FINE PORE DIFFUSER CASE HISTORY FOR FRANKENMUTH, MICHIGAN

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DISCLAIMER

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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

Frankenmuth is a community of 4,000 people in central Michigan. About 25-30% of the flow and 50-70% of the BOD load to the wastewater treatment plant are contributed by a brewery. In January 1986, conversion from a stainless steel broad band coarse bubble diffuser system to fine pore aeration was completed in all of the six existing aeration tanks.

The Frankenmuth retrofit was designed with *in-situ* wastewater oxygen transfer efficiencies (OTE) at average air flow and peak flow based on off-gas tests at other locations. These values were adjusted to account for the significant high strength industrial component of the influent wastewater. The design OTE at 2 scfm/diffuser was only two-thirds that used at 1 scfm/diffuser (αSOTEs of 16.9% and 11.0%, respectively). In spite of lower than expected OTEs, the Frankenmuth retrofit to fine pore diffusers was an economic success. The actual capital cost of installation was slightly more than estimated during the evaluation period, but the projected energy savings appeared to be slightly greater as well.

OTEs were measured by off-gas testing on selected aeration cells on 13 different days between April 1987 and May 1988. Some of the off-gas tests were carried out on consecutive days before and after gas cleaning of the diffusers. No relationship could be developed between gas cleaning and OTE.

The rate of diffuser plugging and fouling at Frankenmuth is significant. The plant staff has employed different methods of determining when cleaning should be done since the fine pore equipment was installed. These have included cleaning when the dynamic wet pressure (DWP) reached 16-18 in. w.g., cleaning with small doses of gas every 2 weeks, and operating at higher air rates than required for oxygen demand to hopefully inhibit biological growth on the diffusers. The first two methods employed in 1986 and 1987 appear to have been successful in maintaining acceptable levels of DWP and system performance. Operating at elevated air flows (January through June 1988) was probably successful in limiting DWP but resulted in a significant increase in system operating cost. The hydrogen chloride gas used was approximately one-third of a pound per diffuser per year during the evaluation state.

The condition of the fine pore diffusers was monitored over the long term by measuring DWP and pressure drop across air distribution orifices in test diffuser assemblies. Four diffusers were placed in one of the six aeration cells, and measurements were obtained at 1 to 2 week intervals. No relationship could be developed between DWP and OTE. However, gas cleaning was effective in controlling diffuser DWP.

This report was submitted in partial fulfillment of Cooperative Agreement No. CR812167 by the American Society of Civil Engineers under subcontract to McNamee, Porter & Seeley, Inc. under the partial sponsorship of the U.S. Environmental Protection Agency. The work reported herein was conducted over the period of 1986-1988.

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SUMMARY

The Frankenmuth retrofit was designed with in waste oxygen transfer efficiencies at average air flow and peak flow based on off-gas tests at other locations. These values were adjusted to account for the significant high strength industrial component of the influent wastewater. The design OTE at 2 scfm/diffuser was only two-thirds that used at 1 scfm/diffuser (11.0% and 16.9% alpha SOTE, respectively).

In spite of the lower than expected OTE's, the Frankenmuth retrofit to fine pore diffusers was an economic success. The actual capital cost of installation was slightly more than estimated during the evaluation period, but the projected energy savings appeared to be slightly greater as well. This results from over-estimating the efficiency of both the coarse bubble and fine pore diffusers during the pre-design evaluation.

The rate of diffuser plugging and fouling at Frankenmuth is significant. The gas cleaning procedure has been practiced at varying intervals as shown in Table 4. The hydrogen chloride gas used was estimated to be approximately one pound per diffuser per year during the evaluation stage. Actual gas use has averaged about one-third that amount.

The plant staff has employed different methods of determining when cleaning should be done since the fine pore equipment was installed. These have included cleaning when DWP reaches 16-18 w.g., cleaning with small doses of gas every two weeks, and operating at higher air rates than required for oxygen demand to hopefully inhibit biological growth on the diffusers. The first two methods employed in 1986 and 1987 appear to have been successful in maintaining acceptable levels of DWP and system performance. Operating at elevated air flows (January through June 1988) was probably successful in limiting DWP, but resulted in a significant increase in system operating cost as shown in Table 5.

CONCLUSIONS

- The off-gas test data clearly shows the effect of changing "alpha" values from inlet end to outlet end of a plug flow aeration tank. Comparing alpha SOTE data for cells 5 and 6 (which always operated in series) found in Tables 7a and 7b shows increases in alpha SOTE ranging from 15% to 103%, for operation at reasonably similar conditions.

- No relationship could be developed between gas cleaning and oxygen transfer efficiency at Frankenmuth.

- No relationship could be developed between dynamic wet pressure (pressure loss across the diffusers) and oxygen transfer efficiency at Frankenmuth.

- Gas cleaning is effective in controlling the diffuser dynamic wet pressure at Frankenmuth.

- Operation at higher than necessary air flows to control DWP does not appear to have been economically successful for Frankenmuth.

- Ceramic fine pore diffusers are economically viable for plants with relatively high plugging/fouling potential.

SYSTEM DESCRIPTION AND PERFORMANCE

Frankenmuth is a central Michigan community of approximately 4,000 people. It is a well known tourist attraction in the State featuring German decor, gift shops and candy stores, and two large restaurants featuring family-style chicken dinners which feed in excess of 10,000 people daily. Frankenmuth is also the home of a G. Heileman Brewery which produces Carling Black Label, and other Heileman products. The City Wastewater Treatment Plant processes all the wastes from the City, and from the brewery as well.

During the study on aerator performance, approximately 25-30% of the flow and 50-70% of the plant influent BOD came from the brewery. The restaurants probably contribute significantly to the plant loading, but there are no long term records to quantify the effect. In the future, brewery waste will be pretreated using an upflow anaerobic sludge blanket system.

The process flow scheme on the plant site consists of a manual bar screen, raw sewage pumping, a square aerated grit tank, two rectangular primary settling tanks, aeration tanks, two fifty-foot diameter final settling tanks, and disinfection with chlorine. Primary and waste activated sludges are combined and anaerobically digested, dewatered with vacuum filters, and hauled offsite to disposal. In-plant recycle streams are returned to the raw sewage pumping station.

The plant's NPDES permit requires 30-day average effluent BOD_5 and SS to be less than 30 mg/l. There is no limit on ammonia nitrogen in the effluent.

AERATION SYSTEM RETROFIT DESIGN

The aeration tankage at Frankenmuth consists of six individual aeration cells, each measuring 44 feet by 22 feet with 15-foot side water depth. The total volume of all 6 cells is 87,000 cubic feet (651,000 gallons). The cells are interconnected as shown in Figure 1. The tank configuration allows considerable operating flexibility, ranging from modified contact stabilization by running up to 4 of the 6 cells in series for return sludge re-aeration followed by the remainder of the cells (2 to 4) for aeration, to conventional plug flow activated sludge with all 6 tanks operated in series. The plant has also been run with Tanks 1 and 2 re-aerating return sludge, and Tanks 4 and 3, and 5 and 6 operating as two parallel two-tank plug flow aeration trains. Normal operation is with Tanks 1 and 2 (and possibly tank 3) re-aerating return sludge, and the remainder of the tanks arranged in series as aeration tanks.

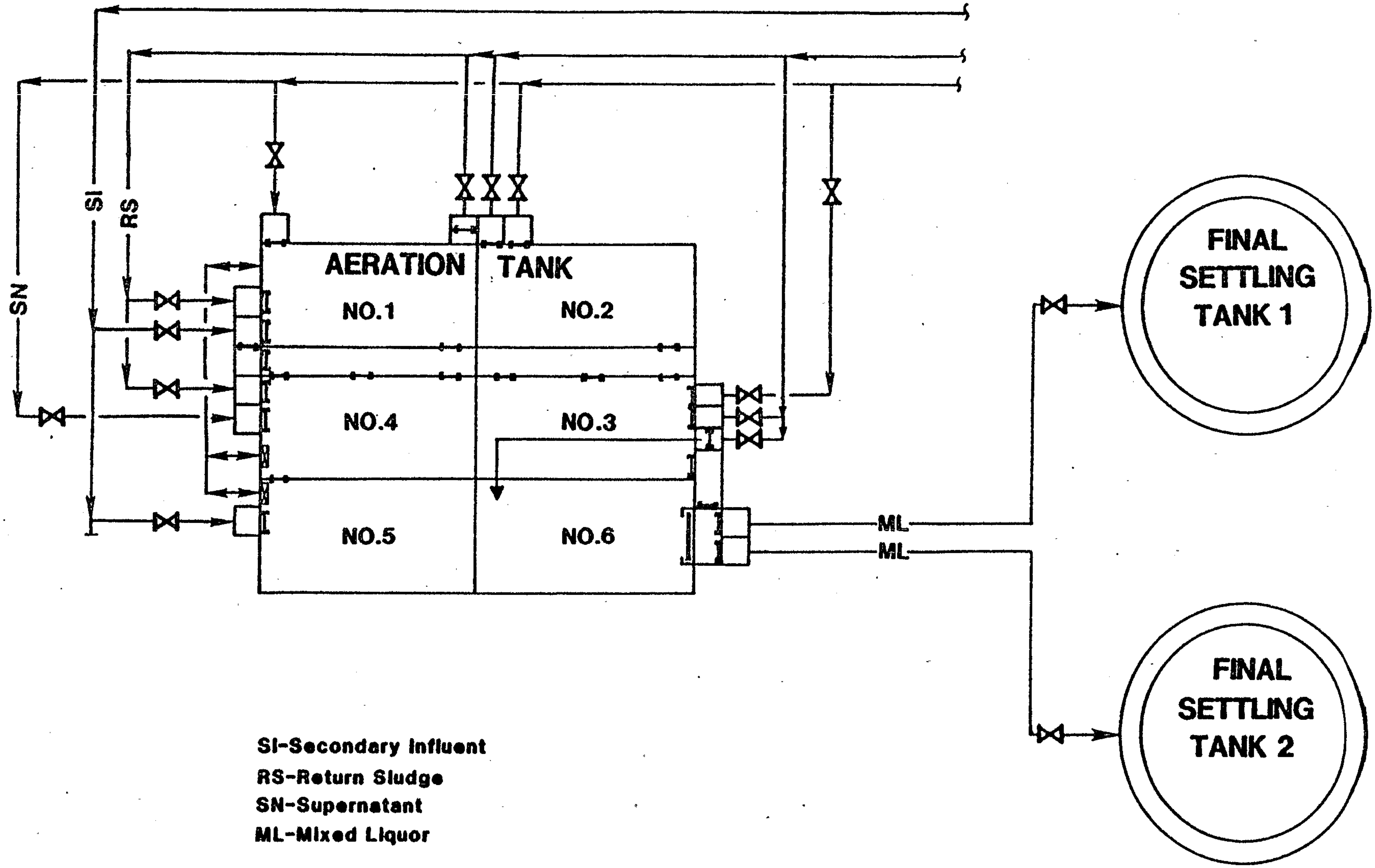


Figure 1
Aeration Tank Arrangement

The air diffusion equipment initially installed was stainless steel broad band coarse bubble diffusers mounted on galvanized steel headers. Four multi-stage centrifugal blowers were provided, each with a nominal capacity of 6,500 cfm. The existing system was not always able to keep up with the oxygen demand of the plant's primary effluent flow. This was at least partly due to the fact that corrosion had caused a significant number of the diffusers to break off.

The existing diffusion equipment needed to be replaced because of the corrosion failure. so this project was not a typical retrofit predicated on recouping the investment in new equipment from energy savings. Before actual detailed design was begun, an economic analysis was performed comparing the replacement of the existing system with new stainless steel coarse bubble diffusers and stainless steel headers and with a retrofit to ceramic fine pore diffusers in full floor coverage, but it did not include consideration of keeping the existing system in service. The results of this pre-design analysis are shown in Table 1. The capital costs of the two systems were judged to be approximately the same. It was estimated that the energy savings available with the fine pore system as compared to the coarse bubble system could repay the investment in new equipment in approximately six years, so the fine pore system was selected.

The estimated capital cost of the proposed ceramic fine pore diffuser system included the diffusers and in-tank piping. new air drop pipes in each tank. in-place gas cleaning, two new smaller blowers and new air inlet filters. The diffuser cost was based on a total of 2400 diffusers. The analysis assumed no salvage value for the existing equipment not incorporated into the new work. Capital costs for the proposed new coarse bubble equipment needed to replace the deteriorated existing equipment included new stainless steel drop pipes. in-tank headers and diffusers. The diffuser cost estimate was based on a total of 2000 stainless steel broad band coarse bubble units.

The analysis assumed an "alpha" value for the fine pore system of 0.50. and for the coarse bubble system of 0.90. "Beta" was assumed to be 0.99 in both cases. Complete design parameters are shown in Table 2.

Table 1

Aeration Retrofit Energy Analysis
Predesign Estimates

	Ceramic Fine Pore	Stainless Coarse Bubble
Primary Effluent Flow (mgd) [1]	1.4	1.4
Primary Effluent BOD_5 (mg/l) [1]	512	512
Primary Effluent BOD (lbs/day)	5977	5977
Actual Oxygenation Rate (AOR) (lbs/day) [2]	6575	6575
In-Waste Oxygen Transfer Effluent [3]	11.9%	7.2%
Average Air Flow Required (scfm) [3]	2214	3641
Average Brake Horsepower	80	180
Estimated Annual Energy Cost ($) [4]	26,140	58,815
Estimated Annual Operation & Maintenance ($)	3,000	
Total Estimated Annual Cost ($)	29,140	58,815
Estimated Annual Savings ($)	29,675	

(1) Flows and loads based on average for November 1983 through October 1984.
(2) Assumes 1.1 lbs oxygen required per lb. BOD applied.
(3) At tank average D.O. of 2.0 mg/l.
(4) Average per kWh cost approximately $0.05.

Table 2

Fine Pore Aeration System Retrofit
Design Parameters

	Average	Peak
Primary Effluent Flow (mgd)	1.8	2.7
Primary Effluent BOD_5 (mg/l)	515	
Lb. BOD per 1000 cf per day	86	147
Lb. BOD_5 per day	7730	11,600
Lb. O_2 Req'd/lb. BOD Removed	1.1	1.1
Tank Avg. D.O. (mg/l)	2.0	0.5
Average MCRT (days)	10	-
NPDES Permit Limits, BOD_5 (mg/l)	30	45
NPDES Permit Limits, SS (mg/l)	30	45

A net energy savings of approximately $32,000 per year was expected using the fine pore diffusers system. The net total savings was estimated to be $29,000 per year by subtracting the estimated $3,000 annual cost of additional maintenance required for the fine pore system. The anticipated operating range of air flows with the proposed fine pore diffuser system was from approximately 800 scfm (the estimated mixing limit) to approximately 4000 scfm required to satisfy the peak oxygen demand to aeration. The estimated annual average air flow was expected to be approximately 2200 scfm.

The minimum operating air flow of the existing blowers (surge point) was approximately 2100 cfm. Evaluation of the blower performance curves indicated that the operating efficiency in the range near surge was very poor when compared to the efficiencies possible with new smaller units. It was determined that to ensure that the anticipated energy savings were actually realized at the plant, new blowers sized to operate with the new equipment would have to be part of the project. As a result, two new units with nominal capacity of 2200 scfm were included as part of the new facilities. Only the blowers were replaced. Blower bases, motor starters, valves, flexible connectors, etc., were re-used with the new equipment.

Plugging/Fouling Potential

Before final design of the retrofit was begun, a test header with four ceramic plate-type diffusers was installed near the inlet end of Aeration Cell 5 to monitor the potential for plugging and fouling, and to ensure that fine pore diffusers were compatible with the waste. The dynamic wet pressure (DWP, pressure drop across the diffuser) was monitored daily for a period of approximately 10 weeks to develop an estimate for the plugging and fouling rate. At the end of that period, the test header was cleaned by injecting hydrogen chloride gas in with the air supply.

The observed fouling rate was significant. DWP was observed to increase more than 1 inch w.g. in as little as one day. However, short term increases in air flow per diffuser (air "bumping") reduced DWP, and the gas cleaning was effective in reducing DWP as well. The actual air flow rate during the "bumping" was not measured. Initial DWP readings were approximately six inches w.g. DWP's as high 24.5 inches were recorded. The DWP following gas cleaning was approximately 9.0 inches w.g., compared to the initial readings of 5-6 inches w.g. A weekly summary of the plugging/fouling test results is shown in Table 3. Daily data is shown in Appendix A. As shown, the DWP fluctuated throughout the test period, dropping abruptly for no apparent reason at times.

Table 3

Summary of Plugging/Fouling Potential Test Results

Date	Diffuser 1		Diffuser 2		Diffuser 3		Diffuser 4	
	Orifice	DWP	Orifice	DWP	Orifice	DWP	Orifice	DWP
8/27/84	5.5	6.0	6.0	6.0	6.0	5.0	7.5	5.5
9/3/84	6.0	15.0	5.5	15.5	6.0	15.5	6.5	15.0
9/10/84	6.0	15.0	6.0	15.0	6.0	15.0	7.5	14.0
9/15/84	6.0	24.5	6.5	23.0	6.0	22.5	7.0	21.0
9/17/84	6.0	17.5	6.5	17.0	5.5	18.0	6.5	17.5
9/24/84 (1)	6.0	17.0	6.0	17.0	5.0	12.0	5.5	18.0
10/1/84 (2)	6.0	11.5	5.5	11.5	5.0	12.0	6.0	12.0
10/8/84	6.0	17.0	6.5	17.0	5.0	19.0	5.5	18.0
10/14/84	6.0	11.0	6.5	11.0	5.0	12.0	4.5	13.0
10/22/84	6.0	10.0	6.0	10.0	6.0	10.0	6.0	10.0
10/31/84 (3)	6.0	14.5	6.0	14.0	6.0	13.5	5.0	14.5
11/4/84 (4)	6.0	9.0	6.0	9.5	6.5	9.5	7.0	9.0

Air flow per diffuser approximately 1.8 - 2.0 scfm.
Orifice = Pressure drop across distribution orifice.
DWP = Pressure drop across diffuser.
All values are inches water gauge
Values are weekly. Daily data is in Appendix A.

(1) Before air bumping.
(2) After air bumping.
(3) Before gas cleaning
(4) After gas cleaning.

It was decided that the plugging and fouling phenomenon could be controlled and that the potential energy savings were significant enough that design and installation of the retrofit to fine pore diffusers should proceed.

EQUIPMENT PROCUREMENT AND SPECIFICATIONS

The new diffused aeration equipment was specified to be ceramic disc-type diffusers in full floor coverage with in-place hydrogen chloride gas cleaning. Two new multi-stage 200 Hp centrifugal blowers, nominal capacity 2200 scfm, were specified to replace two of the existing blowers. Two existing (250 Hp) blowers were left in place to provide standby capacity for anticipated peaks. Because of the age of the existing air piping system, in-line air filters to be placed immediately upstream of the air drop into each cell were specified requiring 97 percent removal of particles 0.3 microns and larger to protect the new equipment from air side fouling. These were not installed. New elements for the existing inlet filters capable of removing 20 micron and above particles were installed instead at the City's request. This relaxation of the air filtration requirements was requested by the City because the inside lining of the existing air piping system was determined to be in excellent condition, thereby minimizing the potential for rust particles to plug the diffusers. City personnel also felt that the maintenance cost savings from the less expensive filter elements outweighed the danger of plugging from airborne particulate matter smaller than 20 microns.

A total of 2400 diffusers, 400 evenly distributed per aeration cell, were specified based on anticipated actual oxygen requirements under the design peak condition. This provides one diffuser for every 2.42 sf of tank bottom area. The anticipated maximum air flow rate per diffuser at peak load was approximately 1.7 scfm. A minimum air flow of approximately 1,750 cfm was anticipated based on review of past plant operating records. The air flow per diffuser at this rate would be 0.7 scfm. There is one air drop pipe into each aeration cell. Air flow to each cell is controlled manually with a butterfly valve.

Construction was begun in December 1985. The installation work was performed by the treatment plant staff, with the aeration equipment manufacturer providing technical assistance as required. The new equipment was placed in service in January 1986. The total project capital cost for equipment was $160,000. The plant staff invested approximately 800 man hours in the installation and startup for the new equipment. The total project cost, including installation and engineering, was approximately $190,000.

PERFORMANCE OF THE NEW EQUIPMENT

Figure 2 shows a graph of total plant energy use versus pounds of BOD treated. Figure 3 shows a plot of kWh per pound of BOD treated. As shown, a marked decrease in energy consumption was experienced in the two years (1986 and 1987) after the retrofit was completed. Data in 1988 indicates that savings may no longer be present. However, the plant staff has chosen, beginning in January 1988, to operate at higher air flow rates than previously to lessen the necessity for gas cleaning and, they believe, enhance treatment efficiency. This has resulted in higher operating levels of D.O. and consequent increased power usage. The efficiency of the primary settling tanks has also been increased, resulting (as shown is Table 4) in lower BOD loading to the aeration system. The 1988 data is not necessarily indicative of a loss in energy savings potential.

Table 4 shows total pounds of BOD treated and total plant electrical power use from December 1984 through May 1988. It also shows kWh per pound of BOD treated. Based on the average monthly BOD from December 1984 through December 1985 (295,939 lbs./month) and the average kWh/lb. BOD for that and succeeding years, estimated power savings are shown in Table 5.

The annual cost of practicing gas cleaning has varied considerably. Gas cost for Frankenmuth is approximately $1.55/lb. Labor costs, including payroll taxes and insurance, average approximately $20.00/hour. During the first 12 months when cleaning was done (4/86 - 5/87), the total gas used was 963 lbs., and the total labor required was 45 man-hours. The cost was approximately $2,400. During the last 12 months reported, 152 lbs. of gas and 8.5 man-hours were used for a total cost of approximately $400. A summary of gas use and cleaning labor is shown in Table 6. These figures would indicate that the preliminary economic evaluation, which estimated cleaning costs at $1.25/year/diffuser, was fairly conservative.

The plant consistently meets its NPDES permit for effluent BOD in spite of the fact that wide daily fluctuation in BOD load are experienced. Appendix B contains a summary of some plant operating parameters for the period since the retrofit was completed. Significant additional decreases in energy consumption for aeration, and in the cost and frequency of gas cleaning are expected following completion and startup of the brewery pretreatment system.

Three diffusers in each cell were equipped for monitoring DWP and the pressure drop across the air distribution orifice in the holder. Readings have been recorded on a reasonably consistent basis since the equipment was installed. Figure 4 shows a plot of the average DWP

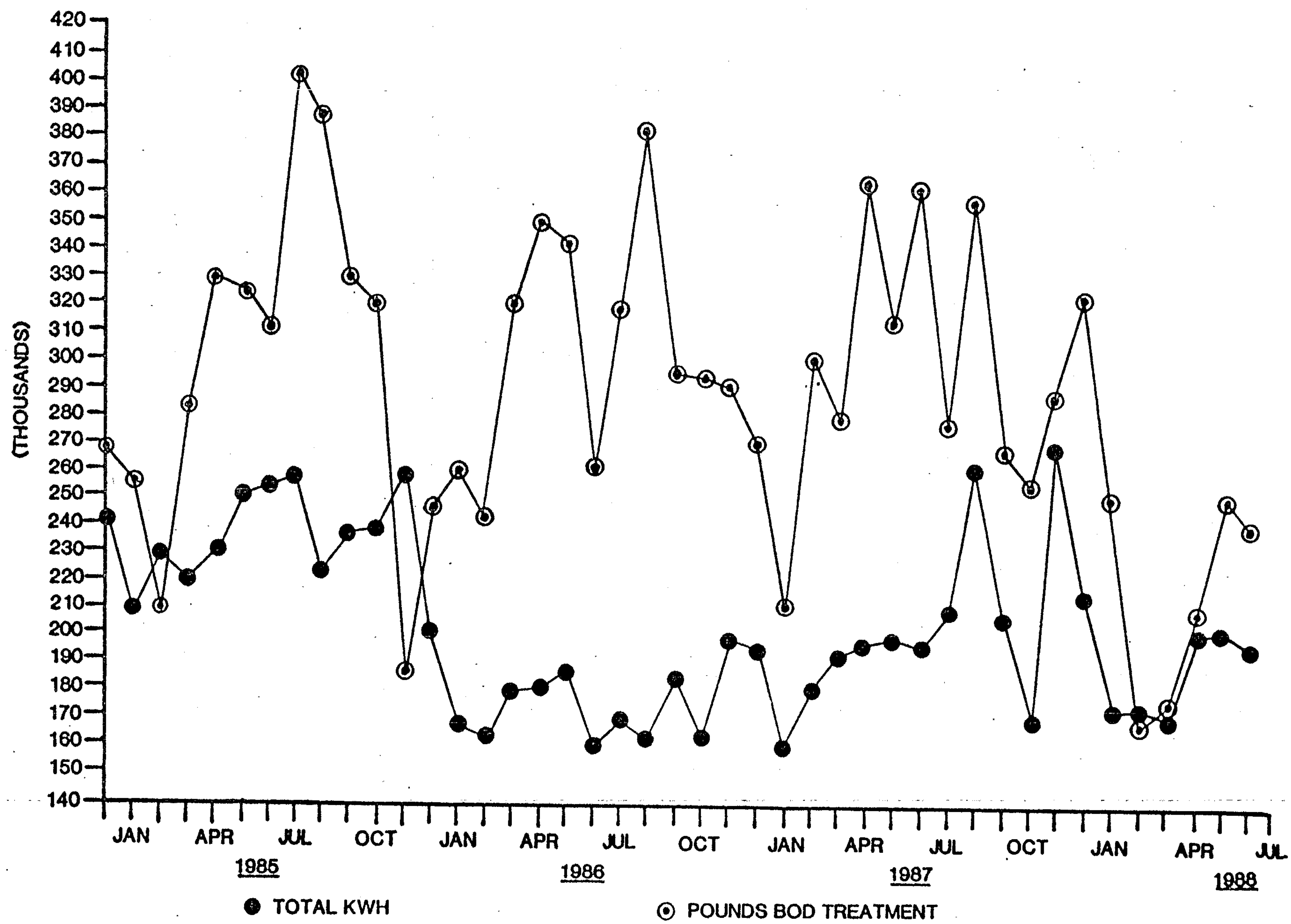


Figure 2
Total Plant Energy Use vs. BOD Applied

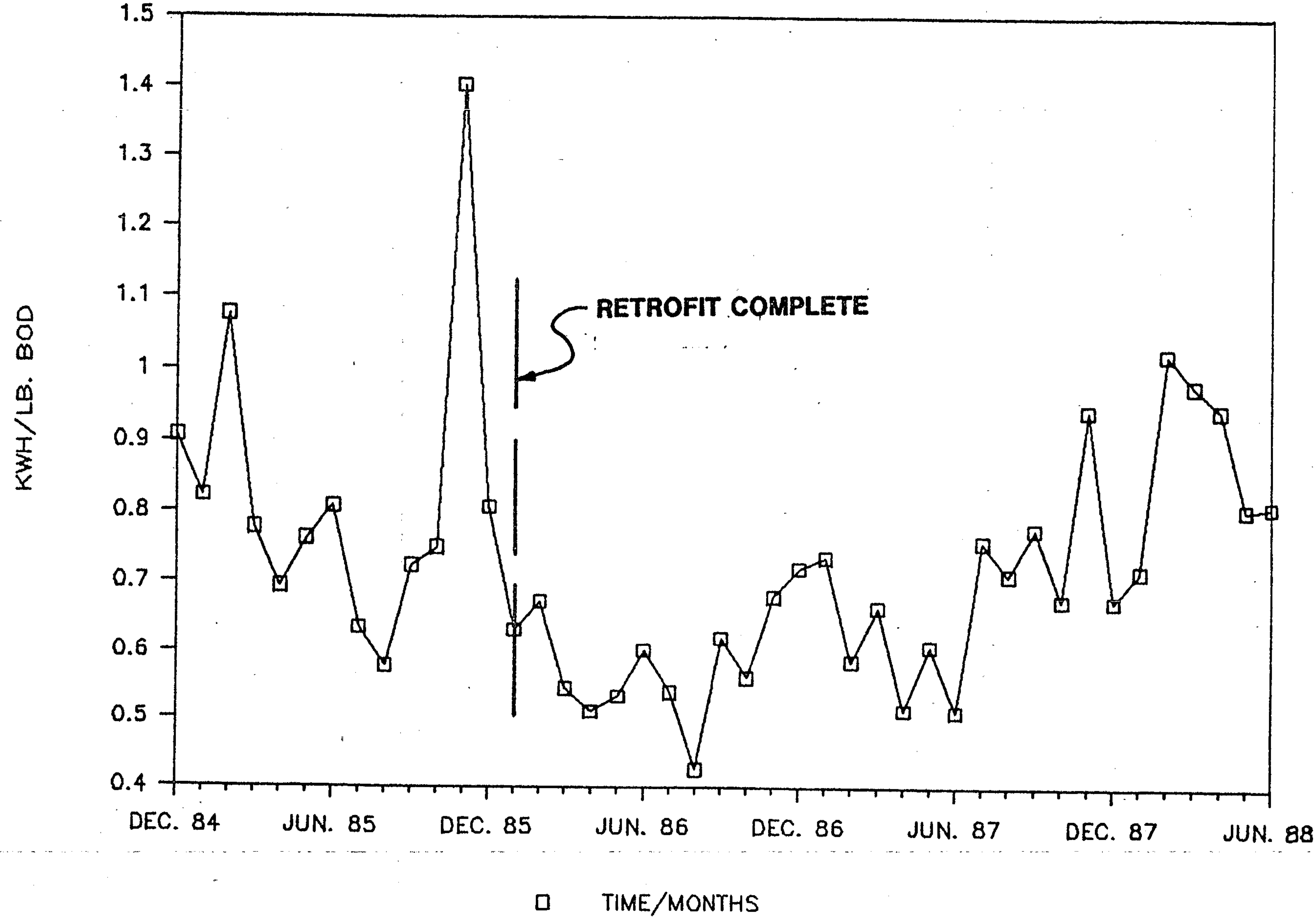


Figure 3
KWH/LB. BOD vs. TIME

Table 4

Electrical Energy Use

MONTH	BOD(lbs)	KW(hrs)	KW/LBS
DEC. 84	266810	242256	0.91
JAN. 85	254340	209316	0.82
FEB. 85	211230	227424	1.08
MAR. 85	283961	220832	0.78
APR. 85	330421	229072	0.69
MAY 85	326600	248848	0.76
JUN. 85	312043	252144	0.81
JUL. 85	402340	255440	0.63
AUG. 85	386795	223612	0.58
SEPT 85	328032	237312	0.72
OCT. 85	318772	238960	0.75
NOV. 85	183000	257088	1.40
DEC. 85	242867	196112	0.81
AVERAGE	295939	233724	0.83
STD. DEV.	61385	17626	0.20
JAN. 86	258458	163152	0.63
FEB. 86	240308	161504	0.67
MAR. 86	320626	174688	0.54
APR. 86	349158	177984	0.51
MAY 86	343273	182989	0.53
JUN. 86	259378	156085	0.60
JUL. 86	314973	169744	0.54
AUG. 86	384139	163152	0.42
SEPT 86	292973	181280	0.62
OCT. 86	291326	163152	0.56
NOV. 86	286486	194464	0.68
DEC. 86	265777	191099	0.72
AVERAGE	300573	173274	0.59
STD. DEV.	41263	11914	0.08

MONTH	BOD(lbs)	KW(hrs)	KW/LBS
JAN. 87	210740	154912	0.74
FEB. 87	298960	174688	0.58
MAR. 87	278445	184576	0.66
APR. 87	366940	187872	0.51
MAY 87	315184	191168	0.61
JUN. 87	365205	186224	0.51
JUL. 87	274125	207648	0.76
AUG. 87	359589	254950	0.71
SEPT 87	261220	202704	0.78
OCT. 87	254339	171392	0.67
NOV. 87	287606	271467	0.94
DEC. 87	321225	215888	0.67
AVERAGE	299465	200291	0.68
STD. DEV.	46374	32390	0.12
JAN. 88	246794	176336	0.71
FEB. 88	172741	176336	1.02
MAR. 88	173479	169744	0.98
APR. 88	209258	197760	0.95
MAY 88	248001	199408	0.80
JUN. 88	238507	192816	0.81
AVERAGE	214797	185400	0.88
STD. DEV.	32133	11643	0.11

Table 5
Estimated Energy Cost Savings

	1985	1986	1987	1988
Assumed pounds BOD treated per Month	295.939	295.939	295.939	295.939
Average kWh/lb. BOD	0.83	0.59	0.68	0.88
Average Monthly Power Cost (at $0.05/kWh)	$ 12.281	$ 8.730	$ 10.062	$ 13.021
Average Monthly Savings	—	$ 3,551	$ 2.219	(-740)
Annual Savings	—	$ 42.612	$ 26.628	(-8.880)

vs. time for the three diffusers in Cell 5 for the period between February 1987 and December 1987. The times at which gas cleaning was performed are also indicated.

OFF-GAS OXYGEN TRANSFER TESTING

The Frankenmuth plant was selected by the ASCE Committee preparing this manual to undergo an extensive set of off-gas oxygen transfer tests. The purpose of this additional testing was to evaluate the effects on in-waste oxygen transfer efficiency of plugging and fouling, and of gas cleaning.

Off-gas testing was performed using techniques developed by Ewing Engineering and described in the literature, analysis equipment constructed in 1982 by Ewing Engineering, and a 2'-0" x 10'-0" fiberglass off-gas collection hood. The data was gathered by placing the collection hood in four locations bracketing the center of the aeration cell being tested as shown in Figure 5, except for data collected in May 1988. This was done in an attempt to make the data as consistant and reproducible as possible. In May 1988, eight hood locations spaced along the entire length of the tank were used. The four additional locations are shown by dashed lines in Figure 5. This alternate sampling scheme was used in an attempt to quantify the change in "alpha" from inlet end to outlet end of the tank. Only average values of the four or eight collection hood locations are reported in Table 7.

Each set of off-gas testing was conducted during two or three consecutive days. At least some test conditions from the first day were duplicated as closely as possible on subsequent days to identify radically changed conditions which might cause the test results to be misleading.

Table 6

Gas Cleaning Costs

Month	Hours Worked	HCL (lbs)
1986		
April (1)	14.00 (1)	332 (1)
May	10.50	142
June	4.25	114
July	2.00	51
August	4.75	121
September	0.00	0
October	2.00	46
November	1.50	32
December	1.50	31
1987		
January	0.00	0
February	1.50	51
March	3.00	43
April	4.60	75
May	2.85	88
June	1.00	50
July	1.00	29
August	0.00	0
September	2.25	47
October	1.00	17
November	0	0
December	2.25	22
1988 (2)		
January	0	0
February	0	0
March	1.00	22
April	1.00	18
May	1.00	16
June	0	0
July	0	0

(1) Demonstration and training period so values may not be representative.

(2) Conscious effort by plant staff to minimize cleaning effort by operating at elevated air flow rates during 1988.

A summary of the cumulative results of the off-gas test program are shown in Table 7a and 7b. Complete test results are in Appendix C. The initial plan for the off-gas testing was to operate the plant with cells 1 and 2 re-aerating return sludge, and cells 4 and 3, and 5 and 6

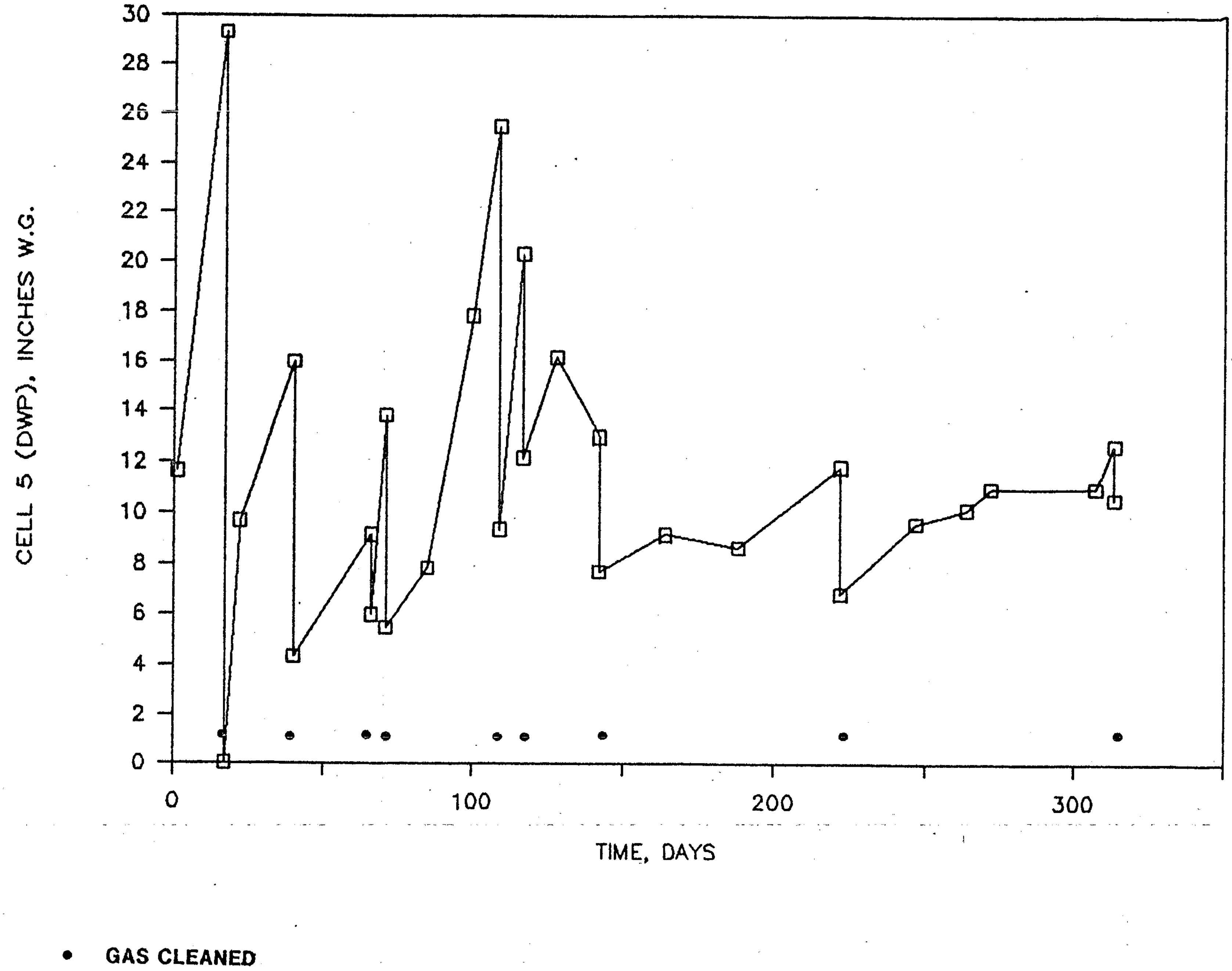
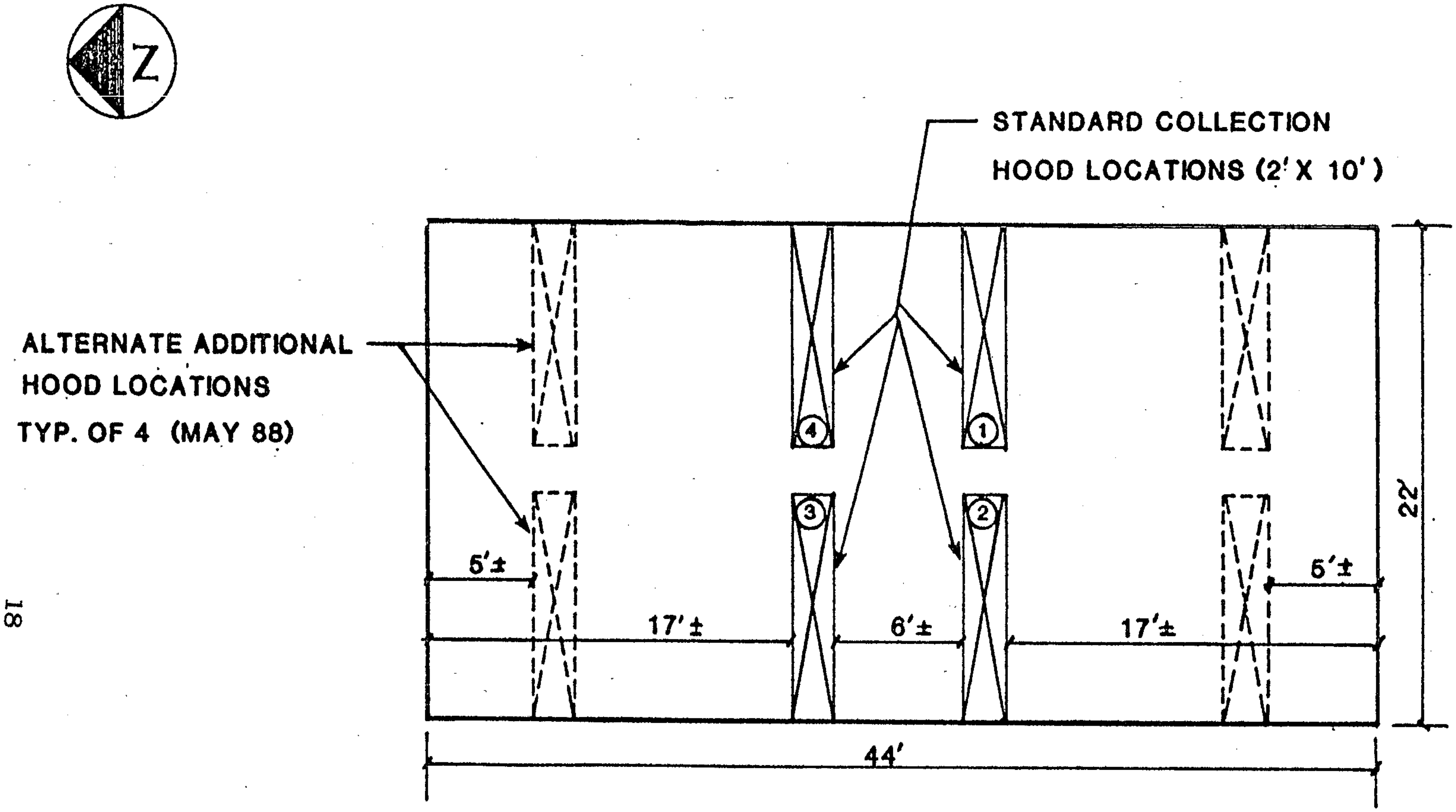


Figure 4
CELL 5 DWP vs. TIME



PLAN OF TYPICAL AERATION CELL

Figure 5
Off-Gas Collection Plan

Table 7a
Off-Gas Oxygen Transfer Efficiency Test Results
Parallel Plug Flow Operation

Date	Tank 3 (NW)		Tank 4 (SW)		Tank 5 (SE)		Tank 6 (NE)		MLSS(6) (mg/l)	MCRT (days)	Prim. Eff.	
	Qa SCFM/ DIFF	OTE(1)	Qa SCFM/ DIFF	OTE(1)	Qa SCFM/ DIFF	OTE(1)	Qa SCFM/ DIFF	OTE(1)			Flow (mgd)	BOD (lbs/ day)
4/14/87	1.75	16.7	1.90	10.6	1.62	9.7	2.08	13.1	5,020	--	1.82	3,988
4/15/87	1.96 0.68	18.9 17.8	1.69	10.1	1.56	9.9	1.72	16.4	5,280	6.7	1.89	4,398
3/28/88 (2)(3)	2.34	10.4			2.24 2.21	7.0 6.7	2.42 2.54	11.0 11.0	6,130	7.8	1.81	5,661
3/29/88	1.98	17.0	2.24	6.8	1.86 2.37	7.3 8.0	2.21 2.40	15.6 15.4	5,900	6.0	1.67	4,882
5/10/88 (5)(3)(2)			1.98	6.6	2.10 2.08	6.7 5.4			5,450	9.4	1.34	4,484
5/11/88(5)			2.06	6.3	2.27	8.1			7,350	10.0	1.22	3,236

(1) "Alpha" SOTE (i.e., 20°C, 760 mm Hg, 0.0 mg/l D.O., C*20 = 10.3 mg/l). SOTE estimated to be 28%± at 14.25' submergence (Ref. L.A. Co. data).
(2) Immediately before gas cleaning.
(3) Immediately after gas cleaning.
(4) Tank Operating in reaeration mode.
(5) Eight data points per set spaced along entire tank.
(6) Average of cells 5 and 6.

Parallel plug flow operation is with cells 4 and 3 operating in series as aeration tanks, and cells 5 and 6 operating in series as aeration tanks in parallel with 4 and 3.
Series flow operation is with cells 1, 2 and 3 in series as RAS reaeration and cells 4, 5 and 6 in series as aeration tanks.
Complete test results are included in Appendix C.

Table 7b

Off-Gas Oxygen Transfer Efficiency Test Results

Series Flow Operation

Date	Tank 3 (NW)		Tank 4 (SW)		Tank 5 (SE)		Tank 6 (NE)		MLSS(6) (mg/l)	MCRT (days)	Prim. Eff.	
	Qa SCFM/ DIFF	OTE(1)	Qa SCFM/ DIFF	OTE(1)	Qa SCFM/ DIFF	OTE(1)	Qa SCFM/ DIFF	OTE(1)			Flow (mgd)	BOD (lbs/ day)
6/22/87 (2) (3)					1.67 1.64	8.3 7.3	2.17 1.83	10.4 6.9	3,630	11.8	1.67	20,580
6/23/87			1.61	10.0 (4)	1.76 1.14	7.4 7.6	1.89 1.03	10.3 9.9	3,820	10.0	1.64	15,018
9/9/87					1.24 2.00	12.1 7.3	1.96	12.2	6,000	6.1	1.37	7,208
9/10/87 (2) (3)					1.89 1.90	9.6 8.2	1.94 1.80	16.2 13.5	2,880	5.6	1.41	7,597
12/9/87	1.68	16.3 (4)	1.74	7.4			2.16	12.9	2,990	5.2	1.84	10,308
12/10/87 (2) (3)					2.14 2.03	7.7 6.6	2.30 2.19	10.7 7.8	3,990	16.7	2.07	10,779
12/11/87	1.75	12.1 (4)			1.95	7.4	2.03	10.0	6,940	36.1	2.05	10,375

operating as two parallel plug flow aeration trains (See Figure 1). One train was to serve as a "control", and the other train was to be gas cleaned at different levels of DWP to determine if the effects of DWP and gas cleaning could be quantified in terms of oxygen transfer efficiency.

The first set of tests (April 1987) were performed in this matter. However, shortly after these tests were completed, the plant staff determined that in order to maintain compliance with their NPDES permit it would be necessary to have more than 2 cells re-aerating return sludge. The plant flow scheme was changed so that RAS went to Tanks 1, 2 and 3 in series. Return sludge and all primary effluent were then directed to Cell 4, then to 5 and 6.

Testing done in June, September and December 1987, was in this revised configuration. The plant was reverted to the original parallel flow scheme in February 1988 and remained so for tests conducted in March and May of that year. These operational changes precluded the possibility to have a parallel operation for comparison purposes.

Alpha SOTE vs. time is plotted for each each cell in Figure 6. A review of the off-gas test results will show that the observed oxygen transfer efficiency varies significantly from one set of test results to another. A review of the materials in Appendix C shows significant variation from one hood location to another at some times. This is possibly the result of short circuiting within an aeration cell caused by the feed point location and lack of "cross mixing" in a tank with fine pore diffusers in full floor coverage. Several sets of tests were run at different locations before and after gas cleaning. In most instances, an additional set of "after" readings were collected on the following date for comparison. This was not the case in September 1987 when the cleaning was done on the second day of testing (9/10/87).

Based on the data collected, no demonstrable effect can be observed on oxygen transfer efficiency as a result of the decreased DWP following gas cleaning. The data from one set of tests to the next is so variable that it is not possible to analyze the effect of DWP on OTE except by comparing values before and after cleaning. In some instances, immediately following gas cleaning, a slight decrease in OTE was observed. However, in each of these cases when additional testing was done the following day, the OTE had rebounded to be approximately the same as it was before the cleaning process took place. In no case did gas cleaning appear to increase OTE. However, it is important to note that it was effective in limiting the increase in DWP. Table 8 shows DWP before and after gas cleaning for each set of comparative off-gas tests, and the amount of HCl used for each cleaning.

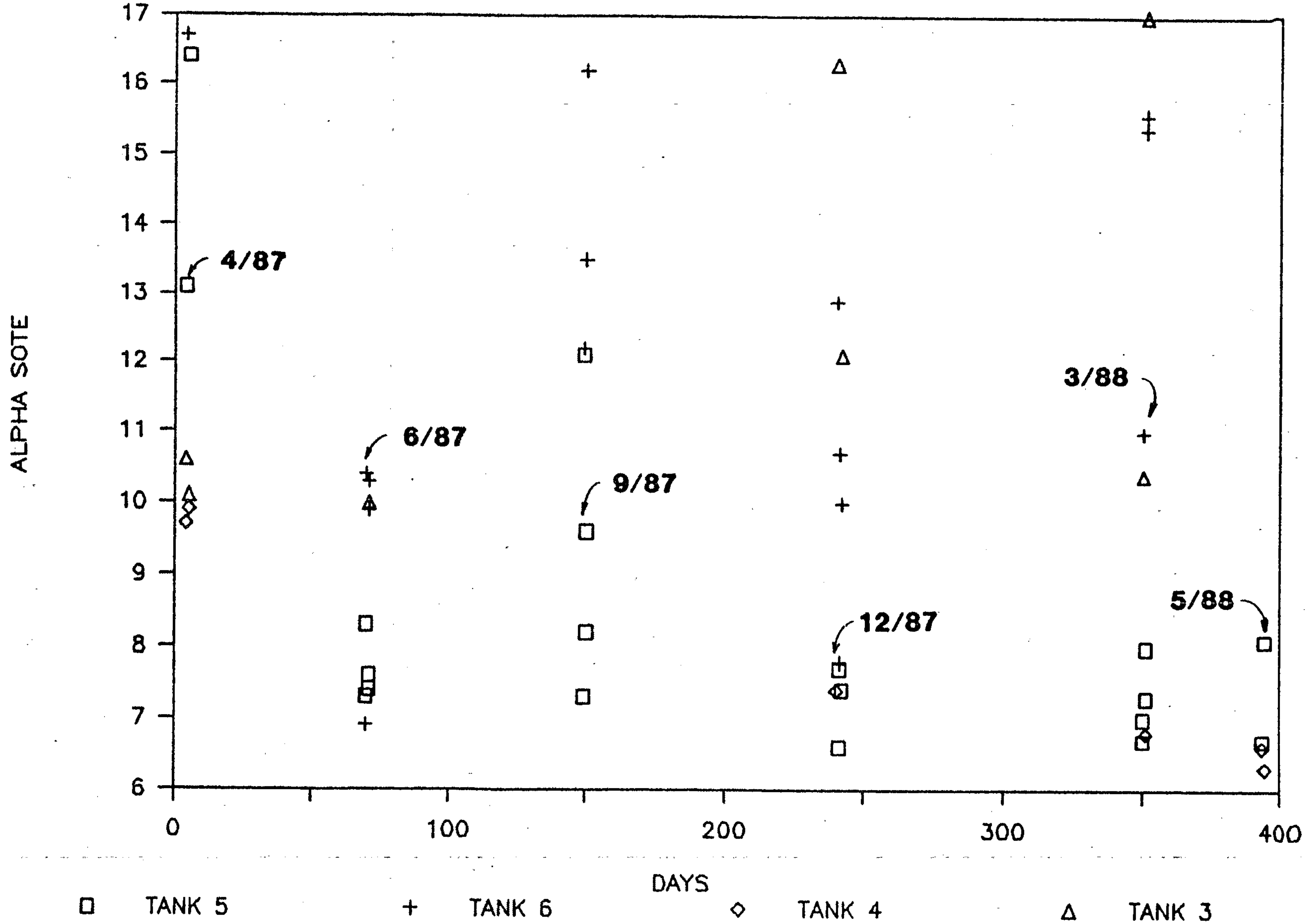


Figure 6
ALPHA SOTE vs TIME

Table 8

Gas Cleaning Results During Off-Gas Testing

Date	Tank 5				Tank 6				Gas Use (pounds)	
	Before		After		Before		After			
	DWP	Orifice	DWP	Orifice	DWP	Orifice	DWP	Orifice	Tank 5	Tank 6
6/22/87	16.0 15.0 12.0	3.0 3.5 7.0	8.5 8.0 6.5	3.0 3.5 5.5	11.0 8.0 8.0	3.5 6.0 6.0	8.5 6.0 6.0	3.5 6.0 6.0	20	6
9/10/87	12.5 12.0 11.0	6.0 6.5 7.0	7.0 6.5 7.0	5.5 6.0 5.0	11.0 10.0 10.5	6.0 8.0 7.0	6.0 5.5 5.0	5.5 6.0 6.0	5	9
12/10/87	12.0 10.5 13.0	6.0 7.5 5.0	6.0 6.0 7.0	6.0 7.0 6.0	9.0 7.0 6.5	4.0 6.0 6.0	6.5 5.0 5.0	6.0 7.5 7.5	6	10
3/28/88	13.5 13.0 13.5	6.0 6.5 6.0	8.0 8.0 9.0	6.0 6.5 6.0	10.0 7.0 7.0	6.0 9.0 8.5	7.0 6.0 6.0	6.0 8.0 8.0	7	15
5/10/88	12.0 12.0 13.0	8.5 8.5 7.0	10.5 9.5 11.0	7.5 8.5 7.0					10	

All values are in inches w.g. except gas use, which is in pounds.

"Orifice" loss is pressure drop across the air distibution orifice to the diffuser where DWP was measured.

Three separate diffusers in each aeration cell are instrumented to read DWP and Orifice losses.

The detailed system design was based on an in-waste alpha SOTE of approximately 16.9% at an air flow of 1 scfm per diffuser. and approximately 11.0% at 2 scfm per diffuser, based on off-gas test results from another treatment plant. Actual in-waste oxygen transfer efficiency as measured by the off-gas testing is in general lower than was anticipated in the design stage, in some instances less than 6 percent. This indicates that alpha was actually lower than expected. The actual observed air flow rates per diffuser are higher than those expected to be required even for the peak design load to the plant, averaging more than 2 scfm per diffuser.

Attempts were made using the off-gas data to establish a relationship between oxygen transfer efficiency and air flow rate per diffuser using linear regression analysis. However, there is no apparent statistically significant correlation between the two, at least at Frankenmuth. As expected, oxygen transfer efficiency improves as alpha changes between the influent and effluent ends of the aeration portions of the system as shown by comparing data from the same dates taken in Tank 5 versus that collected in Tank 6. At all times during the testing Tanks 5 and 6 were operated in series with flow passing from 5 into 6, and then into the final settling tanks. Data collected in Tanks 4 and 3 in April 1987 and in May 1988 also represent series operation with flow from Tank 4 to Tank 3 and then to the final settling tanks. Other data collected in Tanks 4 and 3 were for periods when Tank 3 was operating as the last of 3 stages of return sludge reaeration and Tank 4 as the first of 3 stages of aeration.

APPENDIX A

Summary of Plugging/Fouling Potential Test Results

CITY OF FRANKENMUTH - WASTE TREATMENT PLANT
FINE BUBBLE PRESSURE READINGS

DATE	ORFICE LOSS				DYNAMIC WET PRESSURE			
	GREEN	BLACK	BLUE	GRAY	GREEN	BLACK	BLUE	GRAY
8-27-84	5.5	6	6	6	6	5	7.5	5.5
8-28-84	5.5	5.5	5	4.5	8.5	9	9	9.5
8-29-84	5.5	7	5	5.5	8.5	7	9.5	8.5
8-30-84	6	6	5	4	13	13	13.5	15
8-31-84	6	6	5	5.5	12.5	13	13.5	13
9-01-84	6	5.5	5.5	6	13	13.5	13.5	12.5
9-02-84	6	5.5	5.5	6	25.5	16	16	15.5
9-03-84	6	5.5	6	6.5	15	15.5	15.5	15
9-04-84	6	5.5	5.5	6	16.5	17.5	16.5	16.5
9-05-84	6	5.5	5.25	6	17.5	17.5	17.5	17
9-06-84	6	6	6.5	6.5	18	18	17	16.5
9-07-84	6	6	5.5	6	18.5	18.5	19	18.5
9-08-84	6	6	5.5	7	16.5	17	17.5	15.5
9-09-84	6	5.5	6	7.5	14.5	14.5	14	13.5
9-10-84	6	6	6	7.5	15	15	15	14
9-11-84	6	6	6	7	19	18.5	18.5	17.5
9-12-84	6	6	5.5	6	16	16	16	16
9-13-84	6	7	5.5	6.5	11	10.5	12	12
9-14-84	6	7	6.5	7	23	21.5	21.5	20
9-15-84	6	6.5	6	7	24.5	23	22.5	21
9-16-84	6	6.5	5.5	7	21	20	20	19
9-17-84	6	6.5	5.5	6.5	17.5	17	18	17.5
9-18-84	6	6.5	6	5.5	18.5	17.5	17.5	17.5
9-19-84	6	6.5	5	5.5	16.5	16	17	16.5
9-20-84	6	6.5	5.5	5.5	13	12	13	13.5
9-21-84	6	6.5	5	5	16.5	15.5	17.5	18
9-22-84	6	6	5	4.5	17	16.5	17.5	18
9-23-84	6	6.5	5.5	5	15	14.5	15.5	16
9-24-84	6	6	5	5.5	17	17	18	18
9-25-84	6	6	6	5.5	12.5	12.5	12.5	12.5
9-26-84	6	6	5	5	14	14	14.5	14.5
9-27-84	6	5.5	5	4.5	15.5	16	16.5	17
9-28-84	6	6	5.5	6.5	10.5	11	11.5	10.5
9-29-84	6	6	5	6	15.5	16	16.5	16
9-30-84	6	6.5	5	6	17	17.5	18.5	18

CITY OF FRANKENMUTH - WASTE TREATMENT PLANT
FINE BUBBLE PRESSURE READINGS

DATE	ORFICE LOSS				DYNAMIC WET PRESSURE			
	GREEN	BLACK	BLUE	GRAY	GREEN	BLACK	BLUE	GRAY
10-01-84	6	5.5	5	6	11.5	11.5	12	12
10-02-84	6	5.5	5	5.5	16	16	16.5	15.5
10-03-84	6	5.5	5	5.5	16.5	16.5	17	17
10-04-84	6	5.5	5	6	17.5	17	18	17.5
10-05-84	6	5.5	5	5.5	18	18.5	20	19.5
10-06-84								
10-07-84	6	6	5	5	17	17	18.5	18
10-08-84	6	6.5	5	5.5	17	17	19	18
10-10-84	6	7	4.5	4.5	22	19.5	18	18
10-11-84	6	6	4.5	5	12	12	13.5	13.5
10-12-84	6	6	4.5	4.5	11.5	11.5	13.5	13
10-13-84	6	5	6.5	4.5	11.5	12.5	11.5	13.5
10-14-84	6	6.5	5	4.5	11	11	12	13
10-22-84	6	6	6	6	10	10	10	10
10-23-84	6	6	6	6	10	9	9.5	9
10-24-84	6	7	5.5	6	12	11	12	11.5
10-25-84	6	7	5.5	6	12.5	11.5	13	13
10-26-84	6	7	6	5.5	12.5	11.5	12	13
10-27-84	6	7	6	5.5	12	11	12	13
10-28-84	6	7	6	5.5	11	9.5	11	11
10-29-84	6	6.5	6	5.5	9.5	9	9	10.5
10-30-84	6	5.5	6	6	9	9	8.5	9
10-31-84	6	6	6	5	14.5	14	13.5	14.5
11-01-84								
11-02-84	6	6	6	6.5	9.5	9.5	9.5	8.5
11-03-84	6	5.5	5.5	6.5	9.5	10	10	9.5
11-04-84	6	5.5	5.5	6.5	9	9.5	9.5	9
11-05-84	6	6	6.5	7	13	12.5	11.5	10.5

APPENDIX B

Plant Operating Records

City of Frankenmuth WWTP Summary

1985

Date Summary 1985	Flow (mgd)	Primary Effluent				Aeration Load Application BOD/1000 cf	Final Effluent			
		BOD_5 (mgd)	BOD_5 (lb/day)	Sus.Sol. (mg/l)	Sus. Sol. (lb/day		BOD_5 (mgd)	BOD_5 (lb/day	Sus.Sol. (mg/l)	Sus. Sol. (lb/day
January	1.24	802	8,298	958	9,901	95.4	13	135	18	184
February	1.43	630	7,508	245	2,926	86.3	15	181	22	266
March	2.22	478	8,846	183	3,391	101.7	21	391	27	507
April	1.73	795	11,464	213	3075	131.8	31	453	37	535
May	1.23	877	9,000	213	2,182	103.4	16	160	18	188
June	1.34	923	10,314	344	3,842	118.6	19	212	11	123
July	1.31	938	10,251	304	3,320	117.8	38	416	12	129
August	1.46	816	9,975	247	3,004	114.7	30	370	27	329
September	1.60	624	8,490	229	3,059	97.6	24	322	20	268
October	1.45	782	9,403	240	2,898	108.1	25	297	22	268
November	1.69	--	--	--	--	--	9	122	16	219
December	1.45	568	6,868	288	3,480	78.9	13	157	22	266

City of Frankenmuth WWTP Summary

1986

Date Summary 1986	Flow (mgd)	Primary Effluent				Aeration Load Application BOD/1000 cf	Final Effluent			
		BOD_5 (mgd)	BOD_5 (lb/day)	Sus.Sol. (mg/l)	Sus. Sol. (lb/day		BOD_5 (mgd)	BOD_5 (lb/day	Sus.Sol. (mg/l)	Sus. Sol. (lb/day
January	1.46	539	6,720	283	3,553	83.3	15	183	23	293
February	1.20	729	7,545	430	4,459	79.9	22	233	21	220
March	1.77	587	8,129	288	4,267	86.1	29	452	23	354
April	1.47	838	10,605	378	4,788	112.3	51	658	32	395
May	1.35	866	10,172	479	5,812	107.8	29	339	24	276
June	1.52	621	7,947	231	2,836	84.2	24	316	18	239
July	1.39	769	9,111	422	5,034	96.5	22	262	12	141
August	1.27	723	7,959	248	2,658	84.3	17	174	20	207
September	1.90	474	6,724	220	3,523	71.2	16	220	27	405
October	1.72	490	6,830	232	3,474	72.4	9	125	22	314
November	1.20	673	7,185	289	2,931	76.1	14	137	32	310
December	1.39	520	6,655	222	2,642	71.6	29	349	24	278

City of Frankenmuth WWTP Summary

1987

Date Summary 1987	Flow (mgd)	Primary Effluent				Aeration Load Application BOD/1000 cf	Final Effluent			
		BOD_5 (mgd)	BOD_5 (lb/day)	Sus.Sol. (mg/l)	Sus. Sol. (lb/day		BOD_5 (mgd)	BOD_5 (lb/day	Sus.Sol. (mg/l)	Sus. Sol. (lb/day
January	1.11	418	4,081	200	1,903	43.2	15	142	17	157
February	1.34	604	6,716	268	3,040	71.1	20	226	25	283
March	1.37	472	5,567	246	2,843	58.9	20	241	25	281
April	1.60	479	6,352	323	4,395	67.3	21	278	25	339
May	1.32	610	6,952	343	4,476	73.6	47	536	29	323
June	1.48	673	8,534	385	4,777	90.4	54	689	29	365
July	1.24	588	6,264	306	3,202	66.3	32	338	41	414
August	1.45	819	10,114	279	3,507	107.1	24	286	42	472
September	1.30	573	6,503	247	2,663	68.8	18	205	42	458
October	1.50	527	6,610	186	2,297	70.0	14	175	16	203
November	1.37	509	6,026	226	2,672	63.8	19	239	37	497
December	1.69	462	6,634	150	2,148	70.2	24	355	35	508

City of Frankenmuth WWTP Summary

1988

Date Summary 1988	Flow (mgd)	Primary Effluent				Aeration Load Application BOD/1000 cf	Final Effluent			
		BOD_5 (mgd)	BOD_5 (lb/day)	Sus.Sol. (mg/l)	Sus. Sol. (lb/day		BOD_5 (mgd)	BOD_5 (lb/day	Sus.Sol. (mg/l)	Sus. Sol. (lb/day
January	1.24	481	5,057	220	2,250	53.5	16	182	27	286
February	1.14	420	4,233	250	2,467	44.8	14	139	27	264
March	1.43	288	3,401	200	2,410	36.0	16	189	26	303
April	1.54	399	4,941	177	2,268	52.3	9	109	20	266
May	1.21	491	5,090	264	2,733	53.9	15	160	16	168
June	1.26	454	4,835	261	2,835	51.2	22	224	20	217
July	1.41	413	4,896	297	3,548	51.8	19	227	24	278

APPENDIX C

Off-Gas Oxygen Transfer Test Results

Off-gas Analysis Equations and Nomenclature

Data Collected in Field:

F_{CO_2}	Mole fraction of carbon dioxide in off-gas
H_{OG}, H_R	Absolute humidity, off-gas and reference gas (air), lb. water/lb. dry air.
M_{OG}/M_R	Oxygen sensor output, millivolts, for off-gas and reference gas.
MLT	Mixed Liquor Temperature
$C^*_\infty - C$	Dissolved Oxygen deficit, C* , is D.O. saturation for ML, C is actual D.O. @ test site.
A_s	Area of off-gas collection hood, square feet.
P_s	Absolute Barometric pressure, in Hg
R_{mm}	Rotometer float height, mm
P_1	Hood pressure, inches water column
P_2	Vacuum at oxygen sensor, in w.c.

Data To Be Computed:

Symbol	Definition
F_{OR}	Mole fraction of oxygen in reference gas
	$F_{OR} = 0.2095\ (1 - H_R\ (29/18))$
R_R	Mole ratio, oxygen to inerts in reference gas

$$R_R = \frac{F_{OR}}{1 - F_{OR} - (H_R(29/18))}$$

$$29/18 = \frac{\text{Molecular Wt Air}}{\text{Molecular Wt } H_2O}$$

(continued)

Symbol	Definition
F_{OG}	Mole fraction of oxygen in off-gas $F_{OG} = F_{OR} \times M_{OG}/M_R$
R_{OG}	Mole ratio of oxygen to inerts in off-gas $R_{OG} = \frac{F_{OG}}{1 - F_{OG} - F_{CO_2} - H_{OG}(29/18)}$
OTE_{TF}	OTE at field conditions $OTE_{TF} = \frac{R_R - R_{OG}}{R_R}$
OTE_{SP}	OTE corrected to standard conditions $OTE_{SP20} = \frac{OTE_{TF}}{C^*_\infty - C} \quad (1.024)^{20-MLT}$ Specific OTE, i.e., OTE per unit (mg/l) of driving force.
OTE_{TF}	Mean weighted field oxygen transfer efficiency. $OTE_{TF} = \frac{(OTE_{TF} \times Q_A)}{Q_A}$
$\overline{OTE}_{SP}$	Mean weighted specific oxygen transfer efficiency. $\overline{OTE}_{SP} = \frac{\Sigma(OTE_{SP} \times Q_A)}{\Sigma Q_A}$
X	Flow rate correction factor to air flow rate for oxygen depletion, mixed liquor temperature, pressure and humidity.

(continued)

Symbol	Definition

$$X = \frac{1}{1 - 0.21\,(OTE_{TF})\,A_s} \times \left[\frac{293}{(273 + MLT)}\right]^{0.5} \times \left[\frac{P_s - \frac{P_1 + P_2}{27}}{29.92}\right]^{0.5} \times \frac{1 - H_{OG}\,(29/18)}{1 - 0.007\,(29/18)}$$

Q_{A1}

Q_{A2} Corrected air flow rates for small (1) and large (2) rotameters.

$$Q_{A1} = \frac{0.0235\,R_{mm} + 0.34}{A_S}$$

$$Q_{A2} = \frac{0.0909\,R_{mm} + 1.85}{A_S}$$

AIRFLOW version 3.01 on 29-MAY-1987 10:54:41.71

Aerator name:
Project number: 336.05.01 Title: Frankenmuth ASCE Study
Data created by: OFFGAS version 3.01 on 28-MAY-1987 15:47:23.86

Date of sample: 14-APR-1987
Data entered 28-MAY-1987 15:50:31.06

SW NO. 1

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1011.	0.207	0.265	0.190	0.240	0.09378	0.00932	1.0082	0.8356
2.	1033.	0.207	0.265	0.189	0.238	0.10351	0.01023	1.0103	0.8465
3.	1111.	0.207	0.265	0.187	0.234	0.11741	0.01159	1.0150	0.7120
4.	1124.	0.207	0.265	0.189	0.237	0.10410	0.01029	1.0121	0.7468

Mean weighted OTE : 0.10422
Mean weighted OTESP: 0.01032

Avg. 0.7852

QA/DIFF=1.90 SCFM

Date of sample: 14-APR-1987
Data entered 28-MAY-1987 15:58:58.09

SE NO. 2

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1205.	0.207	0.265	0.194	0.245	0.07386	0.00728	1.0062	0.7150
2.	1228.	0.207	0.265	0.189	0.237	0.10454	0.01031	1.0129	0.6507
3.	1250.	0.207	0.265	0.186	0.233	0.12029	0.01184	1.0163	0.6437
4.	1313.	0.207	0.265	0.192	0.242	0.08631	0.00849	1.0089	0.6711

Mean weighted OTE : 0.09557
Mean weighted OTESP: 0.00941

Avg.= 0.6701

QA/DIFF=1.62 SCFM

Date of sample: 14-APR-1987
Data entered 28-MAY-1987 16:05:24.95

NE NO.3

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1456.	0.207	0.265	0.183	0.228	0.14034	0.01594	1.0191	0.8678
2.	1512.	0.207	0.265	0.187	0.235	0.11428	0.01342	1.0134	0.8031
3.	1425.	0.207	0.265	0.192	0.242	0.08864	0.01078	1.0079	0.8903
4.	1438.	0.207	0.265	0.192	0.241	0.08960	0.01077	1.0081	0.8721

Mean weighted OTE : 0.10795
Mean weighted OTESP: 0.01270

Avg.= 0.8583

QA/DIFF=2.08 SCFM

Date of sample: 14-APR-1987
Data enter 28-MAY-1987 16:10:41.14

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1614.	0.207	0.265	0.200	0.255	0.03629	0.01294	0.9931	0.7373
2.	1627.	0.207	0.265	0.200	0.256	0.03262	0.01204	0.9923	0.8450
3.	1536.	0.207	0.265	0.195	0.247	0.06772	0.01892	0.9998	0.6605
4.	1550.	0.207	0.265	0.194	0.246	0.07123	0.02231	1.0005	0.6519

Mean weighted OTE : 0.05026
Mean weighted OTESP: 0.01615

NO. 4

NW

AVG~.7237 QA/DIFF=1.75 SCFM

Date of sample: 15-APR-1987
Data entered 28-MAY-1987 16:15:42.21

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1105.	0.207	0.265	0.192	0.245	0.07550	0.01253	0.9955	0.2965
2.	1117.	0.207	0.265	0.192	0.244	0.07829	0.01321	0.9961	0.3025
3.	1039.	0.207	0.265	0.187	0.235	0.11320	0.01941	1.0086	0.2672
4.	1050.	0.207	0.265	0.180	0.225	0.15027	0.02535	1.0134	0.2366

Mean weighted OTE : 0.10231
Mean weighted OTESP: 0.01728

NO. 5

NW

AVG~.2807 QA/DIFF=0.68 SCFM

Date of sample: 15-APR-1987
Data entered 28-MAY-1987 16:22:21.73

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1144.	0.206	0.265	0.178	0.223	0.15911	0.01956	1.0150	0.7212
2.	1154.	0.206	0.265	0.180	0.226	0.14614	0.01677	1.0104	0.7043
3.	1211.	0.206	0.265	0.177	0.221	0.16640	0.01773	1.0149	0.7028
4.	1224.	0.206	0.265	0.188	0.239	0.09998	0.01229	1.0021	0.7121

Mean weighted OTE : 0.14287
Mean weighted OTESP: 0.01659

NO. 6

NE

AVG~.7101 QA/DIFF=1.72

Date of sample: 15-APR-1987
Data ente 28-MAY-1987 16:27:05.09

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1415.	0.206	0.265	0.192	0.245	0.07689	0.00757	0.9928	0.7416
2.	1357.	0.206	0.265	0.187	0.237	0.10392	0.01020	1.0002	0.5471
3.	1344.	0.206	0.265	0.186	0.235	0.11372	0.01117	1.0023	0.6302
4.	1334.	0.206	0.265	0.188	0.238	0.10144	0.00997	0.9996	0.6513

Mean weighted OTE : 0.09790
Mean weighted OTESP: 0.00962

AVG-0.6426

NO. 7

SE

QA/DIFF=1.56 SCFM

Date of sample: 15-APR-1987
Data entered 28-MAY-1987 16:31:46.06

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1507.	0.206	0.265	0.190	0.241	0.09185	0.00906	1.0007	0.7611
2.	1457.	0.206	0.265	0.190	0.241	0.09105	0.00896	0.9989	0.6917
3.	1441.	0.206	0.265	0.186	0.235	0.11507	0.01134	1.0024	0.6531
4.	1428.	0.206	0.265	0.188	0.238	0.10058	0.00993	1.0009	0.6794

Mean weighted OTE : 0.09923
Mean weighted OTESP: 0.00978

AVG-.6963

NO. 8

SW

QA/DIFF = 1.69

Date of sample: 15-APR-1987
Data entered 29-MAY-1987 10:50:46.71

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	944.	0.207	0.265	0.199	0.255	0.03942	0.01478	0.9928	0.9221
2.	930.	0.207	0.265	0.198	0.253	0.04589	0.01661	0.9942	0.8918
3.	1019.	0.207	0.265	0.196	0.249	0.05936	0.01946	0.9970	0.7266
4.	1002.	0.207	0.265	0.194	0.247	0.06953	0.02432	0.9992	0.6919

Mean weighted OTE : 0.05213
Mean weighted OTESP: 0.01838

AVG-.8081

NO. 9

NW

QA/DIFF=1.96

Aerator name: Sanitaire Fine
Project number: 356.05.01 Title: SE Tank before Cleaning
Data created by: OFFGAS version 3.01 on 25-JUN-1987 19:12:23.48

Date of sample: 22-JUN-1987
Data entered 25-JUN-1987 19:13:37.78

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	915.	0.205	0.265	0.189	0.242	0.08858	0.00856	0.9837	0.7706
2.	945.	0.205	0.265	0.189	0.242	0.08649	0.00843	0.9832	0.6764
3.	1000.	0.205	0.265	0.189	0.242	0.08873	0.00855	0.9837	0.6588
4.	1020.	0.205	0.265	0.192	0.247	0.06859	0.00662	0.9795	0.6515

Mean weighted OTE : 0.08338
Mean weighted OTESP: 0.00807

AVG-.6893 (2.42)=1.67 SCFM/DIFF

SE

Aerator name: Sanitaire Fine
Project number: 356.05.01 Title: SE Tank after cleaning
Data created by: OFFGAS version 3.01 on 25-JUN-1987 19:30:44.95

Date of sample: 22-JUN-1987
Data entered 25-JUN-1987 19:31:28.61

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1435.	0.206	0.265	0.194	0.248	0.06512	0.00627	0.9798	0.6740
2.	1400.	0.206	0.265	0.190	0.242	0.08557	0.00835	0.9824	0.6937
3.	1340.	0.206	0.265	0.191	0.243	0.08337	0.00800	0.9836	0.5514
4.	1245.	0.206	0.265	0.194	0.249	0.06199	0.00597	0.9775	0.7968

Mean weighted OTE : 0.07313
Mean weighted OTESP: 0.00707

AVG-.6790 (2.42)=1.64 SCFM/DIFF

SE

Aerator name: Sanitaire Fine
Project number: 356.05.01 Title: NE Tank before cleaning
Data created by: OFFGAS version 3.01 on 25-JUN-1987 19:22:33.17

Date of sample: 22-JUN-1987
Data entered 25-JUN-1987 19:23:48.21

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1210.	0.205	0.265	0.191	0.245	0.07405	0.00722	0.9784	0.9665
2.	1200.	0.205	0.265	0.185	0.236	0.11073	0.01075	0.9877	0.9533
3.	1130.	0.205	0.265	0.183	0.231	0.12737	0.01228	0.9929	0.8274
4.	1105.	0.205	0.265	0.186	0.236	0.10996	0.01062	0.9875	0.8454

Mean weighted OTE : 0.10451
Mean weighted OTESP: 0.01012

AVG-.8982 (2.42)=2.17 SCFM/DIFF

NE

Aerator name: Sanitaire Fine
Project number: 356.05.01 Title: NE Tank after Ddiffuser cleanin
Data created by: OFFGAS version 3.01 on 25-JUN-1987 19:40:12.08

Date of sample: 22-JUN-1987
Data entered 25-JUN-1987 19:40:52.21

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1620.	0.206	0.265	0.195	0.252	0.04977	0.00479	0.9712	0.8182
2.	1600.	0.206	0.265	0.190	0.246	0.07320	0.00702	0.9745	0.7766
3.	1540.	0.206	0.265	0.191	0.245	0.07650	0.00733	0.9784	0.6552
4.	1510.	0.206	0.265	0.190	0.244	0.08103	0.00778	0.9793	0.7761

Mean weighted OTE : 0.06959
Mean weighted OTESP: 0.00668

NE

AVG-.7565 (2.42)=1.83 SCFM/DIFF

Aerator name: Sanitaire Fine
Project number: 356.05.01 Title: NE Tank normal air flow
Data created by: OFFGAS version 3.01 on 25-JUN-1987 19:44:44.40

Date of sample: 23-JUN-1987
Data entered 25-JUN-1987 19:45:51.19

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	845.	0.206	0.265	0.185	0.239	0.09840	0.00961	0.9815	0.8268
2.	905.	0.206	0.265	0.182	0.234	0.11588	0.01125	0.9836	0.7660
3.	920.	0.206	0.265	0.182	0.233	0.12042	0.01152	0.9845	0.7488
4.	955.	0.206	0.265	0.188	0.243	0.08213	0.00786	0.9732	0.7845

Mean weighted OTE : 0.10387
Mean weighted OTESP: 0.01003

NE

AVG-.7815 (2.42)=1.89 SCFM/DIFF

Aerator name: Sanitaire Fine
Project number: 356.05.01 Title: NE Tank with reduced air flow
Data created by: OFFGAS version 3.01 on 25-JUN-1987 19:49:35.46

Date of sample: 23-JUN-1987
Data entered 25-JUN-1987 19:50:10.56

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1125	0.205	0.265	0.188	0.244	0.07928	0.00758	0.9666	0.4409
2.	1105.	0.205	0.265	0.187	0.243	0.08281	0.00790	0.9689	0.4243
3.	1045.	0.205	0.265	0.181	0.233	0.12125	0.01159	0.9802	0.4114
4.	1025.	0.205	0.265	0.182	0.233	0.12022	0.01149	0.9800	0.4203

Mean weighted OTE : 0.10048
Mean weighted OTESP: 0.00960

NE

AVG-.4242 (2.42)=1.03 SCFM/DIFF

Aerator name: Sanitaire Fine
Project number: 356.05.01 Title: SE Tank normal air flow
Data created by: OFFGAS version 3.01 on 25-JUN-1987 19:57:42.29

Date of sample: 23-JUN-1987
Data entered 25-JUN-1987 19:58:17.03

SE

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1205.	0.205	0.265	0.193	0.254	0.04120	0.00394	0.9537	0.7688
2.	1225.	0.205	0.265	0.187	0.246	0.07180	0.00686	0.9599	0.7563
3.	1235.	0.205	0.265	0.181	0.236	0.11099	0.01060	0.9697	0.6582
4.	1255.	0.205	0.265	0.185	0.244	0.08025	0.00767	0.9617	0.7184

Mean weighted OTE : 0.07468
Mean weighted OTESP: 0.00714

AVG-.7254 (2.42)=1.76 SCFM/DIFF

Aerator name: Sanitaire Fine
Project number: 356.05.01 Title: SE Tank reduced air flow
Data created by: OFFGAS version 3.01 on 25-JUN-1987 20:02:01.82

Date of sample: 23-JUN-1987
Data entered 25-JUN-1987 20:02:38.83

SE

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1405.	0.205	0.265	0.187	0.247	0.06790	0.00647	0.9523	0.4733
2.	1345.	0.205	0.265	0.184	0.241	0.08897	0.00848	0.9582	0.4762
3.	1330.	0.205	0.265	0.185	0.244	0.07946	0.00758	0.9562	0.4839
4.	1315.	0.205	0.265	0.186	0.246	0.07287	0.00695	0.9565	0.4580

Mean weighted OTE : 0.07737
Mean weighted OTESP: 0.00738

AVG-.4729 (2.42)=1.14 SCFM/DIFF

Aerator name: Sanitaire Fine
Project number: 356.05.01 Title:SW Tank in stabilization mode
Data created by: OFFGAS version 3.01 on 25-JUN-1987 20:06:16.44

Date of sample: 23-JUN-1987
Data entered 25-JUN-1987 20:06:55.04

SW

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1520.	0.205	0.265	0.179	0.239	0.09802	0.00926	0.9512	0.7019
2.	1505.	0.205	0.265	0.179	0.238	0.10059	0.00950	0.9518	0.6893
3.	1450.	0.205	0.265	0.177	0.235	0.11427	0.01081	0.9562	0.6317
4.	1435.	0.205	0.265	0.180	0.239	0.09779	0.00925	0.9545	0.6435

Mean weighted OTE : 0.10248
Mean weighted OTESP: 0.00968

AVG-0.6666 (2.42)=1.61 SCFM/DIFF

Sanitaire Fine 8356.05.01 Frankenmuth ASCE Study OFFGAS version 4.00 on 12-OCT-1987 16:26:33.74

Date of sample: 9-Sep-1987
Data entered 12-OCT-1987 16:29:01.54

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA	
1.	1130.	0.206	0.265	0.182	0.234	0.11648	0.01114	0.9782	0.5594	SE
2.	1155.	0.206	0.265	0.182	0.230	0.13066	0.01248	0.9891	0.4675	
3.	1215.	0.206	0.265	0.181	0.229	0.13460	0.01286	0.9899	0.4769	Low QA
4.	1240.	0.206	0.265	0.184	0.235	0.11199	0.01070	0.9802	0.5526	

Mean weighted OTE : 0.12270
Mean weighted OTESP: 0.01172

0.5141 x 2.42=1.24 SCFM

Date of sample: 9-Sep-1987
Data entered 12-OCT-1987 16:35:55.23

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA	
1.	1430.	0.205	0.265	0.192	0.251	0.05447	0.00523	0.9600	0.8876	
2.	1410.	0.205	0.265	0.184	0.235	0.11148	0.01069	0.9767	0.7051	
3.	1345.	0.205	0.265	0.184	0.236	0.11026	0.01056	0.9764	0.7138	SE
4.	1320.	0.205	0.265	0.190	0.246	0.07074	0.00678	0.9650	0.8592	Higher QA
5.	1505.	0.205	0.265	0.191	0.250	0.05747	0.00553	0.9606	0.9013	
6.	1535.	0.205	0.265	0.191	0.251	0.05315	0.00512	0.9581	0.9001	

Mean weighted OTE : 0.07370
Mean weighted OTESP: 0.00707

0.8279=2.00/DIFF

Date of sample: 10-sep-1987
Data entered 12-OCT-1987 17:00:30.16

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA	
1.	1225.	0.205	0.265	0.186	0.242	0.08747	0.00841	0.9644	0.7977	
2.	1205.	0.205	0.265	0.183	0.236	0.10935	0.01052	0.9705	0.7364	
3.	1140.	0.205	0.265	0.181	0.233	0.12142	0.01168	0.9731	0.7339	SE
4.	1120.	0.205	0.265	0.189	0.245	0.07512	0.00723	0.9667	0.8580	Before Cleaning

Mean weighted OTE : 0.09721
Mean weighted OTESP: 0.00935

0.7815=1.89/DIFF

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1430.	0.205	0.265	0.188	0.246	0.07358	0.00707	0.9592	0.8230
2.	1450.	0.205	0.265	0.180	0.234	0.11740	0.01128	0.9683	0.7116
3.	1510.	0.205	0.265	0.181	0.234	0.11628	0.01117	0.9681	0.6552
4.	1540.	0.205	0.265	0.189	0.247	0.06671	0.00641	0.9578	0.7934
5.	1605.	0.205	0.265	0.187	0.243	0.07461	0.00718	0.9611	0.8497
6.	1625.	0.205	0.265	0.189	0.249	0.06128	0.00589	0.9583	0.8702

Mean weighted OTE : 0.08291
Mean weighted OTESP: 0.00797

SE
After Cleaning

0.7839=1.90/DIFF

Date of sample: 9-sep-1987
Data entered 13-OCT-1987 08:15:03.66

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1820.	0.206	0.265	0.193	0.255	0.03674	0.00844	0.9547	0.7777
2.	1805.	0.206	0.265	0.188	0.245	0.07687	0.01630	0.9628	0.7975
3.	1735.	0.206	0.265	0.185	0.241	0.08901	0.01888	0.9637	0.7906
4.	1715.	0.206	0.265	0.188	0.244	0.07852	0.01665	0.9680	0.7854
5.	1600.	0.206	0.265	0.194	0.254	0.03999	0.00479	0.9585	0.8535
6.	1630.	0.206	0.265	0.193	0.253	0.04540	0.00683	0.9596	0.8655

Mean weighted OTE : 0.06064
Mean weighted OTESP: 0.01182

NE
High QA

0.8117=1.96/DIFF

Date of sample: 10-sep-1987
Data entered 13-OCT-1987 08:21:26.38

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	910.	0.206	0.265	0.194	0.251	0.05373	0.01201	0.9754	0.8012
2.	930.	0.206	0.265	0.190	0.245	0.07403	0.01570	0.9764	0.8176
3.	1000.	0.206	0.265	0.187	0.241	0.09078	0.01831	0.9799	0.8060
4.	1020.	0.206	0.265	0.189	0.245	0.07715	0.01679	0.9738	0.7821

Mean weighted OTE : 0.07393
Mean weighted OTESP: 0.01570

NE
Before Cleaning

0.8017=1.94/DIFF

Date of sample: 10-sep-1987
Data entered 13-OCT-1987 08:25:02.55

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1720.	0.205	0.265	0.186	0.243	0.08161	0.01125	0.9623	0.7323
2.	1740.	0.205	0.265	0.183	0.239	0.09865	0.01484	0.9675	0.7406
3.	1800.	0.205	0.265	0.180	0.235	0.11497	0.01698	0.9693	0.7464
4.	1820	0.205	0.265	0.188	0.248	0.06478	0.00940	0.9605	0.75[illegible]

Mean weighted OTE : 0.08995
Mean weighted OTESP: 0.01311

NE
After Cleaning

0.7436=1.80/DIFF

sanitaire 356.05.01 frankenmuth OFFGAS version 4.00 on 14-DEC-1987 15:55:49.29

Date of sample: 12-9-87
Data entered 14-DEC-1987 15:56:54.49

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
6.	1110.	0.207	0.265	0.187	0.236	0.11046	0.01129	1.0064	0.9061
6.	1137.	0.207	0.265	0.188	0.237	0.10580	0.01092	1.0054	0.9097
6.	1207.	0.207	0.265	0.186	0.234	0.11660	0.01473	1.0093	0.9042
6.	1233.	0.207	0.265	0.190	0.239	0.09685	0.01304	1.0051	0.8546

Mean weighted OTE : 0.10758
Mean weighted OTESP: 0.01248

NE

0.8937 2.42=2.16 scrm/diff

Date of sample: 12-9-87
Data entered 14-DEC-1987 16:02:01.12

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
3.	1307.	0.207	0.265	0.188	0.238	0.10319	0.01563	1.0068	0.8012
3.	1422.	0.207	0.265	0.177	0.221	0.16448	0.02384	1.0219	0.5392
3.	1500.	0.207	0.265	0.193	0.245	0.07449	0.01020	1.0023	0.7110
3.	1520.	0.207	0.265	0.188	0.239	0.09910	0.01548	1.0075	0.7240

Mean weighted OTE : 0.10668
Mean weighted OTESP: 0.01580

NW

0.6939 → 1.68 scfm/diff

Date of sample: 12-9-87
Data entered 16-DEC-1987 10:47:02.14

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
4.	1556.	0.207	0.265	0.193	0.245	0.07495	0.00737	1.0043	0.8586
4.	1630.	0.207	0.265	0.193	0.245	0.07612	0.00746	1.0046	0.6579
4.	1650.	0.207	0.265	0.195	0.247	0.06964	0.00685	1.0032	0.6980
4.	1705.	0.207	0.265	0.194	0.246	0.07084	0.00694	1.0035	0.6663

Mean weighted OTE : 0.07298
Mean weighted OTESP: 0.00717

SW

0.7202 → 1.74 scfm/diff

Date of sample: 12-10-87
Data entered 16-DEC-1987 10:52:17.35

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
5.	857.	0.208	0.265	0.194	0.246	0.07117	0.00703	1.0067	0.8560
5.	915.	0.208	0.265	0.192	0.243	0.08357	0.00821	1.0110	0.8000
5.	950.	0.208	0.265	0.193	0.244	0.08119	0.00798	1.0105	0.9327
5.	1010.	0.208	0.265	0.195	0.246	0.07044	0.00692	1.0065	0.9428

Mean weighted OTE : 0.07643
Mean weighted OTESP: 0.00752

SE

0.8829 ⇒ 2.14 scfm/diff

Date of sample: 12-10-87
Data entered 16-DEC-1987 10:56:04.67

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
6.	1045.	0.208	0.265	0.189	0.238	0.10303	0.01024	1.0094	0.9501
6.	1110.	0.208	0.265	0.190	0.240	0.09291	0.00918	1.0073	0.9526
6.	1130.	0.208	0.265	0.190	0.241	0.09001	0.00893	1.0050	0.9459
6.	1155.	0.208	0.265	0.183	0.230	0.13367	0.01320	1.0145	0.9549

Mean weighted OTE : 0.10495
Mean weighted OTESP: 0.01039

NE

0.9509 ⇒ 2.30 scfm/diff

Date of sample: 12-10-87
Data entered 16-DEC-1987 11:00:53.69

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
6.	1430.	0.208	0.265	0.195	0.248	0.06444	0.00769	0.9995	0.9362
6.	1455.	0.208	0.265	0.189	0.239	0.09995	0.01010	1.0088	0.9036
6.	1515.	0.208	0.265	0.197	0.251	0.05339	0.00528	0.9988	0.8856
6.	1530.	0.208	0.265	0.194	0.246	0.07251	0.00715	1.0029	0.8938

Mean weighted OTE : 0.07260
Mean weighted OTESP: 0.00757

NE

0.9048 ⇒ 2.19 scfm/diff

Date of sample: 12-10-87
Data entered 16-DEC-1987 14:16:33.43

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
5.	1600.	0.208	0.265	0.197	0.250	0.05713	0.00557	0.9998	0.8819
5.	1615.	0.208	0.265	0.198	0.252	0.05054	0.00492	0.9984	0.8807
5.	1640.	0.208	0.265	0.193	0.244	0.08021	0.00781	1.0063	0.7139
5.	1705.	0.208	0.265	0.193	0.244	0.07958	0.00775	1.0046	0.8862

Mean weighted OTE : 0.06622
Mean weighted OTESP: 0.00645

SE

0.8407 ⇒ 2.03 scfm/diff

Date of sample: 12-11-87
Data entered 16-DEC-1987 16:52:32.72

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
5.	855.	0.208	0.265	0.193	0.244	0.07789	0.00775	1.0079	0.8296
5.	1020.	0.208	0.265	0.193	0.244	0.07827	0.00769	1.0063	0.7780
5.	1040.	0.208	0.265	0.196	0.248	0.06407	0.00632	1.0033	0.7984
5.	1100.	0.208	0.265	0.194	0.247	0.06957	0.00684	1.0045	0.8222

SE

Mean weighted OTE : 0.07245
Mean weighted OTESP: 0.00715

0.8071 → 1.95 scfm/diff

Date of sample: 12-11-87
Data entered 17-DEC-1987 11:37:13.00

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
6.	1145.	0.208	0.265	0.190	0.240	0.09587	0.00946	1.0015	0.7970
6.	1210.	0.208	0.265	0.194	0.246	0.07005	0.00691	0.9960	0.8922
6.	1440.	0.208	0.265	0.188	0.238	0.10312	0.01331	1.0030	0.7709
6.	1455.	0.208	0.265	0.194	0.247	0.06810	0.00978	0.9956	0.8963

NE

Mean weighted OTE : 0.08326
Mean weighted OTESP: 0.00975

0.8391 → 2.03 scfm/diff

Date of sample: 12-11-87
Data entered 17-DEC-1987 11:41:06.94

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
3.	1245.	0.208	0.265	0.192	0.245	0.07613	0.00792	0.9956	0.8874
3.	1305.	0.208	0.265	0.184	0.232	0.12410	0.01349	1.0076	0.6599
3.	1400.	0.208	0.265	0.192	0.246	0.07247	0.00810	0.9949	0.7691
3.	1420.	0.208	0.265	0.174	0.218	0.17849	0.02049	1.0195	0.5750

NW

Mean weighted OTE : 0.10646
Mean weighted OTESP: 0.01174

0.7229 → 1.75 scfm/diff

SANITAIRE 356.05.01 ASCE STUDY OFFGAS version 4.00 on 12-APR-1988 08:55:55.99

Date of sample: 3/28/88
Data entered 12-APR-1988 08:56:48.33

	Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
S.E.	1.	1025.	0.208	0.265	0.194	0.248	0.06605	0.00685	1.0078	0.9193
	2.	1040.	0.208	0.265	0.197	0.252	0.04976	0.00514	1.0052	0.9124
	3.	1000.	0.208	0.265	0.195	0.249	0.05860	0.00614	1.0054	0.9491
	4.	1010.	0.208	0.265	0.190	0.242	0.08560	0.00888	1.0112	0.9224

Mean weighted OTE : 0.06500
Mean weighted OTESP: 0.00675

AVG-0.9258

QA/DIFF=2.24 SCFM

Date of sample: 3/28/88
Data entered 12-APR-1988 09:06:21.38

	Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
N.E.	1.	1135.	0.208	0.265	0.196	0.251	0.05335	0.01108	1.0092	0.9756
	2.	1200.	0.208	0.265	0.196	0.251	0.05238	0.01327	1.0081	1.0296
	3.	1220.	0.208	0.265	0.200	0.257	0.03152	0.00836	1.0045	1.0168
	4.	1120.	0.208	0.265	0.198	0.254	0.04113	0.01009	1.0066	0.9731

Mean weighted OTE : 0.04457
Mean weighted OTESP: 0.01071

0.9988

2.42 SCFM

Date of sample: 3/28/88
Data entered 12-APR-1988 09:12:03.03

	Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
N.E.	1.	220.	0.208	0.265	0.195	0.251	0.05346	0.01090	1.0074	1.0426
	2.	210.	0.208	0.265	0.195	0.249	0.06023	0.01500	1.0097	1.0450
	3.	200.	0.208	0.265	0.199	0.255	0.03647	0.00870	1.0054	1.0451
	4.	235.	0.208	0.265	0.198	0.256	0.03567	0.00816	1.0036	1.0660

Mean weighted OTE : 0.04640
Mean weighted OTESP: 0.01068

1.0500

2.54

Date of sample: 3/28/88
Data entered 12-APR-1988 09:15:43.57

	Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
S.W.	1.	330.	0.208	0.265	0.201	0.258	0.02723	0.00629	1.0024	1.0101
	2.	345.	0.208	0.265	0.201	0.259	0.02272	0.00629	1.0015	1.0228
	3.	300.	0.208	0.265	0.195	0.248	0.06388	0.01539	1.0111	1.0648
	4.	315.	0.208	0.265	0.195	0.250	0.05646	0.01304	1.0087	0.7642

Mean weighted OTE : 0.04192
Mean weighted OTESP: 0.01013

0.9655

→ 2.34

Date of sample: 3/28/88
Data entered 12-APR-1988 09:18:36.27

	Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
S.E.	1.	500.	0.208	0.265	0.193	0.247	0.06630	0.00661	1.0084	0.9337
	2.	515.	0.208	0.265	0.197	0.253	0.04554	0.00458	1.0040	0.9341
	3.	430.	0.208	0.265	0.195	0.251	0.05426	0.00546	1.0067	0.8908
	4.	445.	0.208	0.265	0.188	0.240	0.09513	0.00933	1.0147	0.9025

Mean weighted OTE : 0.06518
Mean weighted OTESP: 0.00653

0.9153

→ 2.21

Date of sample: 3/29/88
Data entered 12-APR-1988 09:21:18.06

	Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
S.E.	1.	925.	0.208	0.265	0.194	0.247	0.06783	0.00686	1.0048	0.7979
	2.	935.	0.208	0.265	0.196	0.251	0.05403	0.00552	1.0011	0.7903
	3.	910.	0.208	0.265	0.195	0.248	0.06304	0.00649	1.0046	0.7109
	4.	850.	0.208	0.265	0.190	0.240	0.09325	0.00948	1.0128	0.7674

Mean weighted OTE : 0.06952
Mean weighted OTESP: 0.00708

0.7666

→ 1.86

Date of sample: 3/29/88
Data entered 12-APR-1988 09:23:57.73

	Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
S.E.	1.	1025.	0.208	0.265	0.190	0.242	0.08707	0.00899	1.0084	1.0207
	2.	1015.	0.208	0.265	0.195	0.250	0.05749	0.00593	1.0021	1.0052
	3.	1050.	0.208	0.265	0.194	0.247	0.06646	0.00689	1.0040	0.9432
	4.	1040.	0.208	0.265	0.190	0.242	0.08789	0.00907	1.0086	0.9476

Mean weighted OTE : 0.07471
Mean weighted OTESP: 0.00772

0.9792

→ 2.37

Date of sample: 3/29/88
Data entered 12-APR-1988 09:26:43.39

	Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
S.W.	1.	1145.	0.207	0.265	0.195	0.250	0.05824	0.00602	1.0004	0.9444
	2.	1200.	0.207	0.265	0.193	0.247	0.06882	0.00715	1.0019	0.9503
	3.	1120.	0.207	0.265	0.195	0.249	0.05888	0.00603	1.0014	0.9135
	4.	1130.	0.207	0.265	0.193	0.246	0.07165	0.00738	1.0041	0.8931

Mean weighted OTE : 0.06435
Mean weighted OTESP: 0.00664

0.9253
⇒2.24

Date of sample: 3/29/88
Data entered 12-APR-1988 09:29:32.16

	Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
N.W.	1.	1230.	0.207	0.265	0.198	0.256	0.03491	0.01032	0.9925	0.8152
	2.	1250.	0.207	0.265	0.197	0.255	0.03764	0.01246	0.9923	0.8285
	3.	120.	0.207	0.265	0.188	0.239	0.09714	0.02531	1.0066	0.8084
	4.	135.	0.207	0.265	0.191	0.244	0.07967	0.01818	1.0028	0.8282

Mean weighted OTE : 0.06224
Mean weighted OTESP: 0.01654

0.8291
⇒1.98

Date of sample: 3/29/88
Data entered 12-APR-1988 09:32:29.12

	Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
N.E.	1.	210.	0.207	0.265	0.191	0.244	0.07789	0.01574	1.0014	0.9363
	2.	200.	0.207	0.265	0.193	0.248	0.06340	0.01731	0.9983	0.9016
	3.	235.	0.207	0.265	0.196	0.253	0.04526	0.01177	0.9945	0.9207
	4.	225.	0.207	0.265	0.192	0.247	0.06805	0.01580	0.9993	0.9025

Mean weighted OTE : 0.06369
Mean weighted OTESP: 0.01514

0.9153
⇒2.21

Date of sample: 3/29/88
Data entered 12-APR-1988 09:36:05.33

	Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
N.E.	1.	335.	0.207	0.265	0.195	0.252	0.05025	0.01389	0.9949	1.0296
	2.	350.	0.207	0.265	0.195	0.250	0.05531	0.02015	0.9960	1.0262
	3.	310.	0.207	0.265	0.199	0.257	0.02964	0.01117	0.9914	0.9269
	4.	325.	0.207	0.265	0.197	0.254	0.04269	0.01413	0.9941	0.9791

Mean weighted OTE : 0.04487
Mean weighted OTESP: 0.01494

0.9905
⇒2.40

SANITAIRE 356.05.01 FRANKENMUTH ASCE STUDY OFFGAS version 4.00 on 16-MAY-1988 13:50:59.82

Date of sample: 5/10/88
Data entered 16-MAY-1988 13:53:32.29

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	1210.	0.207	0.265	0.194	0.250	0.05671	0.00586	0.9861	0.8923
2.	1145.	0.207	0.265	0.194	0.250	0.05658	0.00591	0.9861	0.8251
3.	1100.	0.207	0.265	0.192	0.248	0.06336	0.00672	0.9875	0.8711
4.	1040.	0.207	0.265	0.194	0.250	0.05683	0.00612	0.9862	0.8475
5.	1230.	0.207	0.265	0.195	0.251	0.05139	0.00526	0.9850	0.9137
6.	1130.	0.207	0.265	0.188	0.241	0.08929	0.00937	0.9930	0.8534
7.	1115.	0.207	0.265	0.195	0.252	0.04967	0.00524	0.9847	0.8955
8.	1020.	0.207	0.265	0.192	0.248	0.06584	0.00786	0.9881	0.8312

Mean weighted OTE : 0.06104
Mean weighted OTESP: 0.00652

AVG=0.8662

QA/DIFF=2.10

SE, TANK 5
BEFORE

Date of sample: 5/10/88
Data entered 16-MAY-1988 14:00:37.71

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	615.	0.207	0.265	0.199	0.257	0.03067	0.00309	0.9822	0.7549
2.	505.	0.207	0.265	0.191	0.244	0.07758	0.00777	0.9921	0.8796
3.	445.	0.207	0.265	0.195	0.251	0.05456	0.00547	0.9872	0.8753
4.	425.	0.207	0.265	0.196	0.251	0.05241	0.00528	0.9868	0.8705
5.	600.	0.207	0.265	0.195	0.251	0.05443	0.00548	0.9872	0.8708
6.	520.	0.207	0.265	0.195	0.251	0.05434	0.00545	0.9872	0.8753
7.	530.	0.207	0.265	0.196	0.252	0.04879	0.00489	0.9860	0.8698
8.	410.	0.207	0.265	0.197	0.254	0.04171	0.00418	0.9845	0.8685

Mean weighted OTE : 0.05221
Mean weighted OTESP: 0.00524

AVG=0.8581

Q/DIFF=2.08

SE, TANK 5
AFTER (1st DAY)

Date of sample: 5/11/88
Data entered 16-MAY-1988 14:07:49.08

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	900.	0.207	0.265	0.190	0.243	0.08286	0.00845	1.0018	0.9293
2.	930.	0.207	0.265	0.186	0.237	0.10476	0.01068	1.0065	0.9382
3.	950.	0.207	0.265	0.192	0.246	0.07058	0.00720	0.9992	0.9177
4.	1045.	0.207	0.265	0.193	0.248	0.06485	0.00658	0.9979	0.9620
5.	915.	0.207	0.265	0.192	0.246	0.07254	0.00747	0.9996	0.9408
6.	1005.	0.207	0.265	0.189	0.240	0.09339	0.00943	1.0040	0.9222
7.	1020.	0.207	0.265	0.193	0.247	0.06657	0.00686	0.9983	0.9170
8.	1100.	0.207	0.265	0.192	0.248	0.06468	0.00653	0.9979	0.9710

Mean weighted OTE : 0.07744
Mean weighted OTESP: 0.00789

AVG=0.9373

Q/DIFF=2.27

SE, TANK 5
AFTER (following day)

Date of sample: 5/10/88
Data entered 16-MAY-1988 14:12:56.73

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	100.	0.207	0.265	0.189	0.241	0.08942	0.00924	0.9935	0.7861
2.	230.	0.207	0.265	0.194	0.248	0.06512	0.00659	0.9884	0.8180
3.	240.	0.207	0.265	0.195	0.251	0.05240	0.00528	0.9857	0.8292
4.	345.	0.207	0.265	0.195	0.250	0.05375	0.00561	0.9864	0.8702
5.	155.	0.207	0.265	0.198	0.253	0.03768	0.00381	0.9827	0.7731
6.	250.	0.207	0.265	0.194	0.248	0.06381	0.00639	0.9881	0.8268
7.	315.	0.207	0.265	0.191	0.244	0.08076	0.00809	0.9917	0.8207
8.	330.	0.207	0.265	0.194	0.249	0.05976	0.00602	0.9873	0.8350

Mean weighted OTE : 0.06306
Mean weighted OTESP: 0.00638

AVG=0.8199

SW, TANK 4

Q/DIFF=1.98

Date of sample: 5/11/88
Data entered 16-MAY-1988 14:18:30.21

Station	Time	FOR	RR	FOG	ROG	OTE	OTESP	XFACT	QA
1.	100.	0.207	0.265	0.191	0.245	0.07533	0.00755	0.9972	0.8389
2.	1115.	0.207	0.265	0.192	0.247	0.06673	0.00675	0.9953	0.8645
3.	1220.	0.207	0.265	0.195	0.250	0.05663	0.00565	0.9932	0.8445
4.	115.	0.207	0.265	0.197	0.254	0.04161	0.00417	0.9900	0.8419
5.	1235.	0.207	0.265	0.194	0.250	0.05508	0.00552	0.9929	0.8082
6.	1205.	0.207	0.265	0.193	0.249	0.06089	0.00610	0.9941	0.8363
7.	1150.	0.207	0.265	0.191	0.246	0.07326	0.00742	0.9967	0.8928
8.	1130.	0.207	0.265	0.194	0.250	0.05509	0.00555	0.9929	0.8894

Mean weighted OTE : 0.06067
Mean weighted OTESP: 0.00610

AVG=0.8521

SW, TANK 4

Q/DIFF=2.06