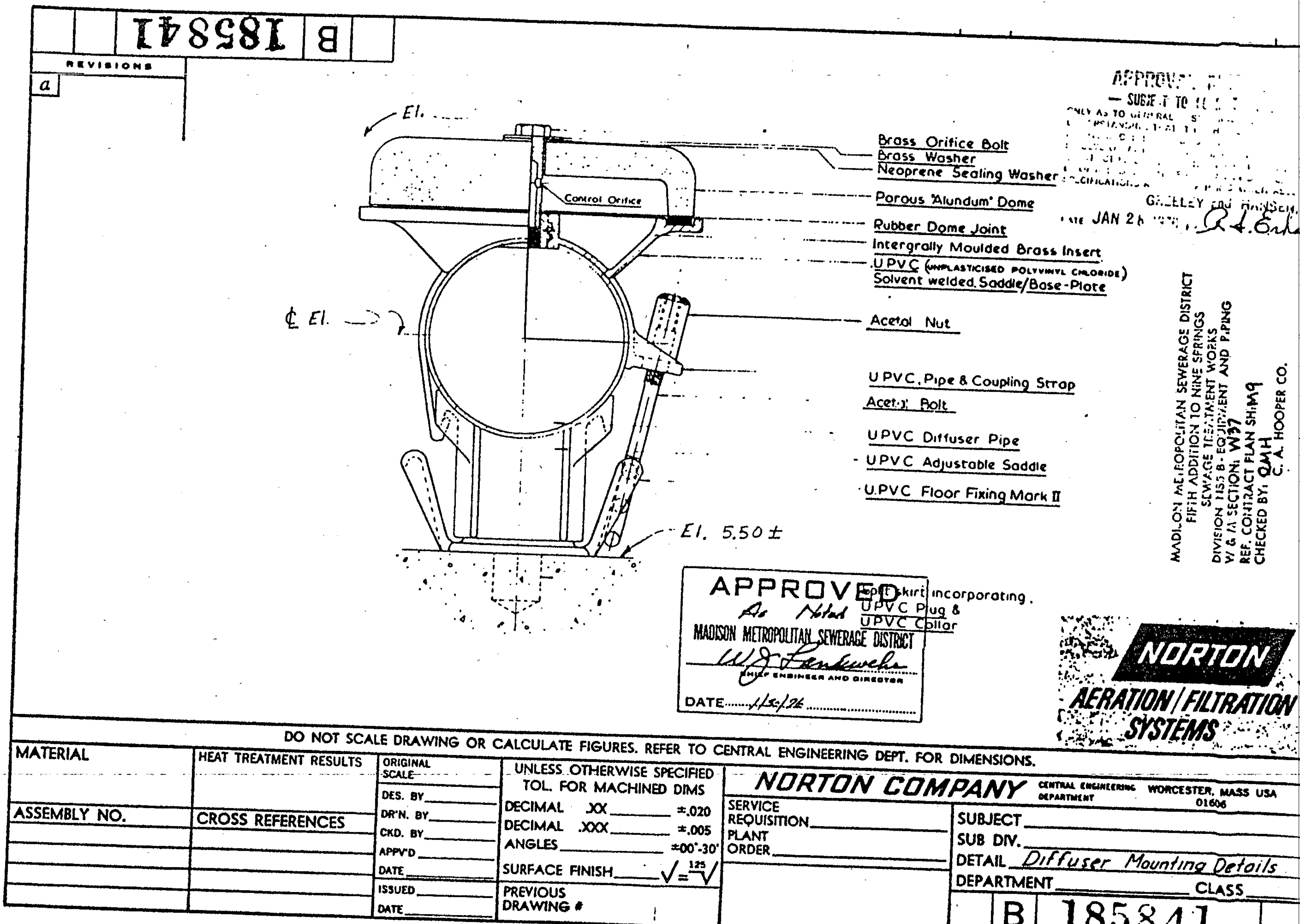


TABLE 2
SELECTED PLANT OPERATION DATA
PLANT 1
(AERATION TANKS 1-9)

Date	MONTHLY AVERAGES BOD Load (lb/1000 cf,d)	SRT* (day)	F/M (day^{-1})	NOTES
10/77	19.9	4.3	0.20	Contact stabilization to 9/13/79
11/77	23.5	2.9	0.31	
12/77	25.0	2.6	0.30	
1/78	15.7	2.9	0.26	
2/78	32.0	---	0.31	Partial nitrification began
3/78	25.5	2.9	0.24	
4/78	27.8	3.4	0.23	Tanks dewatered; diffusers looked okay
5/78	28.2	2.7	0.30	
6/78	25.9	3.3	0.29	
7/78	22.5	3.5	0.22	
8/78	24.7	3.0	0.25	
9/78	24.5	3.2	0.24	
10/78	29.0	3.4	0.26	
11/78	30.1	3.0	0.28	
12/78	28.8	3.1	0.27	
1/79	31.5	3.8	0.25	
2/79	30.3	3.9	0.23	
3/79	30.9	4.0	0.23	
4/79	30.5	3.9	0.22	
5/79	30.5	4.1	0.21	
6/79	30.4	2.9	0.25	
7/79	27.7	3.2	0.28	All nitrification ceased
8/79	30.4	2.6	0.30	
9/79	29.1	1.6	0.42	Step feed initiated 9/13/79
10/79	36.2	2.4	0.49	High influent BOD concentrations noted; heavy whey discharges
11/79	35.7	2.8	0.38	
12/79	32.8	2.8	0.34	
1/80	34.0	2.9	0.36	
2/80	37.5	3.0	0.33	Loss in OTE noted
3/80	38.2	2.9	0.36	
4/80	38.5	2.9	0.36	
5/80	36.8	3.8	0.31	Tanks 4-6 dewatered; hose & steam cleaned
6/80	37.4	3.5	0.27	Tanks 1-3 dewatered; hose & steam cleaned

TABLE 2 (Continued)

Date	MONTHLY AVERAGES BOD Load (lb/1000 cf,d)	SRT* (day)	F/M (day^{-1})	NOTES
7/80	36.8	3.9	0.30	
8/80	33.4	2.8	0.33	
9/80	33.6	2.4	0.36	
10/80	27.8	2.9	0.31	
11/80	26.3	2.6	0.31	
12/80	28.4	2.9	0.36	Tanks 1-3 dewatered; hose cleaned
1/81	30.0	2.8	0.33	
2/81	34.0	2.6	0.34	
3/81	37.6	2.9	0.29	
4/81	32.3	2.6	0.31	
5/81	30.9	2.4	0.34	
6/81	31.1	2.2	0.37	
7/81	29.5	2.2	0.37	Partial nitrification began
8/81	31.2	2.1	0.39	
9/81	29.4	2.2	0.39	
10/81	30.2	2.3	0.38	
11/81	29.1	2.4	0.40	
12/81	28.9	2.5	0.37	
1/82	26.5	2.1	0.34	
2/82	25.9	2.2	0.33	
3/82	27.9	2.0	0.36	Nitrification ceased
4/82	28.3	2.4	0.33	
5/82	29.3	2.0	0.33	
6/82	26.2	2.0	0.34	Dewater Tanks 1-3; steam cleaned Partial nitrification
7/82	23.2	2.1	0.30	Dewater Tanks 4-6; steam cleaned
8/82	22.9	3.1	0.30	
9/82	22.3	3.4	0.30	
10/82	23.2	3.7	0.31	
11/82	23.8	3.5	0.24	
12/82	24.1	3.8	0.26	
1/83	23.7	4.2	0.27	
2/83	24.8	3.8	0.28	
3/83	27.4	2.3	0.45	
4/83	26.0	2.0	0.50	Nitrification ceased Dewater Tanks 1-3; steam cleaned
5/83	27.0	2.0	0.56	Dewater Tanks 4-6; steam cleaned
6/83	31.9	2.2	0.76	
7/83	32.0	3.5	0.57	
8/83	26.9	3.6	0.39	

TABLE 2 (Continued)

Date	MONTHLY AVERAGES BOD Load (lb/1000 cf,d)	SRT* (day)	F/M (day^{-1})	NOTES
9/83	32.9	3.1	0.63	
10/83	32.5	3.6	0.57	
11/83	34.8	3.5	0.61	
12/83	40.5	3.8	0.75	
1/84	39.0	2.6	0.80	
2/84	33.2	2.0	0.80	
3/84	32.9	1.8	0.90	
4/84	29.5	1.7	0.75	Plug flow initiated
5/84	29.7	1.4	0.82	
6/84	30.5	1.5	0.85	
7/84	23.4	1.6	0.69	Dewater Tanks 1-6; steam cleaned
8/84	17.1	1.9	0.66	
9/84	23.5	2.3	0.51	
10/84	28.0	1.9	0.57	Partial nitrification
11/84	26.5	1.7	0.51	
12/84	20.3	1.9	0.55	
1/85	24.2	2.1	0.58	
2/85	25.4	3.3	0.52	
3/85	20.9	3.5	0.41	
4/85	20.7	3.5	0.37	
5/85	22.6	3.7	0.25	
6/85	21.3	4.4	0.29	
7/85	20.2	5.1	0.32	Dewater Tanks 4-6; Milwaukee Method cleaned
8/85	19.9	3.8	0.40	Dewater Tanks 1-3; steam cleaned Out of service to 12/86
12/86	22.2	11.4	0.16	Back in service, Tanks 1-6. Full nitrification
1/87	11.5	12.2	0.16	
2/87	9.6	15.0	0.11	
3/87	7.9	15.3	0.11	
4/87	9.2	16.2	0.11	
5/87	8.0	15.6	0.09	
6/87	11.4	14.8	0.10	
7/87	13.0	9.8	0.15	
8/87	14.8	9.5	0.15	
9/87	15.8	10.3	0.16	
10/87	8.2	11.1	0.12	
11/87	9.3	8.8	0.19	
12/87	8.2	10.1	0.13	

*Based on aeration tanks solids

TABLE 3
RAW WASTEWATER CHARACTERISTICS - MMSD
(mg/L)

Year	BOD	SS	Nitrogen
1977	191	158	--
1978	184	154	--
1979	213	163	--
1980	245	171	--
1981	217	167	--
1982	187	158	--
1983	194	161	--
1984	178	161	--
1985	176	167	27.9
1986	166	159	26.1
1987	180	167	25.7
			26.8

Other analyses performed periodically:

Alkalinity	300-400 mg/L $CaCO_3$
pH	7.2 to 8.0
Hardness	350-400 mg/L $CaCO_3$
Iron	0.6-1.0 mg/L Fe

significant increased requirement for gas flow early in 1980; and when the six aeration tanks were dewatered in May and June of that year, a heavy gelatinous foulant was found on the diffusers. The diffusers were hosed down and put back into service. A second dewatering of Tanks 1-3 in December revealed only minor fouling and the diffusers were again hosed.

Between January 1981 and April 1984, the basins were typically dewatered in late spring or early summer each year and the diffusers hosed off. Only a light foulant was noted during this time. Partial nitrification occurred during this period and SRT values ranged from two to four days.

In April 1984, the aeration tanks were switched to a plug flow mode. The aeration tanks were dewatered in June of that year and the diffusers were steam cleaned. Work began on the new aeration tanks in Plants 3 and 4 (West Plant) in June of 1983. During the period between June 1983 and June 1985, flows and loads to the East Plant (Plants 1 and 2) were erratic. Between June and August 1985, as the West Plant went on line, Aeration Tanks 1-6 were taken out of service for repair. The diffusers in Tanks 1-3 were steam cleaned, and those in Tanks 4-6 were hosed, dosed with muratic acid for about 20 minutes and rehosed (Milwaukee Method). After cleaning, the basins remained out of service until December 1986. In that interval, the diffusers were submerged in about 12 inches of water which became stagnant and heavily infested with algal growth.

The new discharge permit for MMSD required nitrification of wastewater after about 1985. As a result, Aeration Tanks 1-6 were put back into service as a plug flow system at a very light loading. SRTs ranged from about 8 to 16 days between December 1986 and January 1988. Complete nitrification was obtained after start-up in December.

Oxygen Transfer Studies

Oxygen transfer studies using off-gas procedures were initiated in May 1984 and continued through the summer of 1987. Sampling points for off-gas analysis (Figure 5) were selected to cover the inlet and outlet areas of all six grids and to have each hood represent an equal tank surface area. OTE values corrected to standard conditions, αSOTE, were calculated for each sample point and for all three tanks by gas flux weighting of the point values. A typical printout of data from an off-gas test is presented in Figure 2. Note that dissolved oxygen control in Plant 1 was manual up until late 1986 when the aeration tanks were rehabilitated. Manual control was achieved by reading D.O. probe values from probes placed in the effluent end of the three-pass systems (e.g., Tanks 3, 6, etc.) and adjusting gas flow to maintain a set point D.O. (usually approximately 2.0 mg/L during the non-nitrification period). No effort was made to obtain positive D.O. at the influent end. Automatic control of D.O. was instituted in late 1986. D.O. was monitored at each grid and control was provided by set points (and minimum gas flows) in each pass. Typically, D.O. set points were 1.0, 2.0, and 2.0 mg/L for the first, second, and third passes, respectively. During an off-gas study, no effort was made to maintain a specific D.O. or gas flow rate, although tests were normally conducted at a time when loads were reasonably stable. Typically, off-gas tests were conducted at the same time of the day and same day of the week.

Estimates of apparent alpha for Aeration Tanks 1-6 were obtained by comparing αSOTE measurements to clean water test data. Clean water tests performed by Paulson (4) and Yunt (5) for ceramic domes were analyzed for a variety of gas flows and diffuser densities. Extrapolation of this clean water data to Aeration Tanks 1-6 provided clean water SOTE values for each grid at a range of gas flow rates.

In addition to off-gas analyses, occasional oxygen transfer tests were conducted using steady-state methods (6). Typically these tests were conducted in only one pass. Brochtrup (7) showed that steady-state oxygen transfer measurements were comparable to off-gas tests in the MMSD aeration tanks provided DO concentrations were above 2.0 mg/L.

Results of the major off-gas studies conducted in Aeration Tanks 1-3 along with weekly SRT and F/M data and daily BOD loading for the test day appear in Table 4 and in Figures 7, 8, 9, 10, 11, and 12. All data in these tables and figures are for plug flow conditions.

Additional oxygen transfer data are also presented in Table 5. These studies were conducted on occasion by MMSD personnel and UW students using steady-state or off-gas procedures. In most instances, only a single tank was sampled.

In reviewing these tables, a few comments are worthy of attention. In Table 4, test data on July 17 and August 14, 1985, were collected during a very heavy infestation of Nocardia scum. As described by Mueller (8), Nocardia foam can strip significant amounts of oxygen under the hood thereby affecting off-gas analysis. Mass balance calculations suggest that this foam may elevate calculated αSOTE values by as much as 3 to 4 percentage points. These two data points were therefore omitted from further data analysis.

In Table 5, it should be noted that the 1978 data were collected on the reaeration tank (Tank 4) by steady-state methods. The 1980-84 data were collected when the plant was in a step aeration mode. The August 1982 test compared steady-state with off-gas methods and found them to be comparable within the presumed errors of the test methods (7).

A review of the data in these tables and figures reveals several important observations.

Oxygen transfer during the period May 1984 to July 1987 (Figure 7) was significantly impacted by three events:

- A two hour air flow shut off when the diffuser piping filled with mixed liquor which was subsequently purged either through blow-off legs or the diffusers following air restoration (Day 10).

- Cleaning periods, when the aeration tanks were dewatered and the diffusers steam cleaned. One of these cleanings occurred 15 months (Day 61) after the last cleaning event in April 1983. The other occurred 14 months (Day 482) after cleaning in July 1984.

- A significant change in plant loading after 14 months of shutdown when SRT values were increased in order to achieve complete nitrification (after Day 1086).

The increase in αSOTE during air interruption may have been due to the scouring effect of liquid being forced upward through the diffusers. Clogged pores may have been reopened by the purging action, thereby providing greater usable diffuser area and lower local flux rates. The more uniform, lower flux rates would produce higher αSOTE values. This restoration was short lived (2 to 3 weeks) which might have been expected from

TABLE 4

EAST PLANT OXYGEN TRANSFER TEST DATA
TANKS 1-3

Date	Day	αSOTE (%)	Weekly F/M ($days^{-1}$)	Weekly SRT (days)	Daily BOD Load ($lb/1000\ ft^3d$)	NOTES
05/21/84	1	9.44	.82	1.4	34	
05/23/84	3	8.13	.82	1.4	39	
05/30/84	10	8.56	.82	1.4	55	Power out 6/7/84
06/08/84	19	15.53	.85	1.5	37	
06/12/84	23	13.00	.85	1.5	30	
06/21/84	32	10.07	.85	1.5	46	
06/26/84	37	9.99	.85	1.5	54	
07/06/84	47	11.15	.69	1.6	32	
07/12/84	53	9.61	.69	1.6	34	
07/18/84	59	10.23	.69	1.6	16	Steam clean 7/20/84
07/27/84	68	13.96	.69	1.6	34	
08/01/84	73	14.87	.66	1.9	44	
08/07/84	81	13.00	.66	1.9	41	
08/13/84	87	12.94	.66	1.7	37	
08/20/84	94	12.98	.66	1.7	53	
08/29/84	103	11.81	.66	1.7	41	
09/07/84	112	9.68	.51	2.3	26	
09/18/84	123	9.80	.51	2.3	49	
12/20/84	216	9.52	.55	1.9	23	
03/15/85	301	8.16	.41	3.5	32	
04/26/85	343	12.58	.37	3.5	27	
0/20/85	398	10.19	.29	4.4	29	
06/26/85	404	11.33	.29	4.4	28	
07/03/85	411	9.74	.32	5.1	32	
07/17/85	425	15.67	.32	5.1	29	Heavy Nocardia foam
08/14/85	453	16.72	.40	3.8	26	Heavy Nocardia foam
						Steam clean 9/13/85 Out of service from 9/13/85 to 11/18/86; units submerged in 12 in. stagnant water during this period.
05/08/87	1086	15.30	.13	16.2	12	
05/27/87	1105	16.40	.11	16.5	10	
05/29/87	1107	14.60	.08	16.4	7	
06/09/87	1118	15.30	.12	16.6	14	
06/17/87	1125	18.08	.10	16.6	11	
06/25/87	1133	19.60	.10	10.0	11	
06/29/87	1137	20.40	.10	10.0	10	
07/15/87	1154	17.30	.21	10.0	20	

Figure 7. αSOTE vs. Time - Tanks 1-3.

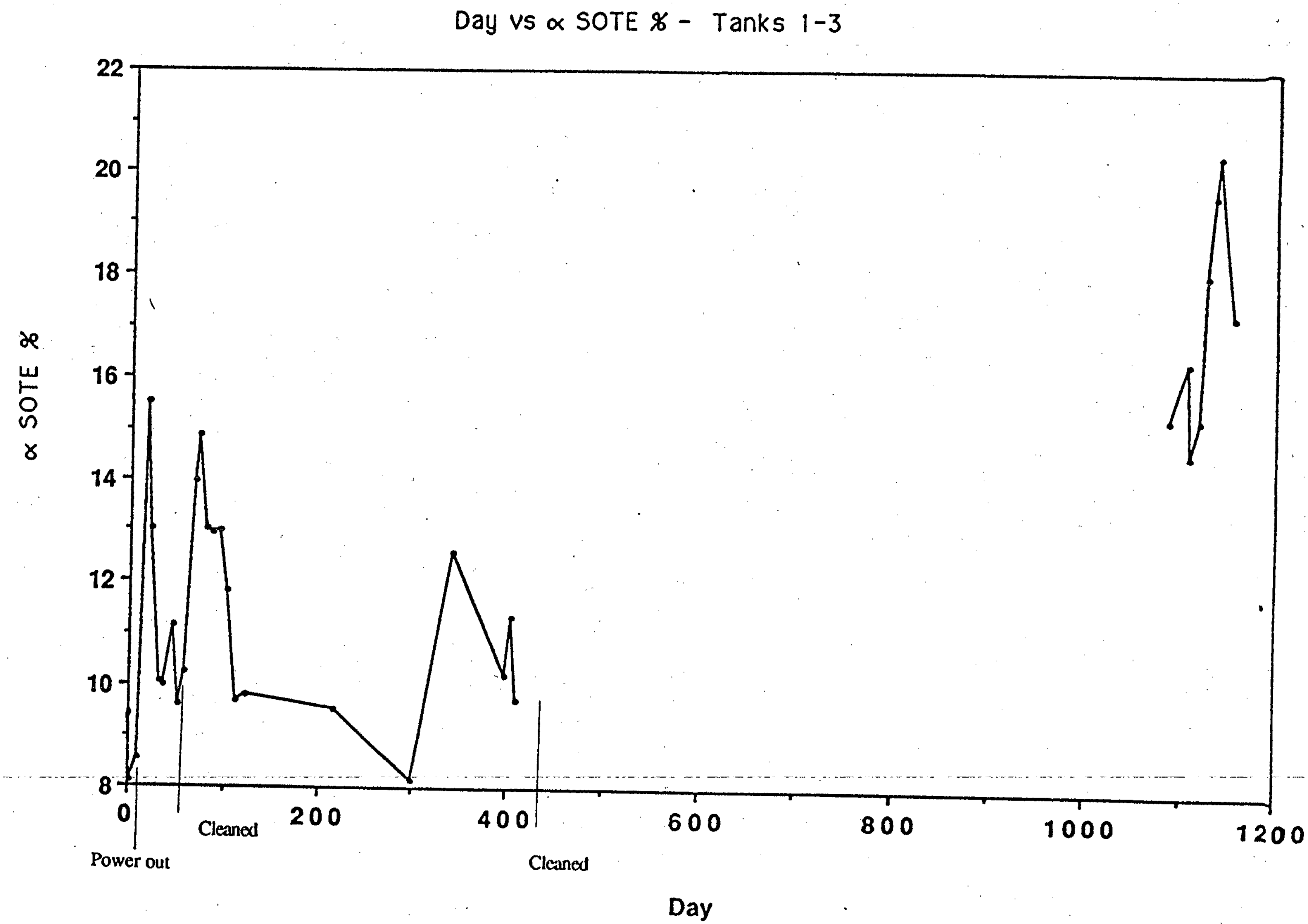


Figure 8a. αSOTE vs. Time - Exploded 0 to 500 days.

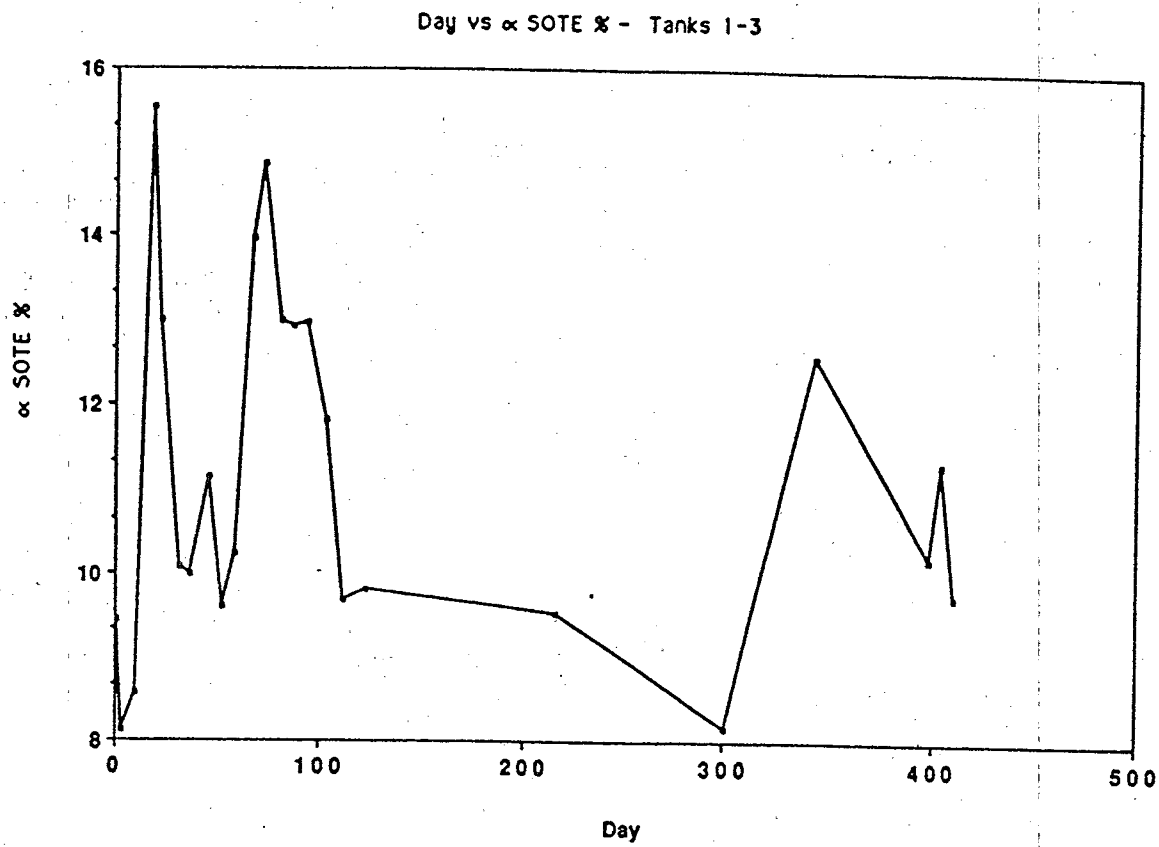


Figure 8b. αSOTE vs. Time - Exploded 1080 to 1160 days.

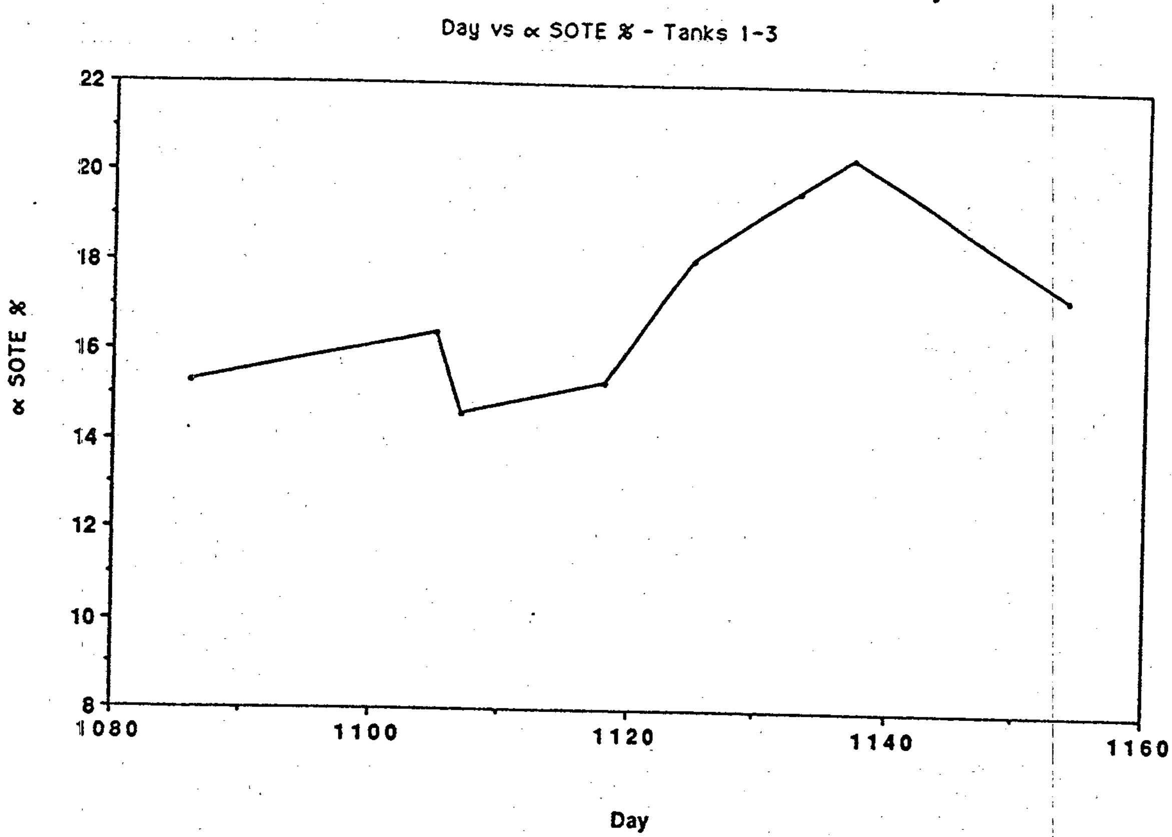


Figure 9. F/M vs. Time - Tanks 1-3.

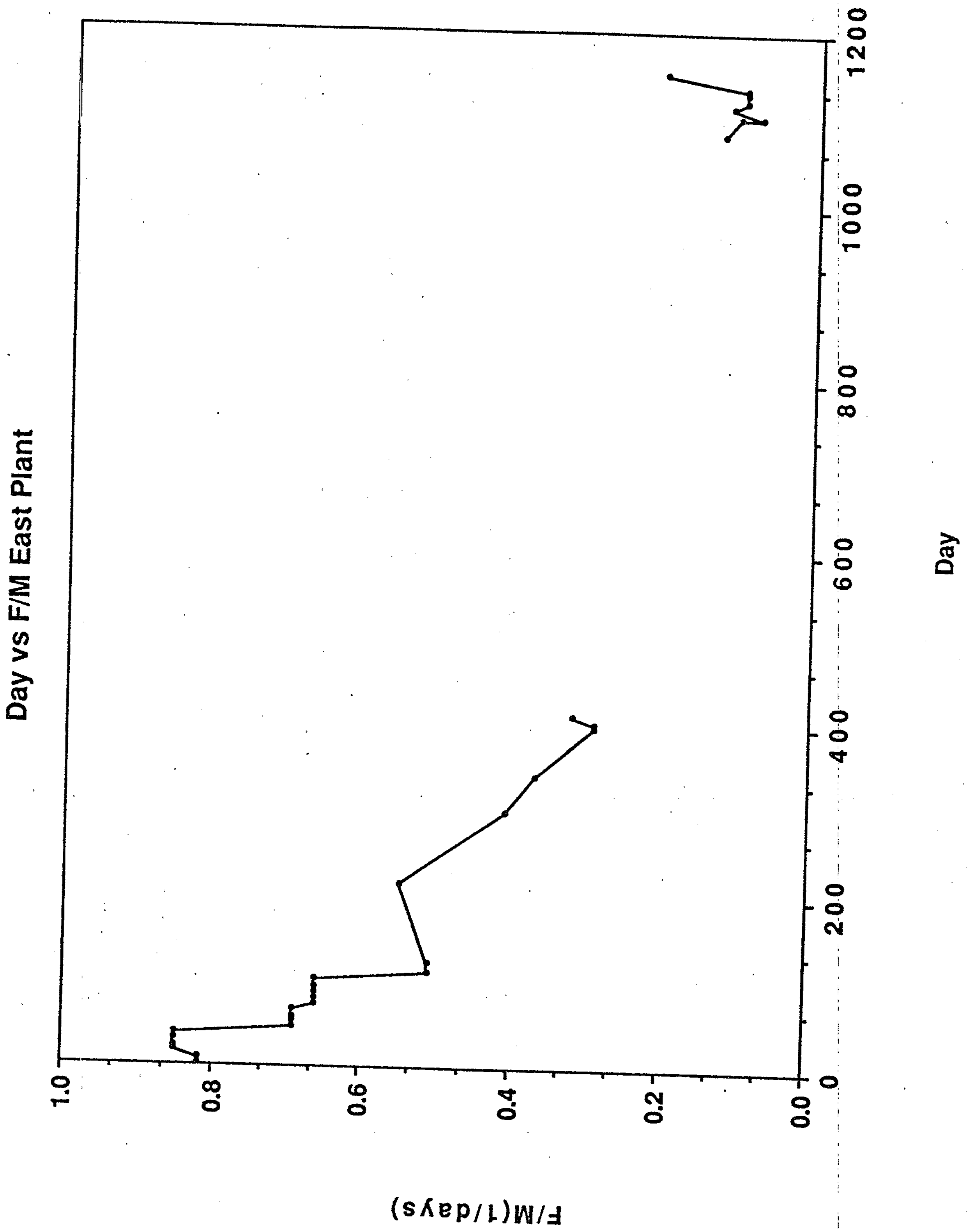


Figure 10a. F/M vs. Time - Exploded 0 to 500 days.

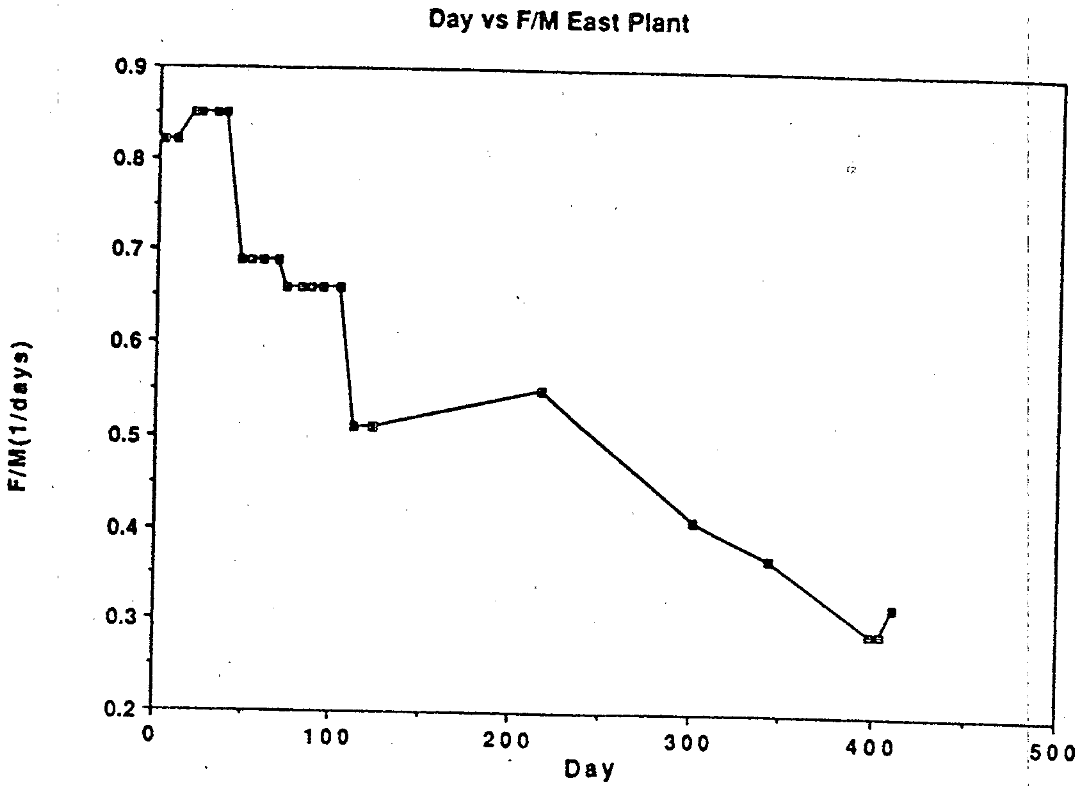


Figure 10b. F/M vs. Time - Exploded 1080 to 1160 days.

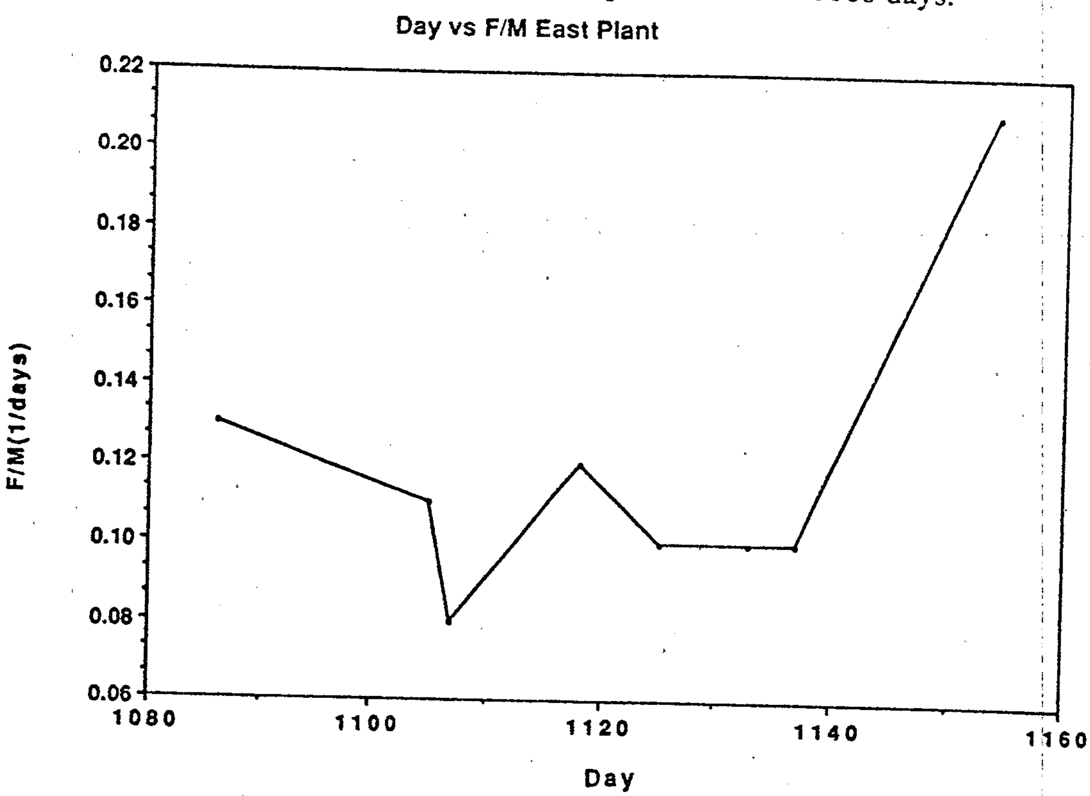


Figure 11. BOD Load vs. Time - Tanks 1-3

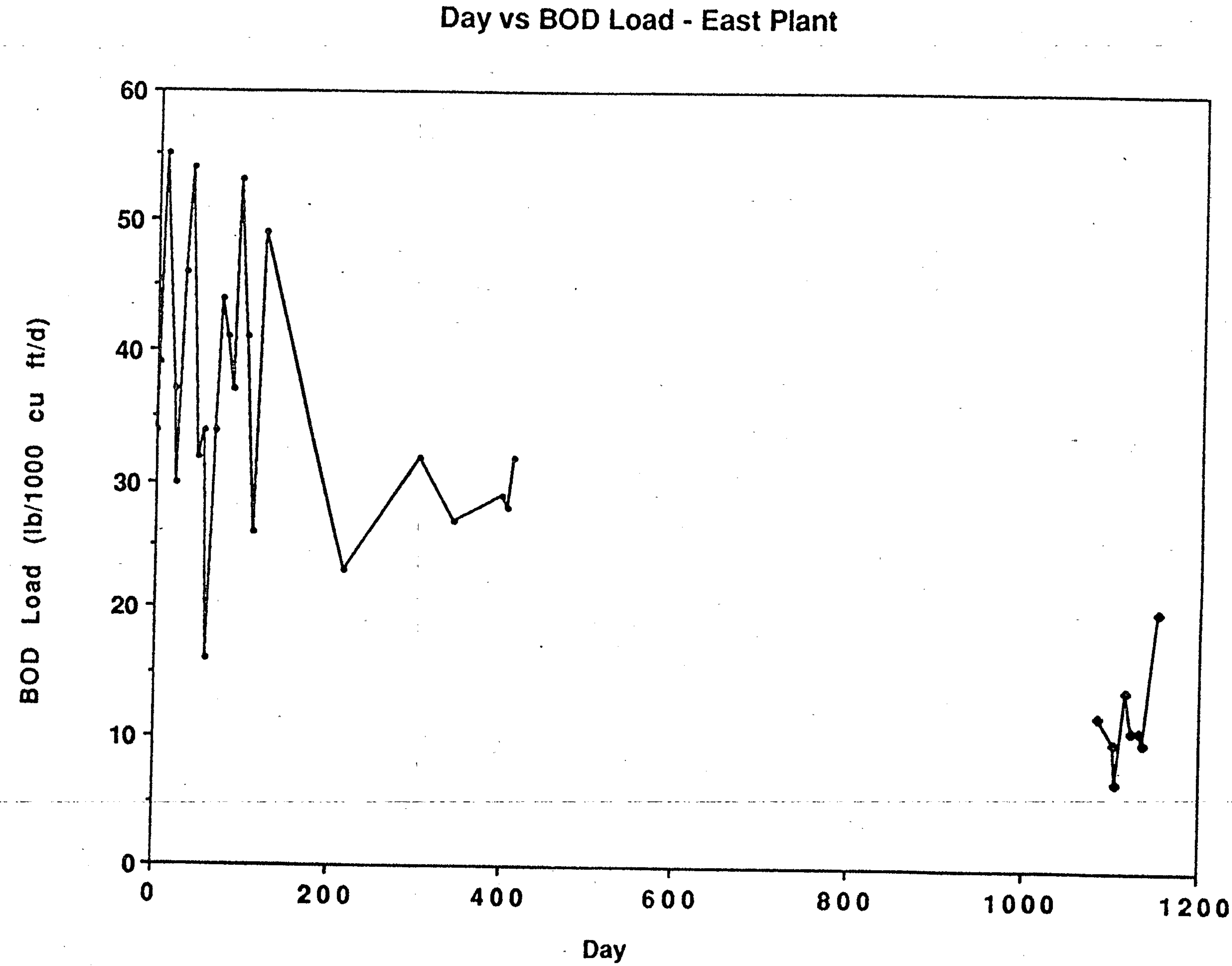


Figure 12a. BOD Load vs. Time - Exploded 0 to 500 days

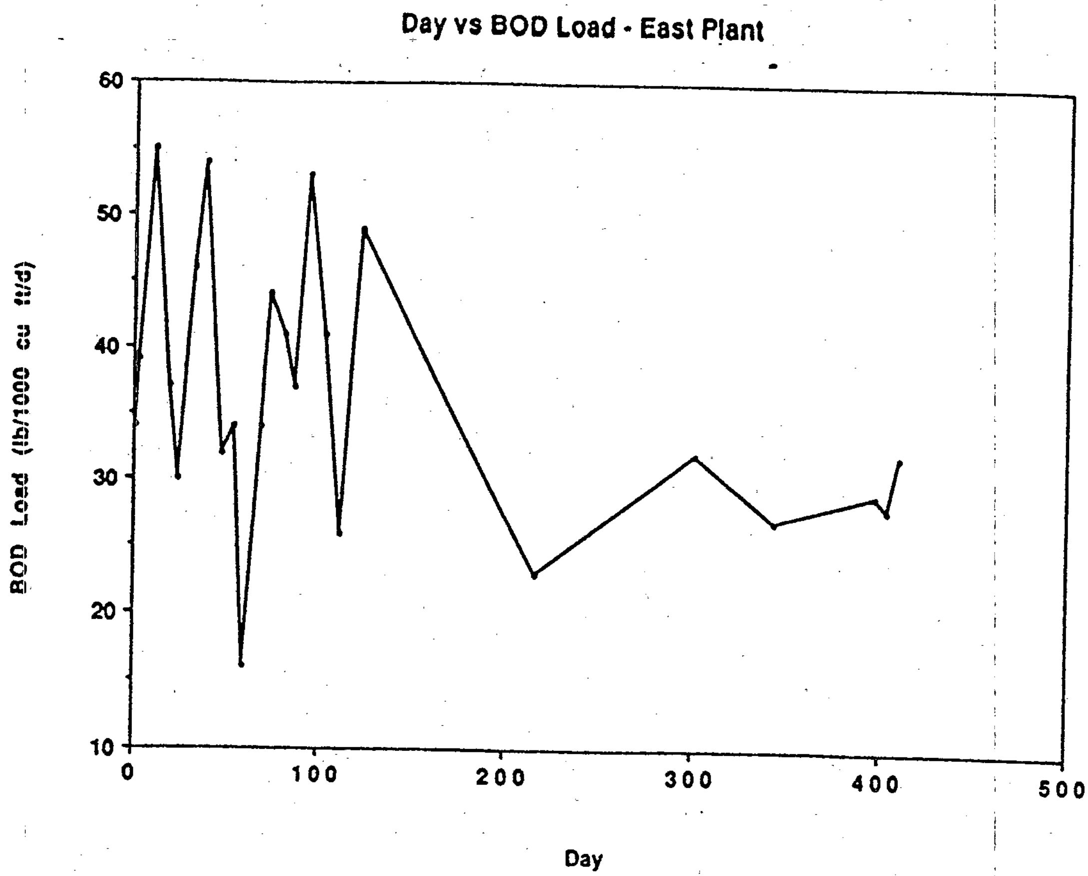


Figure 12b. BOD Load vs. Time - Exploded 1080 to 1160 days.

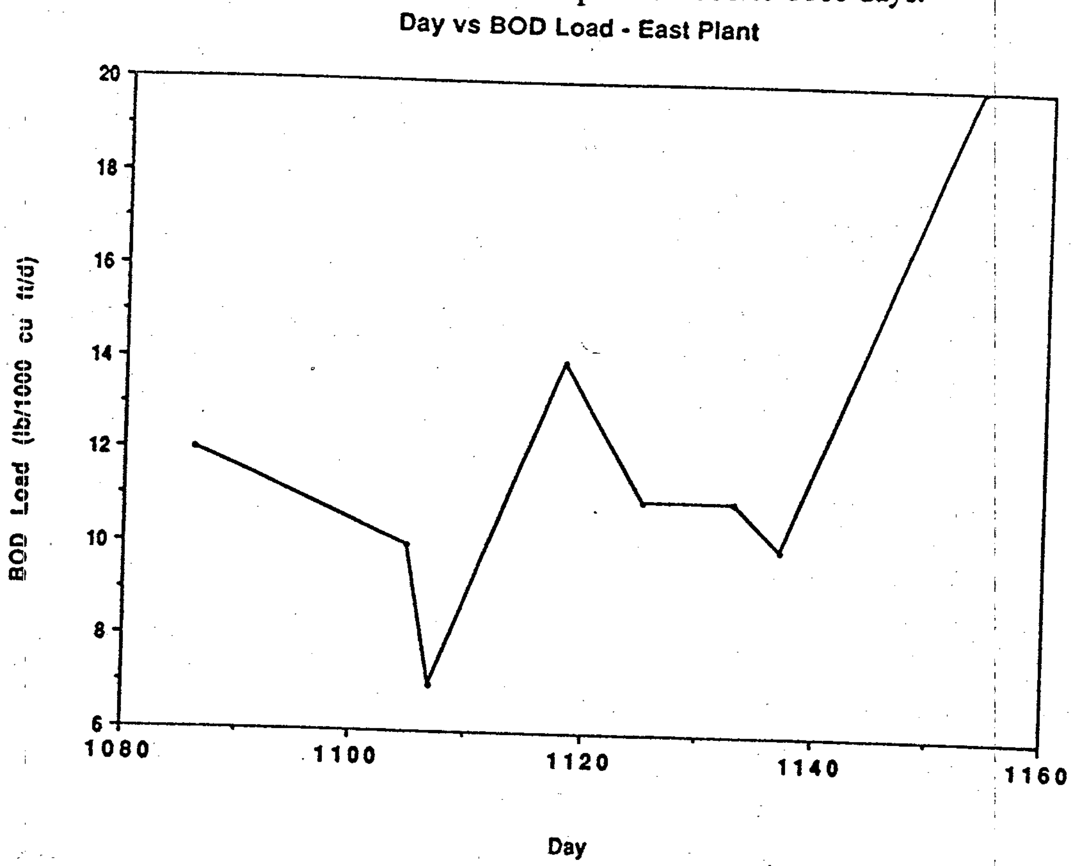


TABLE 5

ADDITIONAL OXYGEN TRANSFER TEST DATA - PLANT 1

Date	Tank Number	Operation Mode	αSOTE	Test Method
March 1978	4	Contact Stabilization	14%	Steady-state
September 1978	4	Contact Stabilization	18%	Steady-state
June 1980	1	Step Aeration	8%	Steady-state
August 1980	1	Step Aeration	9%	Steady-state
August 1982	1-3	Step Aeration	16%	Off-gas/Steady-state
March 1984	1	Step Aeration	7%	Off-gas
March 1984	1-3	Step Aeration	7%	Off-gas

incomplete scouring of the diffusers (see Table 4 and Figure 7). Steam cleaning, however, provided a more thorough surface cleaning of the diffuser and resulted in a longer restoration period (about 7 weeks).

The increase in SRT which occurred after the aeration tanks had been repaired and the diffusers cleaned may have been due to a number of factors. Some of the increase may have been due to cleaning. Unfortunately, the first data collected after the 1986 cleaning event were almost six months after cleaning. The decreased load in 1987 would have likely resulted in more effective removal of surfactants responsible for depressing alpha in the system. The lower loading may also have mitigated against diffuser fouling. Finally, the lower oxygen demands dictated lower gas flow rates per diffuser, producing somewhat higher transfer efficiencies.

In order to look at this in more detail, the data in Table 4 were broken down on a per tank basis and values of apparent alpha calculated. This information appears in Table 6 and Figures 13 and 14. Note that data collected on Days 425 and 453 were not used because of the presence of heavy Nocardia scum.

Several interesting observations may be made from a review of the apparent alpha data. The apparent alpha values in Tank 1 generally remained between 0.30 and 0.35 except following the power outage and steam cleaning events. Decreases in F/M over the first 410 days (Figure 10a) did not appear to affect apparent alpha in this first pass tank. The values of apparent alpha in Tanks 2 and 3 were more variable than in Tank 1 and recoveries after steam cleaning were more pronounced. The loading decreases (F/M) occurring over the 410-day period did not significantly affect apparent alphas in Tank 2, but there appeared to be a slight trend upward in apparent alpha in Tank 3.

As described earlier, the power outage on Day 18 resulted in a significant increase in apparent alpha in all three tanks. This recovery, however, was short-lived although apparent alpha values did appear to remain at a higher level especially in Tank 1 after this event.

Steam cleaning on Day 61 (7/20/84) again elevated apparent alpha values in all three tanks, but most pronounced increases were found in Tanks 2 and 3 (about 50 to 55% recoveries). This recovery appeared to be short-lived in Tank 1 where precleaning apparent alpha values (prior to Day 59) were again measured after only about two weeks. In Tank 2, the elevated values of apparent alpha were in evidence, perhaps as long as four or five weeks. Values in Tank 3 appeared to remain elevated above precleaning levels up to Day 411. This may have been due, in part, to the reduced loading (F/M) to the basins (see Figure 10a), although this was not evident in the first two passes.

Unfortunately, the effect of cleaning after shutdown (Day 483) and return to service (Day 914) was not documented. Intensive off-gas sampling did not resume until six months later (Day 1086). However, it is clear that αSOTE and apparent alpha values were greatly elevated after start-up and operation at lower F/Ms (lowered to achieve nitrification). The mean value of αSOTE between Day 1 and 411 was 11.5% ($\sigma = 2.4$) for a mean F/M of 2.4 days ($\sigma = 1.2$). Between Day 1086 and 1154, the mean αSOTE was 17.1% ($\sigma = 1.2$) at a mean F/M of 14 days ($\sigma = 3.3$). Apparent alpha values increased in all three tanks after being placed back in service at the lower F/M loadings. Greatest increases were registered in Tanks 2 and 3. On a percentage basis, Tank 1 apparent alpha values increased by only about half as much as those in Tanks 2 and 3 (about 45% versus 70 to 90%).

TABLE 6

EAST PLANT ALPHA VALUES FOR EACH AERATION TANK

TANKS 1-3

Date	Day	TANK 1 Gs (scfm/d)	TANK 1 Apparent Alpha	TANK 2 Gs (scfm/d)	TANK 2 Apparent Alpha	TANK 3 Gs (scfm/d)	TANK 3 Apparent Alpha	Notes
05/21/84	1	0.50	.26	0.96	.35	0.84	.43	
05/23/84	3	0.77	.25	1.04	.29	0.95	.38	
05/30/84	10	0.95	.24	1.30	.36	0.87	.42	
06/07/84				POWER OUT				
06/08/84	19	0.52	.44	0.56	.60	0.49	.56	
06/12/84	23	0.49	.38	0.61	.49	0.61	.51	
06/21/84	32	0.76	.33	1.03	.38	0.92	.40	
06/26/84	37	0.83	.34	1.09	.40`	1.15	.36	
07/06/84	47	0.78	.33	1.04	.44	1.12	.51	
07/12/84	53	0.90	.31	0.69	.33	0.86	.40	
07/18/84	59	0.43	.32	0.69	.37	0.64	.41	
07/20/84				STEAM CLEANED				
07/27/84	68	1.05	.43	1.08	.56	0.84	.64	
08/01/84	73	0.65	.38	0.61	.61	0.46	.71	
08/07/84	81	0.93	.30	0.60	.62	0.70	.76	
08/13/84	87	0.62	.30	.40	.49	0.67	.68	
08/20/84	94	0.42	.33	0.40	.44	0.54	.56	
08/29/84	103	0.63	.34	0.82	.43	0.62	.54	
09/07/84	112	1.10	.31	1.40	.36	0.81	.50	
09/18/84	123	0.80	.29	1.04	.38	1.00	.45	
06/20/85	398	0.93	.28	1.15	.39	1.13	.57	
06/26/85	404	0.95	.31	1.15	.48	0.92	.61	
07/03/85	411	0.97	.24	1.28	.38	1.16	.60	
07/17/85	425	0.52	.47	0.63	.57	0.72	.63	Nocardia Scum
08/14/85	453	0.48	.44	0.62	.65	0.70	.71	Nocardia Scum
09/13/85				OUT OF SERVICE				
09/13/85				STEAM CLEANED				
11/18/86				IN SERVICE				
05/08/87	1086	0.73	.33	0.90	.64	0.79	.86	
05/11/87	1089	0.73	.34	0.86	.63			
05/27/87	1105	0.72	.40	0.86	.65	0.61	.91	
05/29/87	1107	0.59	.36	0.51	.54	0.61	.77	
06/03/87	1111	0.62	.38	0.41	.54			
06/09/87	1118	0.62	.38	0.81	.55	0.63	.85	
06/17/87	1125	0.59	.42	0.68	.67	0.73	.97	
06/25/87	1133	0.61	.44	0.84	.78	0.76	1.01	
06/29/87	1137	0.62	.47	0.80	.74	0.14	1.15	
07/15/87	1154	0.61	.43	0.85	.68	0.74	.85	

Figure 13. Apparent Alpha vs. Time - Tanks 1-3.

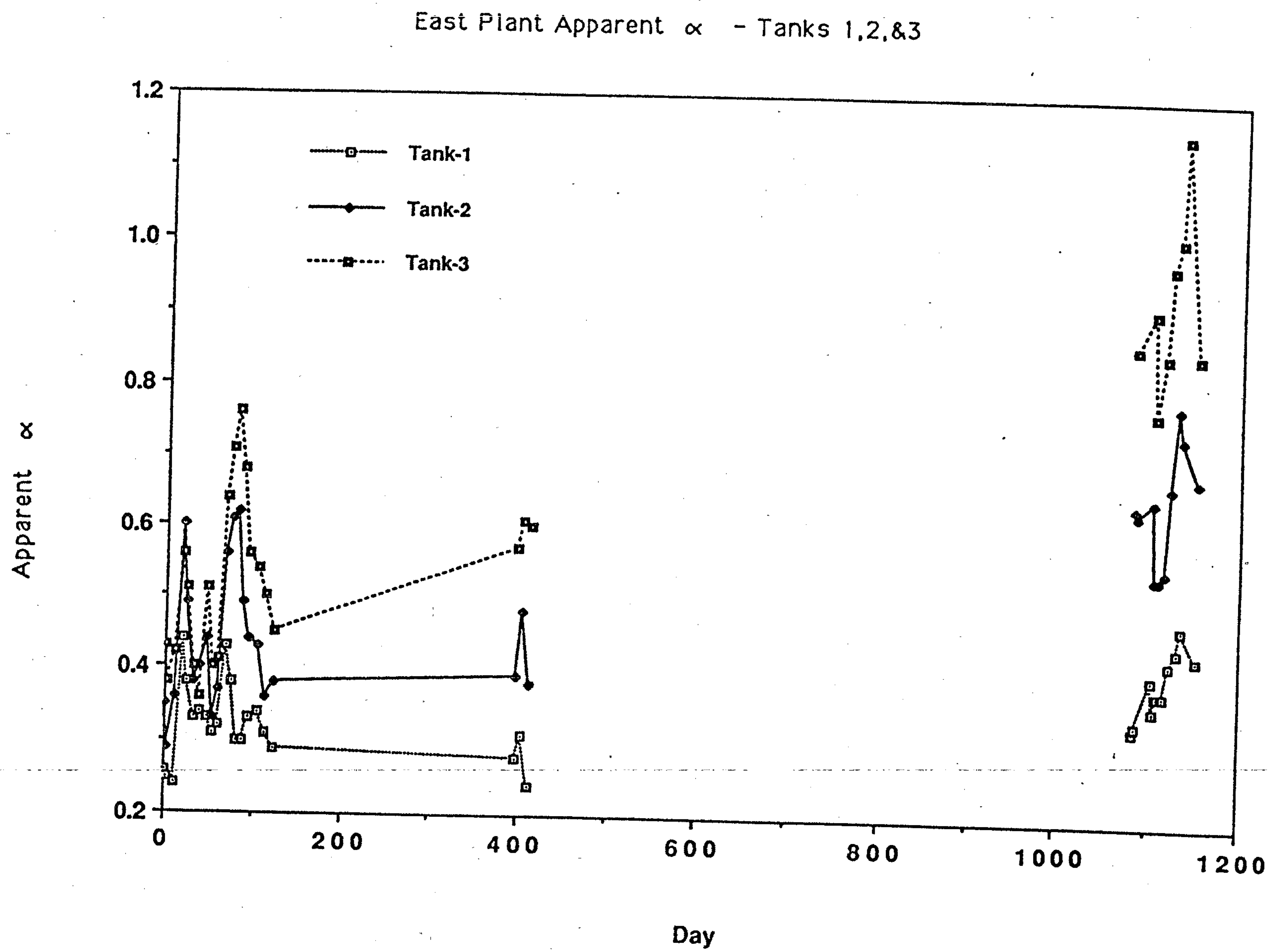
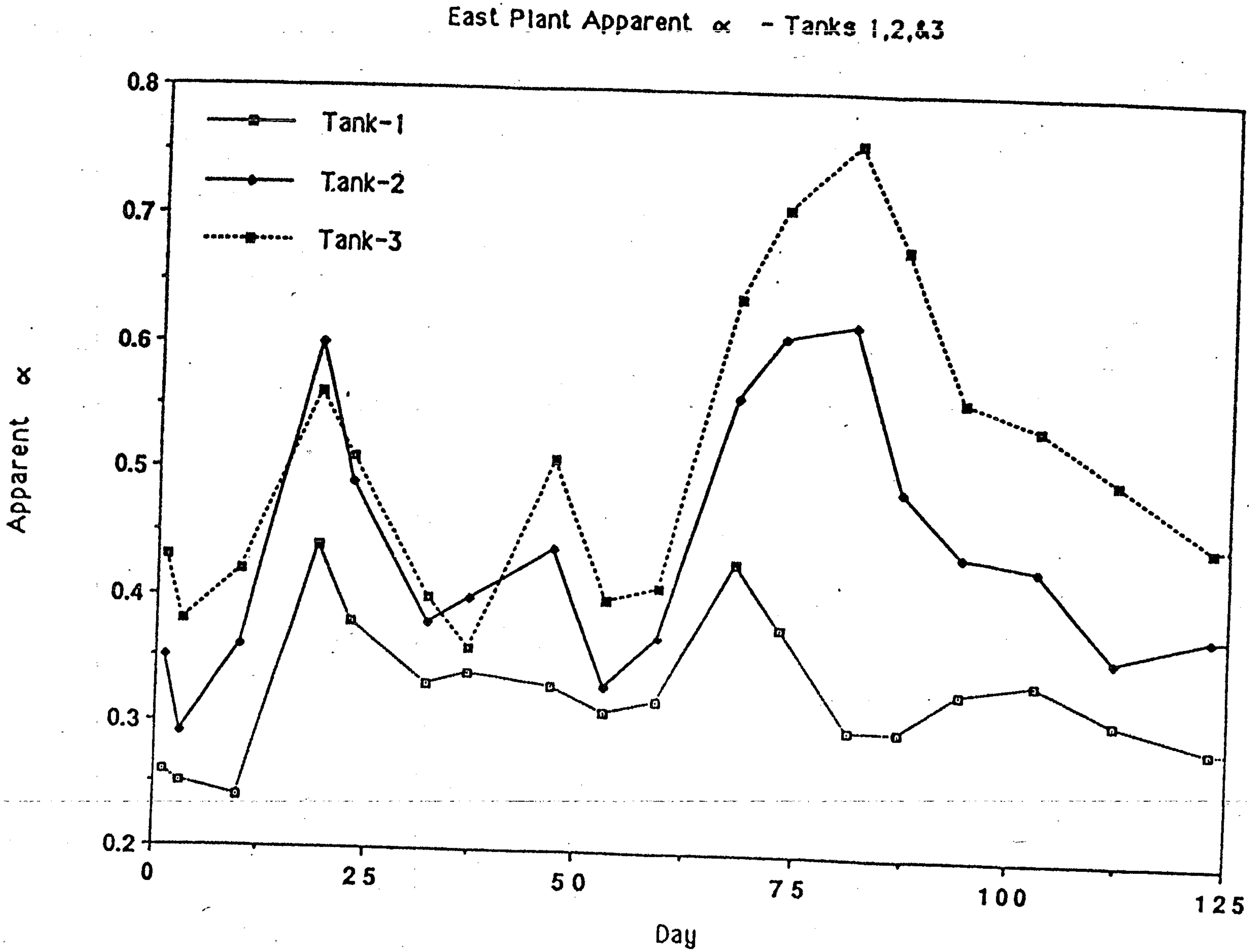


Figure 14. Apparent Alpha vs. Time - Exploded 0 to 125 Days.



Several interpretations may be placed on these results with the understanding that no controls were run in parallel with these tests, and there is a certain variability in the off-gas data due to wastewater characteristic variation, operational variability, and, to a minor extent, off-gas analyzer.

It appears that the dome diffusers after ten years of service still delivered a high αSOTE as demonstrated by the very high alpha values observed in 1987 when plant SRT values were increased. (That is, the units were capable of transferring oxygen in process water almost equivalent to that in clean water, even after ten years of service.) The reasons for this can be speculated as follows. The diffusers were exposed to a wastewater that fouled the diffusers, but routine diffuser cleaning maintained the integrity of the ceramic media such that gas flow distribution was still good. The design of the dome diffuser mounting insured excellent gasket seals at the periphery and at the bolt. The diffusers themselves appeared to have been produced in such a manner as to ensure excellent gas flow distribution. (These last two factors were noted when the aeration tanks were dewatered and during laboratory testing of the used diffusers).

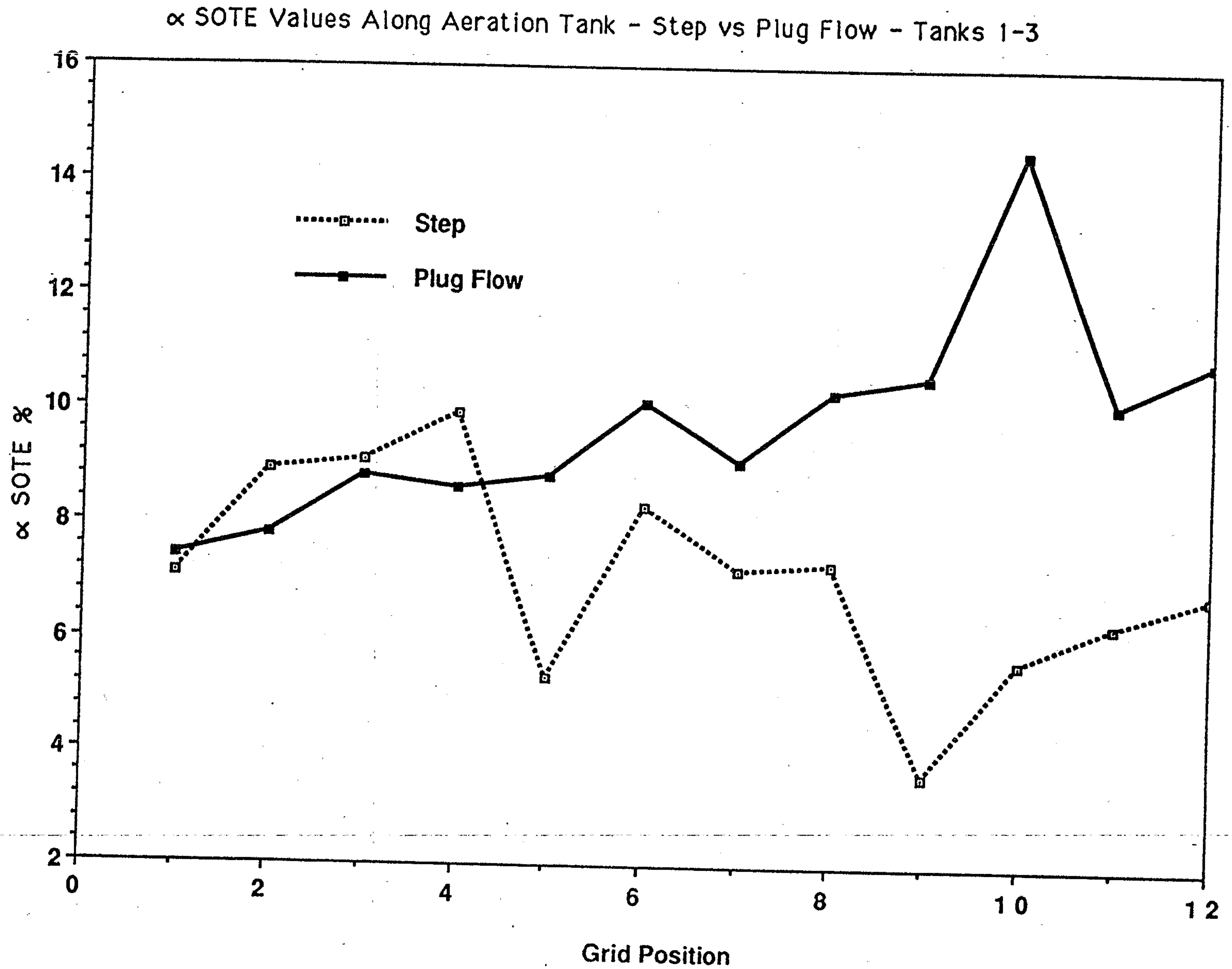
A second interesting interpretation of these data suggests that overall αSOTE values appeared to be greatly affected by the performance of the "downstream" diffusers. It appeared that diffuser performance at the inlet was greatly influenced by wastewater characteristics. Low alpha values, due presumably to high surfactant concentrations, depressed local αSOTE. Coarse bubbling was often detected at the inlet zones, even immediately after cleaning. Furthermore, greater fouling was observed for diffusers at the inlet zones (see Diffuser Characteristics). Cleaning of the diffusers did restore apparent alpha to some degree at the inlet, but substantially greater percent recoveries were seen in the downstream tanks. In the downstream tanks, αSOTE was likely influenced by the wastewater after a cleaning event, but as fouling developed, the apparent alpha in those tanks may have been dictated by diffuser fouling.

Finally, it could be speculated that a decrease in load as measured by high SRT (low F/M) resulted in higher apparent alphas due, in part, to biological degradation of surfactants that were typically present in the final effluents when SRT values were lower and nitrification occurred only sporadically. Furthermore, the high SRT operation appeared to extend the period over which diffuser fouling would significantly influence αSOTE.

Another interesting finding of this work is depicted in Figure 15. In April 1984, Plant 1 was changed over from step aeration to plug flow. An off-gas test on March 14 (step aeration) is compared with a test on May 21 (plug flow). Loads to the plant were comparable, but diffusers were in service for two additional months. The data suggest that a plug flow configuration will produce an overall mean weighted αSOTE somewhat higher than step aeration. The αSOTE profiles explain why this might be true. The influence of apparent alpha appears to be moved downstream at each influent feed point. Coarse bubbling was also noted at each feed point. Coarse bubbling may result from wastewater surface tension effects due to high flux of primary effluent at the feed points. This coarse bubbling will also depress values of αSOTE. One may also speculate that fouling would also be extended further down the system.

Finally, some brief investigations were made into cleaning effectiveness during the course of this study. There is some evidence (Rieth (9), Redmon (10)) to suggest that biological fouling is a dynamic process, the foulant mass increasing and decreasing dependent upon the composition and concentration of wastewater. In August 1984, an experiment was conducted to determine the effectiveness of biological cleaning

Figure 15. αSOTE for Plug Flow and Step Aeration



(endogenous cleaning) of diffusers. Influent to the tanks was discontinued for one week and the mixed liquor was continuously aerated during this time. Results of this experiment appear in Figure 16. It appeared that two days after resumption of influent flow at a comparable load, αSOTE was significantly elevated in this plug flow system. Twelve days later, values began to move downward. The effectiveness of this process of cleaning has not been pursued further, but this work suggests that dynamic swings in αSOTE with loading changes are important in evaluating αSOTE data.

There was also interest in determining the relative effectiveness of "Milwaukee Method" cleaning versus steam cleaning of the MMSD diffusers. During shutdown of Aeration Tanks 1-6, Tanks 4-6 were Milwaukee cleaned and Tanks 1-3 were steam cleaned. Unfortunately, due to equipment and construction problems, these aeration tanks were held out of service for 14 months. During that time, the diffusers were submerged under about 6 inches of water, which became heavily infested with algae. The tanks were put back into service without checking diffuser cleanliness. No off-gas tests were performed until May of 1987 (6 months after being put back into service). Nonetheless, results of these off-gas tests are presented in Table 7. It does not appear that one method produced a superior level of cleansing over the other based on this test.

Diffuser Characterizations

On several occasions, diffusers were removed from the aeration tanks and characterized. Bubble release vacuum (or pressure), dynamic wet pressure, and occasionally residue analyses were performed. Results of this cursory work appear in Table 8.

The data for July 7, 1980, were obtained from a diffuser in Aeration Tanks 1-3 (uncertain as to which tank) after those tanks had been aerated for eight days without influent flow (return sludge only). Unfortunately, no data were obtained on diffusers prior to this biological cleaning procedure.

In July 1984, four diffusers were collected from each of the 6 grids in Aeration Tanks 1-3. These diffusers had not experienced a cleaning event for 14 months (Table 2). It is interesting to note that fouling was fairly uniform as measured by DWP/BRV ratios whereas foulant quantities decreased and percent volatile content increased downstream (Table 8). It is presumed that higher foulant quantities and lower volatile solids on the diffusers at the influent end may be representative of inorganic sedimentation. Table 9 presents the results of inorganic analyses of foulants obtained from diffusers in each grid. Foulant samples were fired at 550°C prior to analysis so that percent by weight figures are based on inert (fixed) solid fraction. A separate set of parallel foulant samples were acidified with 14% HCl after firing to solubilize acid-soluble precipitates like $CaCO_3$. Note the decreases in Si downstream. Increased precipitation of P, Mg, Ca, and Fe were noted in the downstream grids, likely due to pH changes.

The sample reported for July 1985, one year after steam cleaning, indicates substantially less fouling than the previous year. (Note that Tank 5 is parallel to Tank 2; both Systems 1-3 and 4-6 were operated at same load conditions.) This may have been due to a somewhat lower BOD loading in the later period (Tables 2 and 3). Furthermore, there is some indication in the αSOTE and alpha determinations made in June/July 1985 that these values were somewhat higher than June/July values in 1984 (Tables 4 and 6).

Figure 16. Effect of Endogenous Cleaning.

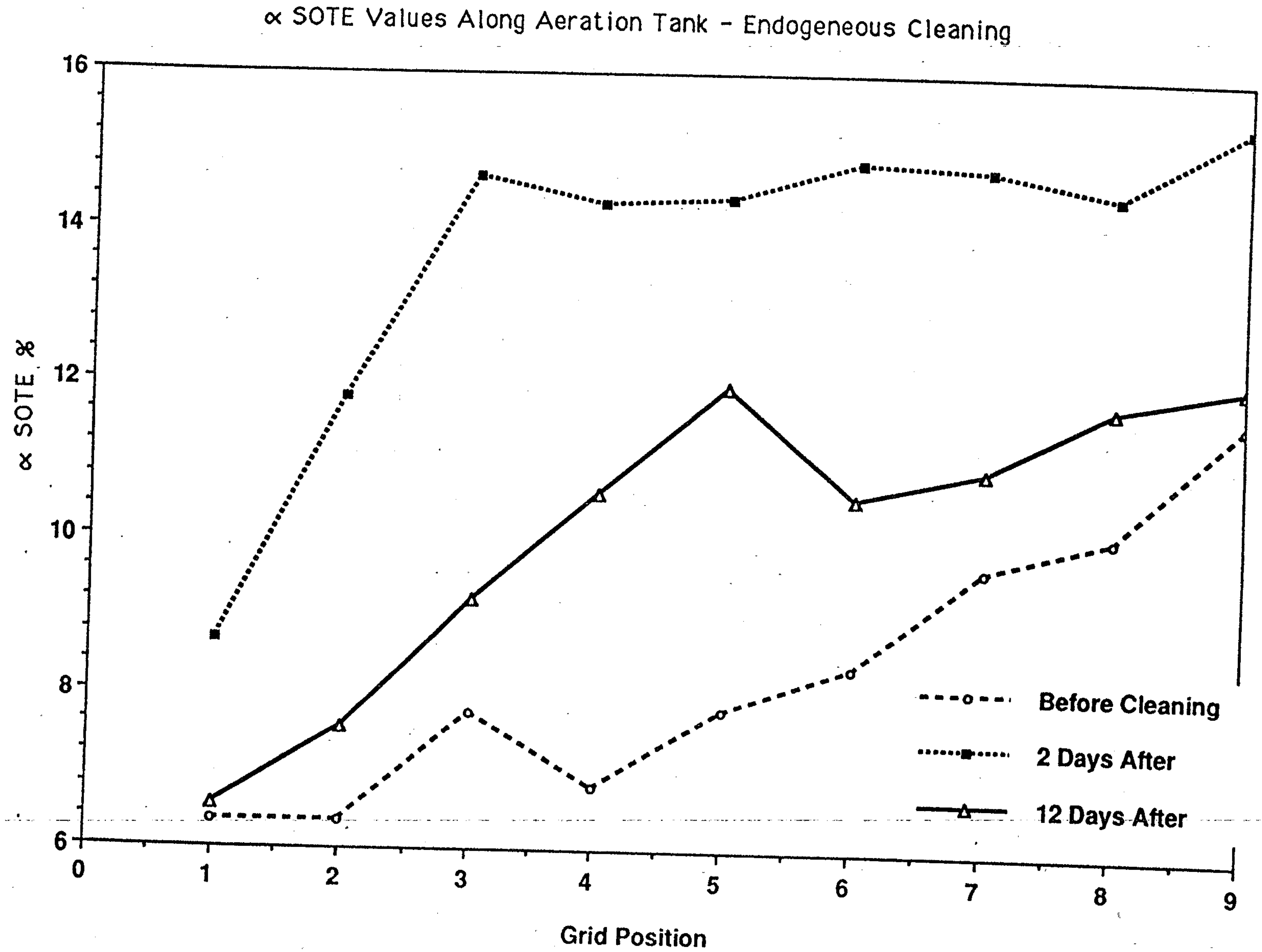


TABLE 7
COMPARISONS OF αSOTE PERFORMANCE
TANKS 1-3 AND 4-6

Date	Tanks 1-3	Tanks 4-6
5/08/87	15.3	
5/11/87		18.3
5/27/87	16.4	
5/28/87		18.4
5/29/87	14.8	
6/09/87	15.3	16.0
6/17/87	18.1	18.2
6/25/87	19.6	20.4
6/29/87	20.4	20.3
7/15/87	17.3	17.5

Tanks 1-3: Steam cleaned

Tanks 4-6: Milwaukee Method cleaned

TABLE 8
DIFFUSER CHARACTERISTICS - PLANT 1
(Mean values for 4 samples)

Date	Location	BRV (in Wg)	s/x	DWP @ .75 scfm (in Wg)	DWP / BRV	RESIDUE Volatile (%)	RESIDUE Mass (mg/cm²)
Clean Dome		6	.06	6.2	1.03	-	-
07/07/80+	Tanks 1-3	18*	.10	12.5	.69	high	low
07/24/84	Tank 1, Grid 1	48	.32	17.7	.37	26	26
07/24/84	Tank 1, Grid 2	52	.22	18.8	.36	47	16
07/24/84	Tank 2, Grid 3	45	.27	17.3	.38	52	19
07/24/84	Tank 2, Grid 4	70	.41	21.5	.31	55	14
07/24/84	Tank 3, Grid 5	46	.34	20.3	.44	65	12
07/24/84	Tank 3, Grid 6	41	.23	15.3	.37	72	9
07/17/85	Tank 5, Grid 3	18	.35	12.1	.67	-	low
09/02/85	Tank 4, Grid 1	6	.10	6.7	1.11	cleaned	
09/02/85+	Tank 4, Grid 2	6	.12	7.4	1.23	cleaned	
09/02/85	Tank 6, Grid 6	6	.07	6.0	1.00	cleaned	

*Bubble release pressure
+One sample only

TABLE 9

INORGANIC COMPOSITION OF FOULANT MATERIALS*

PLANT 1 DOMES

(7/24/84)

% by Weight	AFTER 550°C FIRING						AFTER ADDING ACID, 14% HCl					
	Grid 1	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6	Grid 1	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6
Mg	0.7	0.9	1.2	1.1	1.0	1.3	0.4	-	0.2	0.4	-	0.1
Al	1.2	1.3	2.0	2.0	1.5	1.8	1.5	1.9	1.4	2.0	2.0	1.6
Si	11.5	10.5	10.9	11.4	8.0	9.4	21.3	22.8	20.6	18.5	16.9	15.2
P	4.2	4.9	4.8	5.7	4.9	6.7	0.7	0.5	0.3	-	0.6	0.4
S	0.8	0.3	0.6	0.9	0.5	0.5	0.3	0.1	0.2	-	-	-
Cl	0.4	0.8	0.2	0.4	0.3	0.7	7.1	1.7	1.6	1.5	1.0	1.6
K	1.1	1.1	1.3	1.3	1.0	2.0	0.8	1.4	0.7	1.2	1.2	1.1
Ca	7.5	8.9	9.3	10.4	9.0	10.7	2.1	0.5	0.6	0.5	0.3	0.5
Ti	0.4	0.7	0.6	0.8	0.6	0.7	0.5	0.8	0.5	1.2	1.4	1.2
Cr	0.1	-	-	-	-	0.1	-	-	-	0.1	0.1	-
Mn	-	-	0.2	0.3	0.2	0.2	-	-	-	-	-	0.1
Fe	2.5	3.1	3.6	3.7	2.9	3.8	3.4	2.6	2.5	3.7	2.3	3.0
Cu	0.3	-	-	0.7	0.2	0.7	-	-	0.1	0.2	-	0.4
Zn	0.5	0.9	0.9	1.0	0.6	1.6	0.2	0.3	0.2	0.2	0.2	-
Cd	-	-	-	0.3	-	0.4	-	-	-	-	-	0.2

*Analysis by energy dispersive x-ray spectroscopy.

The effects of Milwaukee Method cleaning are shown for diffusers collected after cleaning from Tanks 4-6. The measurements indicate that based on the BRV and DWP, these stones were "like new." The performance of these diffusers in 1987 tend to confirm this finding.

Summary

The performance of fine pore ceramic domes in the MMSD wastewater treatment facility continues to be excellent after 10 years of service. This conclusion is based on measured oxygen transfer efficiencies, alpha calculations, and diffuser characterization. The excellent performance was likely enhanced by routine maintenance of the diffusers and by the installation of high quality ceramic diffusers and mounting hardware.

There is evidence that operation at high SRTs which produced complete nitrification will result in higher αSOTE values than operation at low SRTs at the MMSD facility. There is also an indication that high SRT operation significantly extends the period over which diffuser fouling would not adversely influence αSOTE.

Cleaning methods including high pressure hosing and steam cleaning, dramatically affected αSOTE (and alpha values) in the downstream grids. It appeared that for this plant, αSOTE at the influent grids was more affected by wastewater characteristics than by fouling, whereas αSOTE at downstream grids was influenced by both wastewater and fouling depending upon periods between cleaning operations. The effectiveness of cleaning appeared to be dependent upon plant operating mode.

Based on one study, biological cleaning appeared to improve αSOTE values, but the effect was short lived. This experiment demonstrated the probable dynamic nature of fouling and its impacts on performance.

The use of the step aeration flow sheet resulted in somewhat lower αSOTE values than that obtained by plug flow operation. Fouling also appeared to be extended further downstream with step aeration processes.

RESULTS AND DISCUSSION - WEST PLANT

Facilities

The West Plant, consisting of four three-pass aeration tanks designated as Plants 3 and 4, was constructed in 1984-85 and put into service in the Fall 1985 (Figure 1). Tanks 19-24 comprise Plant 3 and Tanks 25-30 are designated as Plant 4. While fed from the same primary sedimentation basins, these two plants have independent final clarification and return sludge facilities (Figure 17). Figure 18 presents a layout of a set of three tanks and Table 10 describes the physical characteristics of the basins including diffuser layout. The basins were equipped with fine pore Sanitaire ceramic disc diffusers in a tapered format with three grids per tank. Coarse bubble diffusers (Sanitaire D-24s) were placed in the first grid on two parallel lines perpendicular to flow and 6 and 26 feet from the influent wall. The aeration tanks were designed to operate in the plug flow or step feed mode.

D.O. control is automatically achieved by a D.O. probe located at the tail end of each aeration tank pass which controls an air valve for that pass. A cascade control loop was used for each pass to control D.O. D.O. set points were typically 1.5, 2.0, and 2.0 mg/L for the three consecutive passes, and minimum air flow was 0.75 scfm/diffuser. For a given total air flow to the aeration tank passes, the air header pressure changed as the valves changed at each pass. Centrifugal blowers, equipped with inlet guide vanes, were used to control the main air header pressure at a set point, plus or minus a dead band.

Initially, it was proposed that in situ acid gas cleaning of selected diffuser grids be performed in Plant 3 and 4. Aeration Tanks 24 and 25 were therefore equipped with Sanitaire gas cleaning hardware. In addition, a test header of four Sanitaire diffusers (four-lunger) was placed in Tank 21 at the end of Grid 1 as a part of the ASCE/EPA interplant fouling study.

Plant Operation and Diffuser Maintenance

Plant 3 was started up in late September 1985 and Plant 4 followed in early November. Table 11 provides monthly average values for a number of selected operational parameters from start up through 1987 for both plants, and Table 2 provides data on raw wastewater characteristics.

Both Plants 3 and 4 were operated in a plug flow mode at the outset. They were operated as single-stage nitrification units with sludge ages (based on aeration tank solids only) ranging from about 6 to 11 days. Complete nitrification was achieved shortly after start up and occurred throughout this study. Initially, during the first 4 to 6 months of operation, plant operators began working toward an acceptable set of operating conditions. They also experienced some difficulty in maintaining uniform sludge ages owing to flow and load variations due to start up and shutdown of various aeration basins during this time. Solids wasting was also affected by some automatic sampler malfunctions. Reasonably stable conditions were achieved by March 1986.

Figure 17. Aeration Tank Layout - Plants 3 and 4.

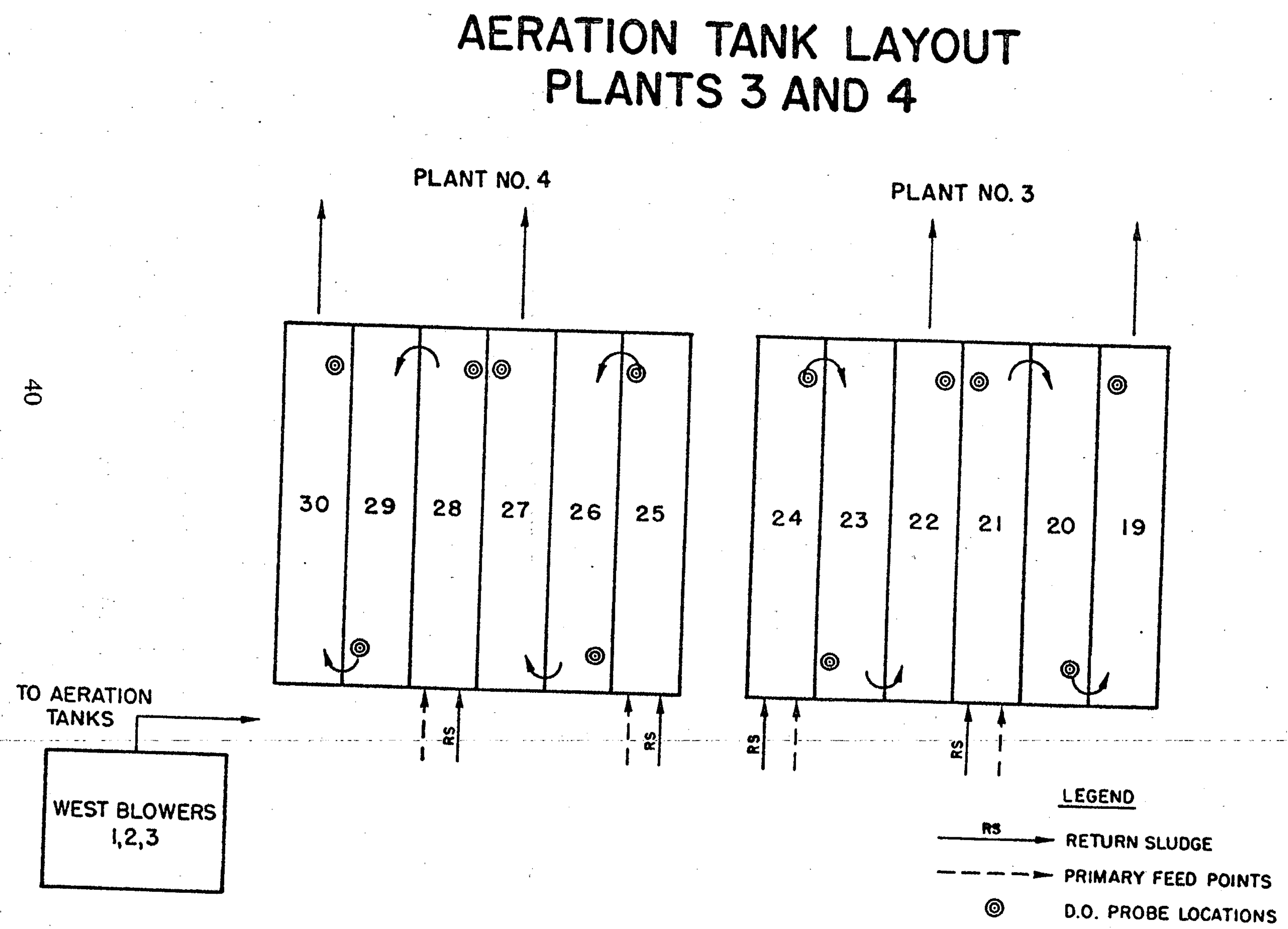


Figure 18. Aeration Tanks 19-30 - Typical.

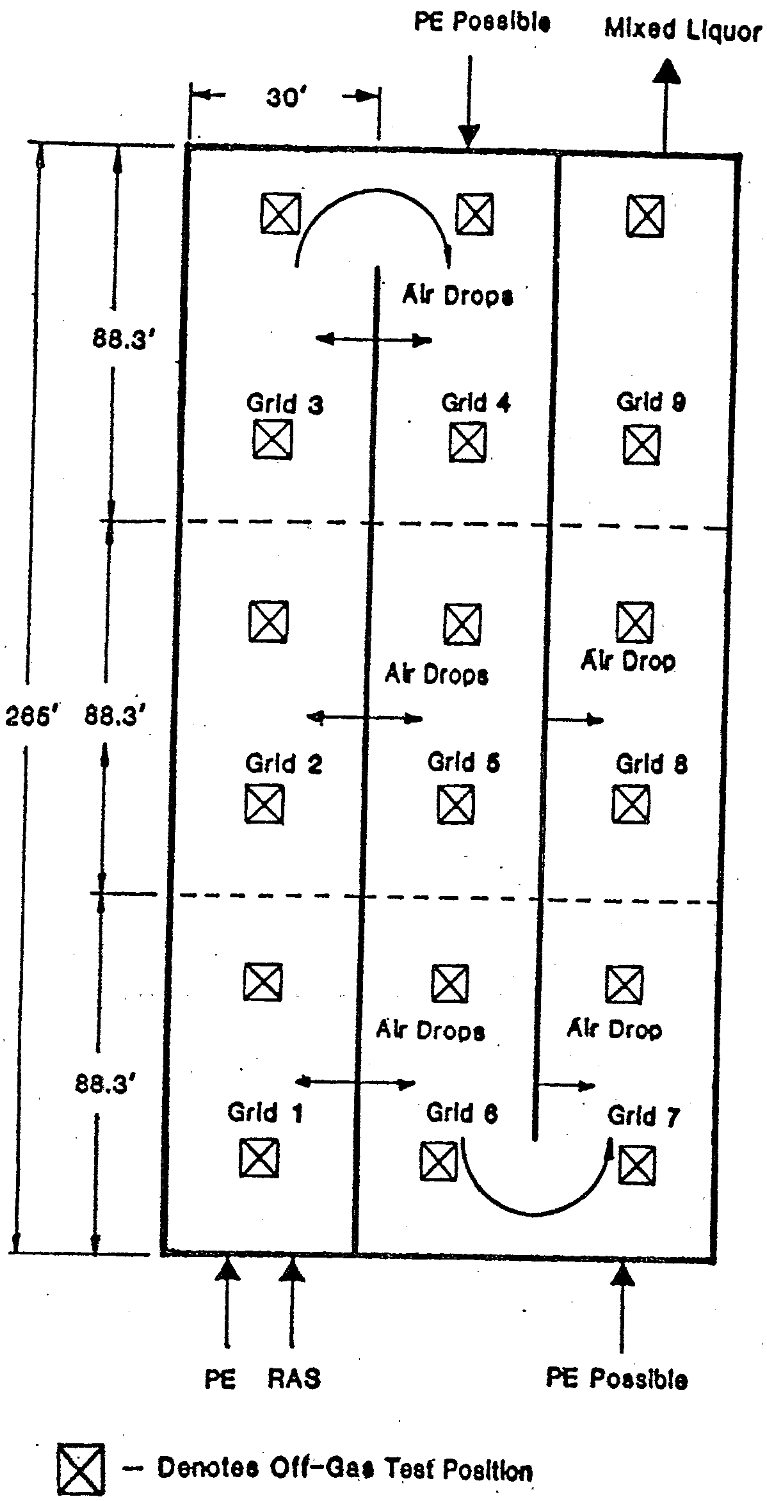


TABLE 10

AERATION TANKS 19-30 - SANITAIRE DISCS

Tank Dimensions:	30' x 265' x 17' (WxLxD)
Liquid Surface:	30' x 265'
Grid Surface:	30' x 88.3' (3 grids per tank)
Tank Volume:	1,000,000 gallons
Diffuser Grids:	Sanitaire discs in full floor coverage
Diffuser Submergence:	16 feet

Note - The above data is for individual tanks, while the data below is for the entire three pass system.

Diffuser Grid	# of Diffusers	Diffuser Density	Tank #
1	744	12%	21, 24, 25, 28 *
2	610	10%	21, 24, 25, 28
3	620	10%	21, 24, 25, 28
4	350	5%	20, 23, 25, 28
5	350	5%	20, 23, 25, 28
6	350	5%	20, 23, 25, 28
7	290	5%	19, 22, 27, 30
8	290	5%	19, 22, 27, 30
9	290	5%	19, 22, 27, 30

Diffuser Density = total projected diffuser surface area/grid surface area.

*Grid 1 also contains two parallel rows of coarse bubble diffusers (Sanitaire D-24s). Each row contains 19 diffusers in a wide band configuration. The two rows of diffusers are perpendicular to flow and are located 6 feet and 26 feet from the influent wall. They are 6.6 feet above the disc diffusers. The interplant fouling study four lunger was located at the end of Grid 1 in Tank 21.

TABLE 11

AVERAGE MONTHLY OPERATING DATA - WEST PLANT

Month	PLANT 3 BOD Load (lb/1000 ft^{3}d)	PLANT 3 SRT (days)	PLANT 3 F/M (days^{-1})	PLANT 4 BOD Load (lb/1000 ft^{3}d)	PLANT 4 SRT (days)	PLANT 4 F/M (days^{-1})	Notes
Oct. 85	16.2	-	.16	-	-	.21	Plant 3 start up
Nov. 85	14.7	6.4	.19	14.9	9.1	.17	Plant 4 start up
Dec. 85	16.5	6.1	.20	17.3	6.3	.23	
Jan. 86	16.0	5.8	.16	16.2	6.1	.22	
Feb. 86	13.2	6.4	.16	13.6	6.1	.22	
Mar. 86	21.9	7.8	.09	22.8	7.4	.14	
Apr. 86	12.4	7.1	.12	11.7	8.0	.14	Stable operation
May 86	10.6	8.2	.09	10.6	8.0	.11	Shut off coarse bubble aeration (5/14/86)
June 86	11.2	8.0	.10	11.2	6.7	.13	
July 86	10.4	5.7	.15	10.4	8.0	.10	
Aug. 86	10.2	7.0	.08	10.2	5.2	.15	
Sept. 86	8.0	11.0	.09	8.0	8.1	.11	Plant 3, high SRT Plant 4, low SRT
Oct. 86	9.8	11.1	.12	9.8	6.0	.20	
Nov. 86	12.3	10.6	.12	12.3	8.9	.15	
Dec. 86	11.9	11.5	.10	11.9	11.3	.12	Plants 3 & 4 resume parallel operation
Jan. 87	12.5	11.2	.11	12.5	11.3	.11	
Feb. 87	13.6	11.2	.12	13.6	11.5	.13	
Mar. 87	13.1	11.5	.11	13.1	11.6	.09	
Apr. 87	13.9	10.6	.11	13.9	10.6	.11	
May 87	12.8	9.7	.12	12.8	9.7	.12	
June 87	13.8	9.1	.16	13.8	9.5	.14	
July 87	13.3	9.6	.14	13.3	9.8	.16	Clean tanks 19-21
Aug. 87	13.3	9.7	.13	13.3	9.7	.13	Experiments with D.O. set points
Sept. 87	13.2	9.3	.12	13.2	9.2	.13	
Oct. 87	13.1	9.7	.12	13.1	9.7	.12	
Nov. 87	14.8	9.6	.14	14.8	9.6	.14	
Dec. 87	12.6	9.6	.11	12.6	9.6	.13	

Initially, it was planned to perform intensive cleaning studies in Plants 3 and 4 in an effort to evaluate the effectiveness of the current cleaning technology. However, after one year of operation, there was no indication that fouling was producing measurable affects on αSOTE. Furthermore, independent tests conducted by Sanitaire in 1985 at MMSD concluded that after five months of operation, little significant fouling had taken place and that in situ gas cleaning at that site was not necessary. As a result, it was determined to evaluate the effects of process operation on αSOTE and to abandon gas cleaning studies. Among the process control variables that were considered were F/M, SRT, BOD loading, and step vs. plug flow operation.

Earlier studies at MMSD indicated that BOD loading did not appreciably contribute to diffuser fouling (9) because of the low soluble fraction. Soluble TOC concentrations in the influent end of the aeration tank were normally less than 20 mg/L. Although a relationship was shown between BOD load and αSOTE, it was not possible at this facility to increase BOD loadings to one set of aeration tanks to a value that would produce measurable effects on αSOTE.

Because MMSD was required to meet stringent effluent requirements for solids and nitrogen and because the plant was undergoing significant remodelling on the East Plant thereby producing greater pressure on the West Plant to deliver high quality effluent, it was not possible to operate the West Plant over a wide range of conditions. There was some reluctance to change flow configurations and SRT (F/M) changes had to be within the range that would still produce complete nitrification.

As a result, Plant 3 was operated at a higher than normal SRT (11 days) and the SRT in Plant 4 was reduced to about six days. This was performed in September and October 1986.

In June of 1987, it was determined that one set of aeration tanks should be dewatered, inspected, and cleaned. Diffuser characterization was performed before and after cleaning. Parallel off-gas testing was conducted in all three passes of the cleaned tank set as well as a control set. Tanks 19, 20, and 21 were dewatered and the diffusers cleaned on June 23, 1987.

Finally, a series of tests were conducted August through December 1987 to determine the effects of different D.O. set points on αSOTE and plant operation.

Oxygen Transfer Studies

Oxygen transfer testing was initiated in September 1985 and continued through December 12, 1987, 800 days later. Most testing was limited to the first pass aeration tanks in Plants 3 and 4 (Tanks 21, 24, 25, and 28). Some testing of all three passes of selected tanks was also performed. The first pass tanks were selected, because it was believed that they would be more affected by fouling conditions. The original objective of these studies was to evaluate the impact of cleaning technology (later changed to process operation) on diffuser fouling and performance.

Test points for these aeration tanks were determined by analyzing gas flux data from the tank and comparing a predicted overall tank gas flow rate to the actual gas flow rate (corrected to standard conditions) as set by the operator prior to testing. An error limit between the two observations of ± 10% was set for an acceptable test. The first set of test points consisted of hood locations at 60, 94, 127, 195, and 230 feet from the influent end of the aeration tank. This selection of hood locations did not sense the effect of the coarse bubble diffusers in the first grid. As a result, this test scheme underestimated air flow to the tank by about 23%. A second set of test points was tested at 30, 127, 161, 195, and 230 feet from the influent wall. This test pattern included a hood near the coarse bubble diffusers but still underestimated gas flow by about 20% and was also abandoned.

A more detailed test pattern was then examined with hood locations at 10, 15, 20, 30, 45, 60, 75, 120, 147, 203, and 230 feet from the influent wall. Results of these tests for Tank 25 are graphically depicted in Figures 19 and 20. The effects of the coarse bubble diffusers are clearly seen. The two points directly above the diffusers correspond to the lowest values of αSOTE and the highest flux. When these values were weighted into the overall grid or tank αSOTE performance, they significantly depressed the overall αSOTE as compared to values excluding them. They served merely to mix the aeration tank contents at the inlet end at a significant cost to αSOTE. Further studies demonstrated that they contributed little to tank mixing and baffles within the tank achieved the same objective. The coarse bubble diffusers were turned off on May 14, 1986.

The final sampling pattern was developed using sampling points at 15, 60, 120, 147, 203, and 230 feet from the influent wall (see Figure 18). The hood location at 15 feet was located between the two coarse bubble headers. When those diffusers were in operation, this pattern estimated air flow that was within about 9% of that set by the operator; and when they were shut off, air flow checked within about ±5%. Note that after May 14, 1986, (Day 230), the coarse bubble diffusers were not used in the West Plant. It should also be noted that since the final sampling locations did not each sense an equal tank area, area weighting as well as flux weighting was performed to estimate overall mean weighted αSOTE values.

Off-gas analyses were performed in accordance with techniques described in Appendix A. The air flow rate in Pass 1 (Tanks 21, 24, 25, or 28) was set at 2000 cfm by the operator and held constant during the test. This eliminated need for correction of αSOTE for gas flow rate fluctuations. When all three passes were tested, air flow rates in the last two passes were allowed to fluctuate in accordance with D.O. and gas flow set points. After the first pass was tested, airflow rates to each successive pass were held constant at the gas flow rates that the system had equilibrated to during first pass testing.

Sampling was normally performed on the same week day and within the hours of noon and 3 p.m., a period when flows and loads were approximately constant. Figure 21 presents a typical printout for off-gas testing in the West Plant.

In October 1986, the effect of air flow rate on αSOTE was determined in Tank 28 at the influent Grid 1. Air flow rates were varied between 0.4 and 1.5 cfm/diffuser. Testing was performed between 6 a.m. and 8 a.m. in an effort to minimize the effects of waste-water load. Using the relationship SOTE = kq^p, where q is gas flow rate in cfm/diffuser, values of k and p were calculated. Table 12 presents the results of these calculations and compares the calculated values of k and p with those values in clean water for the disc

Figure 19. Effect of Coarse Bubble Diffuser.

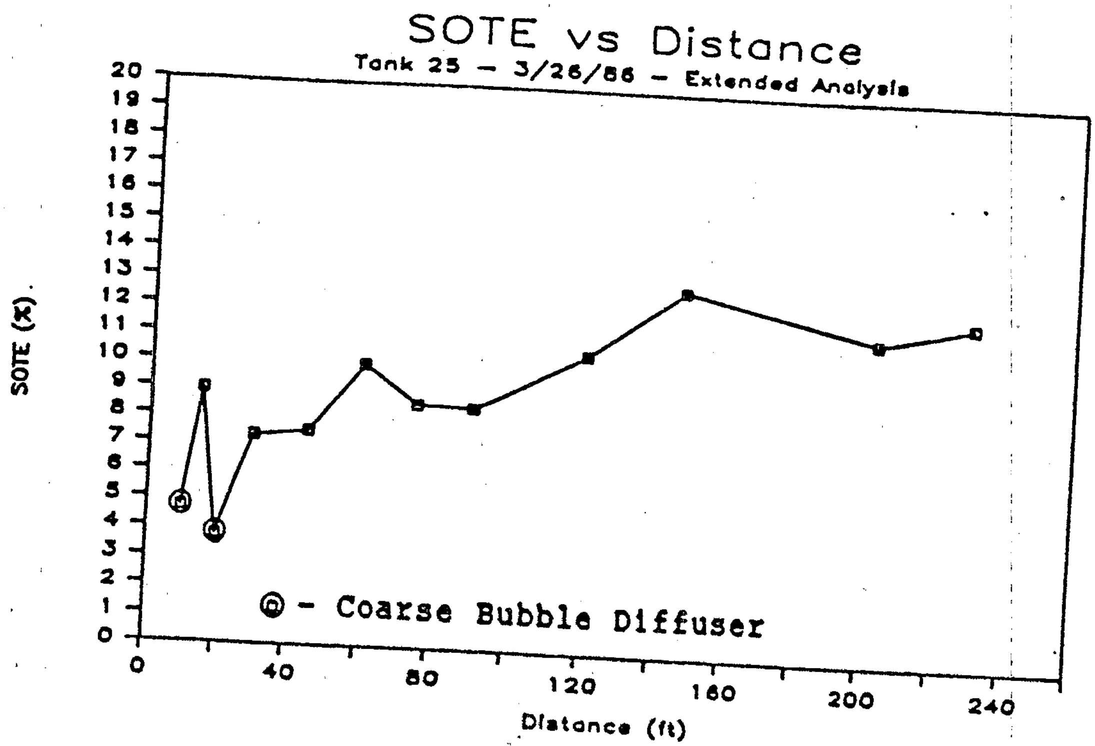


Figure IV-B.22

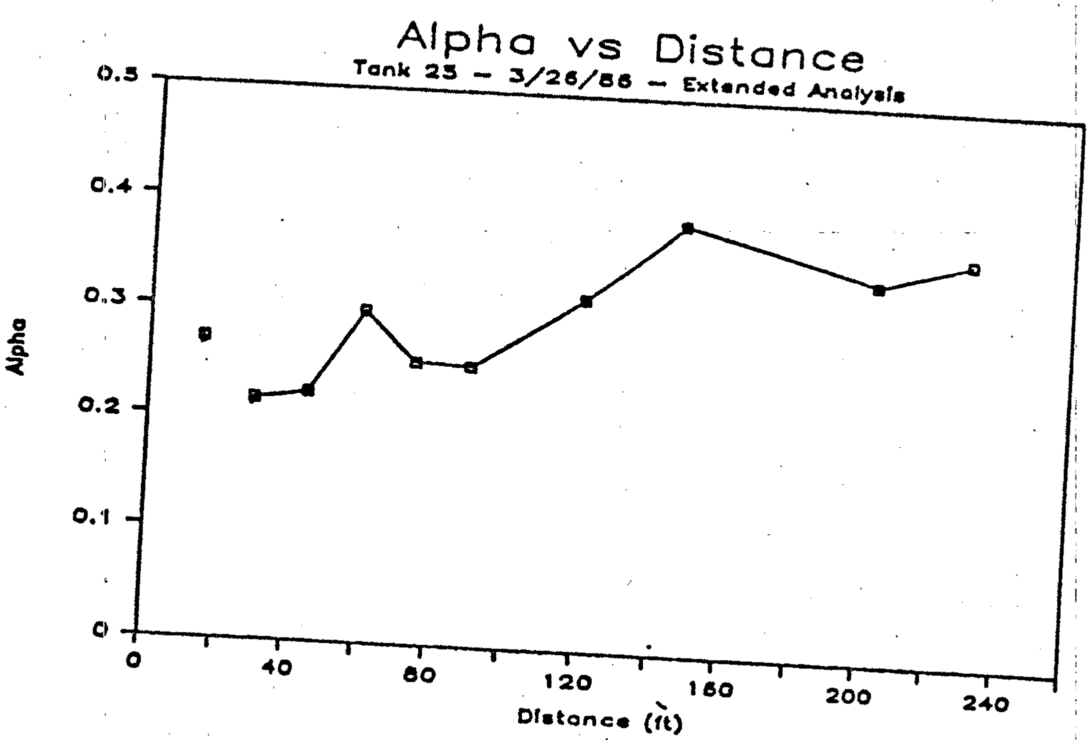


Figure 20. Effect of Coarse Bubble Diffuser.

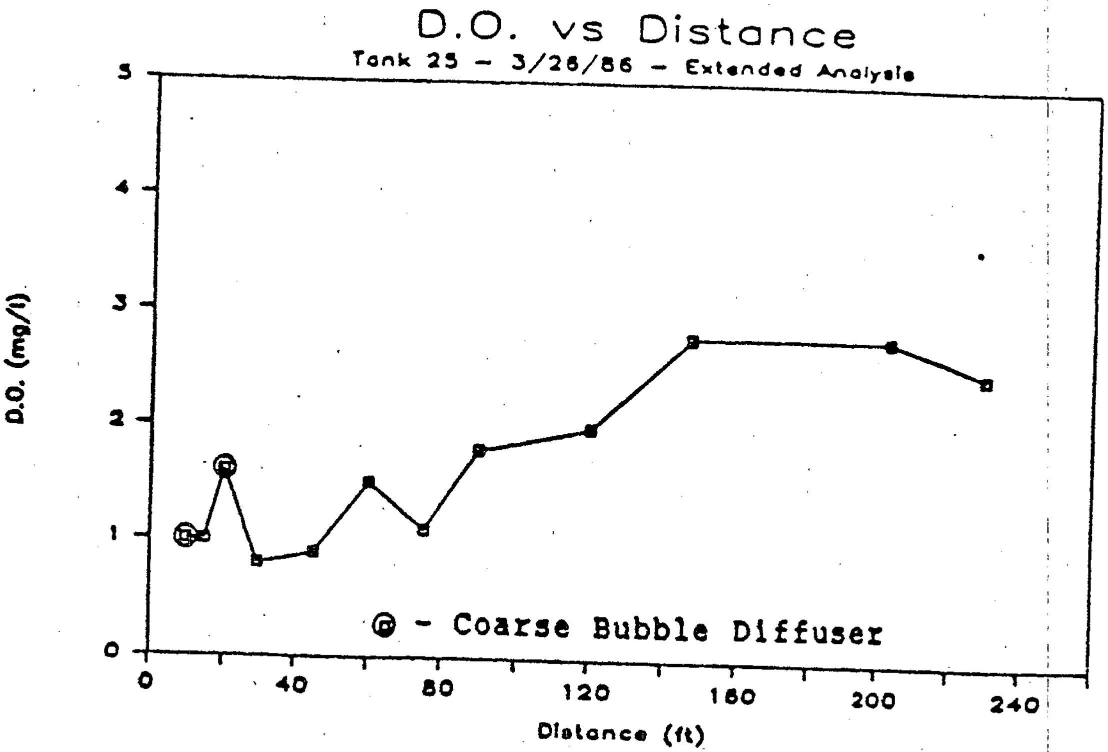


Figure IV-B.24

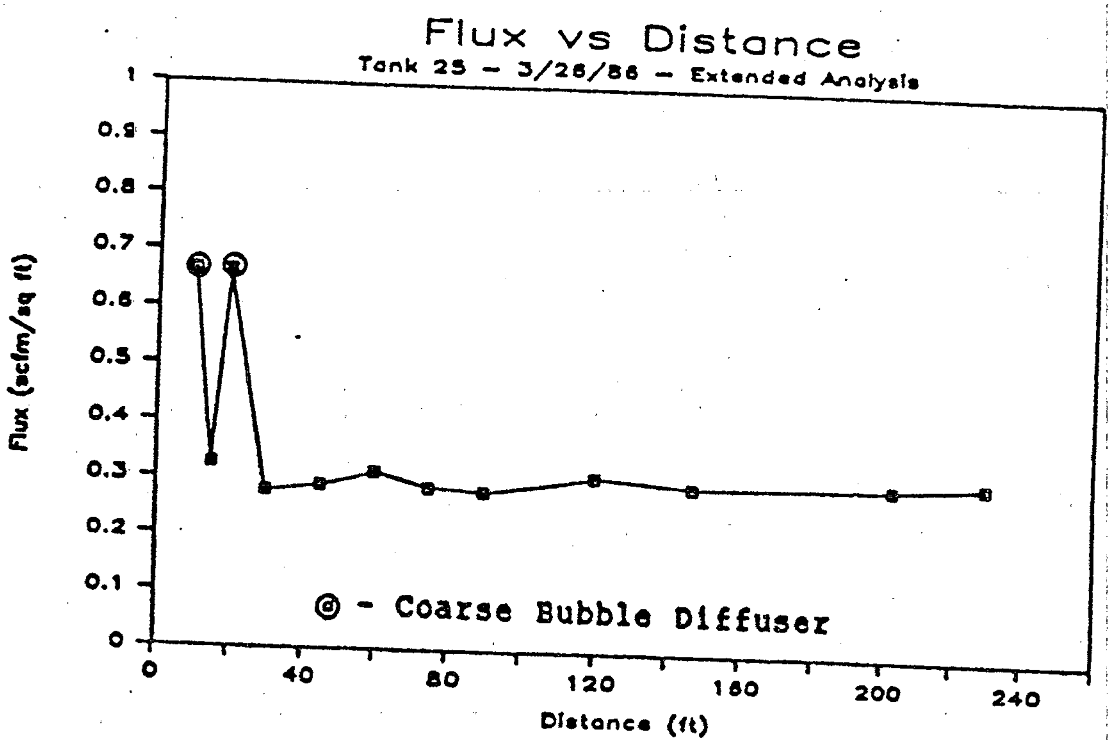


Figure 21. Computer Printout - Off-gas Data.

Summary Data Sheet

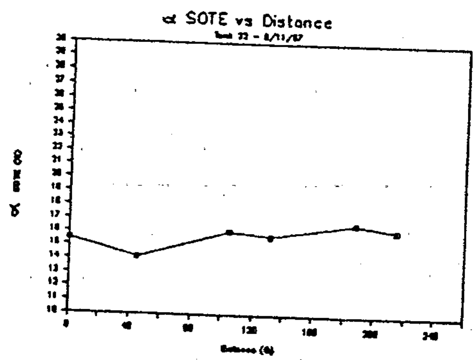
```
Test Site: Madison                            Tank #    22
        Nine Springs                          Date:     6/11/87
Aeration System: Sanitaire
Cleap:                          9.30    Beta:            0.99
Csinf(20) Value:               10.60    Source: Sanitaire
Csinf(fld) Value:              10.48    Source: Calculated
Ratm temp:                     26.11
Tank Volume (MG/Tank (3 tank pass))               1.0
Submergence(ft):               15.0    Sludge Age(days):            0.0
MLSS(mg/l):                        0    TDS(mg/l):                  <1000
Primary Effluent BOD:                       0
Loading(lb/1000cuft/day):                 0.0
Liquid Flow Rate During Test:
        Wastewater(MG):                  0.00
        Recirculation(MG):               0.00
        Total(MG):                          0
        Estimated Ret. Time(hr):                  ERR
Applied Air Rate:            700 cfm
Local Barometer:           29.19
Comments:Note: ** The CO2 indicator and cell were new. **
```

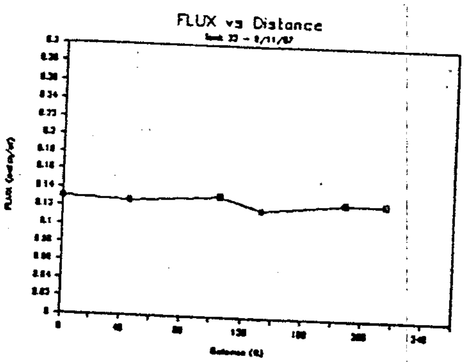
Clock Time	Station	Mole Fraction CO2 (FCO2)	Sensor Output Off-Gas mv MOG	Sensor Output Ref Air mv MR	Mixed Liquor Temp. deg C	DO mg/l C
239	1	2.9	864	998	19.0	1.25
250	2	3.1	870	997	"	1.20
301	3	2.9	860	996	"	1.40
308	4	2.8	880	999	"	2.60
320	5	2.8	895	1004	"	3.90
326	6	2.7	899	1003	"	4.00

Deficit mg/l Csinf(f) - C	Roto 2 Float Height	Field OTE(tf) dec	Specific OTEsp20 dec	Off-Gas Flux Rate scfm/sf	Overall Flux Rate scfm/sf
9.23	28	0.1333	0.0148	0.1301	
9.28	27	0.1226	0.0135	0.1273	
9.08	29	0.1341	0.0154	0.1330	0.1273
7.88	24	0.1157	0.0150	0.1188	
6.58	27	0.1026	0.0160	0.1273	
6.48	27	0.0982	0.0155	0.1273	

$\overline{OTEtf}$	$\overline{OTEsp20}$	α $\overline{SOTE}$	SOTEdw	Clean SOTE dec
			0.1552	
11.84%	0.0150	15.71%	0.1419	
			0.1611	
			0.1578	
			0.1675	
			0.1629	

```
Total Air Flow (calculated):
        842.97 scfm
Total Air Flow (predicted from plant data):
        786.26 scfm
Percent Difference:
        7.21%
```





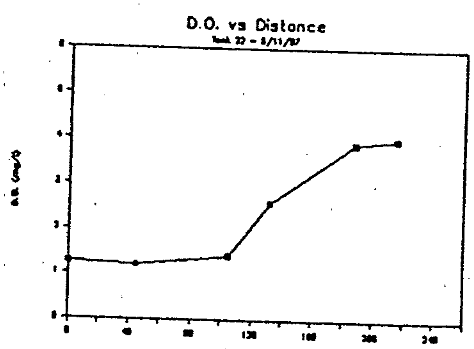


TABLE 12
SOTE VS. AIR FLOW TEST RESULTS
WEST PLANT (TANK 28) - OCTOBER 1986
Grid 1

Total Air Flow (cfm)	Air Flow/Diffuser (cfm/diffuser)	αSOTE
1300	.66	7.87
1700	.86	7.21
2100	1.06	7.62
2700	1.37	7.06

Calculated values of k and p in SOTE = k(Flow)^{p}

Tank 28 Test: k = 7.39 p = -.1170

Clean Water, 1st Pass: k = 34.51 p = -.1319
Clean Water, 2nd/3rd Pass: k = 30.85 p = -.1591

diffuser at diffuser densities representative of those found in the first and second/third pass of the West Plant aeration tanks (11). The change in magnitude in k reflects the impact of wastewater characteristics on alpha. The slopes of the clean and process water curves (p) appear to be about the same, indicating that changes in gas flow in the process wastewater would produce relative changes in SOTE similar to those seen in clean water. This study was conducted almost 400 days after installation.

In order to evaluate the variability in αSOTE over time, a 24-hour study was performed on September 25, 1986. For this, the fiberglass hood was placed in Tank 28, 15 feet from the inlet end. The results of the 24-hour study are presented in Figures 22, 23, and 24. Note that αSOTE values were corrected for variations in gas flow rates to 0.187 scfm/ft^2 (the average flux rate at this point over the 24-hour study). The equation used for this correction was described above.

It is interesting to note that at the influent end of the MMSD aeration tank, the values of alpha varied over a narrow range throughout the 24-hour period (0.22 to 0.29), whereas influent load, as measured by TOC x flow rate varied by a factor of greater than 2. It is apparent that traditional pollutional load parameters such as BOD or TOC may not be the best indicators of wastewater contaminants that affect oxygen transfer. It may also be noted that MMSD wastewater is relatively weak as measured by TOC.

Results of off-gas testing over the 800 day period appear in Tables 13 and 14 for Tanks 21 and 24 and Tanks 25 and 28, respectively. Weekly SRT and F/M values and daily BOD loads are also presented. This data is graphically depicted in Figures 25-32. Reviewing the αSOTE data and discounting the early data prior to about day 150 because of operational difficulties, substantial variability in αSOTE was recorded throughout the study. The mean values of αSOTE (beginning about day 150) were calculated for each aeration basin (Table 15). There was no significant difference between the mean αSOTE values for all four first-pass tanks and review of the data indicated that there was no trend in the αSOTE over the study period (March 1986 through December 1987). As will be discussed later, this observation was confirmed by diffuser characteristic analyses when the Aeration Tanks 19, 20, and 21 were dewatered in June 1987 (Day 635).

The variability in the αSOTE over the study period (s/x ranged from 0.11 to 0.15) could not be attributed to analytical errors of the off-gas method alone. Variability in αSOTE can be attributed to a number of factors including process operation (SRT, F/M, etc.) and wastewater characteristics. Note that all αSOTE measurements were conducted at the same gas flow rate and were corrected for D.O. and temperature. The data collected from the East Plant suggested that SRT (and F/M) might influence αSOTE. A linear regression of αSOTE vs. F/M (and SRT) was performed on the West Plant data. Using F/M as the independent variable, the correlation coefficients, r, for the four tanks ranged from 0.34 to 0.60. An analysis of all four tanks together produced a correlation coefficient of 0.42. Similar analyses were performed for SRT. The correlation coefficients were poorer than for F/M, ranging from .05 to .64. Poorer correlation may have been due to difficulties that plant personnel had in collecting good waste solids data early in the study.

In the period between 350 and 400 days, Plants 3 and 4 were operated at two distinctly different SRTs (and F/M), Plant 3 at about 11 days, and Plant 4 at about 6 days. It was expected that αSOTE values in Tanks 25 and 28 would drop over this interval, which they did. It was unexpected to also find αSOTE values in Tanks 21 and 24 to drop as well, even though SRTs were raised in this plant from about 8 to 11 days. Note that both plants operated at the same BOD loading.

Figure 22. Twenty-four Hour Survey - Alpha.

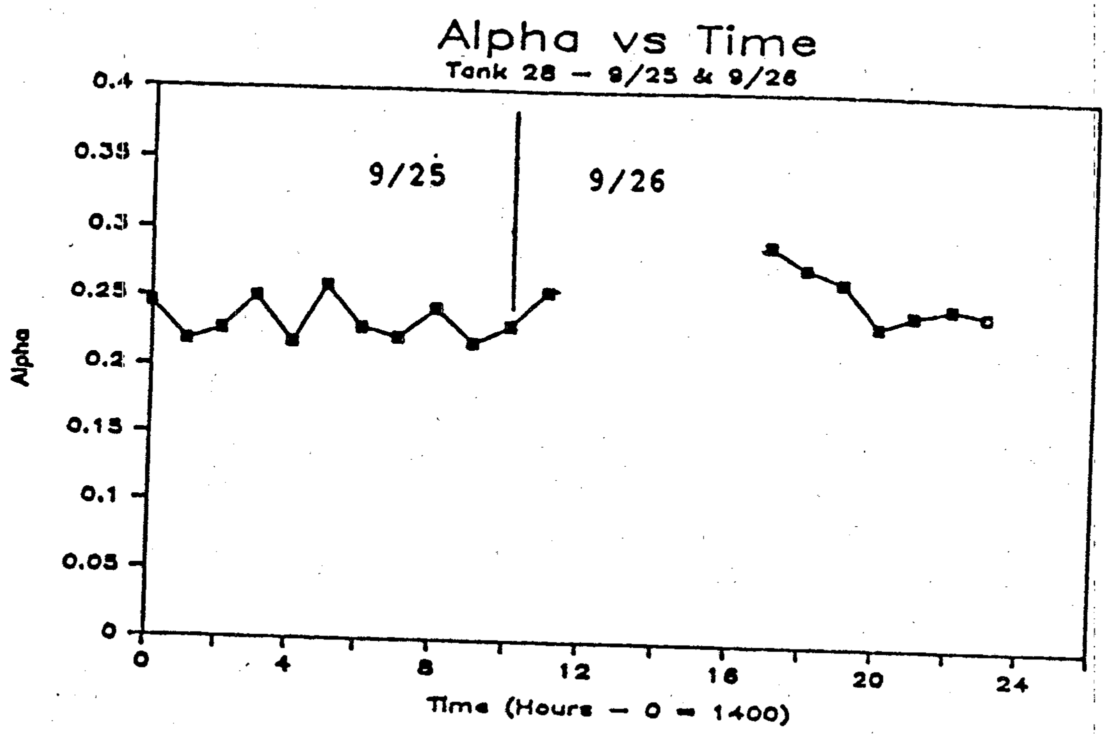
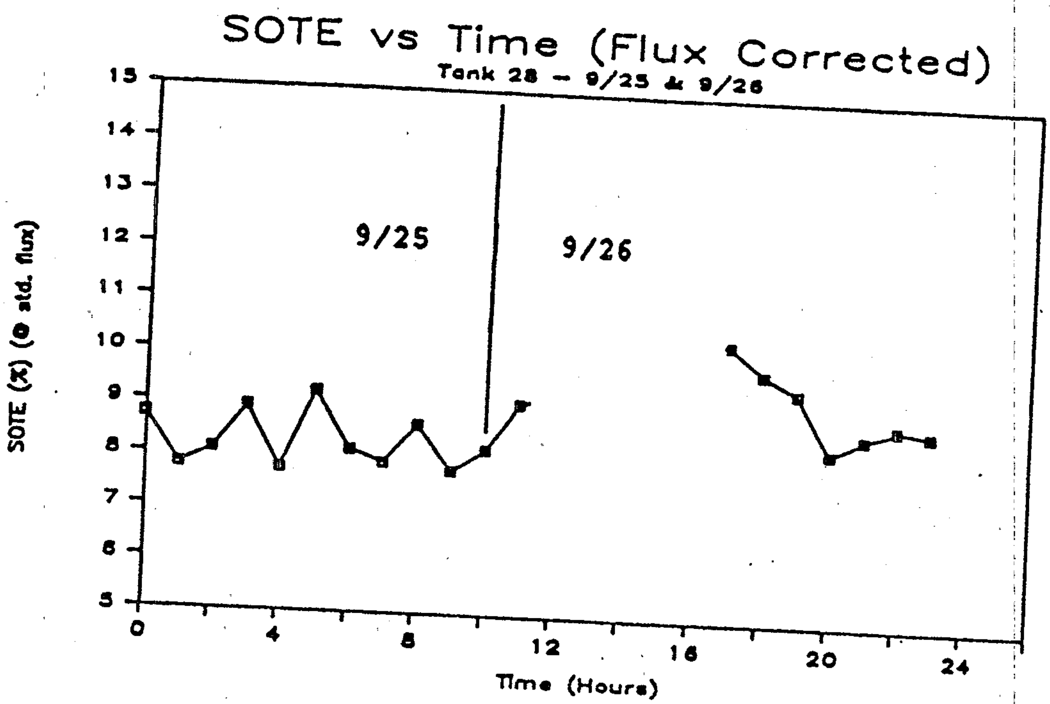


Figure 23. Twenty-four Hour Survey - αSOTE, Airflow.



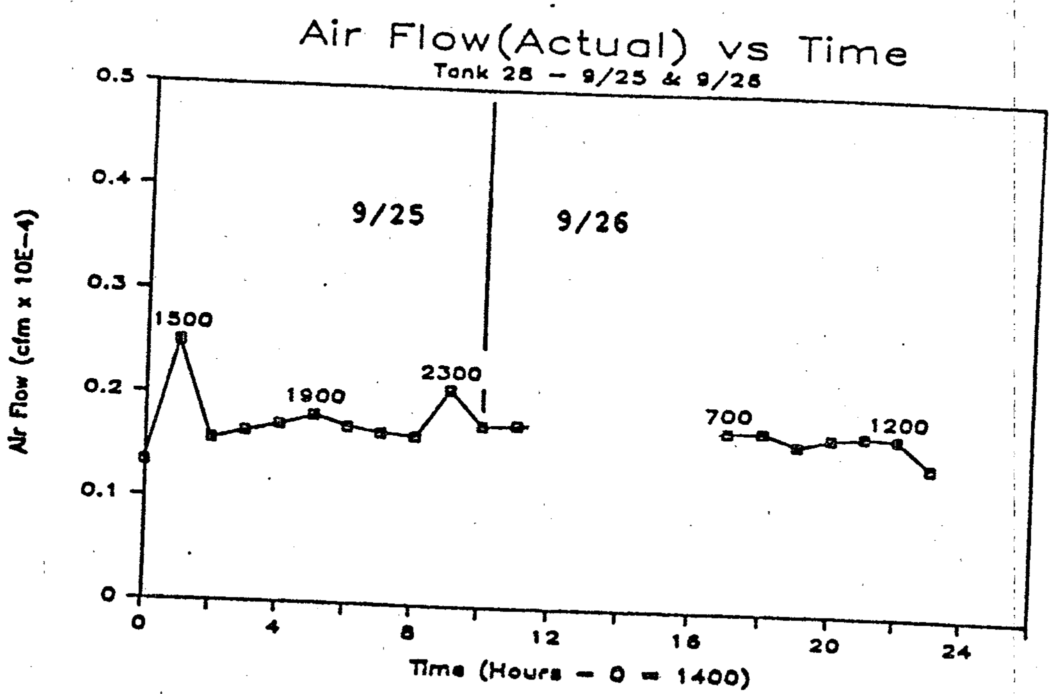
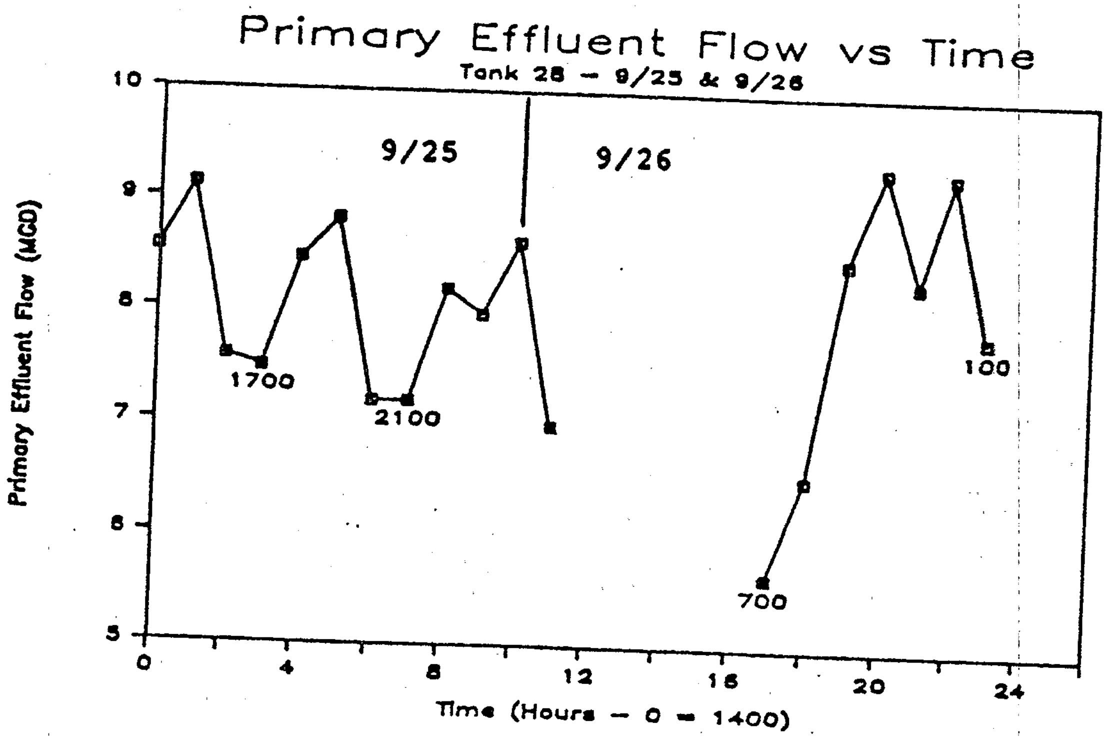


Figure 24. Twenty-four Hour Survey - Flow, TOC.



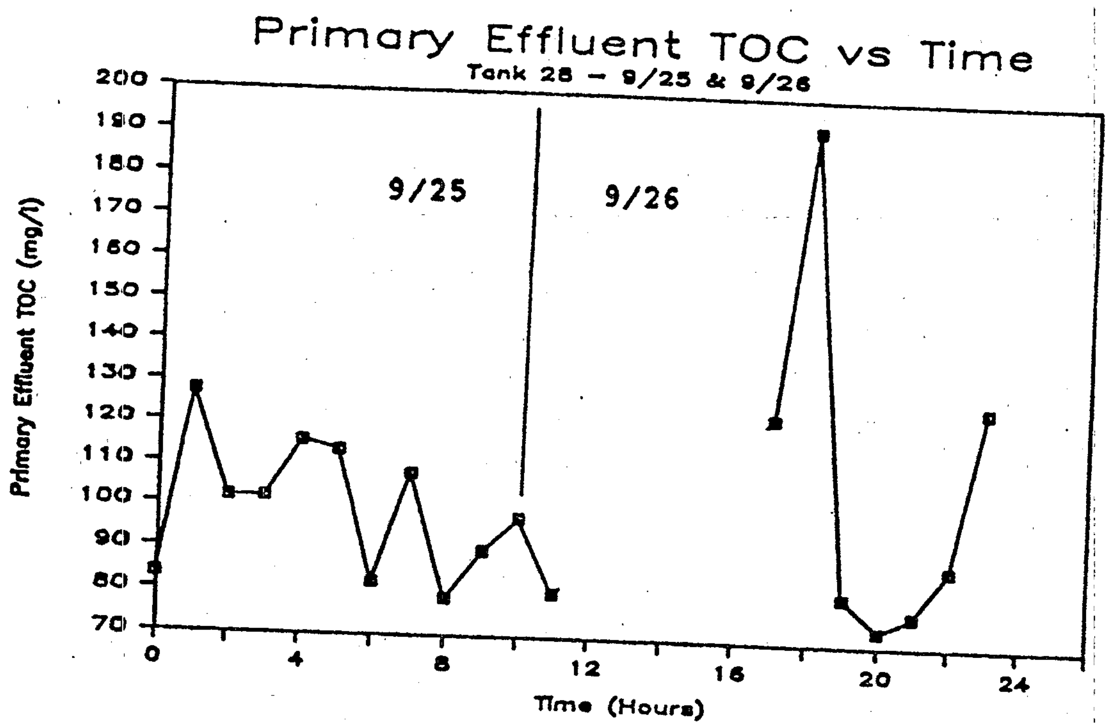


TABLE 13
αSOTE PLANT DATA - PLANT 3

Date	Day	αSOTE 21 (%)	αSOTE 24 (%)	WEEKLY SRT (days)	WEEKLY F/M (days^{-1})	DAILY BOD (lb/1000 ft^{3}d)
09/27/85	1		13.79		0.17	13.0
10/04/85	8	12.18			0.17	26.4
10/11/85	15		10.76	7.0	0.18	27.3
10/18/85	22	12.08			0.19	15.5
10/25/85	29	12.02			0.15	12.9
10/30/85	34		10.49		0.15	18.2
11/08/85	43	7.83	8.21		0.20	18.0
01/22/86	118		6.36	5.5	0.19	18.6
02/05/86	132	6.91		5.6	0.14	11.9
02/19/86	146	5.81		6.8	0.18	11.7
03/12/86	167		12.55	7.9	0.09	11.3
03/19/86	174	11.91		7.6	0.09	11.9
03/26/86	181		11.70	7.9	0.11	12.0
04/02/86	188	10.32		7.1	0.13	15.1
04/30/86	216		11.19	6.9	0.09	9.4
05/14/86	230	11.29		6.5	0.08	10.9
05/22/86	238	11.80	12.32	8.0	0.09	8.7
05/28/86	244		12.48	7.6	0.08	10.9
06/04/86	251	12.19		7.7	0.11	13.9
06/18/86	265		11.61	8.3	0.09	12.4
06/19/86	266	11.42		8.3	0.09	11.7
06/24/86	271		11.78	7.9	0.11	
07/17/86	294	12.10		8.0	0.12	15.5
07/22/86	299		11.97	8.1	0.09	8.8
09/11/86	350		14.39	11.2	0.08	9.2
09/18/86	357	14.16		11.5	0.09	9.6
10/07/86	376		10.99	11.4	0.13	8.1
10/09/86	378	10.13		11.4	0.13	11.6
10/14/86	383		9.89	11.1	0.10	9.2
10/16/86	385	10.07		11.1	0.10	10.0
10/21/86	390		10.51	11.0	0.12	8.6
10/23/86	392	9.62		11.0	0.12	10.6
10/28/86	397		9.85	11.0	0.12	10.8
10/30/86	399	9.71		11.0	0.12	11.1
11/04/86	404	9.96		10.3	0.12	15.1
11/06/86	406		9.52	10.3	0.12	14.6
11/11/86	411	9.74		10.2	0.13	14.6
11/25/86	425		10.64	11.2	0.10	15.4
12/08/86	438	10.75		11.6	0.10	7.0
01/07/87	468	11.77		11.3	0.13	15.7
01/08/87	467		12.13	11.3	0.13	13.7

TABLE 13 (Continued)

Date	Day	αSOTE 21 (%)	αSOTE 24 (%)	WEEKLY SRT (days)	WEEKLY F/M (days^{-1})	DAILY BOD (lb/1000 ft^{3}d)
01/14/87	475	12.66	10.48	11.3	0.10	15.6
01/30/87	491	12.31		10.5	0.11	
02/13/87	505		10.89	11.4	0.13	10.4
02/20/87	512		11.68	11.1		14.3
02/27/87	519	11.80		10.6	0.12	18.3
03/06/87	526		10.18	11.2	0.12	15.1
03/2787	547	11.10	10.59	11.7	0.10	10.7
04/03/87	554	11.97	11.54	11.5	0.10	12.1
04/17/87	568	12.03		10.7	0.10	15.1
04/24/87	575	11.31	11.24	9.3	0.12	14.6
06/01/87	613		10.27	9.7	0.12	9.6
06/02/87	614	11.51		9.7	0.12	14.8
06/10/87	622	11.57		9.5	0.15	13.5
06/11/87	623		10.13	9.5	0.15	19.3
06/16/87	628	11.63	11.29	9.4	0.16	17.4
06/23/87		HOSE CLEAN #21				
07/09/87	651	13.33		9.6	0.16	18.5
07/10/87	652		8.55	9.6	0.16	18.2
07/16/87	658	10.05	10.64	9.8		13.4
07/20/87	662	10.19	11.12	9.6	0.14	15.1
07/30/87	672	9.34		15.7	0.14	16.6
08/05/87	678		11.54	9.7	0.13	14.9
08/11/87	684	13.56	13.74	9.7	0.13	16.1
09/04/87	708	9.89	10.22	9.4	0.16	13.3
09/18/87	722		14.21	9.1	0.11	11.8
09/25/87	729	14.09	11.66	9.3	0.13	22.4
10/30/87	764	10.36	10.08	9.7	0.13	19.8
11/06/87	771	11.34		9.7	0.16	19.0
11/13/87	778		11.08	9.6	0.15	17.6
12/04/87	799	11.79	10.64	10.0	0.12	14.0

TABLE 14
αSOTE PLANT DATA - PLANT 4

Date	Day	αSOTE 25 (%)	αSOTE 28 (%)	WEEKLY SRT (days)	WEEKLY F/M (days^{-1})	DAILY BOD (lb/1000 ft^{3}d)
11/15/85	50	9.87	8.00	5.4	0.16	16.0
01/22/86	118	6.88		5.9	0.24	18.2
02/05/86	132		7.31	6.1	0.18	11.5
02/19/86	146		8.85	6.0	0.26	12.7
03/12/86	167	11.07		7.3	0.15	11.3
03/26/86	181	10.99		7.6	0.13	13.0
04/02/86	188		8.79	8.0	0.14	15.2
04/30/86	216	12.06		9.1	0.11	9.4
05/14/86	230		10.99	10.0	0.10	10.9
05/22/86	238	12.92	12.85	9.8	0.10	8.7
05/28/86	244	12.32		8.1	0.09	10.9
06/04/86	251		11.48	7.8	0.12	13.9
06/18/86	265	10.86		6.4	0.13	12.4
06/19/86	266		12.48	6.4	0.13	11.7
06/24/86	271	12.30		6.2	0.15	
07/15/86	292	11.98		5.6	0.18	12.0
07/17/86	294		11.69	5.6	0.18	15.5
07/22/86	299	12.42		5.7	0.14	8.8
09/11/86	350	13.06		9.2	0.09	9.2
09/16/86	355		11.43	7.3	0.11	13.1
10/02/86	371	10.52		5.9	0.14	7.3
10/09/86	378		9.37	5.9	0.31	11.6
10/14/86	383	7.99		6.1	0.16	9.2
10/16/86	385		9.29	6.1	0.16	10.0
10/21/86	390	9.74		6.1	0.19	8.6
10/23/86	392		9.20	6.1	0.19	10.6
10/28/86	397	8.91		5.8	0.20	10.8
10/30/86	399		9.40	5.8	0.20	11.1
11/04/86	404		8.02	5.8	0.19	15.1
11/06/86	406	8.20		5.8	0.19	14.6
11/11/86	411		8.00	8.3	0.21	14.6
11/25/86	425	11.14		11.2	0.10	15.4
12/04/86	434		11.99	11.2	0.11	11.6
12/08/86	438		11.02	11.2	0.11	7.0
01/07/87	468		12.33	11.2	0.14	15.7
01/08/87	469	11.36		11.2	0.14	13.7
01/14/87	475	10.22	11.59	11.3	0.10	15.6
01/30/87	491		13.51	11.0	0.08	
02/13/87	505	15.42		11.6	0.09	10.4
02/20/87	512	14.53		11.3		14.3

TABLE 14 (Continued)

Date	Day	αSOTE 25 (%)	αSOTE 28 (%)	WEEKLY SRT (days)	WEEKLY F/M (days^{-1})	DAILY BOD (lb/1000 ft^{3}d)
02/27/87	519		15.13	11.4	0.10	18.3
03/06/87	526	13.13		11.5	0.08	15.1
03/27/87	547	11.76	12.79	11.8	0.09	10.7
04/03/87	554	12.14	12.54	11.5	0.11	12.1
04/17/87	568		12.32	10.7	0.10	15.1
04/24/87	575	12.54	11.31	9.3	0.12	14.6
06/16/87	628	12.32	14.34	9.4	0.17	17.4
07/16/87	658	10.39	9.62	9.6		13.4
07/20/87	662	11.14	8.91	9.5	0.17	15.1
07/30/87	672		12.94	9.4	0.13	16.6
08/05/87	678	12.85		9.7	0.14	14.9
08/11/87	684	13.30	12.41	9.7	0.13	16.1
09/04/87	708	13.50	12.18	9.4	0.15	13.3
09/18/87	722	14.36		9.0	0.11	11.8
09/25/87	729	13.63	12.83	9.3	0.12	22.4
10/30/87	764	11.81	9.51	9.7	0.13	19.8
11/06/87	771		12.48	9.7	0.16	19.0
11/13/87	778	12.26		9.6	0.15	17.6
12/04/87	799	10.35	11.75	9.7	0.15	14.0

Figure 25. αSOTE (Tank 21) vs. Time.

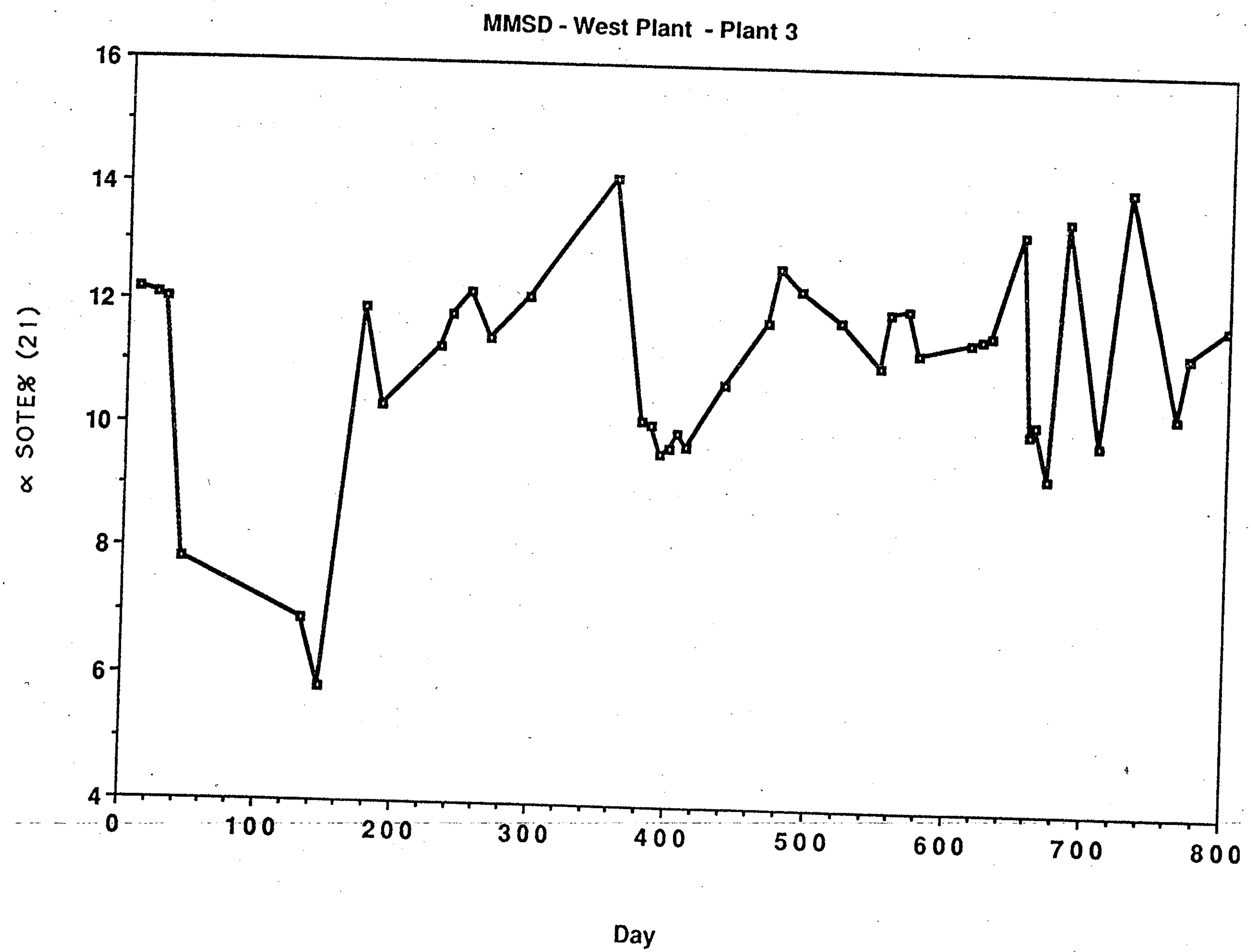


Figure 26. αSOTE (Tank 24) vs. Time.

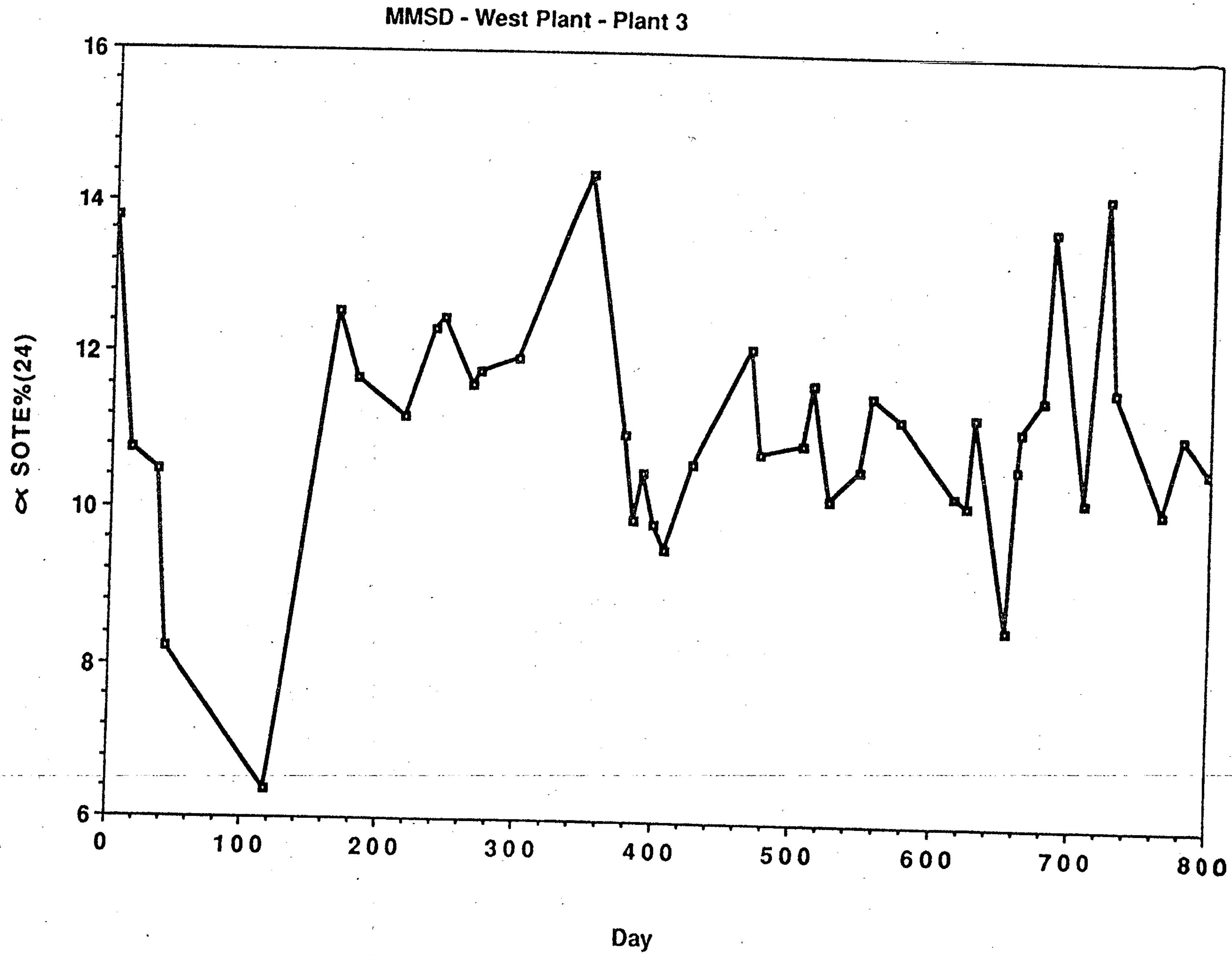


Figure 27. BOD Load vs. Time - Plant 3.

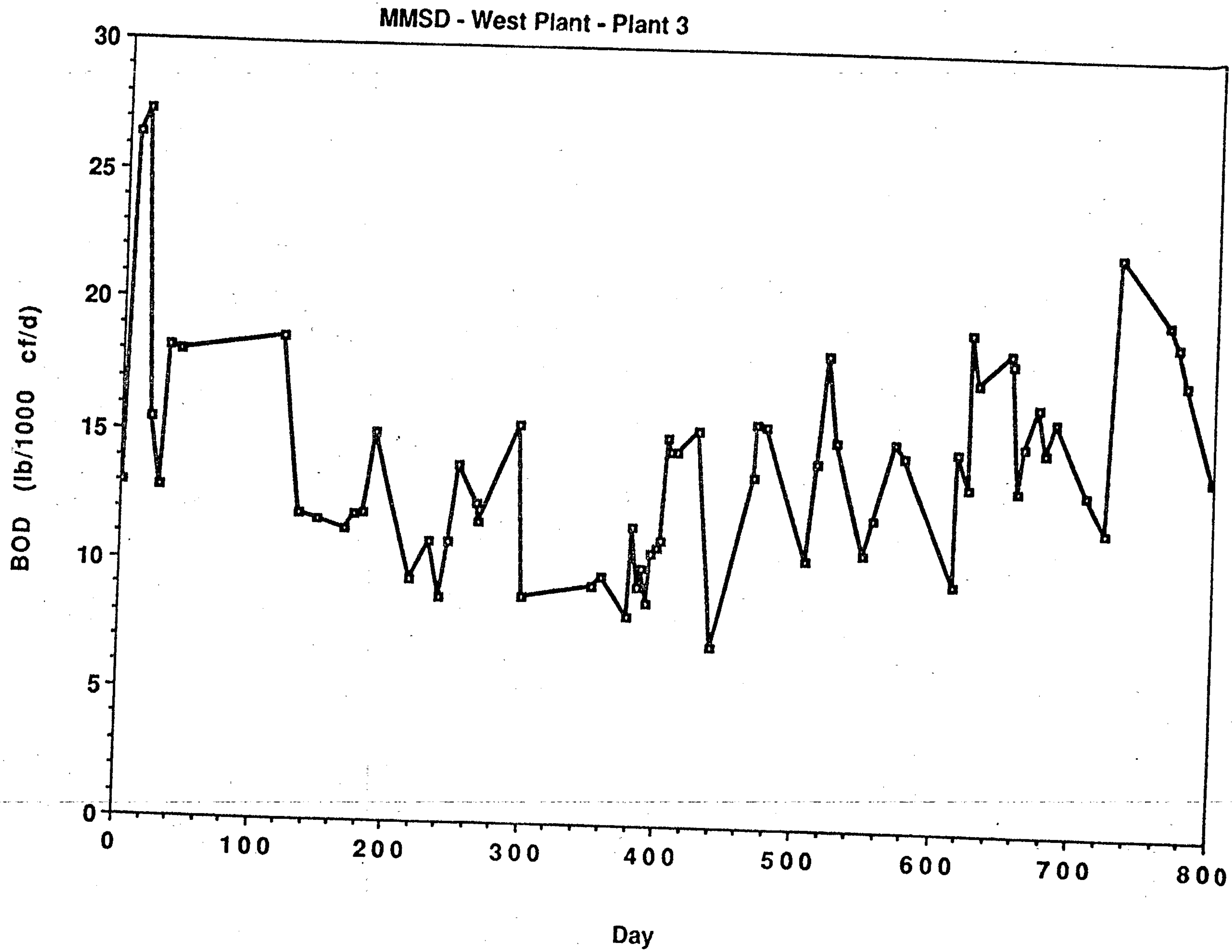


Figure 28. SRT vs. Time - Plant 3.

MMSD - West Plant - Plant 3

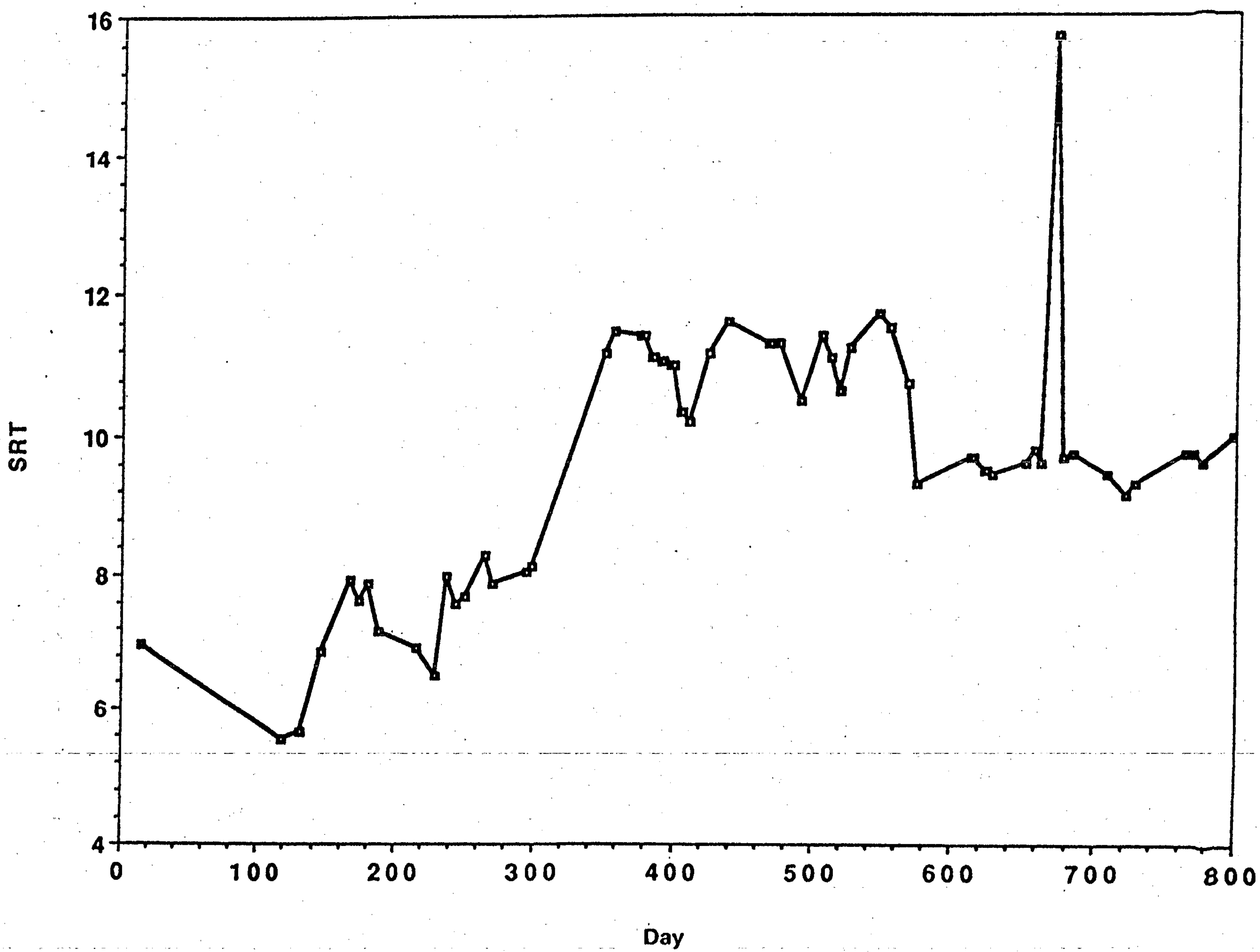


Figure 29. αSOTE (Tank 25) vs. Time.

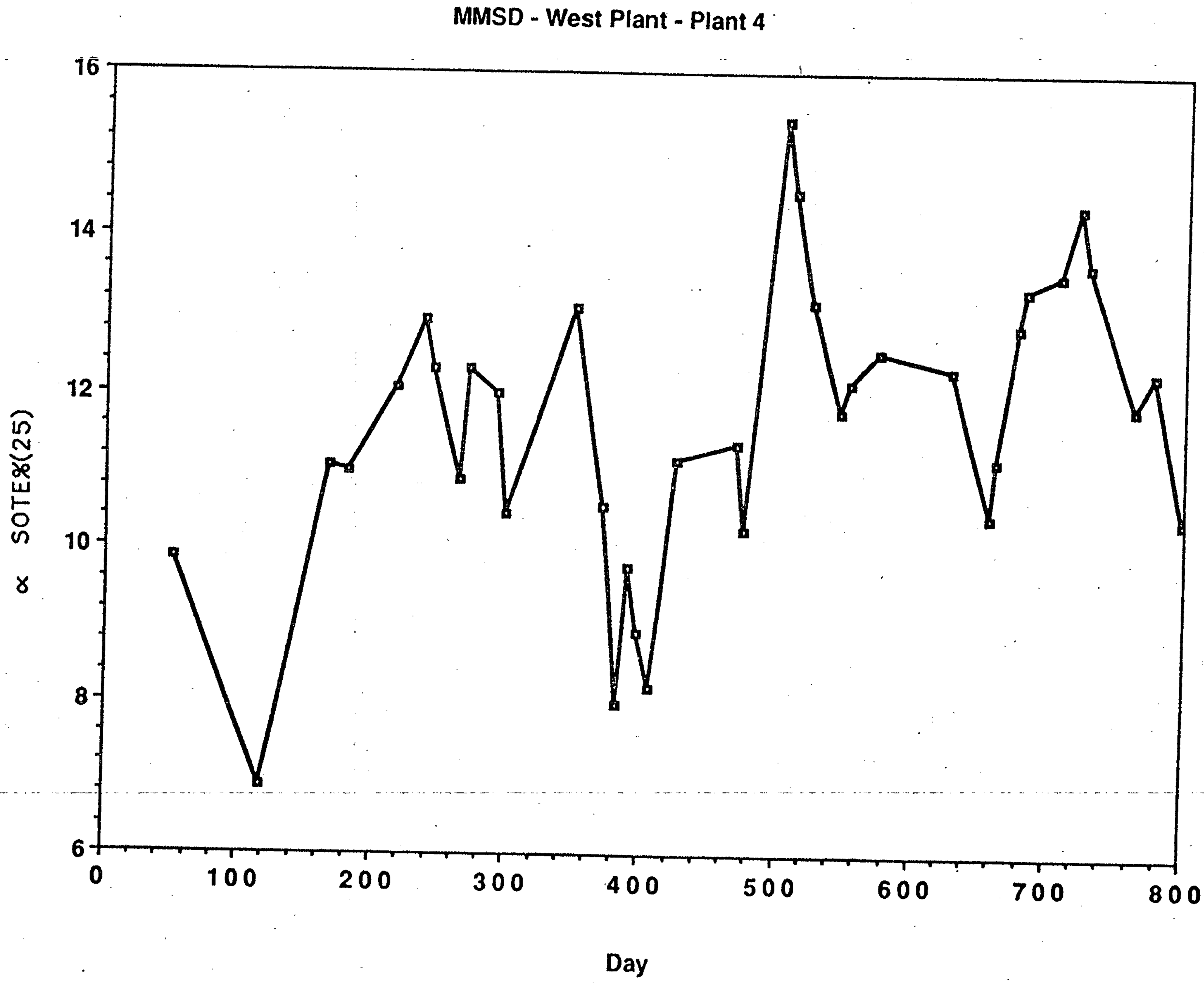


Figure 30. αSOTE (Tank 28) vs. Time.

MMSD - West Plant Plant 4

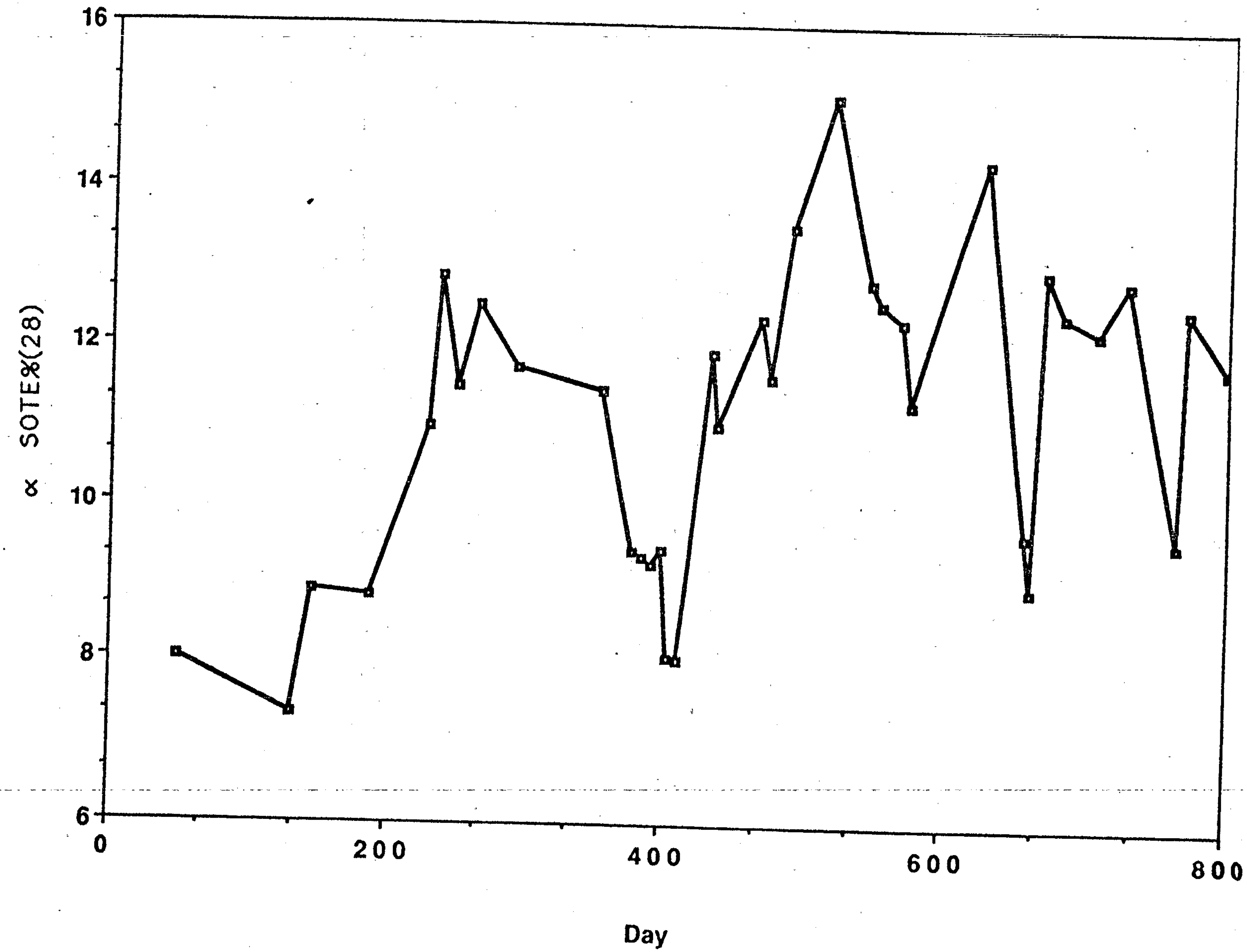


Figure 31. BOD Load vs. Time - Plant 4.

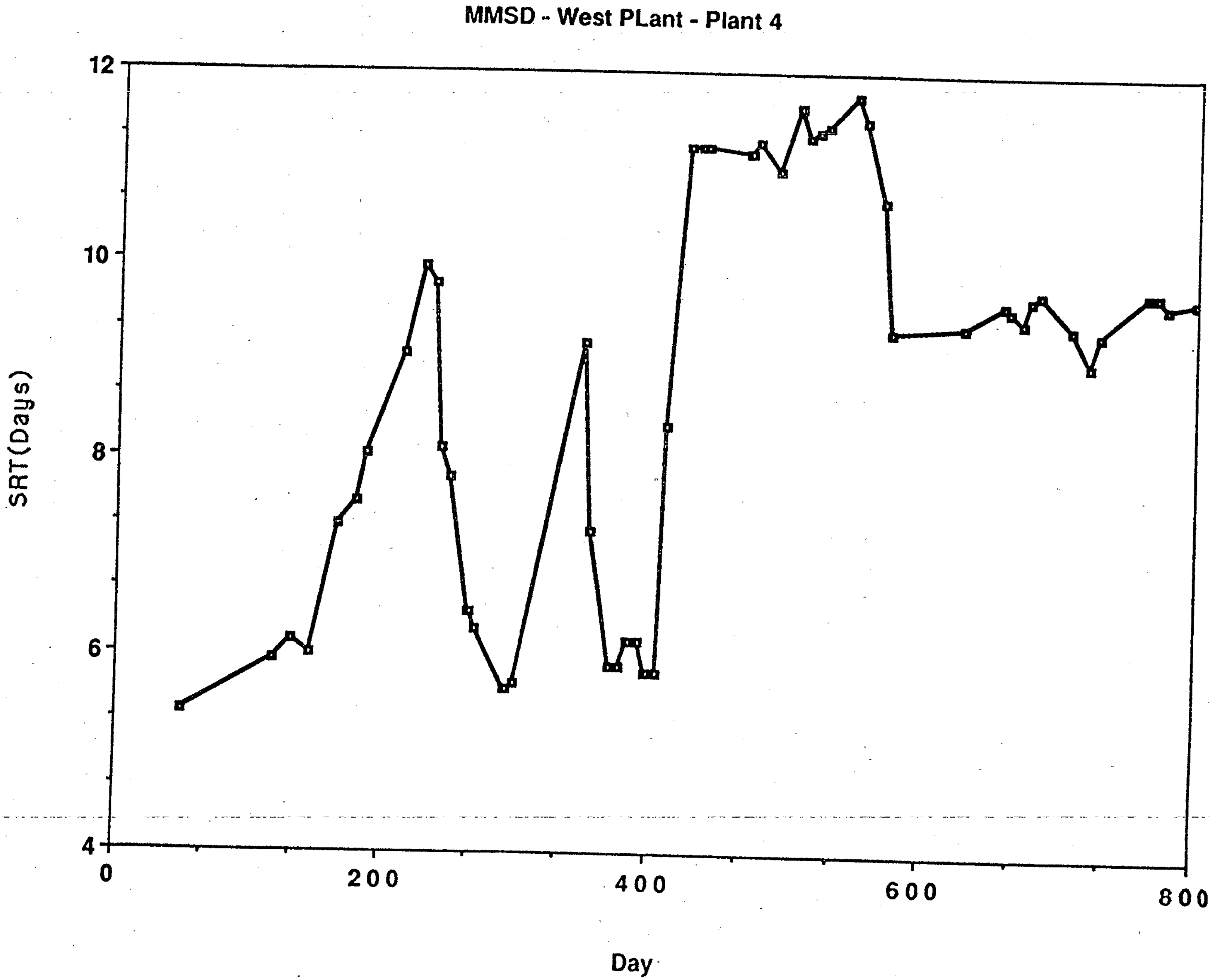


Figure 32. SRT vs. Time - Plant 4.

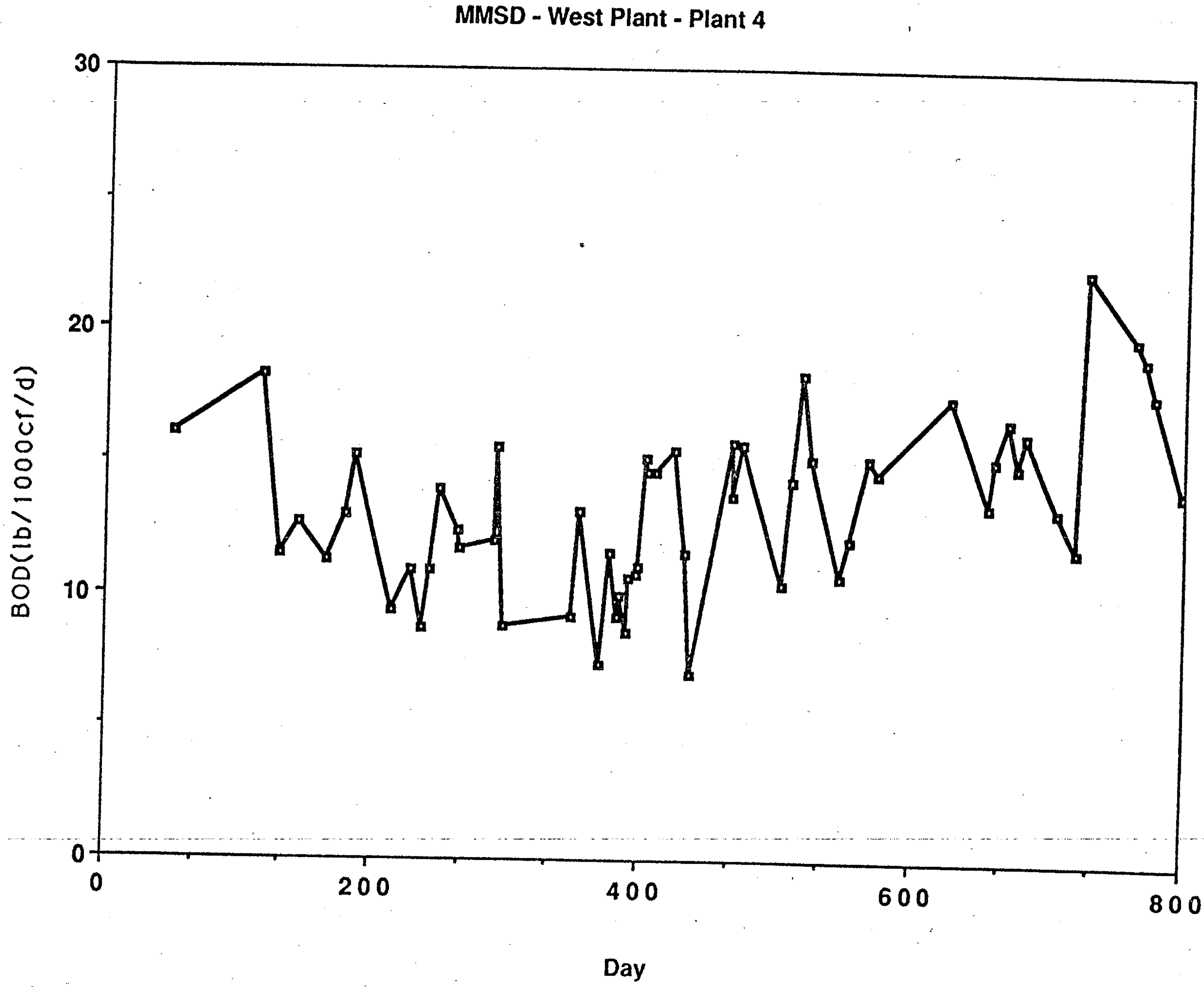


TABLE 15
MEAN α-SOTE VALUES - WEST PLANT
MARCH 1986 - DECEMBER 1987

Tank No.	Mean αSOTE (%)	Standard Deviation αSOTE (%)	n
21	11.35	1.25	36
24	11.22	1.23	37
25	11.81	1.67	35
28	11.43	1.77	32

Results of the fifty day study in Plants 3 and 4 are presented in Table 16. In every instance, Plant 3 αSOTE values were higher than those in Plant 4. At the 95% confidence level, however, there was no significant difference between the αSOTE values for these two operating strategies. Because of the wide fluctuations in αSOTE, it is difficult to show that this process operating variable alone affected diffuser performance in the West Plant.

It is important to note, however, that these analyses were for the first basin of a three-pass system. Results of the East Plant study suggested that the first pass was the least sensitive to variations in operation. Furthermore, with a few exceptions, the West Plant produced completely nitrified effluent during the test period. Thus, it is reasonable to assume that the major variations seen in αSOTE performance for these West Plant first pass basins may have been waste mediated.

One additional observation related to plant operation and αSOTE was noted by Reusser, the plant operations engineer at MMSD. He found that there appeared to be some relationship between αSOTE and effluent ammonia for a given range of F/M values (Figure 33). Although no control studies were conducted, the data suggested that it was the degree of oxidation of the wastewater that most affected αSOTE. Thus, plants operating in warm weather and achieving complete nitrification may generate high αSOTE values at lower SRTs than during the winter when SRTs must be increased to insure nitrification. If oxygen transfer is tied to the presences of surfactants/organics in the wastewater (waste mediated), it is possible that when complete nitrification occurs (regardless of SRT), these surfactant/organics may be depressed to levels that no longer affect oxygen transfer.

Studies were conducted near the end of this investigation to evaluate the effect of D.O. set point variation on αSOTE. Between August 5 and September 4, 1987, D.O. set points in Plant 3 were 1.5, 2.0, and 2.0 mg/L in Passes 1-3, respectively. The set points in Plant 4 were 0.7, 1.5, and 2.0 mg/L. Between September 4 and December 4, these set points were flip-flopped so that Plant 4 had the higher set points. An analysis of αSOTE values during these studies (see Tables 13 and 14) indicated that in the first pass tanks, there was no significant difference between set-point strategies on the value of αSOTE.

Although there was no indication that diffuser cleaning was necessary, it was decided that one set of basins would be dewatered and examined after 635 days of operation. Basins 19, 20, and 21 were dewatered on June 23, 1987. Examination of the basins indicated that significant foulant was accumulating on diffusers, piping, and tank walls in the first pass. The last two passes were virtually "like new." Results of the diffuser characterization are presented in the next section (See Table 20). Pictures of representative diffusers from the three passes are shown in Figure 34.

The diffusers were cleaned by high pressure hosing (line pressures of 120 psig) within the tank and then additional diffusers were removed for characterization. The tanks were put back into service on June 25.

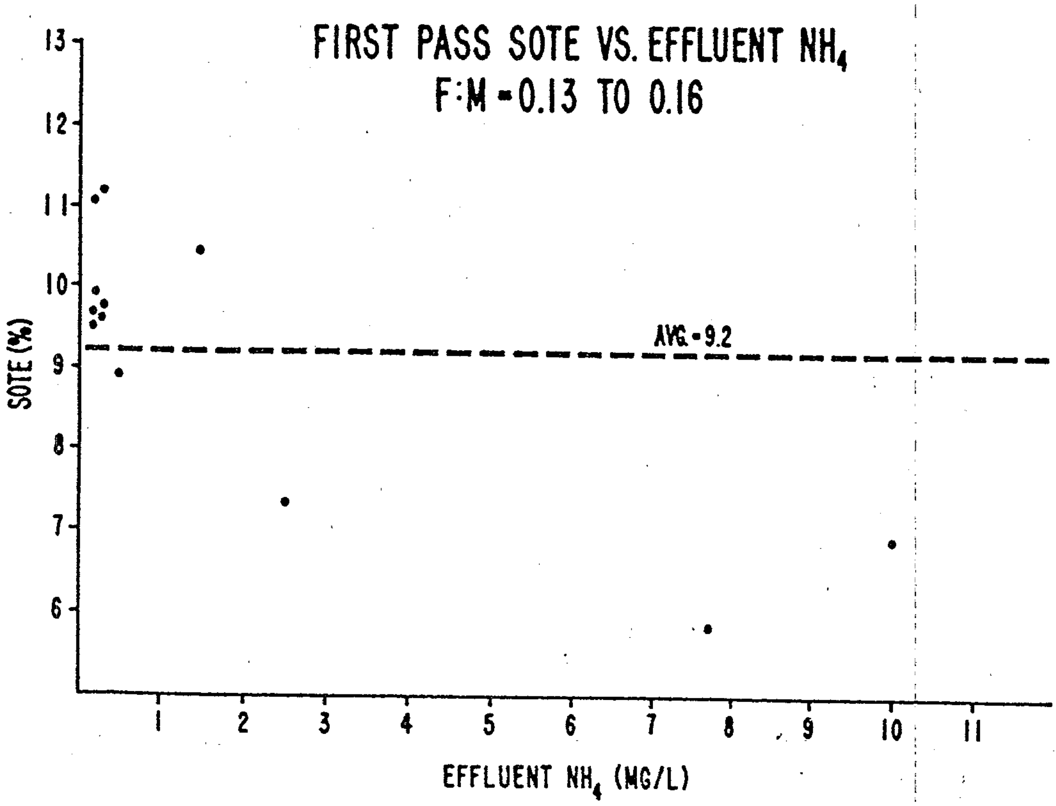
A series of three basin off-gas tests were conducted on Basins 19, 20, 21 and 22, 23, 24 between June 1, 1987, and November 6, 1987. Results of these tests appear in Table 17. Note that these data are for the two sets of aeration basins in Plant 3 operated under the same conditions. Review of this table indicates that cleaning of Basins 19, 20, and 21 did not appreciably affect the performance of that system over the parallel one (22, 23, 24). Comparing data for Tanks 21 and 24 in Tables 17 and 13 suggest that immediately after cleaning there may have been some improvement in Basin 21; but this was short-lived, and

TABLE 16
αSOTE FOR PLANT 3 AND 4 DURING DIFFERENT SRTs*

Date	Plant 3 αSOTE	Plant 4 αSOTE
<u>1986</u>		
09-11	14.39	13.06
10-9	10.13	9.37
10-14	9.89	7.99
10-16	10.07	9.29
10-21	10.51	9.74
10-23	9.62	9.20
10-28	9.85	8.91
10-30	9.71	9.40
$\bar{x}$	10.52	9.62
s	1.59	1.48

*Extracted from Tables 13 and 14.

Figure 33. αSOTE vs. Effluent NH_4.



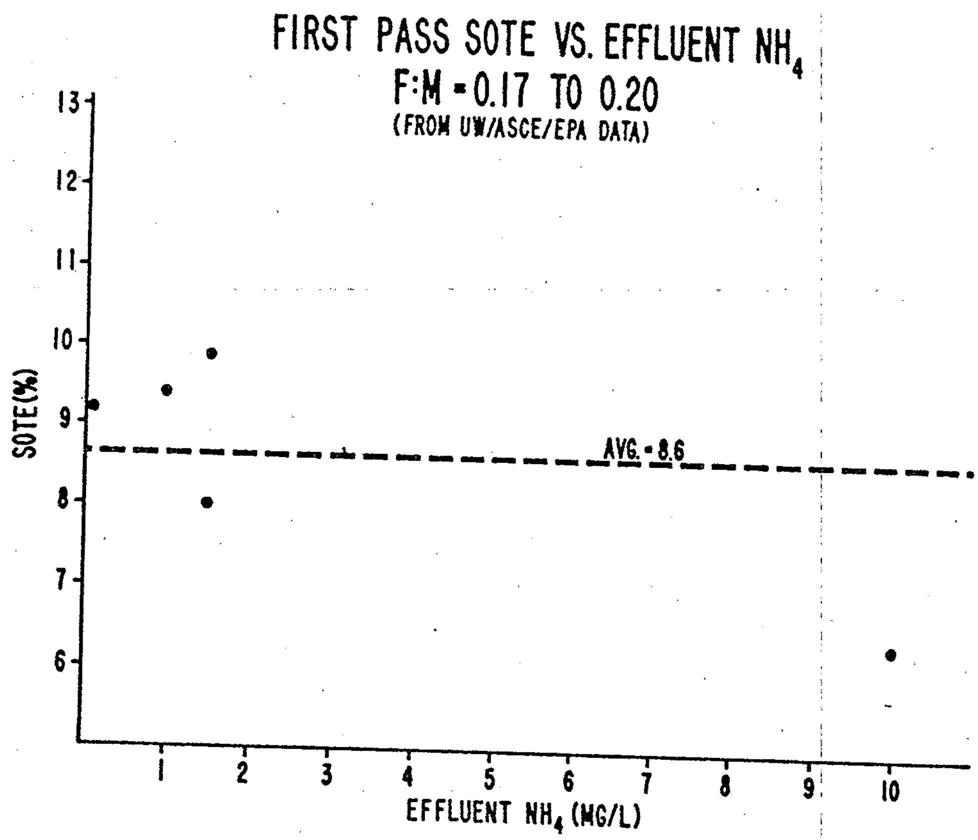
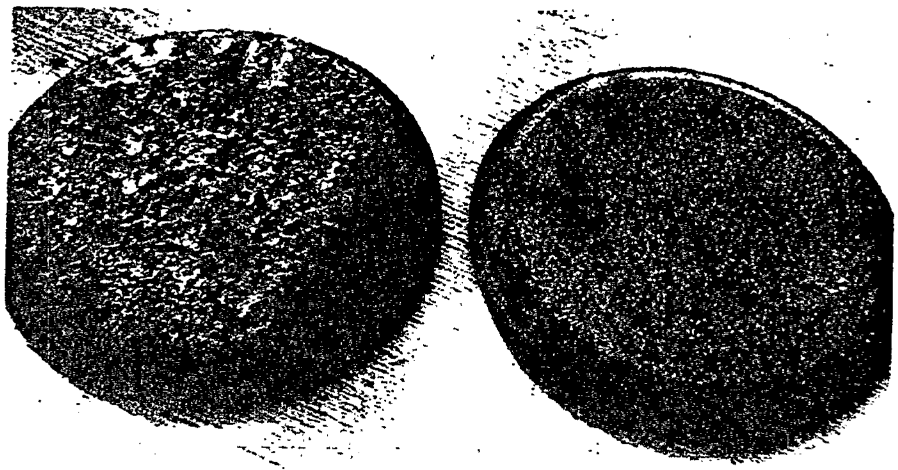
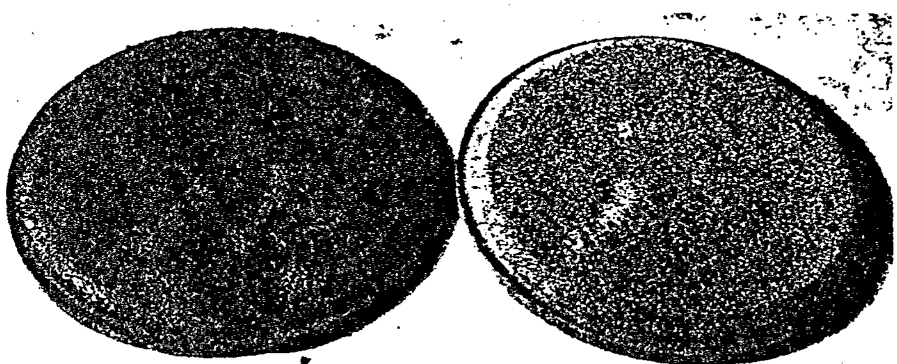


Figure 34. Photographs of Fouled and Clean Diffusers - 600 Days of Service



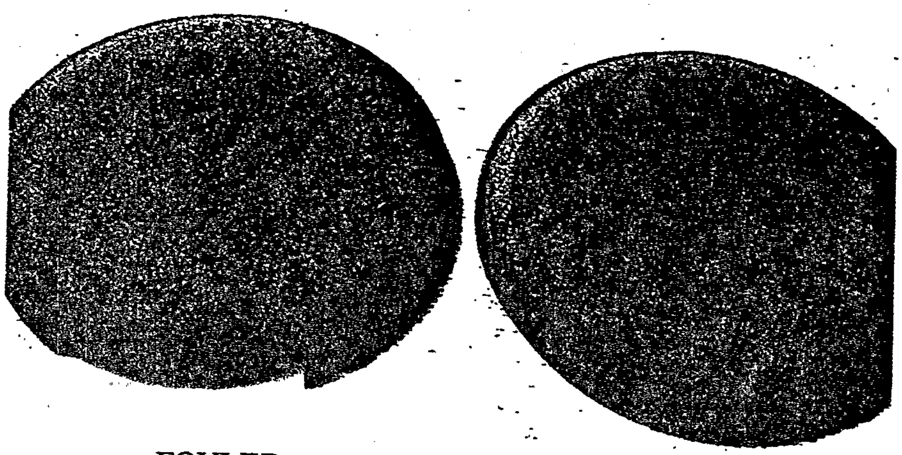
FOULED CLEAN

GRID 1 - TANK 21



FOULED CLEAN

GRID 5 - TANK 20



FOULED CLEAN

GRID 9 - TANK 19

TABLE 17

THREE BASIN OFF-GAS TEST RESULTS

WEST PLANT - PLANT 3

Date	TANK 21 OR 24			TANK 20 OR 23			TANK 19 OR 22			MEAN WEIGHTED
	G_S (scfm/dif.)	αSOTE (%)	α	G_S (scfm/dif.)	αSOTE (%)	α	G_S (scfm/dif.)	αSOTE (%)	α	αSOTE (%)
06/01/87	1.32	10.27	.31(24)*	1.32	16.81	.57(23)	1.19	18.93	.63(22)	13.85
06/10/87	1.32	11.57	.35(21)	1.29	16.11	.54(20)	1.24	17.49	.59(19)	14.05
06/11/87	1.27	10.13	.30(24)	1.53	15.77	.55(23)	1.36	15.70	.53(22)	13.08
06/23/87				CLEAN BASINS 19, 20, and 21						
07/09/87	1.26	13.31	.40(21)	1.04	16.89	.55(20)	1.06	17.12	.56(19)	14.96
07/10/87	1.22	8.55	.25(24)	1.15	16.14	.53(23)	.94	16.78	.54(22)	12.13
11/06/87	1.02	11.36	.33(21)	1.30	17.76	.60(20)	1.29	19.47	.66(19)	15.32

*( ) Tank number

Note that Tanks 21 and 24, 20 and 23, 19 and 22 are parallel first, second, and third pass aeration basins, respectively (see Figure 17).

both parallel basins produced similar αSOTE values three weeks after cleaning. In fact, it was not possible to determine whether the elevated αSOTE (and α) value for Basin 21 on July 9 was due to cleaning or the wastewater characteristics that day. No significant improvement was seen in the downstream tanks.

The three basin mean weighted αSOTE during this sampling period was about 14%. It is instructive to note that between 33 and 49% (average 40%) of the oxygen demand in the system was satisfied in the first pass. This was in contrast to a range of 29 to 39% (mean 35%) for the East Plant under high load conditions and dirty diffusers and 42-45% after cleaning. In 1987, the East Plant values ranged from 30 to 35% during low load conditions. Variation in these distributions are affected by diffuser fouling and degree of nitrification. As the first pass diffusers foul, the percent of oxygen demand satisfied in that region decreases (the demand moves downstream). When nitrification occurs, it has the effect of attenuating demand up front and spreads it more uniformly down the aeration tank. This affect is discussed by Boon and Chambers (12).

The successful long-term performance of the West Plant basins as contrasted to the East Plant basins (prior to nitrification) strongly implicate plant loading (SRT or F/M) as a critical factor in diffuser fouling. The somewhat higher values of alpha recorded for the East Plant in 1987 (Table 6) than for the West Plant (Table 17) may be associated with the lower loadings encountered in the East Plant in 1987.

Indirect Study of Transfer Efficiency (MMSD

Four months of operational data were compared for the West Plant aeration tanks during two different loading conditions over a four month period. During two of the months, 70% of the total wastewater flow was directed to the West Plant; and during the other two months about 54% of the total wastewater flow went to the West Plant. Total plant loading, SRTs (F/M), and effluent quality were comparable in both pairs of months. Dissolved oxygen and air flows were analyzed on a minute-by-minute basis by the supervisory computer. Averages were automatically determined by compression of these data. The average air flow rates were then adjusted to what they would have been had it been possible to turn them down to an air flow that would achieve the D.O. set point. It was assumed that oxygen uptake rate and αSOTE would remain the same at the lower D.O. set point values. The correction was calculated as:

$$\text{Adjusted Air Flow} = \frac{C^*_\infty - C}{C^*_\infty - C_{SP}} \times \text{Actual air flow}$$

where C^*_∞ = steady state D.O. saturation concentration, mg/L

C = average D.O. concentration measured, mg/L

C_{SP} = set point D.O. concentration, mg/L

Results of this analysis appear as Table 18. As shown, there appears to be a significant difference between efficiency of air usage at the higher versus lower loading conditions. Although the assumptions made here may produce some error in this comparison (e.g., effect of low D.O. set point on downstream alpha, seasonal differences, effect of air temperature, etc.), they cannot account for all of the large differences in gas flow shown in Table 18. These data explain, in part, why SRT (and F/M) alone does not effectively predict oxygen transfer performance as measured by air required per unit of oxygen demand satisfied (the reciprocal of αSOTE by virtue of the general relationship: SOTR = SOUR = αSOTE (gas flow) K under steady-state condition). In this instance, an increase in plant load (measured on the basis of BOD) decreased oxygen transfer performance at the same SRT (F/M). In both series of tests, complete nitrification was occurring. The effect of loading on oxygen transfer performance was likely due to a depression in the overall mean weighted alpha value for the system.

Diffuser Characterization

A test header was installed in Aeration Tank 21 and diffusers were removed on a set schedule as a part of the ASCE/U.S. EPA interplant fouling study. Results of that work can be found in a report by Baillod (3). Table 19 presents a tabulation of data from that study for comparison with field test data.

Diffusers were also removed from the full-scale West Plant on Day 635 during cleaning of Aeration Tanks 19, 20, and 21. Samples of diffusers before and after cleaning were tested. Results of these tests appear in Table 20.

Review of Tables 19 and 20 indicate that after 635 days in service, the diffusers appeared to be somewhat more fouled than those in the tank after 4, 8, and 12 months. Table 19 suggests that fouling was a dynamic phenomenon, producing DWP/BRV ratios between 0.4 to 0.7 after only four months. That ratio changed rather imperceptibly after that time and was representative of those found in the full-scale tank (Table 20). There does, however, appear to be some increase in BRV and DWP in Grid 1 over the 21-month period.

It was interesting to note that BRVs and DWPs did not vary much from grid to grid down the first two aeration tank passes (Tanks 21 and 20, see Table 20). Tank 19 (last pass) appeared to be a little less fouled based on these measurements. Comparison of these data with the East Plant data (Table 8) indicate that the higher loadings generally resulted in substantially higher values of BRV and DWP and lower values of the ratio after only one year of service. Quantities of foulant (mg/cm^2) were similar in the first grid but were significantly lower in the dowstream grids for the West Plant even after 21 months of service.

The distribution of volatile solids in the foulant for the West Plant were not as striking as found in the East Plant. Silica and phosphorus did not increase downstream but calcium, iron, and, perhaps, aluminum appeared to increase in the foulant as one progressed downstream.

High pressure hosing did restore the diffusers but not to "new" conditions. DWP/BRV ratios increased to about 0.7 to 0.8 in Grid 1 and to about .85 in Grid 2. All other grids demonstrated ratios of about 1.0, even though both BRV and DWP ratios were

TABLE 18

PLANT DATA FOR TWO DIFFERENT LOADING PERIODS**

Results For Each Plant For Each Month

			ACTUAL			ADJUSTED FOR D.O. SETPOINT		
	lbs BOD Removed	lbs. O_2 Demand Removed	Air Flow (CFM)	CF/lb BOD Removed	CF/lb O_2 Removed	Air Flow (CFM)	CF/lb BOD Removed	CF/lb. O_2 Removed
PLANT 3								
(69%) April 1986*	11,109	19,345	8,440	1,094	628	7,816	1,013	582
(71%) May 1986	10,554	17,971	7,784	1,062	624	7,008	956	561
(57%) Dec. 1987	8,592	15,310	5,478	918	515	4,350	729	409
(56%) Jan. 1988	8,804	15,937	5,912	967	534	4,740	775	428
PLANT 4								
(69%) April 1986	10,423	18,153	7,608	1,051	603	7,116	983	564
(71%) May 1986	10,554	17,971	7,566	1,032	606	6,932	946	555
(57%) Dec. 1987	8,796	15,674	5,864	960	538	4,188	685	385
(56%) Jan. 1988	8,682	15,716	5,912	980	541	3,974	659	364

AVERAGE FOR BOTH PLANTS FOR DIFFERENT LOADING CONDITIONS

	CF/lb BOD Removed	CF/lb O_2 Demand Removed
Average for 70%, actual	1,060	615
Average for 56%, actual	956	532
Average for 70%, normalized	974	565
Average for 56%, normalized	712	396

Note: F:M averaged approximately 0.12 for each plant in each month
*Percent of flow to West side.
**Data after S. Reusser, MMSD.

TABLE 19

INTERPLANT FOULING STUDY RESULTS

WEST PLANT - TANK 21, GRID 1

Date	Period*	BRV (in. wg)	s/x	DWP(.75) (in. wg)	DWP/BRV	FOULANT Total Solids (mg/cm^2)	FOULANT Percent Volatile (%)	Si	P	Ca (% w/w)	Mg (% w/w)	Al	Fe
1/15/87	4 mo.	12.4	0.32	5.4	.44	8	50	10.3	5.3	16.3	0.9	1.3	4.2
4/26/87	4 mo.	7.7	0.16	5.2	.68	5	42	5.3	4.1	11.9	1.4	0.8	2.7
	8 mo.	9.3	0.25	8.2	.88	8	43	11.1	2.7	9.6	1.2	1.2	2.6
8/23/87	4 mo.+	8.4	0.08	--	--	--	--	--	--	--	--	--	--
	12 mo.	9.3	0.06	6.0	.64	7	52	--	--	--	--	--	--

*Time under aeration
+Diffuser stone broken

TABLE 20

RESULTS OF DIFFUSER CHARACTERIZATION - WEST PLANT

Date	Location*	BRV (in. wg)	s/x	DWP(.75) (in. wg)	$\frac{DWP}{BRV}$	FOULANT Total Solids (mg/cm^2)	Percent Volume (%)	Si	P	Ca	Mg	Al	Fe
										(% w/w)			
06/23/87+	Grid1E, 21	17.1	.20	9.0	.53	16	43	6.7	3.4	7.7	0.9	0.6	1.9
	Grid 1M, 21	15.0	.11	7.9	.53	23	53	11.1	5.3	12.2	1.6	0.8	2.9
	Grid 1W, 21	20.4	.19	9.4	.46	22	41	13.6	4.2	13.1	1.4	1.1	1.7
	Grid 2E, 21	12.4	.12	7.1	.57	9	57	10.8	5.2	12.8	0.9	1.2	3.3
	Grid 2M, 21	20.9	.10	9.6	.46	6	59	9.8	7.5	13.3	0.9	0.8	3.1
	Grid 2W, 21	13.4	.15	8.9	.67	11	51	16.4	5.8	16.9	1.5	1.2	4.5
	Grid 2E, 20	16.1	.29	9.8	.61	Trace 0	~100	15.5	4.8	17.5	1.0	3.3	3.7
	Grid 2M, 20	18.3	.38	10.9	.59	Trace 0	42	16.7	3.5	13.7	1.2	1.4	5.0
	Grid $2M_2$, 20	15.4	.16	8.6	.56	Trace 0	64	13.1	5.7	12.8	0.4	5.5	3.4
	Grid 3W, 19	12.1	.26	8.6	.71								
	Grid 3E, 19	7.2	.10	8.1	1.18								
06/24/87◊	Grid 1W, 21	11.0.	.09	8.6	.78								
	Grid 1E, 21	12.6	.35	8.9	.71								
	Grid 2E, 21	10.0	.09	8.7	.87								
	Grid 2W, 21	10.1	.13	8.5	.84								
	Grid 2E, 20	7.7	.18	7.8	1.00								
	Grid 2W, 20	7.6	.13	7.9	1.00								
	Grid 3W, 19	8.1	.07	8.2	1.00								
	Grid 3E, 19	8.3	.12	8.2	.99								

*Location: Tank number and grid; E - East, W - West, M - Middle location in grid.

+After 635 days of service

◊After hosing.

somewhat below "new" conditions. One reason for this observation may be due to the cleaning problem due to the physical layout of the tanks. All three passes had to be dewatered at the same time. Hosing started at the effluent pass (Tank 19), so that by the time cleaning was attempted in the first pass (Tank 21), the foulant had dried. Hosing was ineffective and brushing was attempted.

Comparison of three-tank off-gas tests suggest that the level of fouling found in these tanks did not appreciably affect αSOTE, at least the effect was imperceptible within the range of day-to-day variability experienced in the testing program. The exception to this might have been the first grid or two in the lead aeration tank, but this effect was short-lived.

Summary

The fine pore ceramic discs installed in the MMSD West Plant have been monitored for 800 days. In that period of time, there has been no perceptible decrease in diffuser performance in the first pass aeration tanks based on αSOTE measurements. The mean first-pass αSOTE values over 800 days was about 11.5%. The mean weighted αSOTE for all three passes ranged from 12.1% to 15.3% based on six three-basin tests conducted in 1987 (Days 630-770). The plant operated at a low loading to insure complete nitrification.

There was substantial variability in αSOTE in the first pass tanks. This variability could be attributed in part to variation in operational parameters such as SRT or F/M. These correlations were weak, however, suggesting that other factors including wastewater characteristics complicated the relationship. This analysis may be further complicated by the apparent relationship between degree of stabilization (in this case complete vs. partial nitrification) and transfer efficiency. Based on one day's data, apparent alpha in the first pass varied by about 32%.

An examination of the diffusers after 635 days of service under low load conditions indicated a rather uniform effect of fouling in the first two passes based on BRV and DWP measurements. The fouling did not produce a perceptible change in αSOTE, however, over the 800-day period of the study. This was, perhaps, due in part to the variability of the measurements, although no trend was estimated by regression techniques.

Cleaning of the diffusers with high pressure hosing did reduce DWP and BRV values but not to "new" conditions. This was due, in part, to the physical constraints on basin dewatering but may also suggest that even though perceptible changes in αSOTE were not seen, some changes were occurring within the diffusers. The long-term impact of these changes could not be determined in this study. A conservative operating strategy would dictate routine cleaning (1 to 2 years) at this facility in order to insure that back pressures would not slowly and, perhaps, irreversibly build up. The experience in the East Plant suggests that occasional steam cleaning or acid cleaning may restore diffusers exposed to high loads to "like new" conditions.

Discussion with MMSD personnel indicated that cleaning will be performed at about five-year intervals using the Milwaukee method (hose-acid-hose) on the first and second passes and hosing only on the third pass. Additional studies will be conducted, however, before this strategy is finalized.

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APPENDIX A

OFF-GAS TEST METHODS

(From Quality Assessment/Quality Control Procedures for cooperative agreement research program with U.S. EPA.)

A8.0 OFF GAS FIELD TEST METHOD

Off-gas methods require the accurate measurement of DO, CO_2, and water vapor in the inlet and discharge gases from a test volume within the aeration tank. The greatest drawbacks to the method have been related to the instrumentation. Two practical problems had to be overcome to make the method more acceptable. Recent advances in the design and fabrication of large lightweight gas collection hoods and in the development of a portable field oxygen sensor which can precisely detect small differences in the partial pressure of oxygen have made this a particularly attractive method.

The Off-gas Analysis Equipment (OAE) used to evaluate the full scale performance of diffused aeration systems consists of:

1. An Off-gas Analyzer with vacuum source
2. Flexible off-gas transmission conduit
3. Off-gas collection hood
4. Liquid phase dissolved oxygen measurement equipment.

A8.01 Offgas Analyzer

The analyzer must have the capabilities to:

1. Measure the rate of offgas collection by means of a flow measuring device having a flow capacity from about 0.5 to 25 SCFM, with an accuracy with ± 0.1 SCFM at the lower end of the scale and ± 0.5 SCFM at the upper end of the scale.

2. Provide an air tight water trap to protect analytical stream piping from entrained moisture.

3. Measure temperature of inlet gas to within ± 2°F.

4. Control temperature differential at oxygen sensor between reference and offgas sample streams within ± 0.5 °F, when air and mixed liquor temperature are within the range of 0 °C to 40 °C.

5. Measure and control vacuum at oxygen sensor for both reference and offgas streams to within ± 0.1 inch water gauge of each other and at a predetermined vacuum between 2 inches and 16 inches water gauge.

6. Measure offgas collection hood pressure to within ± 0.2 inch water guage.

7. Measure suction vacuum downstream of flowmeter to within ± 0.1 inch mercury gauge.

8. Monitor and control flow rate of reference and offgas sample streams between 3 and 10 SCFH and within 0.5 SCFH of one another.

9. Capability to change flow through the analytical circuit between reference and offgas streams and maintain the above requirements within 5 seconds or less.

10. Control humidity of the offgas and reference streams within 0.001 lbs water vapor per lb. bone dry air of one another.

11. Maintain oxygen sensor meter drift of less than 0.05% of reading per minute when the cell temperature change rate is 0.25°F per minute or less.

12. Check meter zero with pure nitrogen to within a meter reading equivalent to 0.1% oxygen or less.

13. Demonstrate linearity of the oxygen sensor by drawing reference air past the sensor at ambient pressure and at approximately 4 inches mercury guage and at constant temperature and maintaining the ratio of absolute pressure ratios to meter output ratios at between 0.994 and 1.006.

14. Oxygen sensor output to be displayed by a meter having readable resolution equivalent to 0.02% oxygen.

15. Means of sampling and ascertaining carbon dioxide concentration of offgas stream to within ± 0.1%.

A8.02 Vacuum Source

The vacuum source must be sized to maintain flows through the conduit and analyzer module of up to 25 SCFM.

A8.03 Conduit

Flexible crush-proof conduit with air tight fittings should be used to convey offgas from the collection hood(s) to the offgas analyzer. The conduit and fittings used must be air tight and have a minimum inside diameter of 1 1/2 inches.

A8.04 Collection Hoods

The hood employed must be constructed so as to be airtight under small positive and negative pressure in the range of -2.0 to 2.0 inch water gauge. The hood must have a minimum length of 8.0 ft and must be equipped with floats and/or ballast to ensure it remains stable at a given sampling location. The hood should have eye bolts or similar fittings at each end to allow for attachment of mooring lines which will be used to reposition and secure the location in the aeration basin. The cross sectional area of the hood at the water surface must be sufficient to allow for proper operation of the OAE for offgas flow rates in the range of 1.0 to 25 SCFM.

A8.05 Liquid Phase D.O. Hardware

A minimum of two liquid phase dissolved oxygen meter and probe systems are to be used to measure residual D.O. at each hood position during the test period. One probe should be suspended at about 3/4 of the diffuser submergence and the other about 1/4 of the submergence. Dissolved oxygen equipment equivalent to the Yellow Springs Instruments Model 54 meter with D.O. probe and waterproof cable should be used. Sufficient cable must be provided to allow placement of the probes immediately adjacont to the hood for each hood position tested. The D.O. probes should be constructed to automatically compensate for temperature and pressure.

A8.06 Test Procedure

The Chronology of the daily test procedure is:

1. Leak test the umbilical hose and analyser module.
2. Calibrate and check gas oxygen sensor for linearity.
3. Calibrate the liquid phase DO measurement probe.
4. Position hood and begin testing.

A8.061 Leak Test Umbilical Hose and Analyzer Module

The umbilical hose and fittings are leak tested by inserting a rubber stopper in the hose connection where it is attached to the hood and connecting the other end to the off gas analyser. Figure A.4 shows a diagram of an off gass analyser manufactured by Ewing Engineering. Open wide valves: OFV-7, OFV-4, MV-4, Roto-4, MV-6, MV-2, MV-1, and OFV-1. Close all other valves and be sure that the vacuum source is not connected to the analyzer. Start the vacuum source and bring the vacuum hose into the vicinity of the vacuum connection on the analyzer until Rota-1 reads 10 inches w.g. Read and record Mano-3 and Rota-4 which should read less than 3 SCFH.

A leak test of the offgas analyzer module itself is conducted to asses the presence and magnitude of leaks into the analytical circuit. This is done by introducing Nitrogen gas into the analytical circuit under a slight positive pressure at the oxygen sensor until equilibrium conditions are obtained relative to the millivolt output from the oxygen sensor. The vacuum source is then activated, with nitrogen gas still flowing in the system, and the analytical circuit operated at the same sample flowrate and vacuum at the oxygen sensor as during normal offgas testing. An unacceptible leak into the system is evidenced by an increased meter output of more than 5 millivolts when nitrogen is flowing past the oxygan sensor under normal operating conditions as compared to nitrogen flowing past the sensor under slight pressure (0-8 in.wg.).

A8.062 Oxygen Sensor Calibration

Linearity of the gas phase oxygen sensor is demonstrated by drawing ambient air past the sensor at normal operating vacuum (4-10 in.wg.), and at approximately a vacuum of 4 in. mercury gauge at constant temperature and sample flow rate. Acceptable meter response to changes in the partial pressure of oxygen is demonstrated when the quotient of the ratios of the absolute pressure to the millivolt output for each of the two conditions is between 0.994 and 1.006.

In equation form:

$$0.9994 \leq \frac{\text{Abs P1/Output 1}}{\text{Abs P2 /Output 2}} \leq 1.006 \qquad (41)$$

Where: Abs P1, Abs P2 = the absolute pressure of ambient air at the oxygen sensor under the operating condition, #1 or #2 (4 to 10 in w.g. or 4 in Hg)

Output 1, Output 2 = is the millivolt output from the oxygen sensor under the operating condition , #1 or #2.

A8.062 Dissolved Oxygen Meter Calibration

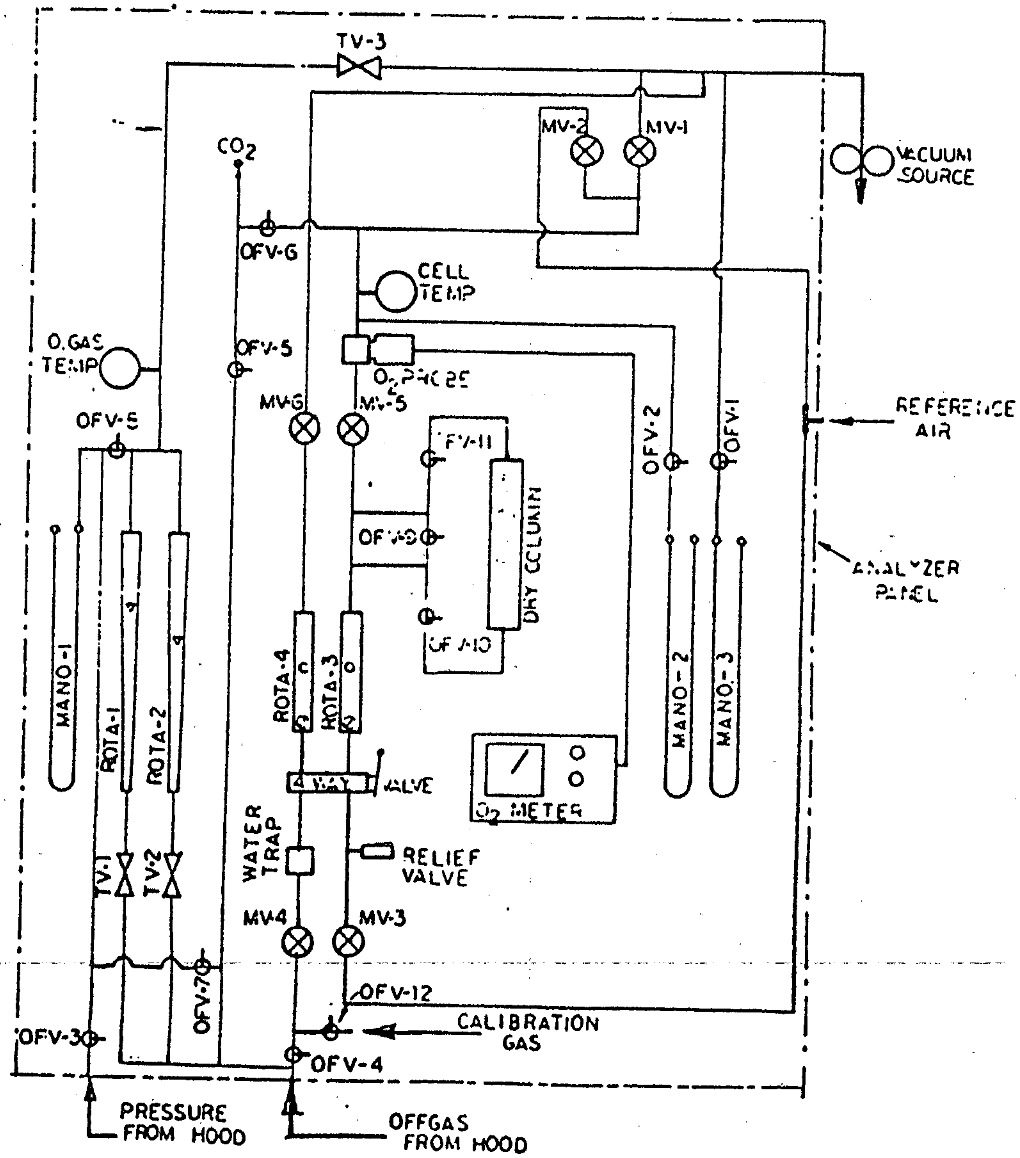
Prior to initiation of testing, the dissolved oxygen equipment used to measure residual D.O. at each hood test position must be zero adjusted and calibrated according to Section A4. Calibration checks of the probe and meter should be conducted on four hour intervals and at the end of the day.

A8.063 Ancillary Offgas Data

In addition to other data obtained during offgas testing, the value of local barometric pressure, P_b, the clearwater saturation value $C^*_{\infty 20}$ for the system under test and the salinity correction factor (β) to be applied to $C^*_{\infty 20}$ must be determined in order to calculate the offgas results.

Local Barometric Pressure: The local uncorrected barometric pressure, P_b, obtained from the nearest airport or weather bureau, taken before and after each day's testing should be used for calculation purposes.

D.O. Saturation Value: It is preferrable that $C^*_{\infty f}$ be calculated from Equation 27 based on a value of $C^*_{\infty 20}$ obtained from clearwater test data at comparable submergence and diffuser disposition. If no comparable clear water data are available, $C^*_{\infty f}$ should be calculated from Equation 28 based



LEGEND

- TV - THROTTLING VALVE
- MV - METERING VALVE
- OFV - ON OFF VALVE
- REFERENCE AIR
- OFFGAS
- BYPASS STREAM
- ANALYTICAL STREAM
- PRESSURE
- CARBON DIOXIDE

FIGURE A4.

UNLESS SPECIFIED, DIMENSIONAL TOLERANCES ARE: FRACTIONAL ± DECIMAL ± ANGULAR ±	
REVISION 4-2-85	EWING ENGINEERING CO. MILWAUKEE
	SCHEMATIC DIAGRAM
	MARK V OFFGAS ANALYZER
	DRAWN DTR SCALE — DATE 7/1/84
	CHKD. APPR. B-

on the surface saturation value corrected for temperature, pressure and a reasonable value of d_e.

<u>Airflow Rate Measurements</u>: The measured airflow rate in cubic feet per minute should be recorded at hourly intervals for each aeration basin that is offgas tested during the offgas test period. Comparison of the measured rate with that calculated from the offgas air rate measurement can be used to judge the adequacy of the offgas sampling plan.

A8.064 <u>Offgas Sampling</u>

The sampling plan should be representative of the tank on an areal basis and should yield collected air rates generally consistent with the applied rates.

Not less than two (2.0) percent of the aeration tank area, represented by the width of the liquid surface times the length of the basin, should be offgas sampled. For tapered grid aeration, not less than two (2.0) percent of each grid should be sampled.

On rectangular tanks not employing grid aeration, e.g. spiral flow, at least ninety percent of the exposed liquid surface shall be offgas sampled at each cross-section tested.

A8.065 <u>Analyzer Operation and Data Requirements</u>

After the components have passed the leak test, the oxygen sensor has passed the calibration criteria, the D.O. meters are calibrated and specified conditions regarding D.O., airflow rate and the like are achieved for the tank to be tested, offgas testing may begin. The test procedure requires that for each offgas determination, there be two reference air (ambient air) determinations, immediately prior to and following the offgas measurements. For a given set of reference and offgas readings, the temperature, absolute pressure, humidity and flow rate of the gas at the oxygen sensor must be the same.

The operating vacuum at the oxygen sensor must be at a predetermined level between 2 inches and 10 inches water gauge. Vacuum at the sensor for both the offgas and reference streams must be controlled to within ± 0.1 inch water gauge of one another. The flow rate of reference and offgas streams must be between 3 and 10 SCFH and within 0.5 SCFH of one another.

The humidity of reference and offgas streams within the analytical circuit must be controlled to within 0.001 lbs. water vapor per lb. bone dry air of one another. The temperature of the reference and offgas sample streams at the oxygen sensor must be controlled within ± 0.5°F of one another.

A minimum of two volumes of offgas, with respect to the volume of gas inside the hood above the liquid surface must pass through the collection system at the existing flux rate prior to recording offgas data from any hood location.

Recorded Data : All data obtained at the test site must be recorded on field data sheets. Data pertaining to offgas testing must be recorded on Offgas Field Data Sheets. Exhibit A.3 is a recommended offgas data sheet. Additional plant data must be recorded on the Overall Plant Data Sheet given in Exhibit A.1.

When possible, the following data should be observed and recorded on one minute intervals: time, station designation, gas stream in circuit-offgas or reference, the rotameter in use measuring flux rate, float height, magnitude of pressure (0 to 2.0 in Hg) beneath the collection hood, operating vacuum at the oxygen sensor, digital output from the gas phase oxygen meter, and the residual D.O. from the probes. A minimum of two readings for each hood position tested must be recorded for inlet gas temperature and gas temperature at the oxygen sensor.

At least three carbon dioxide determinations must be made on offgas for each hood position tested. The mixed liquor temperature shall be observed and recorded at least once per hour.

Sampling Duration : For each hood location tested, it is required that a minimum of five (5) minutes active data acquisition be obtained in accordance with Section A8.065 and data acquisition must continue until apparent equilibrium conditions in terms of offgas flux rate and offgas oxygen concentration are observed.

Stable flux rate conditions may be considered to exist after successive observations over approximately two volume changes, indicate essentially constant hood pressure and freeboard for the same offgas flow setting.

Stability from an oxygen concentration viewpoint is considered to exist when substantially constant meter output is observed and no persistent upward or downward trends are evident. Experience has shown these conditions to be established after about two sample volume changes. The period of observation under stablized conditions should be equal to the time required for one hood volume change or five minutes, which ever is greater.

A8.07 Offgas Calculations

After acquisition, the data recorded on to the Field Data Sheet must be reduced prior to analysis. The reduced data, representing equilibrium conditions for each hood location, should be transferred to a Summary Data Sheet. (See Exhibit A.4).

A8.071 <u>Summary Data Sheet</u>

The Summary Data Sheet should indicate the test site, the aeration system tested, diffuser submergence, date, barometer, $C^*_{\infty 20}$, $C^*_{\infty f}$, beta, mixed liquor suspended solids, total dissolved solids, temperature and applied air rate to the basin tested.

In addition, the following parameters representing equilibrium conditions should be shown for each hood position: time, station designation, mole fraction carbon dioxide in offgas, absolute humidity of offgas and reference air within the analytical circuit, electrical output from oxygen sensor of offgas and reference air, mixed liquor temperature, residual D.O., dissolved oxygen deficit ($C^*_{\infty f} - C$), rotameter used and float height used to determine offgas flux rate. See Exhibit A.4 for a sample of this data sheet.

The parameters to be computed for each hood position include: offgas flux rate, OTE , SOTE, and OTE_{sp20}. From these computations, the overall mean weighted average OTE , SOTE and OTE_{sp20}, can be computed for each device and operating condition tested, using the following generalized expression:

$$\text{Mean Weighted OTE} = \overline{OTE} = \frac{(\text{flux rate x OTE})}{(\text{flux rate})} \qquad (42)$$

Where:

OTE = Oxygen transfer efficiency as a decimal fraction at a particular hood position under existing mixed liquor temperature and field conditions.

OTE_{sp20} = Oxygen transfer efficiency in the process water per mg/l of driving force under standard conditions (barometric pressure of 1.00 atm and temperature of 20.0 °C)

SOTE = Oxygen transfer efficiency in process water at zero D.O., under standard conditions.

$$SOTE = OTE_{sp20} \quad x \quad C^*_{\infty 20} \ \beta$$

Offgas Flux Rate = Rate of offgas evolution per square foot of collection area as measured by offgas rotameters. (scfm/sq.ft.)

$\overline{OTE}$ = Mean weighted OTE based on collected offgas flow rates.

The mean weighted SOTE shall be used to evaluate the gas phase oxygen transfer efficiency of the system under study.

A8.072 Steady State Data

The steady state values of operating residual D.O., and electrical meter output from the oxygen sensor for offgas and reference streams shall be determined from the field data sheets by computing the average values of these data over the entire observation period for each hood location. In the case of carbon dioxide, the reproducible value obtained from multiple analyses shall be used.

Steady state offgas flux rates are determined by the offgas operation in the field. Typically the last flux readings represent the steady state reading for the period, since it may take several adjustments to stabilize hood pressure.

A8.073 Calculations

Offgas flux rates must be determined for each test station using steady state hood pressure and rotameter conditions in combination with the offgas hood collection area. The flux rate in standard cubic feet per minute per square foot (scfm/sq.ft.), is obtained by determining flow conditions at 68°F, 36% relative humidity, and 29.92 inch Mercury absolute pressure, and dividing by the hood area in square feet.

The field oxygen transfer efficiency, OTE , is determined by Equations 19, 20, and 21. The specific oxygen transfer efficiency per unit of driving force is determined by correcting the field oxygen transfer efficiency to a unit driving force and 20 °C,

$$OTE_{sp20} = (OTE \ / (C^{*}_{\infty f} - C)) \times 1.024^{(20-T)} \qquad (43)$$

Where:

T = Mixed liquor temperature, oC.

$C^{*}_{\infty f}$ = Saturated D.O. value under field test conditions of temperature, barometer and prevailing value of beta.

Remaining terms - as previously described.

EXHIBIT A.3: OFFGAS FIELD DATA SHEET

Test Site...

Test Date.................. Tank.................... Air Rate, scfm.........

Diffuser (type and no.)...........................Tank Volume, gal...........

Water Temperature °C......... Local Barometer, mm Hg.......... TDS mg/l......

Test Conducted by...

Time	Sta	Rot No.	Rot Fl.Ht mm	Hood Pres in	Rot T °C	Rot Pres in	Cell Pres. in	Sensor Out. mv	Cell T °C	DO mg/l	CO_2 %	Comm.
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EXHIBIT A.4. SUMMARY DATA SHEET 1 EQUILIBRIUM CONDITIONS

Test Site.. Test Date................. Aeration Tank........................ Aeration System... Submergence.........

Tank Volume, gal.............. Applied Air Rate, scfm................ Liquid Flow Rate During Test: Wastewater.......... Recirculation .... Total.......... Tank Ret. Time, hr.............

MLSS, mg/l.................... TDS, mg/l.............. Estimated Load During Test: lb.BOD/lb.MLVSS.Day.............. Estimated Actual Sludge Age, days........... Test Conducted by..............

Local Barometer, mm Hg.......... Local Air Temp. .... $C^*_{\infty 20}$, mg/l........... Source of $C^*_{\infty 20}$ Value................................ $C^*_{\infty f}$ Value......... Source of $C^*_{\infty f}$ Value.......... Beta......

Comments:

Clock Time	Sta.	Mole Fract CO_2 F_{CO2}	Off Gas Hum. g/g H_{og}	Ref Air Hum. g/g H_R	Sensor Output Off Gas mv K_{og}	Sensor Output Ref air mv K_R	Mix.Liq Temp °C	D.O. mg/l C	Deficit mg/l $C^*_{\infty f} - C$	Rotam 1 Float Ht	Rotam 2 Float Ht	Field OTE_{Tf} dec	Specific OTE_{sp20} dec	O.G.Flux Rate scfm/sf	Station OTE_{20} dec	Ave Field OTE_{Tf} dec	Ave Specific OTE_{sp20} dec	Ave SOTE x alpha dec	Clean SOTE dec	Alpha
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APPENDIX B

DIFFUSER CHARACTERIZATION TEST METHODS

(From QA/QC Procedures for cooperative agreement with U.S. EPA.)

A11.0 DIFFUSER CHARACTERIZATION

A11.01 Foulant Analysis

An important aspect of the characterization of fouled fine bubble diffusers is the analysis of the nature of the foulant on the diffuser. Foulant analysis provides insights as it pertains to the mechanism of fouling and can aid in the selection of diffuser cleaning techniques.

Foulant analysis consists of scraping the foulant off the surface and analyzing for the weight of dry solids per unit area, volatile and non-volatile content, acid solubility and elemental composition of the folulant by energy dispersive spetroscopy or inductively coupled plasma. The procedure for foulant analysis is:

1. Specify a certain area on the surface of a diffuser disc.
2. Scrape the materials off the surface, divide and put them into two vials.
3. Place each vial's contents in a tared evaporation dish.
4. Measure the wet weight.
5. Dry at 105°C for > 1 hour (To constant weight).
6. Cool, dessicate and weigh for total solids.
7. Put the dishes into furnace, firing them at 550°C for 20 minutes.
8. Cool, dessicate and weigh the dishes for fixed solids.
9. Take one dish content for metallic ion analysis. Place in a vial.
10. Add approximately 10 ml of 14% HCl to the other dish and stir gently until the formation of gas bubbles ceases.
11. Centrifuge the solution at 20,000 rpm for 15 minutes. Decant the upper portion, add deionized water into the tube centrifuge again and decant. Repeat once more for a total of three decants.
12. Repeat the steps 5, 6, and 9 using the centrifuged solids. Compare the results with those of the non-acidified foulant.

A11.02 Bubble Release Vacuum

The bubble release vacuum, BRV, test provides a means of determining the effective pore diameter at any point on the surface of a ceramic element relative to other point(s) on its surface. This test procedure is useful as a tool to assess the uniformity of pores on the surface of clean, as well as, fouled conditions.

The bubble release vacuum, as indicated by the name, is a measure of the vacuum in inches of water gauge, required to emit bubbles from a localized point on the surface of a thoroughly wetted porous diffuser element. This is accomplished by applying a vacuum to a small area on the working surface of a wetted diffuser, and measuring the differential pressure when bubbles are released from the diffuser at the specified flux rate at the point in question.

A large number of points are sampled to obtain a distribution of bubble release pressures. Typical test points for a Norton dome are shown in Figure A.5.

The test apparatus consists of a probe, manometer, vacuum source, and rotameter as shown in Figure A.6. The manometer is filled with either water or mercury depending upon foulant buildup. Water is fine for clean and lightly fouled diffusers. A switch to mercury is required when BRV pressures surpassed the capacity of the water-filled manometer.

The probe to be used in this study is shown in Figure A.6. It has interchangeable tips for testing vertical and horizontal surfaces. Test points 1, 6, 7, and 12 require the vertical surface tip while other points require the horizontal surface tip.

The dome minimum flow rate is normally 0.5 scfm. BRV flow rates are kept under this so diffuser foulant will not be pulled off the stone. This translates to a flow rate of 0.9 ml/sec for the 1.13 cm^2 probe. A method for calibrating flow rate is shown in Figure A.7. With an in-line rotameter, flow calibration is done just once to check the rotameter calibration curve.

The recommended practive for BRV testing is listed below:

1. If the diffuser is new, immerse it in tap water until wetted. Remove from water just prior to test and let drain by gravity for not more than 30 minutes. Keep diffuser in a horizontal plain while draining. Do not soak fouled diffusers.

2. Set BRV flow rate.

3. Apply probe to BRV test location. The water surface will rise in the probe while bubbles are released at the diffuser surface. If the water level becomes too high, discard excess water by a quick lateral and upward movement of the probe. If water level is too low, apply additional water onto the diffuser adjacent to the probe. This is especially useful when testing fouled diffusers.

4. Equilibruim has been reached when the rate of rise of water in the probe equals the rate of rise in the manometer (inches water gauge). If time to reach equilibrium is excessive, it may be reduced by operating the by-pass valve momentarily. The flux rate increases dramatically when the by-pass valve is open. The large suction force will pull foulant off a dirty diffuser. Because the loss of foulant may effect test results, the by-pass valve should be used judiciously.

5. At equilibrium, read and record the manometer readidng and height of water in the probe. BRV equals the manometer reading (corrected to inches water gauge if using mercury) less height of water in the probe.

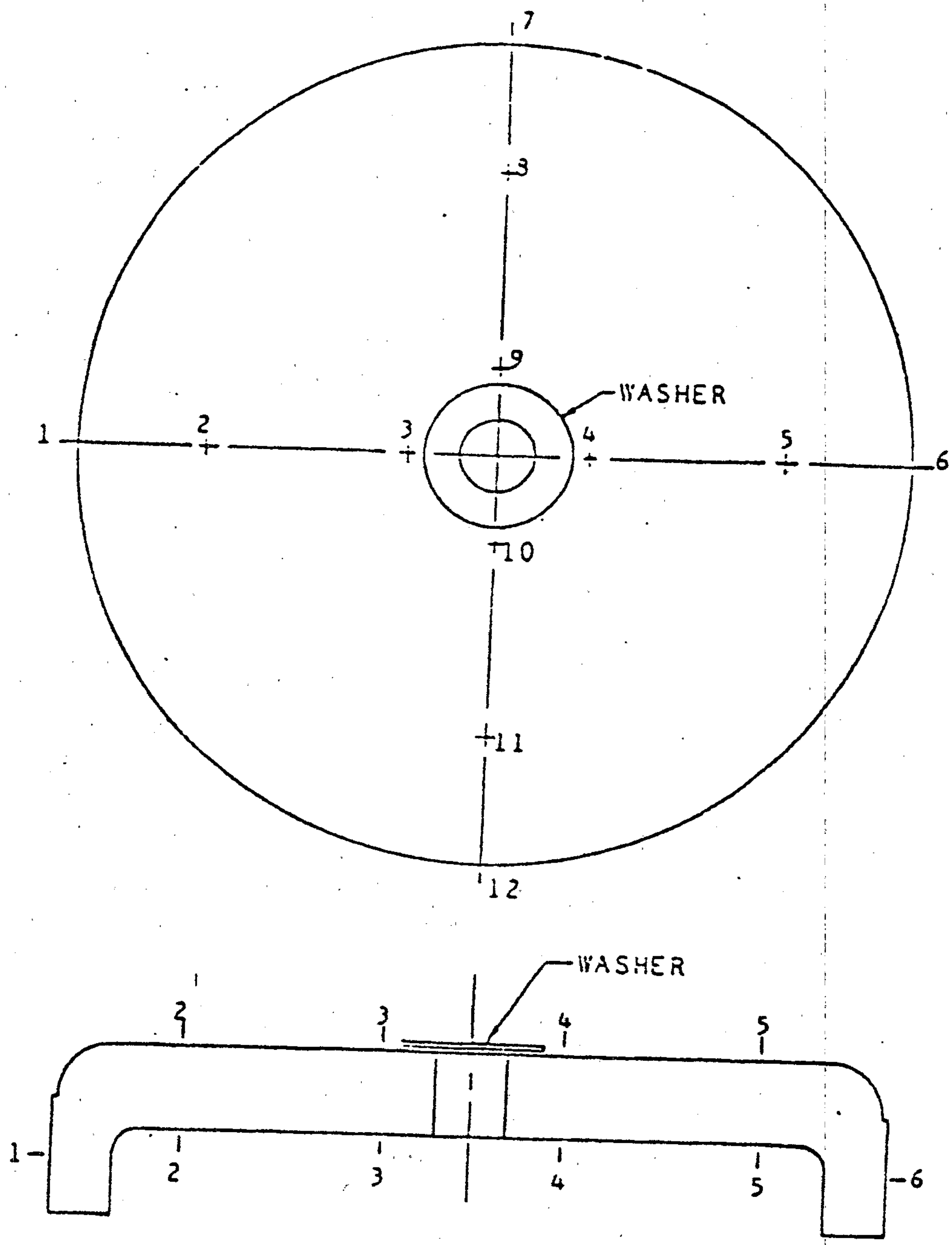


Figure A5. BRV Test Points - Norton Dome.

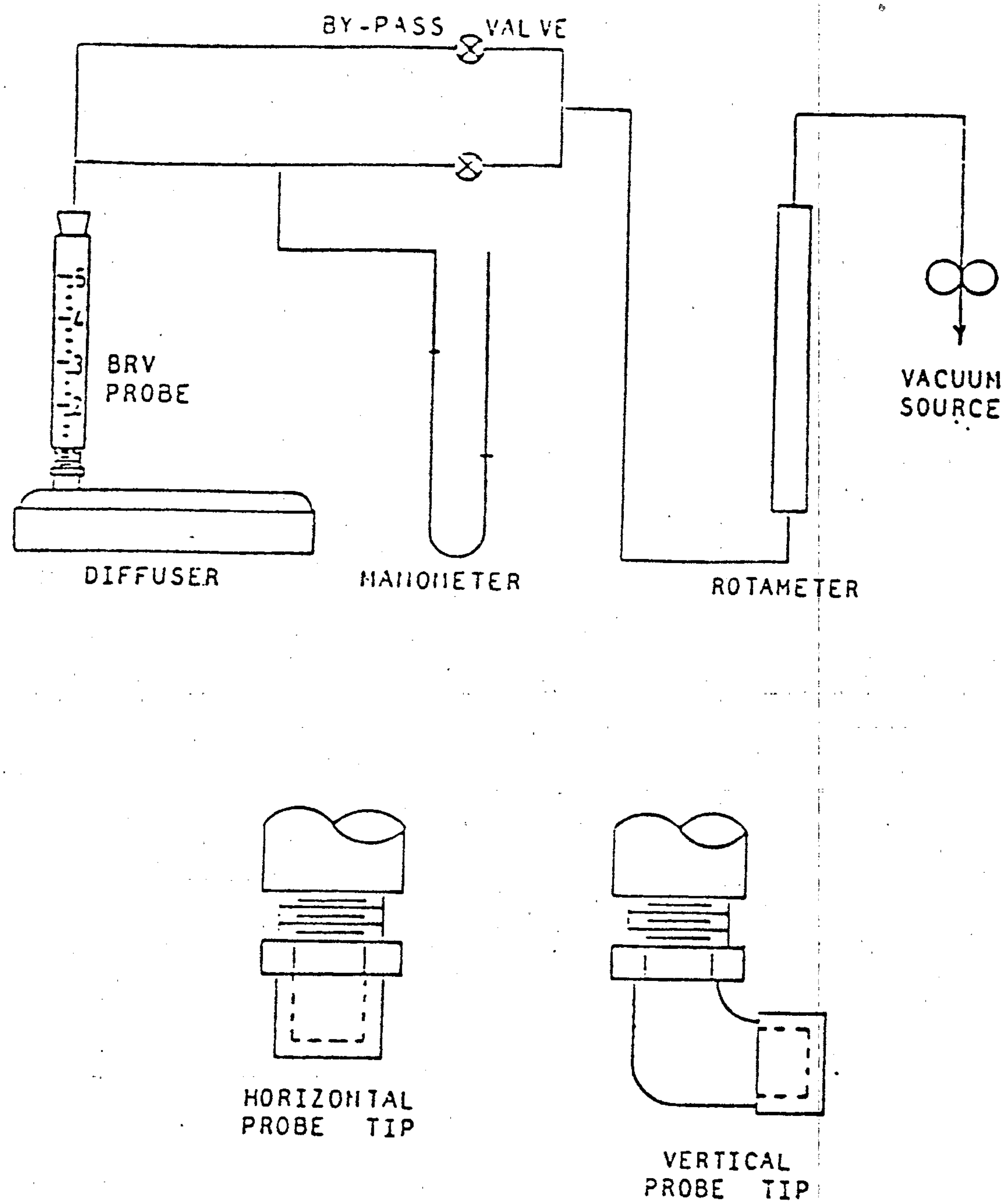
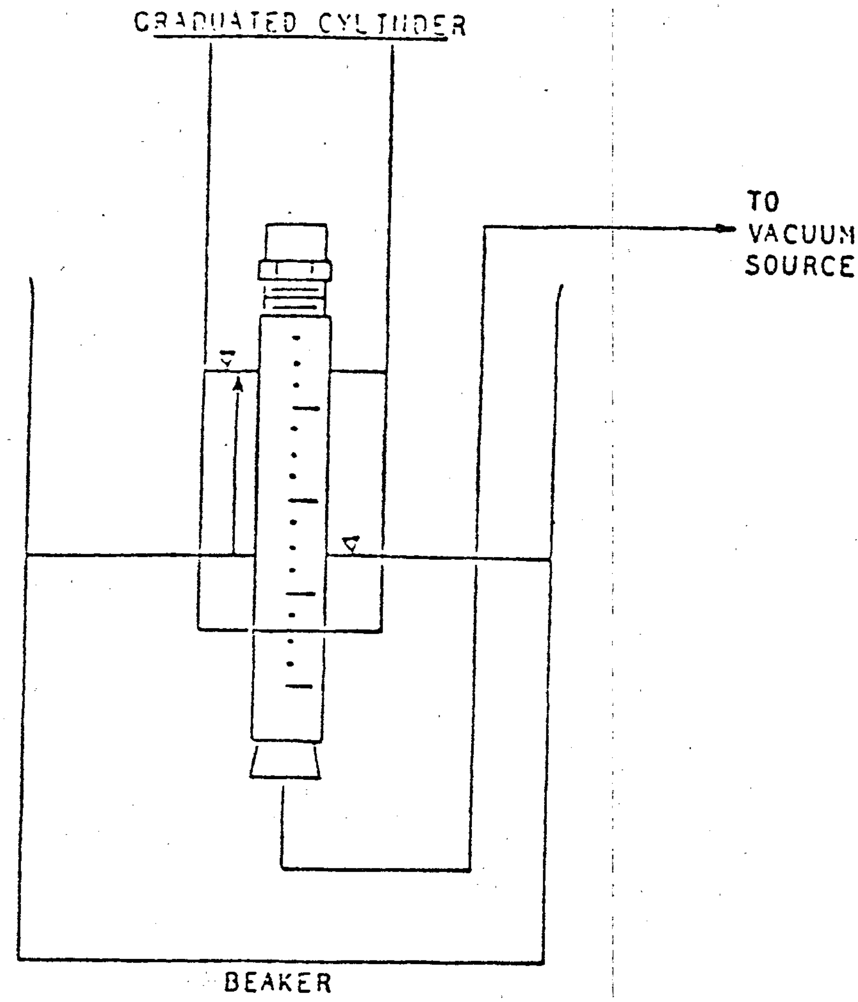


Figure A6. BRV Apparatus.



Measure rise in water column (↑) with time.

Figure A7. BRV Flow Calibration.

6. Repeat steps 3 through 5 for all test locations.

A11.03 Dynamic Wet Pressure

The dynamic wet pressure, DWP, is the pressure differential across the diffusion element alone when operating in a submerged condition, and is expressed in inches of water gauge.

In the dynamic wet pressure test, most of the pressure differential is due to the force or pressure required to form bubbles against the force of surface tension and only a small fraction of the total pressure gradient is required to overcome frictional resistance.

In situ DWP is measured in the aeration basin as indicated in Figure A.8. These measurements are normally made two or three times per week. Comparison of the in-situ DWP to the clean DWP as measured in the laboratory will indicate the degree of fouling. In making this comparison, correction should be made for possible differences in air flow.

DWP and BRV test both measure bubble release pressure. DWP measures it for the whole diffuser while BRV gives a distribution of pressure. For a new stone, the average DWP/BRV ratio is close to 1.0. As a stone fouls, the average BRV for the 12 points tested on the top surface becomes greater than DWP. The average DWP/BRV ratio becomes less than 1.0.

The equipment required for measuring DWP in the lab includes an air source, rotameter, in-line mercury manometer, thermometer, diffuser plenum with standard orifice, water-filled manometer and aquarium. The test set-up looks very much like Figure A.8 without manometer A and the bubbler. The water-filled manometer (manometer B in Figure A.8) is tapped into the plenum at one end and open to atmosphere at the other end. The water in the aquarium is high enough so the diffuser was covered with water.

Laboratory Measurement of DWP

1. The aquarium should be filled with tap water so there will be several inches of water over the diffuser. If this is done the day before testing, the water will warm to room temperature.

2. New diffusers should be wetted the same as for the BRV test. Do not soak fouled diffusers.

3. Place diffuser securely in plenum.

4. Hold plenum over aquarium and turn air on. This allows water entrained in the diffuser to drain into the tank and not on the floor. If the diffuser is fouled, do not turn air flow any higher than its operating air flow rate.

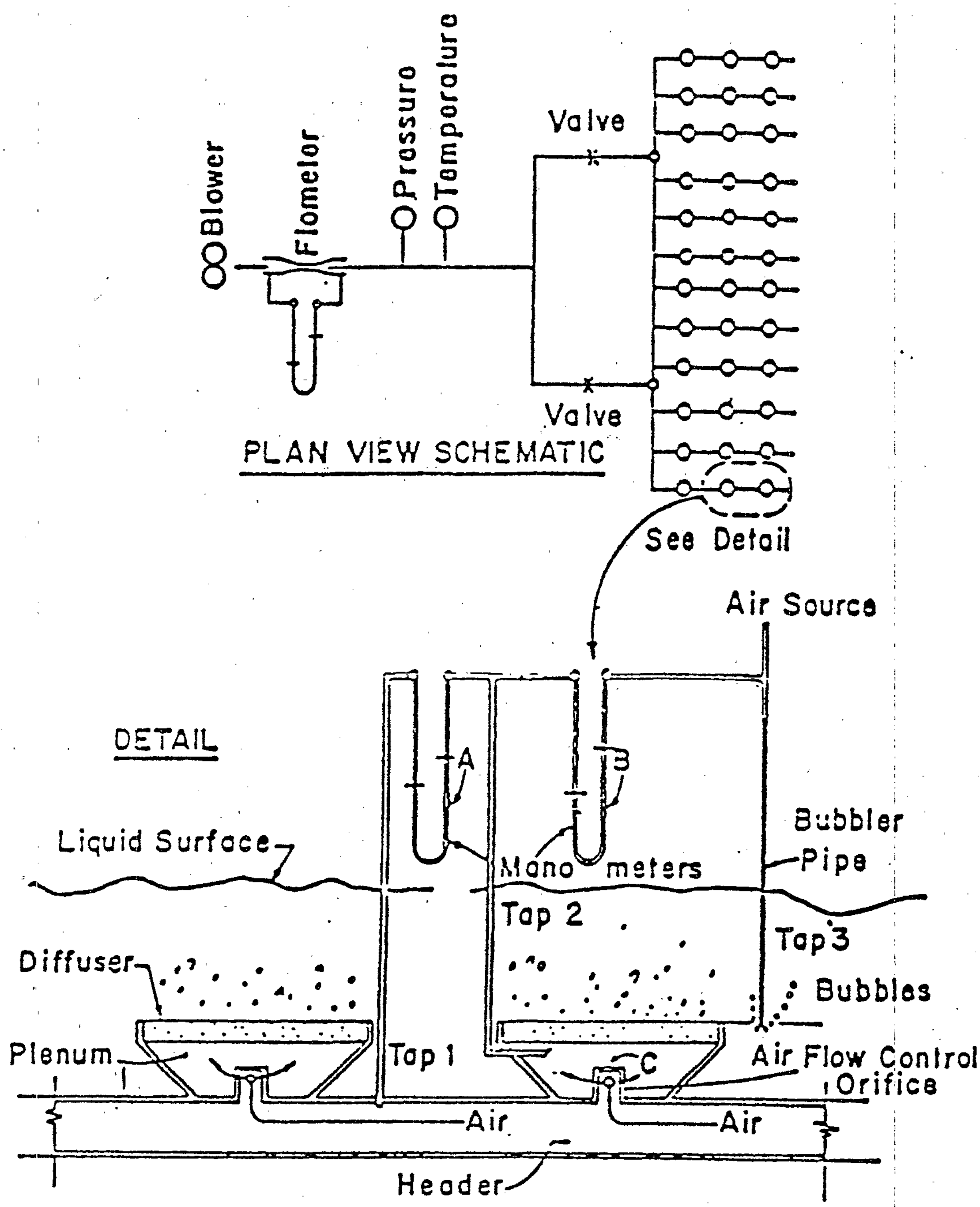


Figure A8. Measurement of Air Line and Diffuser Pressure.

5. Place plenum in aquarium. Adjust air flow to minimum suggested rate (0.5 scfm/dome). Visually inspect the flow profile. If the diffuser is not mounted correctly, coarse bubbling will be evident. If this is the case, take plenum out of the aquarium and reseat the diffuser.

6. Adjust air flow to maxium allowable rate for the test being performed. Let equilibrate for several minutes. This allows time for excess water to be driven out of stone. When testing fouled diffusers, do not exceed the operating air flow rate.

7. Perform a DWP profile. This is done by checking DWP at three or more air flows. Typical air flows are 2, 4, 6, and 8 scfm/ft2. A bucket catch may be performed to check air flow rate. In line pressure and temperature readings are taken so air flow rates can be translated to standard conditions.

8. After the last DWP reading, turn the air flow to almost zero. Measure the static head over the diffuser. The static head is subtracted from DWP manometer readings to give true DWP readings.

9. Correct air flow data to standard conditions. Regress DWP (y) on air flow (x). The correlation coefficient should be close to 1.0.

A11.04 Gas Flow Profile Test

The gas flow profile test uses quantitative techniques to evaluate the uniformity of air release across the surface of ceramic diffusers, while operating, rather than appraising uniformity by visual means. This is accomplished by testing the element at an air rate which is approximately equal to 2 scfm/sq. ft., or at the recommended design rate, with anywhere from 2-8 inches of water over it.

The rate of air release from selected areas is measured by displacing water from an inverted container and recording the rate of displacement of discharge, a flux rate, expressed as scfm/ sq.ft. or other convenient units, can be calculated. By combining the container area and the rate of air with one another, a quantitative measure or graphical reprresentation of the profile can be generated. By comparing the flux rate of the selected area readings

Flux rate is measured by displacement by the rising gas stream of water from a vessel inverted over the area of diffuser to be characterized. The vessel must first be filled with water, covered and deftly inverted so that the mouth of the vessel is just submerged. Captured gas volume is measured over a time of a few seconds taking care so that the captured volume is recorded at atmospheric pressure, i.e. equal water surface levels inside and outside of the inverted vessel. The flow rate is determined by dividing the captured volume by the time interval. The flux rate is defined as flow rate divided by the area of the capture vessel. A flow profile for a typical diffuser requires flow measurements on each of three concentric circles as shown in Figure A.9. Flow rates for the annular areas are determined by difference.

These measurements are made by using three vessels, each with a different surface capture area. The large, 13.5 liter vessel captures the entire flow. The two liter vessel captures all but the periphery flow, whereas the 1000 ml graduated cylinder captures the flow around the washer. By subtraction, flux rates are obtained for the outer, middle and inner areas of the diffuser. These flux rates are then compared to the average flux rate for the diffuser.

The combination of DWP, BRV, and flow profile tests applied to new diffusers and at various stages in their operating history, provides a very useful diagnostic tool in evaluating the rate, the nature and the effect of fouling, be it organic or inorganic, on fine bubble porous diffusion elements. It is also effective, if judiciously applied, in appraising the effectiveness of various cleaning procedures.

A11.05 Specific Permeability

The manufacturers of ceramic diffusers have used and are familiar with the permeability test. It has served as a quality control procedure to assure that the units sent to a jobsite are similar with respect to their average farictional resistance to flow, when dry, to within some specified limits. This was especially important in many older plants where several plates were installed into a single plenum without individual flow balancing means toward the objective of improved uniformity of air flow among the units when in operation.

The test generally consists of sealing the ceramic unit in a test fixture substantially as it is sealed, in an actual aeration tank and then passing sufficient air through the dry element to produce a pressure differential of 2.0 inches water gauge. The permeability is reported as the air rate required to produce this differential. In the U.S., the air rate is in SCFM (standard cubic feet per minute) where a standard cubic foot of air is considered to occupy 1.0 cubic foot of volume at one atmosphere, 70°F, and 36% relative humidity. Historically, the test was carried out on ceramic plates 12 inches x 12 inches x 1 inch thick.

In the way of an example, if we ran a permeability test on such a ceramic plate, we might find it took 25 SCFM to produce a 2.0 in. wg. differential pressure. In this case, the permeability rating would be 25. A plate of identical material, but half as thick, would be expected to have a permeability of 50 instead of 25, since the flow paths through the ceramic would be about half as long and offering correspondingly less frictional resistance. Had the element been 1.0 in. thick and had an area of 72 sq. in. instead of 144 sq. in., the permeability would be approximately 12.5, since there would have been only about half the area of the first case.

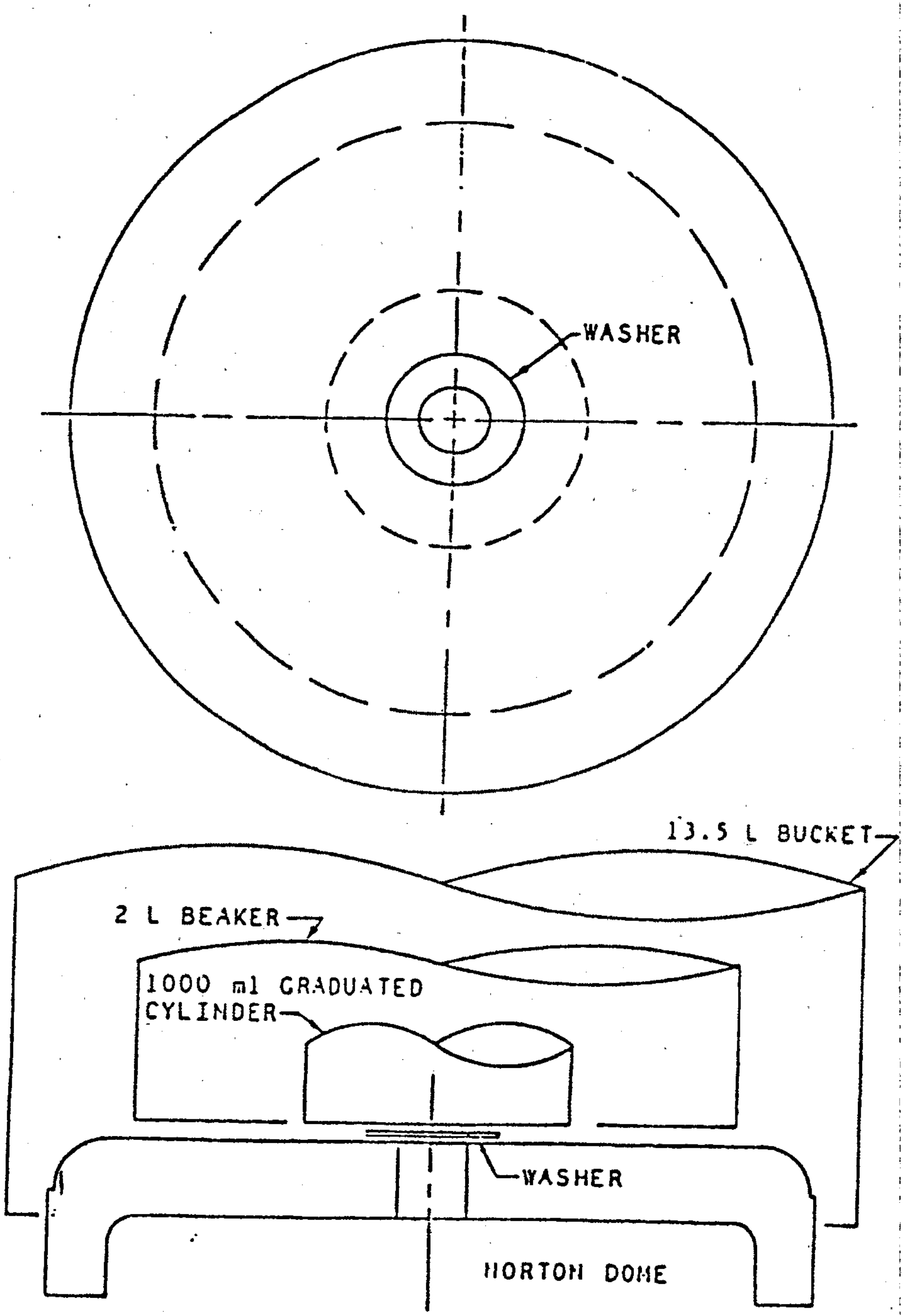


Figure A9. Flow Profile.

Even though these elements were made in identical ways with identical materials, the permeabilities of the three vary from 12.5 to 50 . Thus, using permeability to compare ceramic elements of different shape, thickness, materials of construction and the like, is not meaningful and has been a confusing factor in the engineering community.

In an effort to employ permeability test results as a measure of resistance characteristics of the material, we adopted the term "specific permeability" which is the equivalent amount of air at standard conditions to produce 2.0 in. differential pressure across the dry element if the element were 1.0 sq. ft. in area (12 in. x 12 in.) and 1.0 in. thick.

An approximate expression to convert the permeability of any porous structure to specific permeability is as follows:

$$S.P. = P \times (A/t)$$

Where:
- S.P. = specific permeability, SCFM
- P = permeability of the element itself, SCFM
- A = area of element, sq. ft., when made to hypothetically conform to a flat surface
- t = mean weighted thickness of the element, inches.

A12.0 DIFFUSER CLEANING METHODS IN FIELD

A12.01 Low Pressure Hosing

This method is frequently used in conjunction with other methods and consists of hosing at a distance of 2 to 24 feet using a low pressure nozzle at 30 to 70 psi. The hosing period should continue until the readily removable foulant has been washed away. This time is generally on the order of 10 seconds but can vary from five seconds to one minute depending on the resistance of the foulant, pressure and distance. The air should be on during the hosing operation with each diffuser operating at roughly 1 cfm.

A12.02 High Pressure Hosing

This method consists of hosing at a distance of about two feet using a high pressure nozzle at 80 to 100 psi. The hosing period should continue until the readily removable foulant has been washed away. This time is generally on the order of 15 seconds but can vary from about 5 seconds to one minute depending on the resistance of the foulant and pressure. Each diffuser should be operating at an air rate of approximately 1 cfm during the hosing operation.

A12.03 Milwaukee Method: (Acid Plus Hosing)

This method has been used at the Milwaukee wastewater treatment plants for many years. A high pressure water jet is applied to the diffuser surface followed by acid spraying and hosing. The rationale is to first hose off the easily removable foulant so that the applied acid can solubilize the inorganic precipitate inside the pores of the diffuser. A second hosing is then performed to remove the solubilized foulant and residual acid. The materials needed for this method are: high or low pressure water hosing equipment, acid spray applicator (Hudson Acid Sprayer or equivalent) and 50% by volume of 18 Baumeʃ inhibited muriatic acid. This is equivalent to a 14% HCl solution.

The procedure to be followed is:

1. Clean diffuser by high pressure or low pressure hosing with the air on at approximately 1 cfm per diffuser.

2. Apply approximately 50 ml of 14% HCl to the surface of the diffuser using the spray applicator. No air should be applied to the diffuser during the acid application period.

3. Let acid remain on the diffuser for 30 minutes. Turn air on 5 minutes.

4. Hose the diffuser again for one minute or so to remove all the residual acid.

A12.04 Steam Cleaning

This method has been used at the Madison treatment plant for several years. The principle of the method is to use the scrubbing and heating power of a steam jet to remove the material attached on the diffuser's surface. The high temperature of the steam may lessen the ability of the foulant to attach to the diffuser surface. Equipment required for this test includes a steam generator and nozzle. The procedure to be followed is:

1. Turn on the steam generator and let it run for several minutes to reach constant temperature (200 C).

2. Apply the steam jet to the diffuser surface from a distance of two feet at a minimum pressure of 150 psig until all the foulant has been visibly removed. The diffuser air should be on during this operation.

3. Let the diffuser cool to ambient temperature.

A12.05 Firing Method (Kilning)

This method is widely used in England. The diffuser stones are removed, placed in a kiln, fired to remove foulant material, and gradually cooled. A typical British furnace is capable of firing 650 domes per 24 hour cycle. The procedure to be followed is:

1. Load the diffuser stones into the furnace and heat the furnace to 950°C over a period of 10 hours.

2. Hold the temperature at 950-1000 °C (1742-1832°F) for 4 hours.

3. Cool down over 10 hours.

A12.06 Gas Cleaning

Gas Cleaning refers to a method whereby a fine bubble diffusion system is cleaned by injecting a small percentage of HCl gas into the air supply line leading to the diffusers. The HCl gas solubilizes deposits of foulant and restores the diffuser to its clean condition. The gas cleaning system to be evaluated in this study is a proprietary system marketed by SANITAIRE - Water Pollution Control Corporation under U.S. Patent 4,382,867. The test installations will be operating under license from SANITAIRE and the gas cleaning operations will be carried out following the recommendations of SANITAIRE personnel.

Gas cleaning test results to date have indicated that a minimum gas concentration is required for effective periodic cleaning. Above the minimum concentration, the amount of gas required to clean inorganic deposits is substantially constant. However, the time required to clean is less at higher concentrations. Mole ratios of HCl gas in air between 0.0000818 and 0.0309 have been used successfully in gas cleaning. Based on experience, it appears that about 0.25 lb of HCl gas is required per diffuser.

In operation, the need to apply the gas cleaning treatment is judged by monitoring the dynamic wet pressure drop across each of four diffusers installed on a removable header. The onset of fouling is indicated by an increase in the dynamic wet pressure loss across the diffuser at a constant air rate. The pressure increase before initiating cleaning would be specified on a case by case basis. If the dynamic wet pressure is allowed to rise to a level where the desired combined system pressure during cleaning exceeds the blower capability, one available option is partial dewatering of the tank being cleaned.

During the cleaning cycle, it is important to get uniform distribution of gas both between diffusers and throughout the area of the individual element. The orifice system is more effective in promoting uniform distribution of air at higher air rates. Because of this, it is recommended that cleaning be done at a higher air rate than normally fed, e.g. about 6 to 8 scfm/sq. ft. of diffuser, or 2.5 to 3 scfm/diffuser. The increased air rate also increases the pressure differential across the diffuser element thus distributing cleaning gas to partially clogged pores.

Only the grid being cleaned needs to have the increased air rate. This can be done by operating an extra blower for a short period of time or throttling of air to the rest of the tanks, or dropping the water level in the tank being cleaned. If the water level is reduced a few feet, the normal system pressure would be adequate to provide the increased rate of air to the tank being cleaned. This may be the most economical as no more power is required at the blowers.