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OFF-GAS ANALYSIS RESULTS AND FINE PORE RETROFIT CASE HISTORY FOR HARTFORD, CONNECTICUT

by

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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/625/1-89/023) 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

In the summer of 1982, the Hartford Metropolitan District Commission, Hartford County, Connecticut, Water Pollution Control Facility underwent a retrofit form a spiral roll coarse bubble to a full floor coverage fine pore aeration system. Work performed included all new in-tank piping and diffuser equipment and the installation of new filters on the blower air intakes. From November 1985 through August 1987, on-site studies were performed using off-gas analysis as part of the ASCE/EPA Fine Pore Aeration. This report presents the results of over 340 off-gas tests together with a case history of the retrofit to upgrade the aeration system. Historical information, retrofit evolution and implementation, aeration performance after the retrofit, cleaning and maintenance experience, and comparison of performance with pre-retrofit data are included in the report.

This report was submitted in partial fulfillment of Cooperative Agreement No. CR812167 by the American Society of Civil Engineers under subcontract to Aeration Technologies, Inc. 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

This investigation and study would not have been possible without facilities use authorization by the Metropolitan District Commission, Hartford, CT. Messers. Paul Gilbert, James Chase, and Richard Ehman together with the Water Pollution Control Facility staff provided information and support which were invaluable to the study. Their cooperation and assistance are greatly appreciated.

1.0 INTRODUCTION

In 1968 the consulting engineering firm of Metcalf & Eddy, Boston, MA, was retained by the Metropolitan District Commission, Hartford County, CT, to initiate the design and to prepare plans and specifications for the construction of a secondary activated sludge wastewater treatment facility at the main wastewater treatment plant at South Meadows, Hartford, CT.

In November 1972 the new secondary activated sludge wastewater treatment facility began operation. The plant was designed for a hydraulic capacity of 60 MGD at average flow and 109 MGD at peak flow. The activated sludge aeration system consisted of six identical four-pass aeration tanks, each 80 feet wide by 194 feet long with nominal operating liquid depth of 15.5 feet. The original aeration equipment consisted of Chicago Pump Co. "Deflectofusers." These diffusers were coarse bubble devices with large 3/8-inch diameter orifices on the periphery of the diffuser. Approximately 250 of these diffusers were installed in each aeration pass on seven drop pipe/manifold assemblies per pass. Each of the six aeration tanks contained four aeration passes. The diffuser assemblies were located approximately 2.5 feet above the tank floor and 2.5 feet from the tank side wall. A spiral-roll aeration and mixing pattern was established by this design geometry and diffuser placement. The Standard Oxygen Transfer Efficiency (SOTE) of the "Deflectofuser" system at Hartford was estimated to be between 6 and 7 percent.

From the beginning of operation of the new secondary activated sludge wastewater treatment facility through 1979, total plant electrical costs increased steadily from about $300,000 per year in 1973 to over $900,000 per year in 1979. Between 1979 and 1982 a large decrease in energy usage was realized by the upgrading of sludge handling and treatment equipment from coil filters to belt filter presses and initiation of a new incinerator operating mode. In spite of these electrical cost reduction improvements, the total plant electrical costs continued to rise at an alarming rate. With the prediction for steadily increasing costs for energy due to electrical rate increases through the 1980's and 1990's and the demand for greater air flow to supply increasing amounts of oxygen to the activated sludge process, it became apparent to the MDC personnel that energy efficient aeration equipment must be considered for the treatment facility.

Beginning in 1978, MDC staff engineers undertook an in-house investigation to evaluate the feasibility of replacing the existing coarse bubble spiral-roll aeration equipment with high efficiency (low energy usage) aeration equipment.

This report contains a detailed presentation of the aeration equipment upgrade project at the Hartford facility together with the results of over 340 off-gas tests conducted during eleven site visits from September 1985 through August 1987. Table No. 1 contains a chronological summary of the activities which have taken place from the initial design of secondary wastewater treatment facilities to the completion of off gas testing of the fine pore dome diffuser equipment in August of 1987.

The report is divided into the following major topical sections:

1. Introduction
2. Summary
3. Historical Background Information
4. Fine Pore Aeration Retrofit Design Description
5. Operational Performance and Evaluation
6. Economic Considerations for Fine Pore Aeration
7. Recommendations

This Report also contains the following four appendices:

- I-A Summary of Individual Test Field Measurements and Computations for Off Gas Analysis
- I-B Photo Plates of Aeration Diffusers, Cleaning, and Off Gas Equipment
- I-C Overall Plant Data Sheet Based on Previous Year of Record
- I-D Dome Diffuser Characterization Tests Before and After Cleaning

Table 1

CHRONOLOGICAL SUMMARY

TIME	EVENT
Early 1968	Begin design of secondary treatment facilities by Metcalf & Eddy.
Nov. 1972	Startup of new secondary treatment facilities.
Early 1978 through Nov. 1979	Hartford MDC staff undertakes research and investigation project for Fine Pore retrofit.
1980 through Sept. 1981	Metcalf & Eddy conducts cost-effectiveness study for Fine Pore retrofit.
Late 1981 through Feb. 1982	MDC staff prepares contract documents documents for bid of Fine Pore retrofit.
March 1982	Fine Pore retrofit project bid.
Summer 1982	Fine Pore retrofit installation.
Nov. 1982	Fine Pore retrofit placed on line.
Aug. 1985 through Jan. 1986	Metcalf & Eddy conducts air blower replacement evaluation.
Sept. 1985 through Aug. 1987	ASCE/EPA Oxygen Transfer Study undertaken undertaken in Aeration Tank No. 2 (342 off-gas tests conducted).
Oct. 1985	Aeration Tank No. 2 diffusers cleaned for the first time.
May 1987	Aeration Tank No. 2 diffusers cleaned for the second time.

The Summary, which follows this section, contains the significant overview results, observations, conclusions, and recommendations based on the detailed findings and evaluations presented in the main body of the report.

2.0 SUMMARY

2.1 GENERAL

The replacement of coarse bubble spiral-roll aeration equipment with full floor coverage fine pore dome diffuser aeration equipment at the Hartford Water Pollution Control Plant has proven to be cost-effective. Mixed liquor oxygen transfer efficiency more than doubled, and blower power consumption was reduced by over 40 percent of the previous baseline usage. Annual electrical cost savings resulted in a project payback of less than three years.

A chronological presentation of plant and aeration system performance is summarized in Table No. 4. Average monthly data is presented for airflow and blower power consumption versus plant flow and BOD removed. Table No. 5 contains wastewater characteristics and plant operations data for the off-gas site visits, and Table No. 8 contains a summary of whole tank average off-gas performance results for seven site visit tests conducted over a two-year period.

Figure Nos. 5, 7, 8, 11, 12, and 13 contain information on the secondary treatment process and fine pore diffuser system details. Clean water and mixed liquor oxygen transfer efficiency data for both the fine pore and existing coarse bubble systems are presented on Figure No. 9. Whole tank average off-gas performance results are presented chronologically on Figure Nos. 22, 23, 24, and 25.

2.2 OFF-GAS TESTING RESULTS

The results of the field off-gas measurements were consistent with the wastewater characteristics and process parameters--there was a great degree of variability in all data. Off-gas oxygen transfer efficiency varied widely from site visit to site visit, test to test, and from sample point to sample point. Replicate off-gas results of one sample location generally varied by a small amount. Wastewater flow rate and organic loading varied significantly during site visits and from visit to visit. Process parameters such as MLSS concentration, diffuser airflow, and mean cell residence time also varied widely throughout the study.

Because of the wide variability in off-gas results, wastewater characteristics, and process parameters, it was not possible to establish clear trends between oxygen transfer performance and operating modes, or the effect of cleaning diffusers on oxygen transfer performance.

There was no definite trend in oxygen transfer performance results to indicate that diffuser cleaning was effective, or that oxygen transfer efficiency degraded over time. Possible reasons for these results could be:

1. variations in the primary effluent quality and process operation,
2. rapid slime buildup on diffusers shortly after cleaning (possibly due to the high concentration of soluble BOD in the primary effluent),
3. coarse bubbling of diffusers due to gasket and dome bolt leaks, especially at high diffuser airflow rates, and
4. general wide variability in off-gas results from test to test.

The average whole tank oxygen transfer efficiency (alpha×SOTE) for all tests was 10.0 percent and ranged from 8.2 to 12.6 percent on a site visit by site visit basis. In comparison, average diurnal oxygen transfer efficiency tests for one twenty-four hour period averaged 8.3 percent with a range of 6.4 to 11.3 percent over the test period.

The average whole tank apparent alpha for all tests by site visit was 0.37 and ranged from 0.29 to 0.45. The average diurnal apparent alpha was 0.30 and ranged from 0.23 to 0.41. Apparent alpha* values ranged from under 0.2 to as high as 0.6 throughout the aeration tank, with the lower values usually representative of inlet sampling locations at the head end of the aeration passes.

2.3 OPERATION AND MAINTENANCE OBSERVATIONS

Operation and maintenance practices for the new fine pore aeration system differed very little from those practices used

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*Includes impact or wastewater characteristics and diffuser characteristic and any factor on transfer performance due to fouling.

when the coarse bubble spiral-roll system was in operation. Automatic control of air supply by dissolved oxygen monitoring was attempted as the fine pore aeration system came on-line, but automatic control of air supply was not successful. Manual air supply control with twice daily adjustment was initiated soon after start-up of the new system.

Dissolved oxygen monitoring is primarily limited to the fourth pass of the aeration tanks with no finite value of dissolved oxygen used as a set point upon which to adjust air supply.

Mixed liquor suspended solids concentration (MLSS) varies over a wide range and is usually higher in concentration than desirable for optimum process operation and control. As MLSS concentrations change so do food to biomass (F/M) ratios and mean cell residence times (MCRT). These parameters have a significant impact on oxygen demand per unit of BOD removed and the transfer of oxygen to the mixed liquor.

There is no routine inspection and cleaning schedule for the aeration equipment. Maintenance consists of repair to equipment based on visual observation of any air distribution problems at the liquid surface. Significant air leaks are noted and repaired as soon as a tank can be scheduled for shutdown.

2.4 DIFFUSER CLEANING COMMENTS

Cleaning of the diffuser equipment with hosing and acid application after three years of continuous, uninterrupted operation was beneficial. Although no clear improvement in oxygen transfer efficiency could be noted, diffuser headloss (dynamic wet pressure (DWP)) improved, and air leaks at gaskets and bolts were repaired.

Significant deposits of biological slime as well as inorganic materials covered the dome diffusers. Inorganic deposits were dispersed in patches on the top surface of the domes and along the vertical sides of the domes. Slime deposits generally were uniform over the dome surface. Wastewater inlet points at the head end of each pass contained grit and other solids on the tank floor to a depth of over one foot. Some dome diffusers were nearly buried in these deposits.

After three years of operation the dome and dome bolt gaskets originally supplied with the fine pore aeration system were badly cracked, causing air leaks at numerous points throughout the aeration system. The dome bolts, constructed of plastic, were loose in several places and many had failed, allowing air to exit in large quantities from the broken dome bolt.

A few of the stainless steel gear clamp-type pipe supports which attach the 4-inch grid piping to the pipe support and anchor had failed, allowing the grid pipe to bow up by as much as 2 to 3 inches. This condition caused greater air release at the high points, and over stressing of the adjacent supports.

Air leaks were repaired by rotating the dome and gasket on the saddle and retightening the dome bolt. If this did not work, new gaskets were installed. Several dome bolts were broken during this operation because of the tendency to overtighten the dome bolt to stop the air leak. With the plastic dome bolts, only 25 inch-pounds of torque are allowed on the dome bolt. This very small torque level is not sufficiently large to compress the old gaskets to seal tightly. Greater tightening of the dome bolt caused bolt failure. Failure did not always occur immediately. In some cases several days elapsed before the bolt failed--and after the aeration tank was placed back in service.

2.5 DESIGN COMMENTS

A preliminary evaluation of retrofit feasibility was completed and included qualitative pilot studies to determine the relative oxygen transfer efficiency differences between the existing and potential new equipment.

The engineer's cost-effectiveness study included good design detail for the proposed new equipment. No pilot work was done to establish actual values for alpha, and as a result, very high values were selected based on manufacturer experience and other information available at that time (1980). The resulting airflow requirements estimated by the engineer were on the low side (based on an alpha x SOTE of about 17.5 percent and an alpha value of 0.75). The engineer's estimated project cost was two to three times the actual cost, so the low cost offset the over estimated oxygen transfer performance (greater power savings), and the payback period for the project was reasonably close to the estimated payback period.

2.6 RECOMMENDATIONS

Evaluation of field oxygen transfer performance by off-gas testing is viable and useful. In systems where significant variations in plant loading and process operating modes occur, a greater number of off-gas tests, over a longer time base, provide more accurate average performance information than the results from specific sample point and/or point-in-time testing.

Fine pore retrofit or new applications' design should be based on accurate full scale Standard Oxygen Transfer Efficiency (SOTE) data, and realistic alpha factor values covering the range of process conditions, tank spatial location, and wastewater characteristic parameters. Where possible, pilot and/or full scale alpha testing should be undertaken, especially if unique conditions exist (i.e. industrial waste, special process streams, or other factors which could influence the alpha factor value). Pilot tests should use fouled as well as clean diffusers.

In the absence of alpha factor values based on specific testing, a design average range of 0.3 to 0.4 should be used for full floor coverage dome/disc fine pore aeration. The full range of alpha values could be from less than 0.2 to over 0.6, depending on the several factors which must be considered when designing the new system.

Mixed liquor alpha × SOTE values of 9 to 10 percent should be considered for fine pore dome/disc full floor coverage aeration systems operating at 15 feet of liquid depth (14-feet of diffuser submergence) in the conventional step-feed activated sludge process treating domestic wastewater.

Consideration should be given for the design of full floor coverage coarse bubble diffuser equipment at inlet feed points where alpha values could be as low as 0.2 for fine pore diffusers and where heavy slime buildup is expected to occur. The coarse bubble diffuser system at the inlet would provide maintenance-free service and a greater degree of mixing and dispersion of the influent stream.

In diffuser systems using dome hold-down bolts, plastic bolts should not be used. If metal bolts are used, gasket materials should be made of the longest lasting materials available. Currently-available gasket materials may last less than 3 years before requiring replacement to prevent air leakage around the dome diffuser.

Grit removal or prevention should be evaluated for each treatment facility. Significant grit carry-over from preliminary and primary treatment could require costly and inconvenient removal after system start-up. Grit removal from around and under a fixed plastic pipe aeration grid is a slow and difficult operation.

Dissolved oxygen monitoring and airflow control instrumentation should only be as sophisticated as necessary. The simpler the control system, the better the results.

Air supply equipment should match the aeration system. The airflow range and system pressure requirements of the aeration equipment must integrate with the blower equipment performance characteristics if aeration efficiency is to be optimized. In cases where retrofit of the aeration equipment requires substantial reduction in air supply, blower turndown capabilities, shutdown of incremental units, or replacement of old equipment with new, smaller equipment must be considered and evaluated for maximum power reduction potential.

Dissolved oxygen monitoring instrumentation should be checked and calibrated frequently, if the measurements are to be meaningful.

Fine pore aeration equipment should be tested for oxygen transfer efficiency and back pressure on a routine basis. The results of this testing should be used to compare equipment performance with expected values of performance, and to establish maintenance schedules for cleaning of the equipment.

Air leaks should be repaired as soon as possible to limit intrusion of mixed liquor into the air piping system, thereby reducing the potential for air-side fouling, to minimize deterioration of the aeration system, and to ensure that oxygen transfer efficiency is not reduced unnecessarily.

3.0 HISTORICAL BACKGROUND INFORMATION

3.1 THE TREATMENT FACILITY

The Hartford Water Pollution Control Plant treats wastewater from six greater Hartford area towns. The secondary activated sludge treatment facility, designed in 1968 and completed in late 1972, processes an average daily flow of about 45 MGD. The secondary facilities are designed for an average daily flow of 60 MGD and a peak hydraulic flow of 109 MGD.

The pollution control plant contains preliminary, primary, secondary activated sludge, and waste sludge treatment and incineration. Sludges from this plant and three other smaller water pollution control plants are pumped to dissolved air flotation thickeners and then blended with primary sludge. The combined sludge mix is then pumped to belt filter presses for dewatering prior to incineration in two of the three multiple hearth incinerators located at the site.

3.2 THE ACTIVATED SLUDGE PROCESS

The activated sludge process is designed to treat a 60 MGD average daily flow. However, over the past several years the average daily flow has been about 45 MGD and has not increased due to the lack of increased growth in the service area as projected at the time of the original plant design in 1968.

Historical data for plant flow, loading, airflow, and process conditions are contained in Tables 2 to 4 and Figures 1 to 4. Wastewater characteristic information for the days in which off gas testing was conducted is contained in Tables 5 and 6.

The flow from primary treatment is pumped to the secondary facilities and split among four of the six aeration tanks (Aeration Tank Nos. 5 and 6 have never been in operation). Each aeration tank is 194 feet long and 80 feet wide with a nominal liquid depth of 15.5 feet. Each aeration tank is divided into four passes of equal size. The normal mode of operation is step-feed. Return activated sludge (RAS) is fed into the head end of Pass No. 1 of each aeration tank, and primary effluent (PE) is normally split equally among Pass

Table 2

HISTORICAL PLANT DATA

MONTH & YEAR	PLANT FLOW, MGD	BOD_r, lbs/day	TOTAL AIRFLOW, SCFM	BLOWER POWER, KWH/day	PLANT POWER, KWH/day
05-82	42.70	N/A	51,813	34,750	54,328
06-82	53.60	N/A	45,403	30,776	54,328
07-82	47.07	N/A	49,944	32,717	54,328
08-82	41.57	N/A	40,042	28,112	51,200
09-82	46.69	N/A	37,979	27,767	49,117
10-82	45.92	N/A	45,035	33,047	53,569
11-82*	44.74	N/A	25,319	21,625	47,214
12-82	41.96	N/A	27,910	22,875	49,189
01-83	44.32	43,986	27,438	22,000	50,577
02-83	54.29	37,128	23,771	19,375	46,712
03-83	59.11	29,086	22,215	18,600	45,776
04-83	61.08	20,886	17,986	15,625	41,904
05-83	54.69	22,350	15,792	14,375	37,938
06-83	54.63	20,503	18,201	16,000	38,239
07-83	37.89	32,864	20,493	17,375	40,472
08-83	37.62	37,650	24,500	19,375	41,943
09-83	38.33	36,762	28,521	22,000	44,180
10-83	35.35	28,597	20,924	17,375	39,886
11-83	35.78	31,333	23,076	18,700	41,543
12-83	41.98	21,007	18,708	16,000	42,754
01-84	39.10	29,022	22,111	17,875	42,800
02-84	45.23	19,993	24,458	16,300	41,508
03-84	54.70	20,985	16,708	14,500	41,257
04-84	59.42	22,796	16,472	14,625	40,800
05-84	56.06	28,520	20,792	17,300	42,560
06-84	50.27	26,832	19,736	16,750	42,457
07-84	49.86	35,346	21,076	17,375	40,971
08-84	47.95	34,792	21,715	18,400	42,057
09-84	46.14	56,952	28,576	22,250	43,943
10-84	45.52	46,316	29,028	22,400	44,708
11-84	45.15	37,655	28,597	22,250	44,971
12-84	49.29	32,886	27,097	21,433	46,686
01-85	48.47	49,721	27,299	21,100	40,091
02-85	49.89	37,864	26,389	21,250	46,743
03-85	45.60	37,270	32,083	23,875	49,886
04-85	42.84	33,228	33,729	25,500	51,657
05-85	46.09	35,748	29,882	23,000	48,320
06-85	44.42	36,676	35,590	26,500	52,171
07-85	45.46	29,952	31,875	24,800	48,960

*Fine Pore On Line

Table 2 (Continued)

HISTORICAL PLANT DATA

MONTH & YEAR	PLANT FLOW, MGD	BOD_r, lbs/day	TOTAL AIRFLOW, SCFM	BLOWER POWER, KWH/day	PLANT POWER, KWH/day
08-85	50.39	26,476	23,771	18,375	44,972
09-85	47.15	30,672	27,514	20,750	44,972
10-85*	46.94	34,450	31,410	23,300	47,543
11-85	50.72	20,304	23,840	18,750	43,771
12-85	52.74	26,391	26,715	20,525	47,892
01-86	48.73	25,604	31,938	24,200	52,903
02-86	53.48	20,517	24,868	19,500	49,600
03-86	53.72	20,609	25,451	19,750	47,486
04-86	53.55	33,942	28,361	21,600	48,183
05-86	50.61	39,676	31,396	23,875	49,286
06-86	51.15	43,939	33,132	24,250	52,543
07-86	51.52	43,827	38,368	27,700	53,028
08-86	48.94	39,183	33,986	24,125	48,286
09-86	46.19	50,079	38,319	28,250	52,972
10-86	42.44	41,766	35,847	26,400	52,067
11-86	49.24	25,872	29,701	22,500	49,656
12-86	58.41	27,767	24,049	18,875	47,611
01-87	58.26	31,097	31,285	19,638	49,737
02-87	55.09	31,243	30,813	23,125	52,971
03-87	59.53	33,264	30,132	22,375	51,429
04-87	58.42	22,412	26,083	20,500	47,179
05-87**	54.87	27,457	28,063	21,500	47,716
06-87	47.83	33,109	33,229	24,375	52,558
07-87	43.02	37,673	37,778	28,300	56,241
08-87	39.37	36,446	37,021	27,250	55,059
09-87	44.41	38,519	36,368	26,500	53,974
10-87	43.46	40,595	37,500	27,625	54,049
11-87	43.39	38,720	41,319	30,125	58,928
12-87	44.98	41,265	36,535	27,250	58,907
01-88	46.65	40,851	32,590	24,403	58,457
02-88	55.64	38,051	28,521	22,000	55,436
03-88	59.80	48,876	31,910	24,100	56,338
04-88	53.29	40,888	36,639	25,750	53,779
05-88	54.66	35,102	30,694	23,125	51,246
06-88	49.83	40,727	36,139	26,400	52,777
07-88	52.64	49,609	50,722	30,875	60,261
08-88	49.35	40,746	34,819	25,875	54,257
09-88	41.14	38,428	44,507	28,800	57,837

*First Cleaning
**Second Cleaning

Table 3

HISTORICAL AIRFLOW DATA

YEAR	MONTH	TOTAL AIRFLOW RATE (1000×CFM)	AERATION TANK AIRFLOW RATE (1000×CFM)	CHANNEL AIRFLOW RATE (1000×CFM)
83	AUG	24.8	21.6	3.2
	SEP	29.0	24.2	4.8
	OCT	21.0	19.3	1.7
	NOV	23.3	20.7	2.6
	DEC	19.0	18.1	1.0
84	JAN	21.8	19.8	2.0
	FEB	19.7	18.5	1.2
	MAR	16.7	16.7	0.1
	APR	16.6	16.6	0.0
	MAY	21.3	19.5	1.8
	JUN	19.3	18.2	1.1
	JUL	21.1	19.3	1.8
	AUG	22.3	20.1	2.2
	SEP	28.5	23.9	4.6
	OCT	29.1	24.3	4.8
	NOV	28.5	23.9	4.6
	DEC	27.1	23.0	4.1
85	JAN	27.3	23.1	4.1
	FEB	26.4	22.6	3.8
	MAR	32.1	26.1	6.0
	APR	33.8	27.1	6.6
	MAY	29.9	24.7	5.1
	JUN	35.6	28.3	7.3
	JUL	31.9	26.0	5.9
	AUG	23.8	21.0	2.8
AVERAGE		25.2	21.9	3.3

Table 4

HISTORICAL AERATION SYSTEM PERFORMANCE

MONTH & YEAR	BOD_r/ MGD	AIR-FLOW/ MGD	AIR-FLOW/ BOD_r	KWH/ MGD	KWH/ BOD_r	KWH/ AIR-FLOW	AIR-FLOW/ KWH
05-82	N/A	1213.42	N/A	813.82	N/A	0.67	1.49
06-82	N/A	847.07	N/A	574.18	N/A	0.68	1.48
07-82	N/A	1061.06	N/A	695.07	N/A	0.66	1.53
08-82	N/A	963.24	N/A	676.26	N/A	0.70	1.42
09-82	N/A	813.43	N/A	594.71	N/A	0.73	1.37
10-82	N/A	980.73	N/A	719.66	N/A	0.73	1.36
11-82*	N/A	565.91	N/A	483.35	N/A	0.85	1.17
12-82	N/A	665.16	N/A	545.16	N/A	0.82	1.22
01-83	99.25	619.09	0.62	496.39	0.50	0.80	1.25
02-83	68.39	437.85	0.64	356.88	0.52	0.82	1.23
03-83	49.21	375.82	0.76	314.67	0.64	0.84	1.19
04-83	34.19	294.47	0.86	255.81	0.75	0.87	1.15
05-83	40.87	288.75	0.71	262.85	0.64	0.91	1.10
06-83	37.53	333.17	0.89	292.88	0.78	0.88	1.14
07-83	86.74	540.86	0.62	458.56	0.53	0.85	1.18
08-83	100.08	651.25	0.65	515.02	0.51	0.79	1.26
09-83	95.91	744.09	0.78	573.96	0.60	0.77	1.30
10-83	80.90	591.91	0.73	491.51	0.61	0.83	1.20
11-83	87.57	644.94	0.74	522.64	0.60	0.81	1.23
12-83	50.04	445.64	0.89	381.13	0.76	0.86	1.17
01-84	74.23	565.50	0.76	457.16	0.62	0.81	1.24
02-84	44.20	540.75	1.22	360.38	0.82	0.67	1.50
03-84	38.36	305.45	0.80	265.08	0.69	0.87	1.15
04-84	38.36	277.21	0.72	246.13	0.64	0.89	1.13
05-84	50.87	370.89	0.73	308.60	0.61	0.83	1.20
06-84	53.38	392.60	0.74	333.20	0.62	0.85	1.18
07-84	70.89	422.70	0.60	348.48	0.49	0.82	1.21
08-84	72.56	452.87	0.62	383.73	0.53	0.85	1.18
09-84	123.43	619.33	0.50	482.23	0.39	0.78	1.28
10-84	101.75	637.70	0.63	492.09	0.48	0.77	1.30
11-84	83.40	633.38	0.76	492.80	0.59	0.78	1.29
12-84	66.72	549.75	0.82	434.83	0.65	0.79	1.26
01-85	102.58	563.21	0.55	435.32	0.42	0.77	1.29
02-85	75.89	528.94	0.70	425.94	0.56	0.81	1.24
03-85	81.73	703.57	0.86	523.57	0.64	0.74	1.34
04-85	77.56	787.32	1.02	595.24	0.77	0.76	1.32
05-85	77.56	648.34	0.84	499.02	0.64	0.77	1.30
06-85	82.56	801.22	0.97	596.58	0.72	0.74	1.34
07-85	65.89	701.17	1.06	545.53	0.83	0.78	1.29

*Fine Pore On Line

Table 4 (Continued)

HISTORICAL AERATION SYSTEM PERFORMANCE

MONTH & YEAR	BOD_r/ MGD	AIR-FLOW/ MGD	AIR-FLOW/ BOD_r	KWH/ MGD	KWH/ BOD_r	KWH/ AIR-FLOW	AIR-FLOW/ KWH
08-85	52.54	471.74	0.90	364.66	0.69	0.77	1.29
09-85	65.05	583.54	0.90	440.08	0.68	0.75	1.33
10-85*	73.40	669.15	0.91	496.38	0.68	0.74	1.35
11-85	40.03	470.03	1.17	369.68	0.92	0.79	1.27
12-85	50.04	506.54	1.01	389.17	0.78	0.77	1.30
01-86	52.54	655.41	1.25	496.61	0.95	0.76	1.32
02-86	38.36	465.00	1.21	364.62	0.95	0.78	1.28
03-86	38.36	473.77	1.23	367.65	0.96	0.78	1.29
04-86	63.38	529.62	0.84	403.36	0.64	0.76	1.31
05-86	78.40	620.35	0.79	471.74	0.60	0.76	1.32
06-86	85.90	647.74	0.75	474.10	0.55	0.73	1.37
07-86	85.07	744.72	0.88	537.66	0.63	0.72	1.39
08-86	80.06	694.44	0.87	492.95	0.62	0.71	1.41
09-86	108.42	829.60	0.77	611.60	0.56	0.74	1.36
10-86	98.41	844.65	0.86	622.05	0.63	0.74	1.36
11-86	52.54	603.19	1.15	456.95	0.87	0.76	1.32
12-86	47.54	411.73	0.87	323.15	0.68	0.78	1.27
01-87	53.38	536.99	1.01	337.08	0.63	0.63	1.59
02-87	56.71	559.32	0.99	419.77	0.74	0.75	1.33
03-87	55.88	506.16	0.91	375.86	0.67	0.74	1.35
04-87	38.36	446.47	1.16	350.91	0.91	0.79	1.27
05-87**	50.04	511.45	1.02	391.84	0.78	0.77	1.31
06-87	69.22	694.73	1.00	509.62	0.74	0.73	1.36
07-87	87.57	878.15	1.00	657.83	0.75	0.75	1.33
08-87	92.57	940.34	1.02	692.15	0.75	0.74	1.36
09-87	86.74	818.91	0.94	596.71	0.69	0.73	1.37
10-87	93.41	862.86	0.92	635.64	0.68	0.74	1.36
11-87	89.24	952.27	1.07	694.28	0.78	0.73	1.37
12-87	91.74	812.25	0.89	605.82	0.66	0.75	1.34
01-88	87.57	698.61	0.80	523.11	0.60	0.75	1.34
02-88	68.39	512.60	0.75	395.40	0.58	0.77	1.30
03-88	81.73	533.61	0.65	403.01	0.49	0.76	1.32
04-88	76.73	687.54	0.90	483.21	0.63	0.70	1.42
05-88	64.22	561.54	0.87	423.07	0.66	0.75	1.33
06-88	81.73	725.25	0.89	529.80	0.65	0.73	1.37
07-88	94.24	963.56	1.02	586.53	0.62	0.61	1.64
08-88	82.57	705.55	0.85	524.32	0.64	0.74	1.35
09-88	93.41	1081.84	1.16	700.05	0.75	0.65	1.55

*First Cleaning
**Second Cleaning

FIGURE NO. 1

HISTORICAL PLANT DATA
AVERAGE MONTHLY PLANT FLOW AND BOD_r

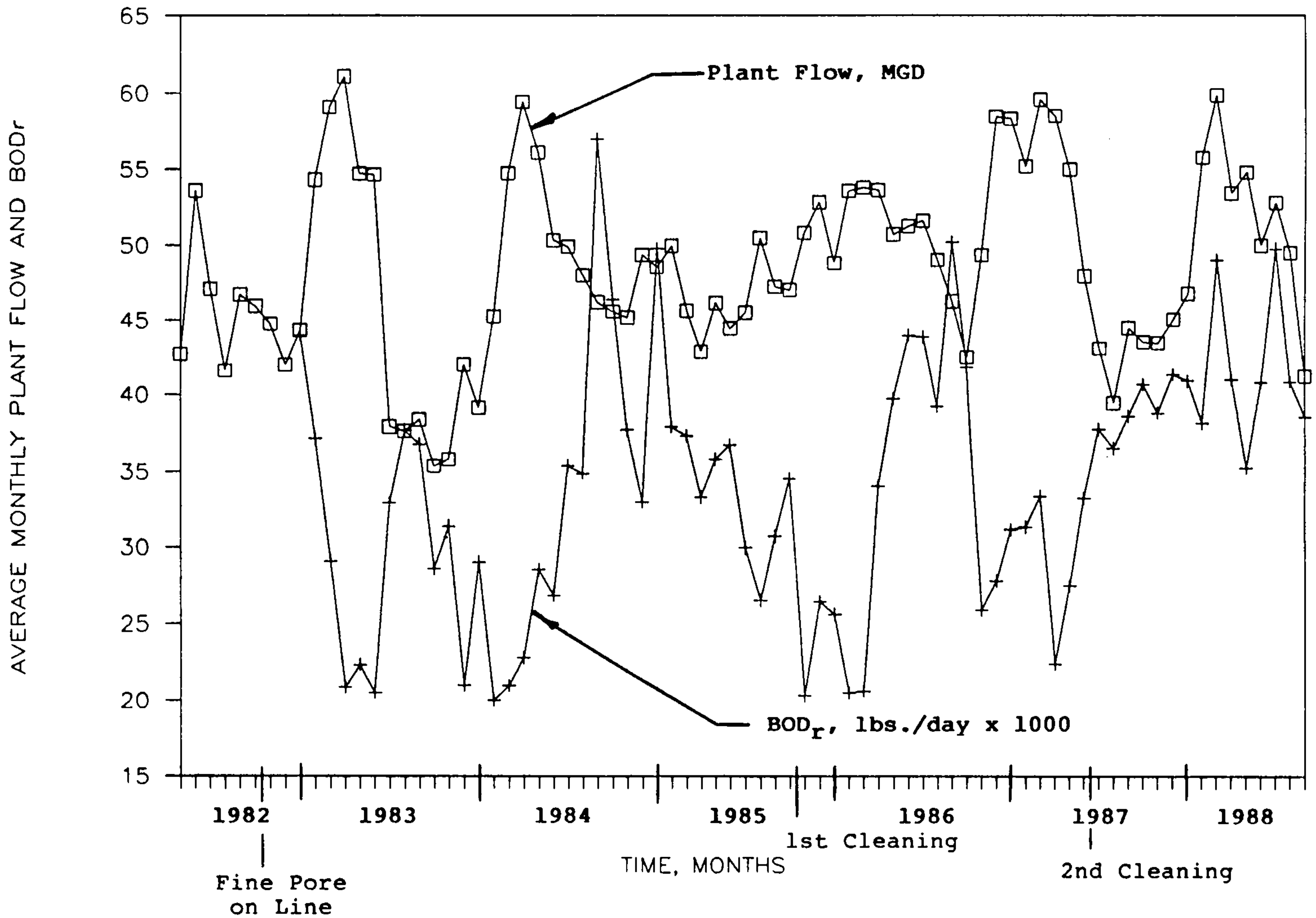


FIGURE NO. 2

HISTORICAL PLANT DATA
AVERAGE MONTHLY AIRFLOW AND BLOWER POWER

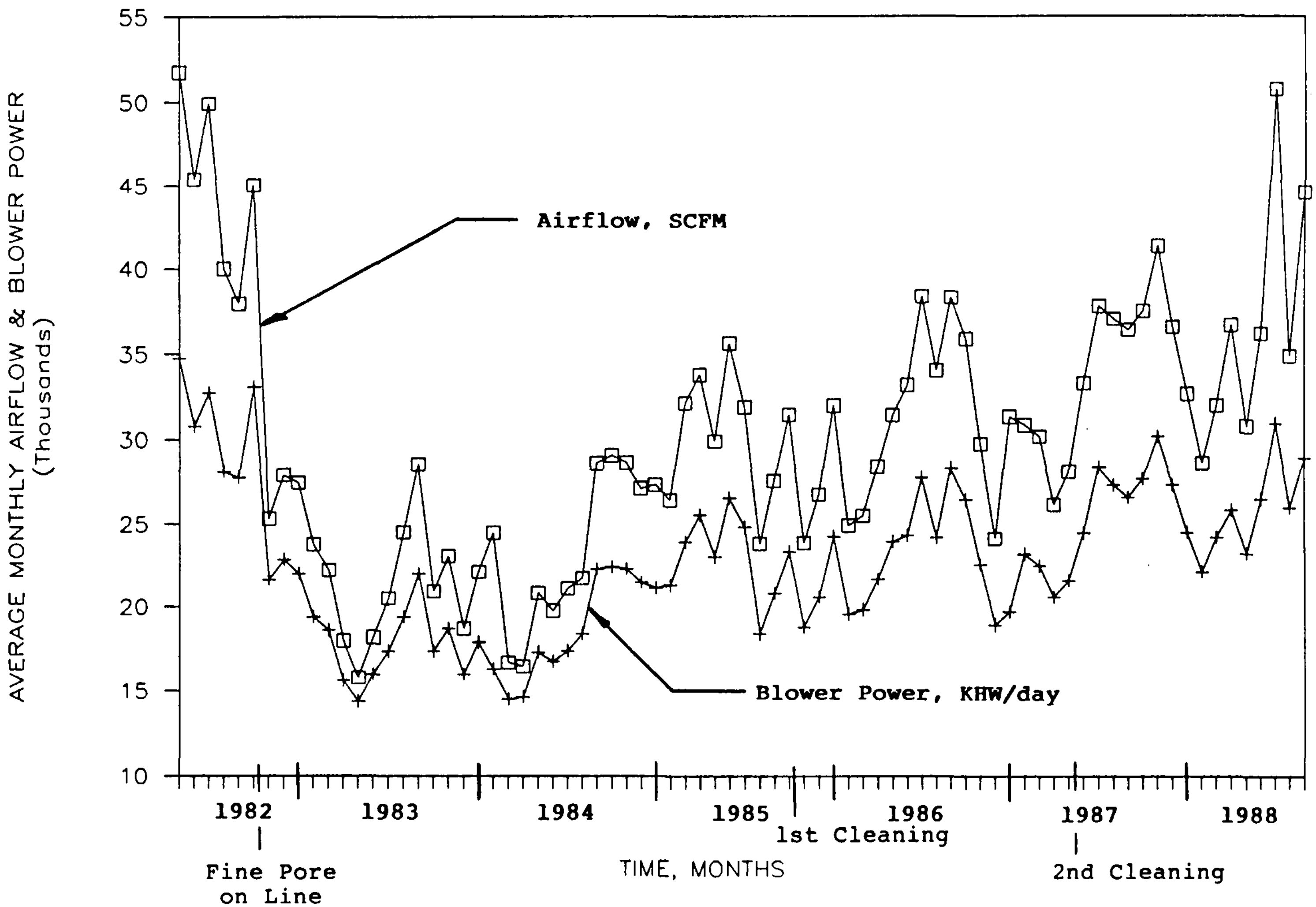


FIGURE NO. 3

HISTORICAL AERATION SYSTEM PERFORMANCE
AVERAGE MONTHLY PLANT BOD_r, AIRFLOW, AND KWH PER MGD

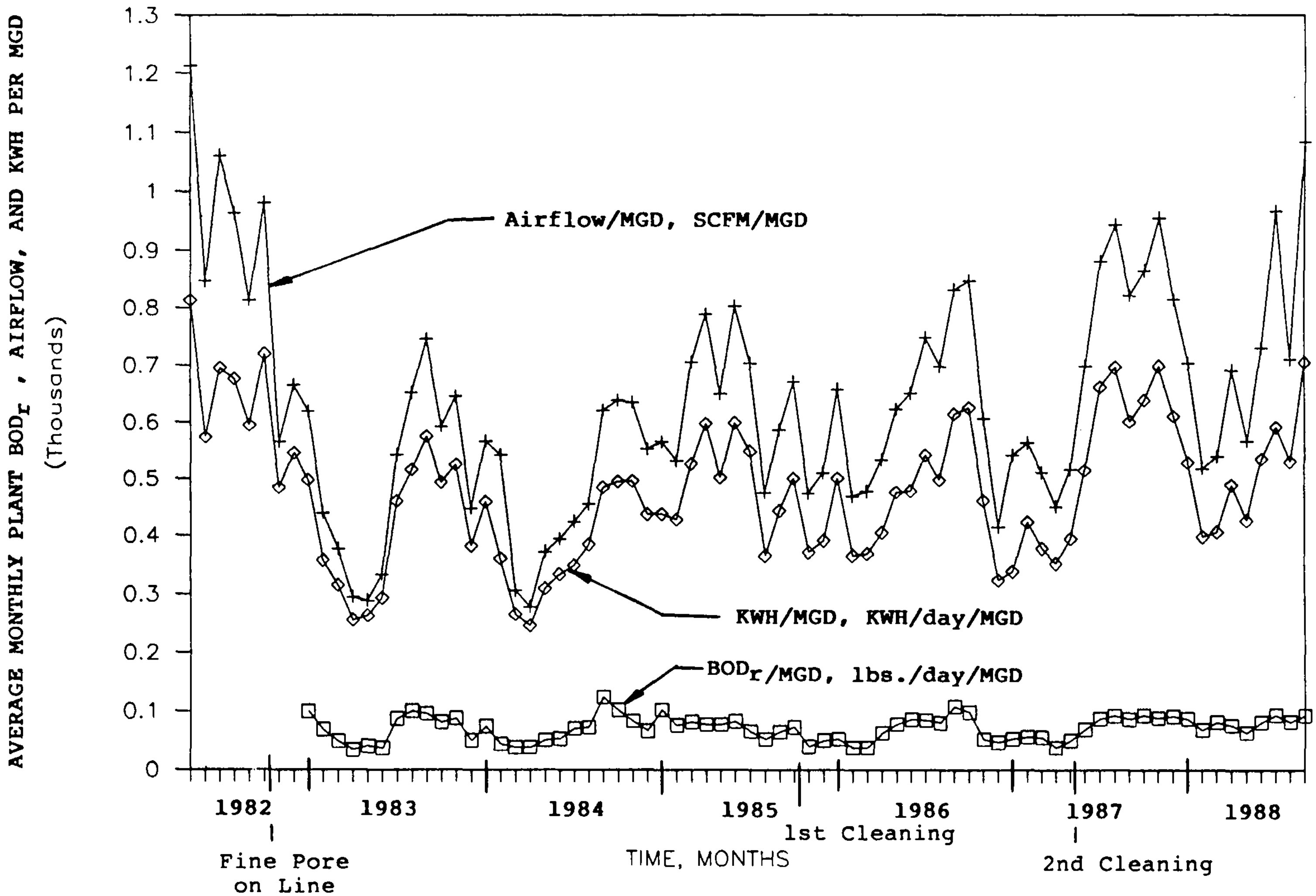


FIGURE NO. 4

HISTORICAL AERATION SYSTEM PERFORMANCE
AVERAGE MONTHLY PLANT AIRFLOW AND KWH/BOD_r AND KWH/AIRFLOW

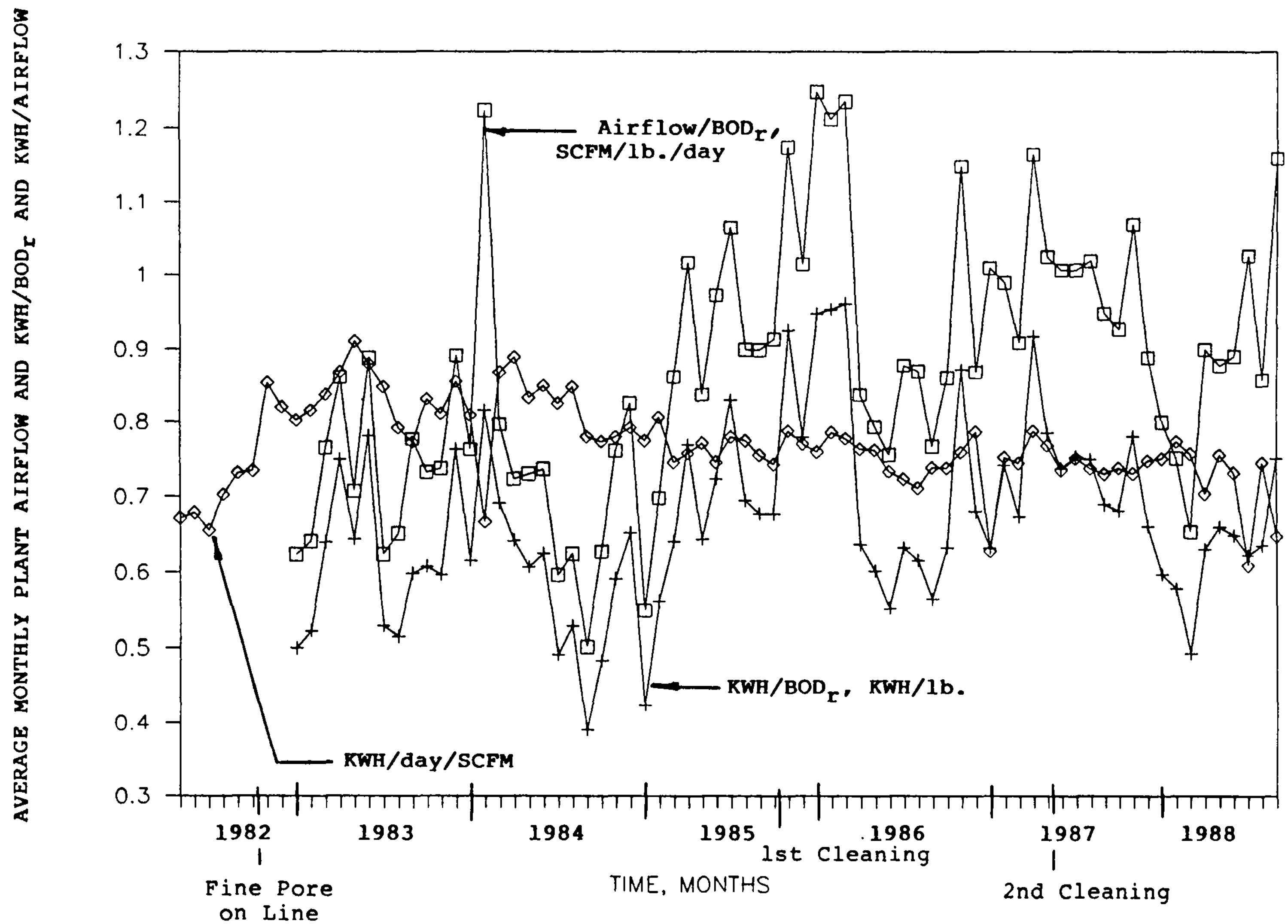


Table 5

WASTEWATER CHARACTERISTIC INFORMATION FOR OFF-GAS TEST VISITS

DATE	BOD5 PRI. INF., mg/l	BOD5 PRI. EFF., mg/l	BOD5 FINAL EFF., mg/l	TSS FINAL EFF., mg/l	PLANT FLOW, MGD	MLSS, mg/l	MVLSS, mg/l	PERCENT RECYCLE, %	WASTE SLUDGE, lbs.x1000	WASTE SLUDGE, mg/l	WASTE SLUDGE, % VOL.	F/M RATIO	(1) MCRT
09-14-85	122	81	4	7	47.70			42	51.93	5666	--	--	--
10-21-85	97	44	5	18	45.40	2953	2313	53	44.36	4920	--	0.13	4.0
11-12-85	66	68	4	10	48.60	2378	1797	53	25.75	3598	75.5	0.20	7.3
11-13-85	76	52	6	18	49.05	2872	2140	47	32.93	4544	73.5	0.22	5.2
11-14-85	90	55	6	13	55.20	2950	2201	49	31.32	4434	72.2	0.19	5.9
12-19-85	217	53	7	11	52.30	2222	1713	47	36.82	4054	77.0	0.18	6.6
12-20-85	121	42	12	25	51.90			49	29.70	3434	77.1		
03-24-86	50	73	10	11	53.36	3459	2608	38	36.32	5598	73.9	0.17	7.6
03-25-86	56	42	20	12	53.82	3660	2788	31	41.99	6678	75.4	0.09	7.1
04-01-86	176	67	7	10	56.67	3000	2323	35	40.63	5970	76.9	0.18	6.1
04-02-86	109	58	6	8	58.60	3759	2881	34	39.15	5724	76.5	0.13	7.9
07-14-86	152	105	10	17	54.37	5032	3748	42	48.54	7648	75.2	0.16	7.6
07-15-86	153	146	9	14	52.53	4850	3607	45	43.44	6880	75.1	0.22	8.4
02-04-87	102	66	7	16	59.89	4086	2899	39	38.35	6636	71.1	0.14	7.8
02-05-87	137	60	8	16	56.35	3732	2646	37	49.02	7320	70.9	0.13	5.7
04-22-87	60	47	4	7	62.58	3214	2367	34	34.04	5830	73.0	0.13	8.3
04-23-87	81	51	4	7	62.07	3124	2312	34	32.88	5840	73.2	0.14	7.5
06-18-87	181	122	9	12	47.15	4465	3498	44	34.18	5872	78.0	0.18	9.7
08-13-87	164	119	5	11	39.75	5812	4477	40	49.50	10712	77.1	0.11	8.2

(1) MCRT Computed as follows:

$$\text{MCRT} = \frac{\begin{pmatrix}\text{Volume of Aeration}\\ \text{Tanks, mil.gal.}\end{pmatrix} \times \begin{pmatrix}\text{MLVSS,}\\ \text{mg/l}\end{pmatrix} \times \begin{pmatrix}\text{Volume of Clarifiers}\\ \text{\& Channels, mil.gal.}\end{pmatrix} \times \begin{pmatrix}\text{4th Pass MLVSS,}\\ \text{mg/l}\end{pmatrix}}{\begin{pmatrix}\text{Return Sludge}\\ \text{MLVSS, mg/l}\end{pmatrix} \times \begin{pmatrix}\text{Waste,}\\ \text{MGD}\end{pmatrix} \times \begin{pmatrix}\text{Final Effluent}\\ \text{VSS, mg/l}\end{pmatrix} \times \begin{pmatrix}\text{Plant Flow,}\\ \text{MGD}\end{pmatrix}} = \text{DAYS}$$

Table 6

PRIMARY EFFLUENT TOTAL AND SOLUBLE CARBONACEOUS BOD_5

DATE	TOTAL BOD_5, mg/l	SOLUBLE BOD_5, mg/l	PERCENT SOLUBLE, %
11-21-85	44	17	38.6
11-25-85	53	20	37.7
11-26-85	40	14	35.0
12-02-85	48	17	35.4
12-03-85	95	17	17.9
12-04-85	40	18	45.0
12-05-85	60	14	23.3
12-12-85	53	19	35.8
12-18-85	44	19	43.2
12-23-85	110	78	70.9
12-31-85	111	44	39.6
01-07-86	90	53	58.9
01-14-86	90	44	48.9
01-21-86	109	6	5.5
01-26-86	63	26	41.3
01-28-86	65	25	38.5
02-04-86	55	17	30.9
02-19-86	67	24	35.8
02-26-86	81	37	45.7
03-03-86	100	60	60.0
03-10-86	79	31	39.2
03-18-86	75	14	18.7
03-25-86	42	18	42.9
04-01-86	67	20	29.9
04-09-86	113	30	26.5
04-15-86	65	24	36.9
04-22-86	62	26	41.9
04-28-86	115	112	97.4
05-05-86	98	28	28.6
05-12-86	117	33	28.2
05-19-86	101	48	47.5
06-04-86	157	92	58.6
06-10-86	97	24	24.7
06-17-86	119	32	26.9
06-24-86	80	12	15.0
06-30-86	94	39	41.5
07-08-86	103	54	52.4
07-14-86	105	20	19.0
07-21-86	105	39	37.1

Table 6 (Cont.)

PRIMARY EFFLUENT TOTAL AND SOLUBLE CARBONACEOUS BOD_5

DATE	TOTAL BOD_5, mg/l	SOLUBLE BOD_5, mg/l	PERCENT SOLUBLE, %
08-04-86	101	43	42.6
08-12-86	87	41	47.1
08-18-86	85	28	32.9
08-26-86	88	47	53.4
09-02-86	158	83	52.5
09-05-86	137	60	43.8
09-15-86	137	97	70.8
09-22-86	150	89	59.3
10-06-86	167	54	32.3
10-14-86	220	84	38.2
10-22-86	116	64	55.2
10-27-86	68	59	86.8
11-03-86	139	63	45.3
11-10-86	149	69	46.3
12-01-86	92	32	34.8
12-08-86	114	31	27.2
12-15-86	74	36	48.6
12-22-86	62	34	54.8
12-29-86	85	52	61.2
01-05-87	54	31	57.4
01-12-87	79	105	132.9
01-20-87	57	52	91.2
01-26-87	71	41	57.7
02-02-87	71	40	56.3
02-09-87	59	29	49.2
02-16-87	105	38	36.2
02-23-87	88	53	60.2
03-02-87	48	24	50.0
03-09-87	60	43	71.7
04-13-87	23	20	87.0
04-20-87	51	25	49.0
04-27-87	65	65	100.0
05-04-87	84	39	46.4
05-11-87	59	34	57.6
05-18-87	72	41	56.9
05-26-87	109	58	53.2
06-02-87	99	45	45.5
06-16-87	83	36	43.4

Table 6 (Cont.)

PRIMARY EFFLUENT TOTAL AND SOLUBLE CARBONACEOUS BOD_5

DATE	TOTAL BOD_5, mg/l	SOLUBLE BOD_5, mg/l	PERCENT SOLUBLE, %
06-22-87	95	28	29.5
06-29-87	82	56	68.3
07-06-87	137	116	84.7
07-13-87	88	60	68.2
07-20-87	150	58	38.7
07-27-87	162	49	30.2
08-03-87	111	37	33.3
08-10-87	88	30	34.1
AVG. FOR PERIOD	81.8	40.7	49.2
11-21-85 TO 02-04-86	69	26	37.7
02-19-86 TO 12-29-86	104	46	44.2
01-05-87 TO 08-10-87	83	46	55.4

Nos. 2, 3, and 4. Figure No. 5 contains a schematic of the secondary treatment process. Schematics of the aeration tanks are contained on Figure Nos. 6 and 7.

The step-feed mode of the activated sludge process proves beneficial at Hartford. When the mixed liquor suspended solids (MLSS) are high, the step configuration tends toward a contact mode of operation to relieve the solids loading rate on the final clarifiers. When the MLSS concentration is lower, a more conventional mode is established which shifts solids from the aeration tanks to increased clarifier loading, and thereby improves the density of waste sludge being fed to the thickeners.

Only four of the six 1.8 million gallon aeration tanks are used because wastewater flows and organic loadings have not increased as rapidly as predicted at the time the facility was designed. The mixed liquor flows from the four aeration tanks to six, 125-ft. diameter circular final clarifiers. The overflow from the final clarifiers is chlorinated between May and September and discharged to the Connecticut River.

The settled sludge from the final clarifiers is returned to a common wet well where 95 percent of the sludge is returned to the aeration system at a rate equal to 25 percent of plant flow. All return activated sludge (RAS) is fed to the head end of pass no. 1 of each of the four aeration tanks. The waste sludge is pumped to the dissolved air flotation thickening system for further treatment.

3.3 ORIGINAL AERATION SYSTEM

The "original equipment" aeration system installed in 1972 was Chicago Pump Co. "Deflectofusers", which were coarse bubble diffusers with large, 3/8-inch diameter orifices on the periphery of the device. The diffusers were placed on manifolds and drop pipe assemblies with seven drops per pass. There were 252 diffusers installed in each aeration pass. The diffusers and manifolds were placed 2.5 feet above the tank floor and 2.5 feet from the tank wall, thus providing a spiral roll configuration in each pass. Although this diffuser configuration kept the tank floor free of equipment, facilitating cleaning of the tank as necessary, the resulting oxygen transfer efficiency was very low. It was estimated that the

FIGURE NO. 5

SCHEMATIC OF SECONDARY TREATMENT PROCESS

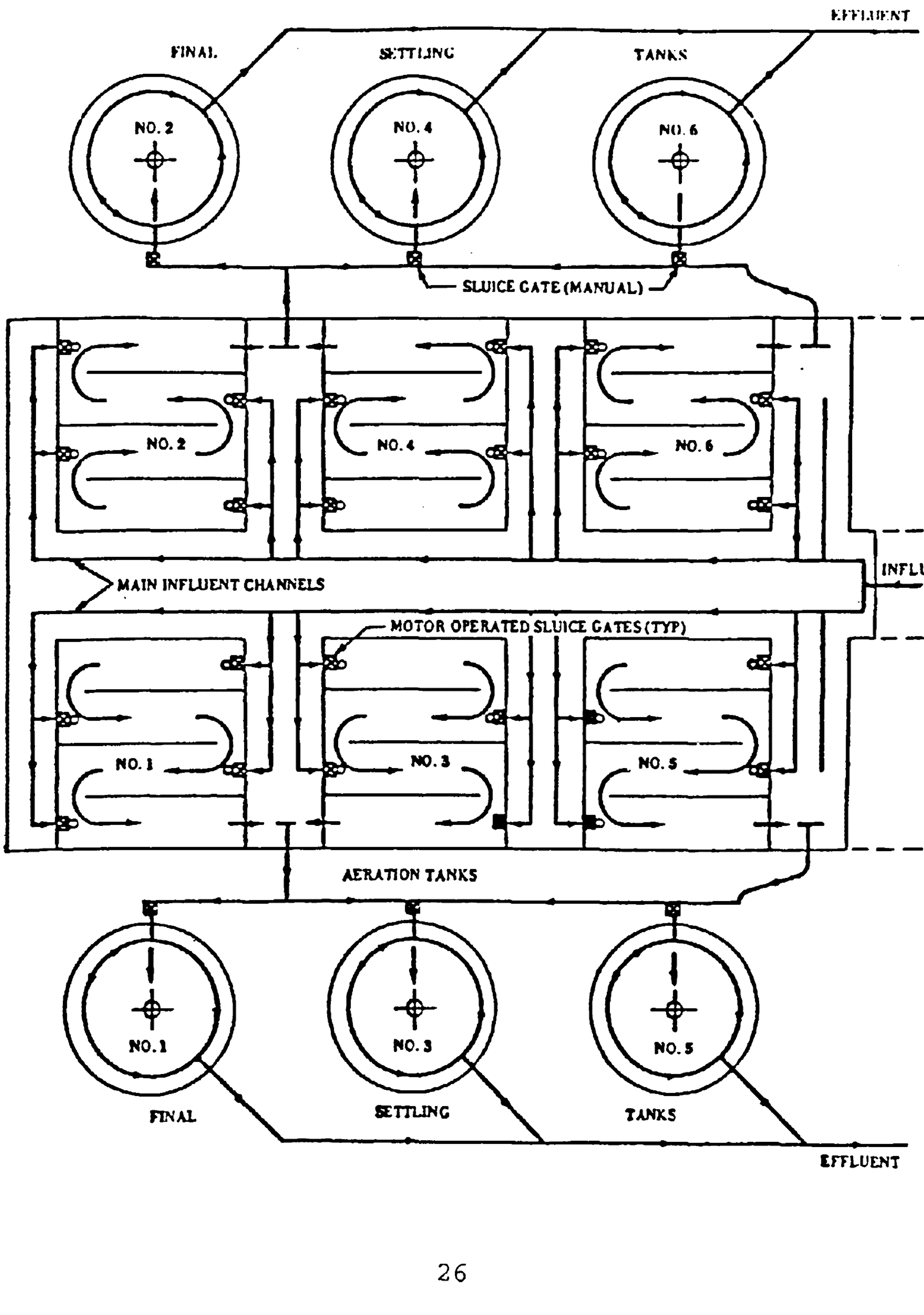
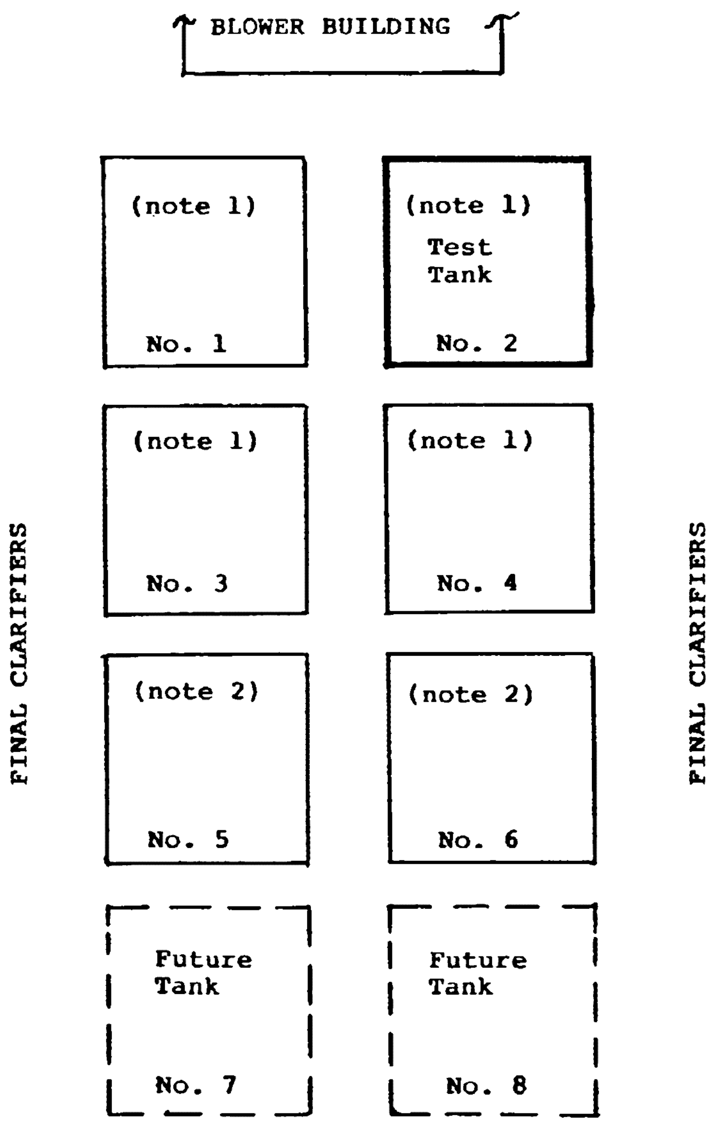


FIGURE NO. 6

SCHEMATIC OF AERATION SYSTEM



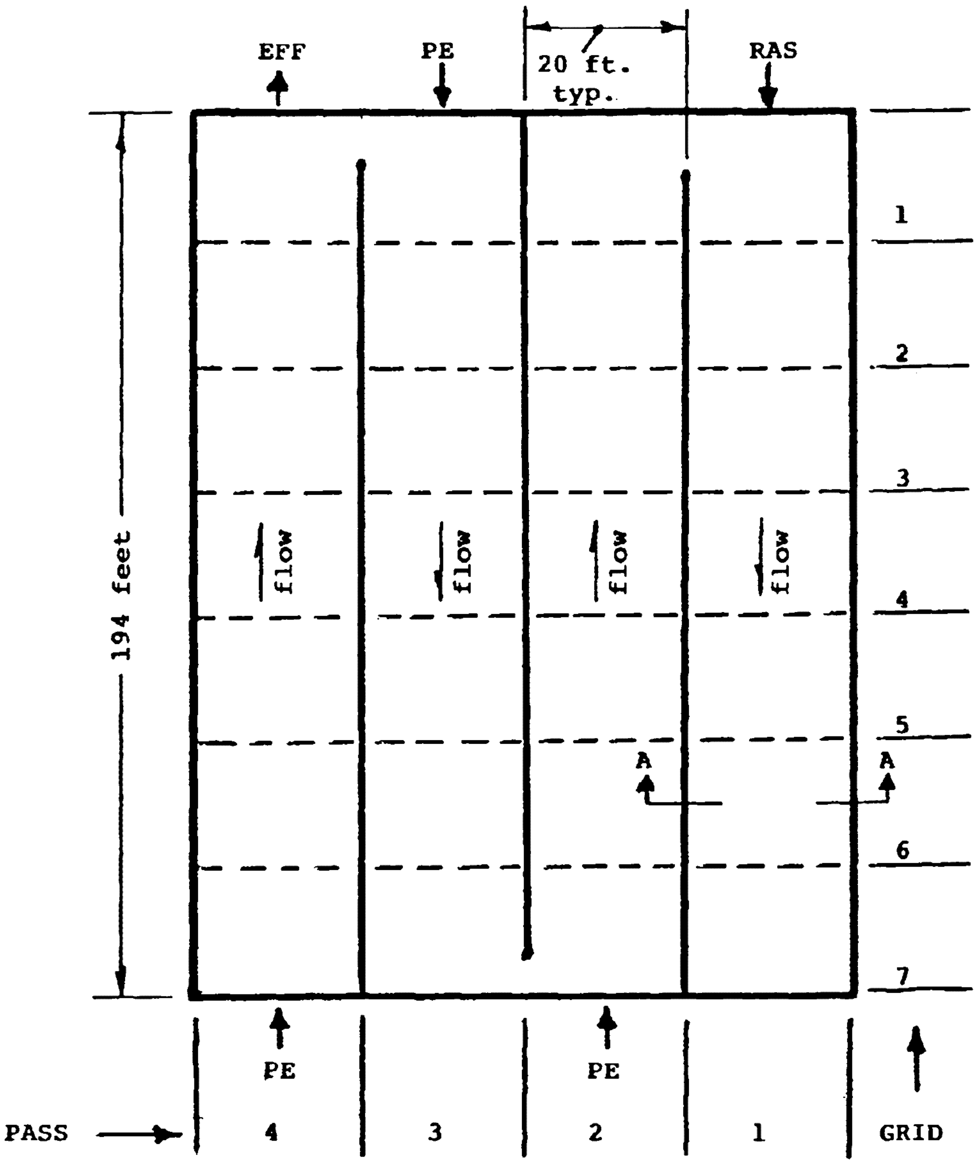
FOUR-PASS AERATION TANKS

Notes: 1. Retrofitted with dome diffusers and in service.

2. Not retrofitted and not in service.

FIGURE NO. 7

PLAN SKETCH WITH TANK DIMENSIONS



Nominal liquid volume per pass:	60,140 cu. ft. 449,850 gal.
Nominal total liquid volume:	240,560 cu. ft. 1,799,400 gal.
Nominal liquid side water depth:	15.5 ft.

Standard Oxygen Transfer Efficiency (SOTE) of the original diffuser equipment was between 6 and 7 percent. As long as energy was relatively inexpensive, emphasis was placed on an uncomplicated system that required little maintenance.

The air supply for the activated sludge process is furnished by one of three identical Brown-Boveri rotary vane blowers. Each blower is rated at a maximum output of 60,000 SCFM at 7.5 psig. Each blower is driven by a 3,000 HP motor. The rate of airflow generated by the blower is adjusted by the positioning of the inlet guide vanes on the suction side of the blower.

The air supply control system is designed with flow control and flow indicators for each pass of each aeration tank. A dissolved oxygen (DO) probe senses the amount of dissolved oxygen in the pass, then the signal is fed to an analyzer, and then to an electronic controller where the DO is manually set. The output signal from the controller modulates the 12-inch motor operated butterfly valves which meter the correct amount of air to match the set-point DO which is manually set at the controller.

As the air supply control valve to each aeration pass is modulated, the main venturi senses the change in pressure and airflow throughout the entire system. A pressure controller modulates the vanes in the blower to maintain constant system pressure.

3.4 OPERATIONAL PROBLEMS

Due to an inefficient sludge dewatering operation which prevented sludge from being wasted at a sufficient rate, the MLSS and MCRT (mean cell residence time) were far above design. As a result, foam in large amounts was always present on the surface of the aeration tanks, with foam overflow to the walkways, pipe galleries and surrounding area occurring frequently.

Large quantities of scum were also present on the final clarifiers, creating serious problems in the winter months. The formation of "scumburgs" would trip the collection equipment necessitating the use of a crane with clamshell to remove the frozen scum from the clarifiers.

The installation of new belt filter presses in 1978 and 1979 provided for more efficient processing of waste sludge, thereby reducing MLSS, MCRT, and sludge inventories. The lowered operating parameters provided for better process control and reduced the foam and scum problems. However, mixed liquor DO remained very low, and oxygen demand frequently exceeded the capacity of one blower.

From startup in 1972, one blower always operated at full capacity. Yet DO demand in the aeration system, particularly at the inlet points, was not fulfilled during the summer months. The only operational solution was to turn on a second 3,000 HP blower. This was a costly proposition for providing a small amount of additional air supply.

3.5 RETROFIT OBJECTIVES

Faced with the need for additional aeration capacity (greater oxygen transfer), steadily increasing electrical rates, and the demand charge for placing a second 3,000 HP blower on line, MDC staff engineers initiated an in-house retrofit evaluation project in 1978 for the purpose of reducing future energy usage and power costs. Since the electrical consumption for the aeration system accounted for more the 60 percent of total plant electrical usage, any substantial reduction in energy usage for the aeration system would significantly reduce overall plant usage, thereby reducing power costs accordingly.

In addition to the objective of significant electrical power cost savings, other objectives included:

1. payback of capital cost of the project in approximately 3 years,
2. minimum additional operational and maintenance costs over the existing aeration equipment,
3. operational flexibility,
4. additional aeration capacity sufficient to use only one blower as long as possible, and
5. no reduction in process results and effluent water quality.

3.6 BASIS FOR CHANGING TO FINE PORE AERATION

From early 1978 to the startup of the fine pore aeration system retrofit in November 1982, several tasks were undertaken to determine the best technology to use, type of equipment design to specify, and interface with the existing equipment such as piping, blowers, and control and instrumentation.

The initial phase of investigation was undertaken by MDC staff engineers from early 1978 through 1979. The objective of this phase of the retrofit evaluation was to determine and select the most efficient, cost-effective, and compatible with the existing facilities air-diffusion equipment. The investigation was divided into the following phases:

1. Available Technology Investigation
2. Pilot Testing
3. Estimated Air Usage with New Equipment
4. Blower Turndown Evaluation
5. Electrical Power Monitoring
6. Piping System Investigation
7. Air Filtration Requirements
8. Instrumentation System Requirements

3.6.1 Available Technology Investigation

The MDC contacted manufacturers of aeration equipment, consultants, and end users of fine pore retrofit systems to gather information on the various types of high efficiency diffuser equipment available and in use at that time. Initial review of mechanical and jet aerators indicated that they would not be compatible with the existing tank geometry and other facility equipment. The investigation narrowed to diffused air equipment such as ceramic domes and discs, plastic tubes, static mixers, and other diffusers with high oxygen transfer efficiency claims. After further review of this group of devices, it was evident that ceramic domes and discs seems to indicate the greatest oxygen transfer efficiency and satisfied the compatibility requirements with tank geometry and the air supply system. Therefore, dome/disc type diffusers were chosen for pilot testing.

3.6.2 Pilot Testing

Initial pilot tests consisted of mounting a single ceramic dome on the bottom of a large container. A "Deflectofuser" was also tested and used for comparison with the ceramic dome. Tests consisted of bubbling air through the diffusers in clean water. Observations were made of bubble size, formation, and flow patterns.

The second pilot test phase consisted of evaluating the performance of two, side-by-side, 55-gallon drums containing one type of diffuser in each drum. Each drum was also equipped with an air supply with airflow measurement, and a portable DO meter. This experiment provided comparable performance under identical test conditions for the fine pore dome diffuser and the coarse bubble diffuser operating in the plant aeration system. With the drums filled with activated sludge and airflow held constant, the fine pore dome diffuser drum would rapidly develop and maintain at least double the dissolved oxygen concentration of the coarse bubble diffuser drum. When airflows were adjusted to maintain the same DO in each drum, the dome diffuser required only one half as much air as the coarse bubble diffuser.

A third pilot test program was conducted with the use of a 300-gallon activated sludge pilot plant. Four ceramic dome diffusers and one coarse bubble diffuser were mounted on identical piping systems in the bottom of the pilot plant. The pilot plant was set up as an aeration tank with a continuous flow-through of activated sludge from one of the four main aeration tanks. While the 55-gallon drum tests had compared the diffusers on a one-on-one basis under batch conditions, the continuous flow-through pilot plant tests utilized more realistic fine pore dome to coarse bubble diffuser ratios of 2-to-1 and 4-to-1. Each diffuser system was operated alternately over short periods of time until a steady dissolved oxygen concentration was achieved. The amount of air required by each diffuser system was measured and recorded. Several tests were performed, and it was determined that the fine pore dome diffuser system required only 40 to 50 percent of the air required for the coarse bubble diffuser system when both systems operated at the same dissolved oxygen concentration. One observation noted during this comparison testing was that the fine pore system produced more foam than the coarse bubble system. However, sludge wasting was limited at that time, and it was felt that foaming could be minimized when the new belt filter presses were installed and operating.

3.6.3 Estimated Air Usage with New Equipment

The pilot test program indicated that there could be a 50 to 60 percent reduction in total air supply requirements for aeration. Plant operating data indicated that approximately 8,000 SCFM of air was required to maintain solids in suspension in the influent channels with an estimated 14,000 SCFM of air necessary for aeration in the activated sludge process.

The total estimated air supply requirements were set at 18,000 to 22,000 SCFM. With one blower normally operating at maximum capacity of 60,000 SCFM for the existing aeration system, the next concern was to investigate the turndown capability of the blower equipment.

3.6.4 Blower Turndown Evaluation

With the assistance of the blower manufacturer, the turndown characteristics of the rotary vane blowers were investigated. Surge point, efficiency, and power consumption were studied, and a procedure was devised to reduce the blower output while maintaining a fixed discharge pressure. Site tests were conducted, and it was determined that the blower could be turned down to below 10,000 SCFM without surging. However, operating efficiency did diminish as airflow was reduced.

3.6.5 Electrical Power Monitoring

It was determined that blower energy usage information would be necessary for retrofit comparative purposes. Prior to the investigation accurate power consumption data was not available. Watt meters were installed at the motor control center and daily readings of KWH and total airflow were made and recorded. This base line data for the blower power consumption was necessary to determine what portion of the entire plant's electrical power consumption was for aeration.

3.6.6 Piping System Investigation

The original air piping system at the Hartford Water Pollution Control Plant was constructed of spiral welded steel and wrought iron pipe. Some corrosion, rusting, and scaling of these types of pipes usually occurs after a few years of service, but normally, this does not cause an operating and maintenance problem in coarse bubble aeration equipment. In order to be certain that the existing air pipes were rust free and capable of being used for the fine pore diffusers, it was necessary to field inspect the air piping system.

Air blowers were shut off during the inspection period. The main 60-inch diameter air header and branch piping down to 24-inch diameter were inspected from within. Smaller diameter piping was inspected by removing fittings. The suction lines from the air filters to the blowers were also inspected.

The results of the air piping inspection revealed the following:

1. The bituminous epoxy coating in the air mains and suction lines were in excellent condition and would be suitable for the fine pore system without repair.

2. The coating in the 12-inch air pipes in Aeration Tank Nos. 1, 2, 3, and 4 was in good condition. The coating in the same air pipes in Aeration Tank Nos. 5 and 6 (never operated) was damaged with resulting rusting and scaling.

3. The 6-inch drop pipes and manifolds to which the "Deflectofusers" were connected were rusted, and the drop pipes could not be used with the fine pore aeration system.

3.6.7 Air Filtration Requirements

The fine pore ceramic domes would require removal of 95 percent of all particles 0.3 microns and larger in size in the air supply. The existing automatic oil bath filters were capable of removing only 25 to 30 percent of the particles and; therefore, were not usable alone with the fine pore system. Several alternate systems were evaluated including American Air Filter Co. "Biocell" and "Electro-pak" filters.

The "Biocell" filters, which could be installed inside the existing inlet plenums, would require only a structural frame. There was sufficient space in the inlet plenum to permit installation of the "Biocell" filters.

The "Electro-pak" filter is an electrostatic precipitator. Because of its expense and large size, it was not considered feasible for this installation.

3.6.8 Instrumentation System Requirements

The air control system was designed with flow control and flow indicators for each pass of each aeration tank. One DO probe in each pass sensed the amount of dissolved oxygen in the mixed liquor. A signal was fed to an analyzer and then to an electronic controller where the desired DO concentration had been previously set. The output signal from the controller modulated a 12-inch motor operated butterfly valve which controlled the amount of air to match the set-point DO. As each aeration pass was modulated, the main venturi sensed the change in pressure and flow in the entire system.

With low airflows anticipated due to the retrofit to the fine pore system, the range efficiency of the instrumentation system and the effects of low airflows on the DO problems were of concern. The equipment manufacturers were contacted and given the projected operating parameters. It was recommended that the existing range tubes in each flow transmitter be replaced with new range tubes so that the transmitters would be sensitive to future operation with the reduced airflow. Recalibration of the transmitter would also be required. In addition, the airflow totalizer gears and airflow indicator scales for each flow controller would require replacement. The DO probe manufacturer indicated that the existing probes would function satisfactorily with the fine pore system without modification. The small bubbles and vertical rise of the fine pore system versus the spiral roll of the coarse bubble system were considered not to be a problem.

3.7 COST EFFECTIVE EVALUATION

In 1980 Metcalf & Eddy, the original designers of the plant, was retained by the MDC to review the evaluation conducted by

MDC staff engineers. Metcalf & Eddy concurred with the finding of that investigation and were subsequently retained in 1981 to conduct a detailed cost-effectiveness analysis study of the retrofit from coarse bubble to fine pore aeration. The work by Metcalf & Eddy consisted of evaluation of the existing coarse bubble diffuser system as well as proposed installation of fine pore ceramic domes or disc and fine pore tube diffuser systems. The evaluation included investigating the oxygen transfer efficiencies of these systems, present and projected air requirements and power usage of these systems, present and future wastewater flows and load projections, and each system's relative cost-effectiveness over a planning period of 20 years.

Based on the cost-effectiveness study by Metcalf & Eddy, the following major conclusions were drawn:

1. For the future operating conditions expected at the Hartford Water Pollution Control Plant, clean water oxygen transfer efficiencies for the existing coarse bubble would be 7%; the proposed fine pore tube efficiencies would be 15% and the efficiencies for the fine pore ceramic domes would be 29%.

2. Minimum air requirements for the fine pore domes would be dictated by the air needed for mixing to keep the MLSS in suspension.

3. Peak air demand for proposed fine pore domes could be supplied by one existing blower throughout the planning period.

4. Peak air demands for the existing coarse bubble system, as well as for the proposed fine pore tubes, would require simultaneous operation of two blowers during warm summer months.

5. Even with increased submergence and increased headlosses with fine pore domes and tubes, the total system head on the blowers would be well within the capacity of the existing equipment.

6. Blower surging would not be expected to occur for the expected air demand with the proposed fine pore systems.

7. The capital as well as operating costs of the fine pore domes/discs would be smaller than those for the fine pore tubes.

8. Due to higher initial capital expenditures and higher operational costs of the fine pore tubes (resulting from lower oxygen transfer efficiencies), the fine pore domes would have a distinct cost advantage over the tubes.

In 1981 the estimated capital cost for all recommended improvements to retrofit to fine pore domes or discs was between $1,115,000 and $1,830,000 with an estimated payback of between 3 and 6 years based upon the finding in the Metcalf & Eddy report.

Based upon the work conducted by MDC staff personnel and the cost-effectiveness study conducted by Metcalf & Eddy, it was recommended to:

1. Initiate design to prepare plans and specifications to retrofit four of the six aeration tanks to fine pore ceramic domes.

2. Modify the existing valves and rate controllers on air lines to each individual pass of each tank and replace the associated range tubes in the transmitters. Change the air flow rate indicator scales.

3. Install "Biocell" air filters in all three inlet plenums of the three blowers.

The design phase (Recommendation No. 1) was initiated by the MDC in early 1982.

4.0 FINE PORE AERATION RETROFIT DESIGN DESCRIPTION

4.1 BASIS FOR DESIGN

The 1981 cost-effectiveness study conducted by Metcalf & Eddy included a complete design review for sizing the fine pore aeration system to meet the process needs through the year 2001. Existing and projected flow rates and process loadings were estimated as follows:

Parameter	1982	2001
Plant Inflow		
Average daily flow, mgd	46.4	60.0
Peak daily flow, mgd	86.0	120.0
Average daily BOD_5, mg/l	125	136
lbs/day	48,400	68,100
Primary Effluent		
Average daily BOD_5, mg/l	78	95
lbs/day	30,200	46,800
Peak daily BOD_5, lbs/day	44,200	72,700
Ratio of peak/average BOD_5	1.46	1.53
Average daily TKN, mg/l	22.2	23.1
lbs/day	8,600	11,600

The design basis for the operating MLSS concentration was 2,000 to 2,500 mg/l, although actual MLSS concentrations in past years rose as high as 6,000 mg/l and averaged about 4,000 mg/l due to sludge wasting restrictions. The projected F/M ratio for the retrofit was 0.2 to 0.3 which resulted in a ratio of oxygen required/BOD removed (lb. O_2/lb. BOD) of about 1.0 based on design criteria in WPCF MOP No. 8.

Earlier operation at much higher MLSS concentrations and lower F/M ratios results in oxygen required/BOD removed ratios of

1.8 to 2.0. It was obvious that significant energy savings could be realized by operating the process at lower MLSS concentrations.

Based on the above criteria the average daily oxygen requirements at field conditions (OTR) were projected as follows:

Case	Time of Year	Average daily oxygen requirement, lbs/day 1982	1987	1994	2001
4 aeration tanks from 1982 through 1997;	May-Oct.	49,900	56,000	40,700	73,000
6 aeration tanks from 1998 through 2001	Nov.-Apr.	30,200	34,600	40,700	46,800

The determination of the required oxygen transfer rate at Standard Condition (SOTR) was made for the existing aeration equipment and two types of high efficiency fine pore diffuser systems using the following equation and oxygen transfer parameters:

$$SOTR = \frac{OTR}{\alpha \left(\frac{\beta C_W - C_L}{C_S} \right) 1.024^{(T-20)}}$$

Where:

α = Relative rate of oxygen transfer in wastewater as compared to clean water, dimensionless (equal to 0.75 for ceramic fine pore domes/discs, 0.80 for ceramic fine pore tubes, 0.85 for existing diffusers).

β = Relative oxygen saturation value in wastewater as compared to clean water, dimensionless (commonly equal to 0.95).

C_S = Oxygen saturation value of clean water at Standard Conditions, 9.17 mg/l.

C_W = Oxygen saturation of water at given temperature and altitude, 10.15 mg/l.

C_L = Operating DO level, 2.0 mg/l.

T = Average temperature of mixed liquor, 15°C.

Using the above relationship, the estimated oxygen ratios of SOTR-to-OTR for three types of diffusers were as follows:

Diffuser Type	SOTR/OTR Ratio
Fine pore domes/discs	1.80
Fine pore tubes	1.69
Existing coarse bubble	1.59

The selection of alpha factors (based on the process operational modes, wastewater characteristics, and type of diffusers under consideration) was not based on pilot or other testing, but rather from existing general information and criteria available to the consultant and from information supplied by the various diffuser manufacturers.

The average oxygen transfer efficiencies at Standard Condition (SOTE) selected by the consultant for each type of diffuser were as follows:

Diffuser Type	SOTE, Percent
Fine pore dome/disc	29
Fine pore tubes	15
Existing coarse bubble	6

The resulting airflow requirements for each type of diffuser for the 1982 estimated oxygen transfer criteria were:

Condition	Average Daily Air Requirement, SCFM Coarse Bubble	Tubes	Domes/Discs
Without nitrification	45,900	27,100	20,500
With nitrification	68,100	36,900	26,000

The above values do not include airflow requirements for influent channel mixing. Estimated total airflow requirements for the dome/disc diffuser aeration system plus influent channel air were as follows:

	1982			2001		
	Min.	Avg.	Max.	Min.	Avg.	Max.
Air requirements without channel air, SCFM	3,900	17,900	19,200	6,100	25,900	27,800
Total air required, SCFM	15,900	29,900	31,200	18,100	37,900	39,800

4.2 AERATION TANK CONFIGURATION

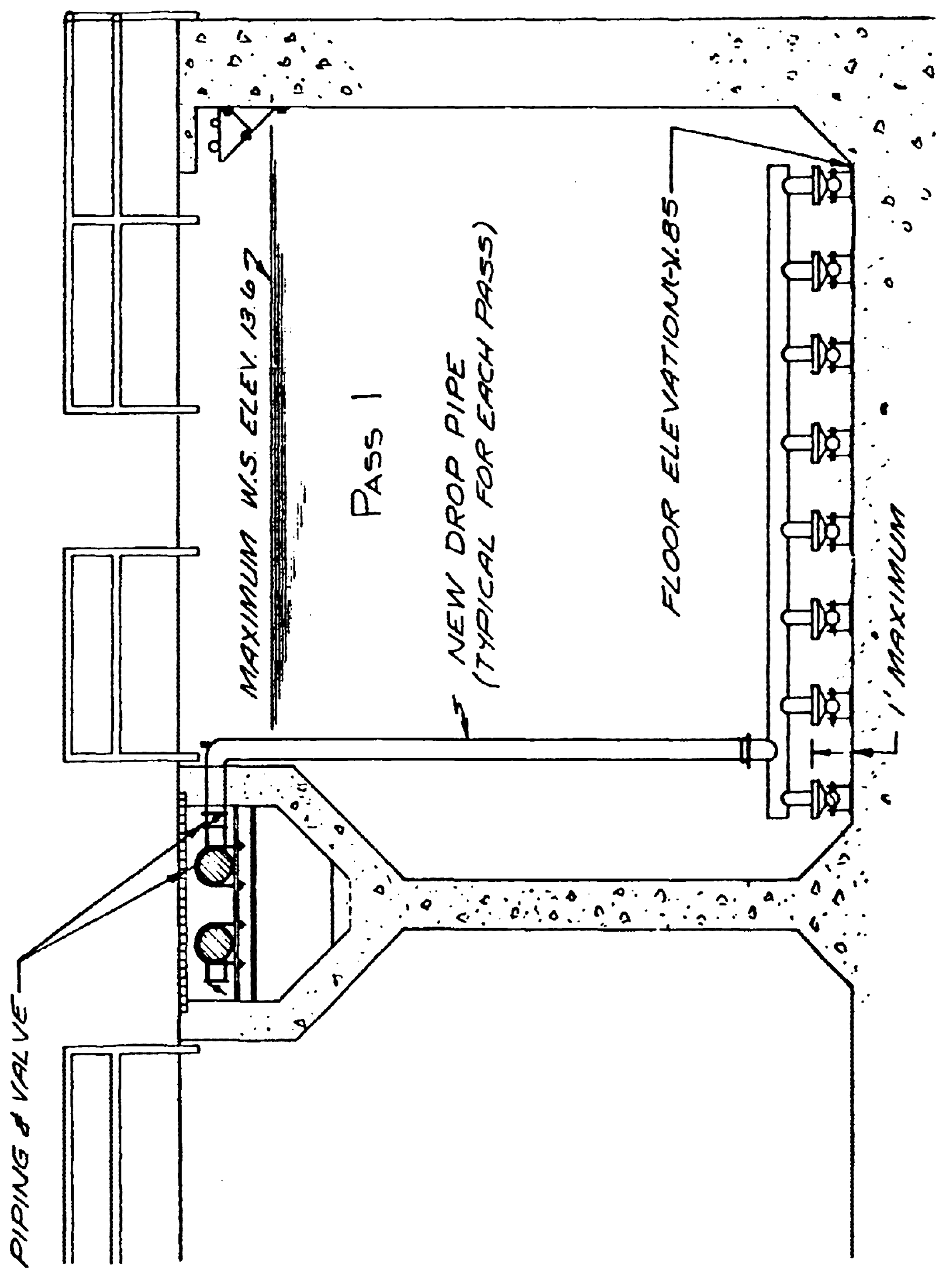
The existing four of six aeration tanks originally placed in service in 1972 would continue to be used after the retrofit to fine pore aeration. No modifications to the tanks or to the process liquid piping would be necessary. Only in-tank air piping would be changed.

Details of the aeration tank dimensions are contained on Figure No. 7. Each of the four tanks is identical in size, and each contains four aeration passes. The overall tank dimensions are 194 feet long by 80 feet wide. The nominal average operating liquid level is 15.5 feet. Each aeration pass is approximately 20 feet wide by 194 feet long. Primary effluent or return activated sludge enters one end of the pass and exits the opposite end, 194 feet away.

Figure No. 8 contains a typical cross section of one aeration pass. The walls between aeration passes are the Y-wall type, and the bottoms of the aeration passes contain fillets to

FIGURE NO. 8

SECTION A-A: TYPICAL CROSS SECTION



prevent solids deposition and build-up at the intersection of the wall and floor. Process air piping for each aeration pass is contained in the Y-wall directly beneath the walkway.

4.3 OPERATING METHOD

The mode of operation both before and after retrofit to fine pore aeration equipment is step-feed. Aeration pass no. 1 is used for reaeration of the return activated sludge. Normally one third of the primary effluent is fed into the head end of the remaining three passes. Figure No. 7 shows each of the feed points and flow pattern through the aeration tank.

Process liquid flow to each aeration pass is introduced through a sluice gate in the center of the end wall and about 3 feet below the liquid surface. Flow from one aeration pass to the next is through a large opening in the wall between passes. The opening is approximately 12 feet wide by 12 feet high. Primary effluent entering any of the three aeration passes is mixed with the effluent from the upstream pass. Some back mixing occurs at the ends of the aeration passes. Flow from the aeration tank at the end of pass no. 4 is via a U-shaped weir to effluent channels. There is approximately a 2-foot drop in the hydraulic profile at this point.

4.4 FINE PORE DIFFUSER DESIGN

The layout and design of the fine pore dome diffuser system was planned so that most of the existing air piping could be utilized without modification. This was an especially important consideration since all of the air piping outside of the aeration tanks was in good condition and usable. The new submerged air distribution piping and diffuser grid piping was designed to facilitate an easy and economical installation.

Since the full floor coverage dome/disc type of fine bubble diffuser aeration equipment resulted in the lowest total airflow requirements of any type system evaluated, contract drawings and specifications were prepared for either a dome- or disc-type ceramic diffuser aeration system. Specifications were written to allow equipment furnished by the Norton Co., Worcester, MA, and by Sanitaire, Milwaukee, WI, or by a manufacturer of equal equipment.

The acceptable fine pore diffuser system had to have guaranteed oxygen transfer efficiencies of 28 percent SOTE at 0.5 SCFM/diffuser, 26 percent SOTE at 1.0 SCFM/diffuser, and 23 percent SOTE at 2.0 SCFM/diffuser when operated at the average design diffuser density of 5.1 sq.ft. per diffuser in 15.5 feet of clean water. In addition, the minimum airflow criteria of 0.5 SCFM/diffuser was established to prevent water-side fouling. Furthermore, a minimum mixing requirement of 0.12 SCFM/sq. ft. of tank bottom was established together with a minimum diffuser spacing of 2 feet on center. Certified oxygen transfer and mixing test results were required as part of the bid documents of each manufacturer submitting a bid. (Diffuser performance data are presented on Figure Nos. 9 and 10).

The air distribution piping was specified to have built-in additional diffuser capacity of 50 percent over the minimum number of diffusers specified. This would be accomplished by supplying 50 percent more diffuser saddles or base plates than the base design called for. Each air distribution pipe grid would have the 50 percent excess diffuser capacity. The air distribution piping would be manufactured of 4-inch UPVC (unplasticized polyvinyl chloride) pipe and 4-inch UPVC expansion tees. The grid would be installed so that the top of the diffuser grid was level, and the top of the diffusers would be 14.5 feet below the liquid surface. The new grid piping would be connected to the existing 12-inch air supply mains with a new 4-inch diameter stainless steel drop pipe and manually operated throttling valve. Each aeration pass would have seven grids, one for each of the existing air drop pipes. Each of the diffuser grids would contain a moisture blowoff assembly to remove any residual moisture after the startup of the aeration system. (Figure No. 11 contains a typical diffuser grid piping layout).

The plastic piping and fittings would be supported and anchored to the concrete floor slab using an adjustable stainless steel pipe support assembly which would allow for vertical adjustment increments of 1/8-inch (A detail of the diffuser and pipe support system supplied is presented on Figure No.12). Each grid pipe support would be anchored to the tank floor with two, 1/4-inch diameter stainless steel anchor bolts. The 4-inch UPVC pipe would be secured to the pipe support with a 4-inch stainless steel gear clamp or approved equal attachment.

Figure 9

OXYGEN TRANSFER EFFICIENCY CHARACTERISTICS

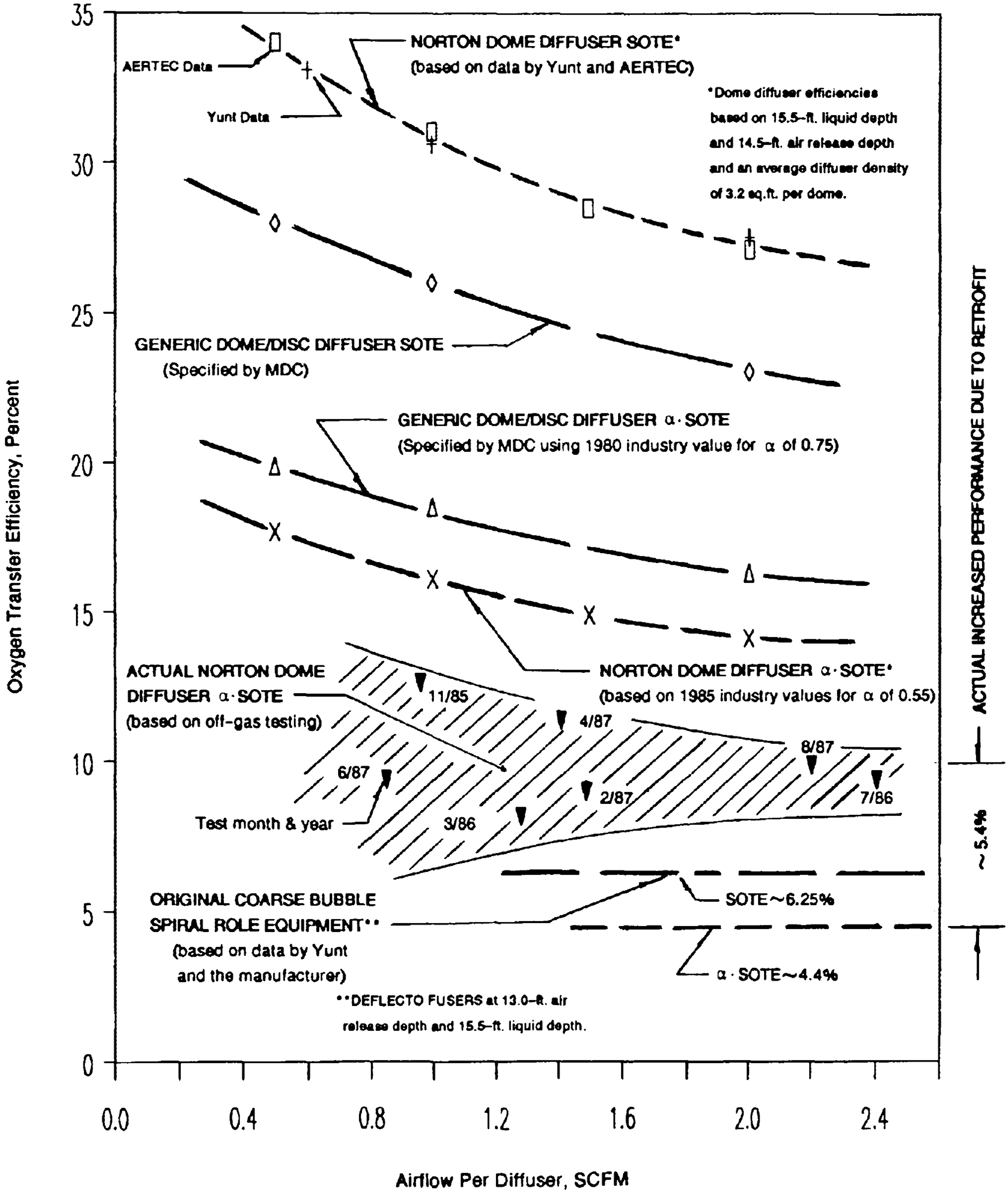


FIGURE NO. 10

DOME DIFFUSER HEADLOSS CHARACTERISTICS

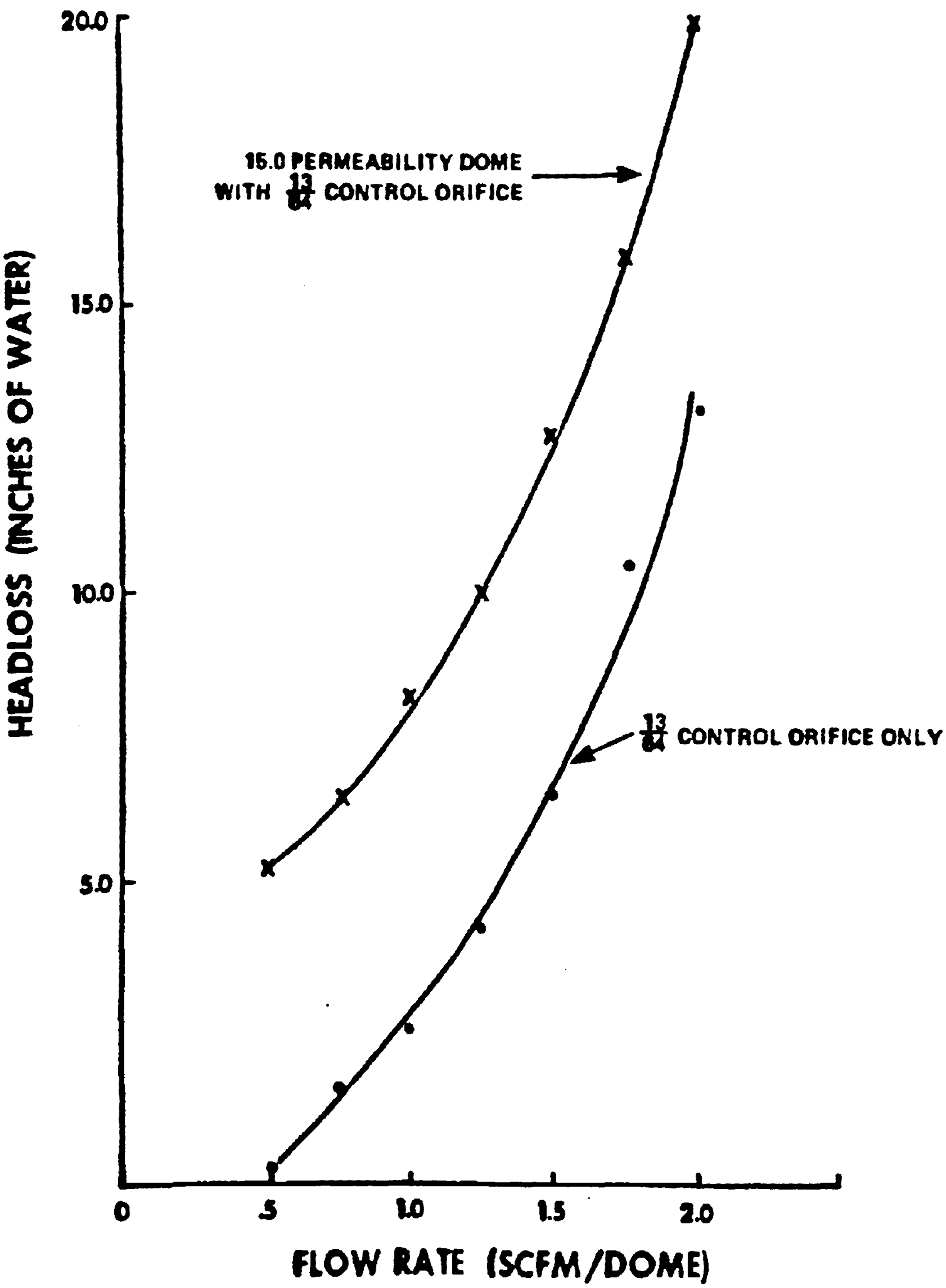
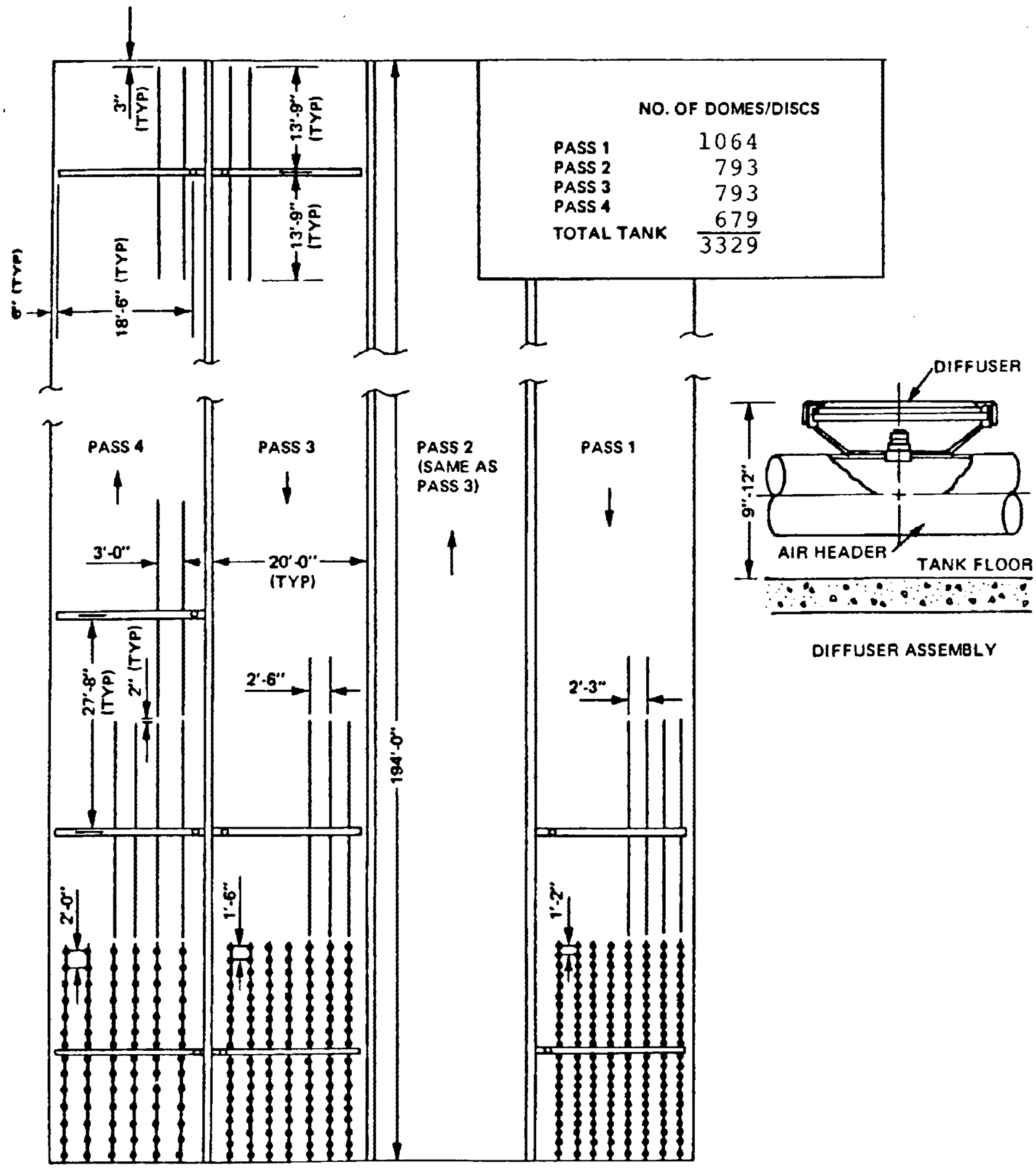


FIGURE NO. 11

TYPICAL LAYOUT FOR DOME/DISC DIFFUSERS

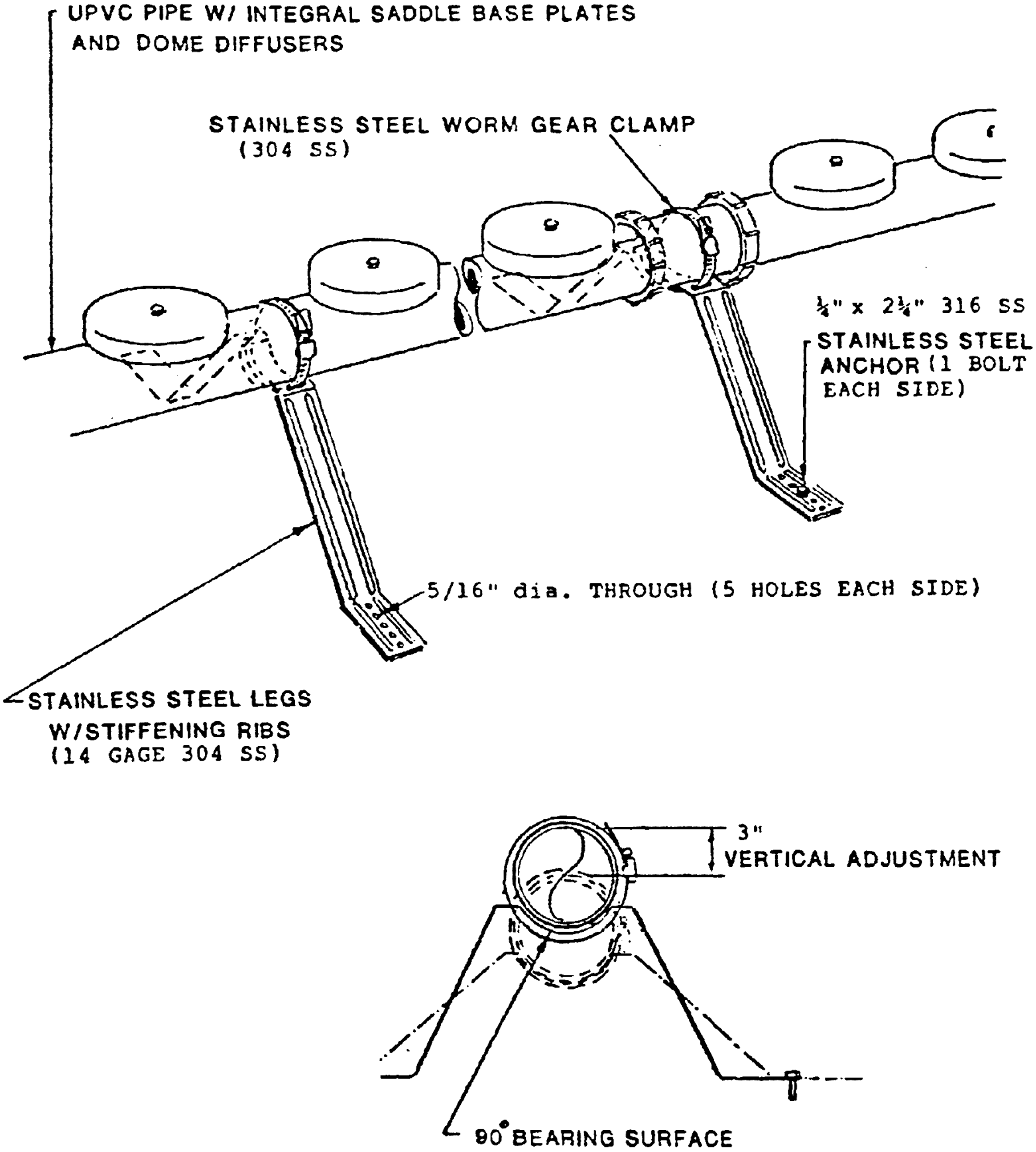


NO. OF DOMES/DISCS	
PASS 1	1064
PASS 2	793
PASS 3	793
PASS 4	679
TOTAL TANK	3329

DOME/DISC DIFFUSER LAYOUT (TYPICAL TANK)

FIGURE NO.12

STAINLESS STEEL PIPE SUPPORT ASSEMBLY



4.5 DIFFUSER LAYOUT AND DISTRIBUTION

The specified minimum number of diffusers and layout were based on the maximum projected airflow for the design period and the minimum airflow and diffuser spacing for mixing and solids suspension. Based on the minimum mixing criteria at 0.12 SCFM/sq. ft. of tank floor area, the minimum airflow for the design was as follows:

All four aeration tanks	7,500 SCFM
One aeration tank	1,860 "
One aeration pass	470 "

In addition, a minimum airflow of 0.5 SCFM per diffuser was specified.

Based on a maximum airflow per diffuser of 2.0 SCFM, the total number of diffusers specified was 3,100 per tank or 12,400 for the four aeration tanks. Based on a step feed mode of operation with return sludge being fed to the head end of the first aeration pass and one-third of the primary effluent being fed to the head end of each of the remaining three aeration passes, estimated percentages of the total air required in each pass were as follows:

Pass	Percent of total tank air required	No. of diffusers
1	35	1,085
2	25	775
3	25	775
4	15	465
Total/tank	100	3,100

In addition, the above estimates of oxygen demand distribution were verified by oxygen uptake studies in one of the operating tanks. The studies were conducted by MDC staff personnel at sixteen locations along the four passes of one aeration tank prior to retrofitting.

Possible future alterations of the step-feed mode called for flexibility of diffuser placement and density (tapering) in the design of the diffuser grids. The additional excess 50 percent saddle capacity in the grids and the provision for a throttling valve at the drop pipe provided for flexibility and fine tuning of the diffuser tapering as might be required.

It was planned for the first two aeration tanks to be retrofitted first and then placed on line before completion of the retrofit in Aeration Tank Nos. 3 and 4. These first two tanks would be field tested and additional diffuser density modifications would be incorporated into Aeration Tank Nos. 3 and 4 as needed.

Dissolved oxygen measurements were taken in Aeration Tank Nos. 1 and 2 soon after being placed in operation. Operational changes since the initial design was completed had caused a shift in the oxygen demand pattern. The dissolved oxygen profiles indicated that more diffusers were needed at the influent end of the passes. Redistribution of the diffusers was easily accomplished by use of the spare saddles specified in the design. (Diffuser density and quantity information by grid, pass and tank are contained on Figure Nos. 13 and 14).

4.6 BLOWER DESIGN AND OPERATION CONSIDERATIONS

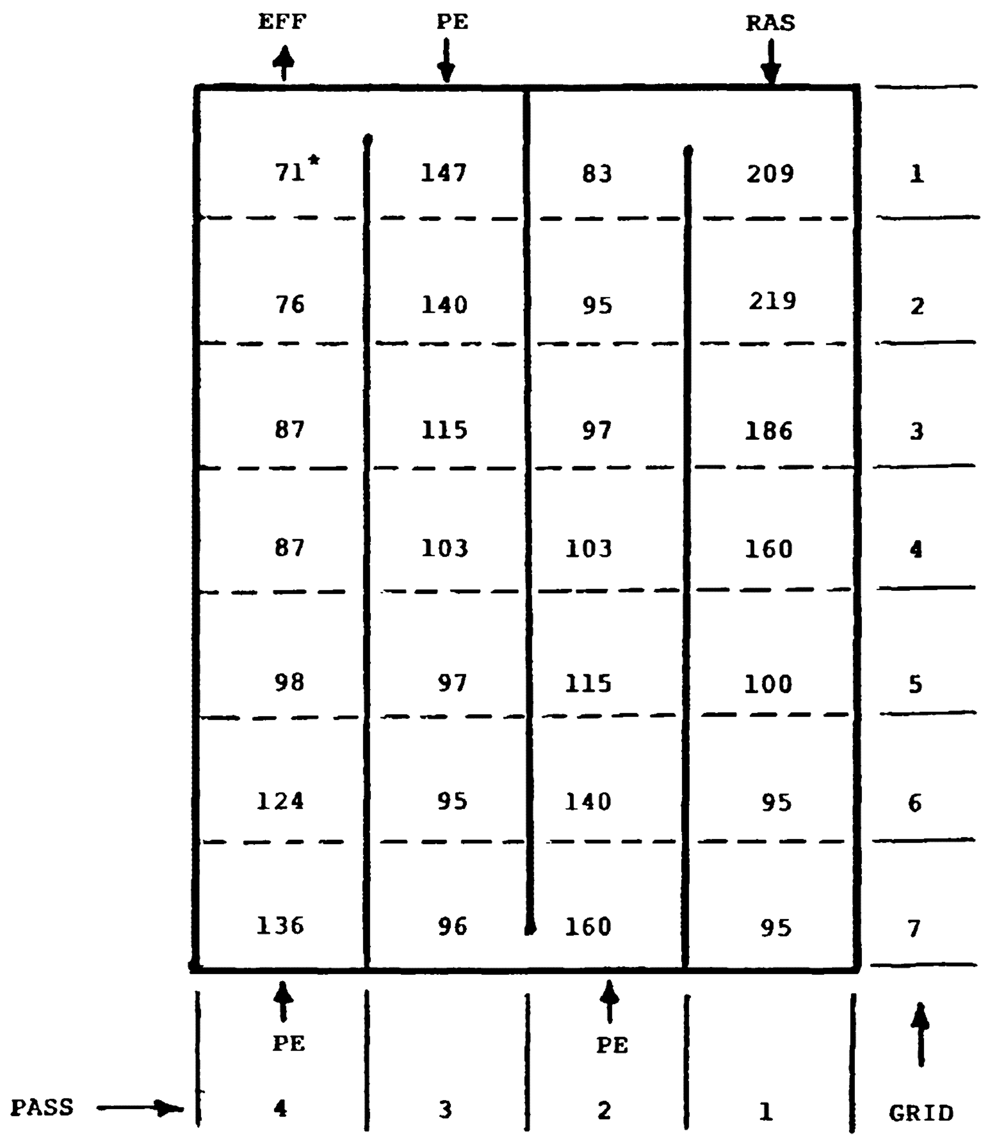
No blower air handling capacity modifications were planned as part of the aeration system retrofit. The existing Brown-Boveri 60,000 SCFM rotary vane blowers were tested during the retrofit feasibility study and found to be suitable for use with the new fine pore diffuser system. Although preretrofit airflow from a single blower had been at the 60,000 SCFM level, the new fine pore aeration system would require less than 30,000 SCFM. By inlet guide vane adjustment, turndown of the blowers was possible to a surge point of approximately 8,000 SCFM. The only cost of turndown was in the reduced efficiency of the blower at lower airflow output rates. (Reducing a blower output from 40,000 to 20,000 SCFM increases power consumption from 30 KW/1000 SCFM to 40 KW/1000 SCFM.)

The only modification to the blowers as part of the retrofit would be the provision for automatic surge protection for each blower. (Specific blower performance data is contained in Appendix I-C).

The only modification required for the air filtration system would be the installation of American Filter Co. "Biocell" cartridge filters and frames in the intake plenum just after the existing oil screen filters. With the installation of the

FIGURE NO. 13

PLAN SKETCH WITH NUMBER OF DOMES
PER GRID, PASS, AND TOTAL

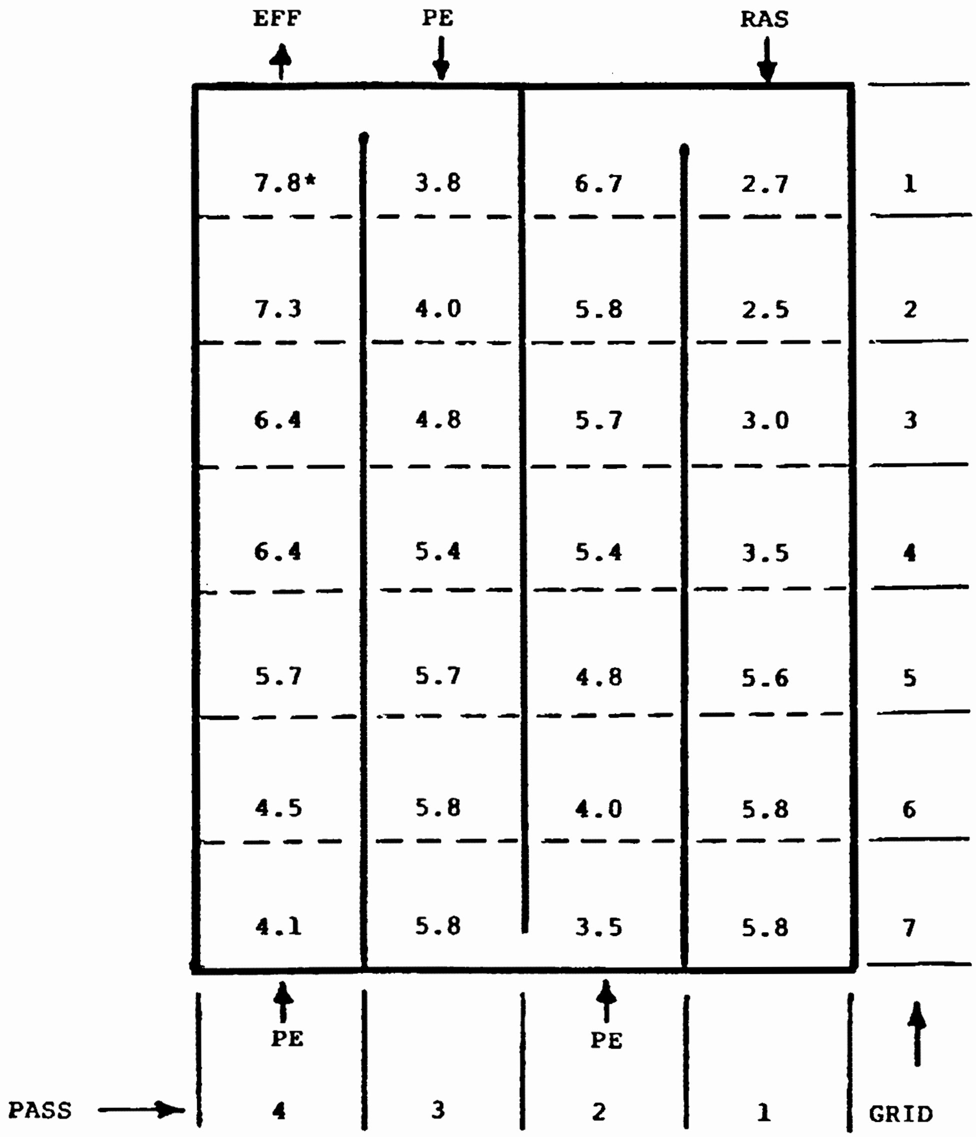


DOMES/PASS 679 + 793 + 793 + 1064 = 3329

* denotes number of domes per grid
RAS denotes Return Activated Sludge
PE denotes Primary Effluent (one third per feed pt.)
EFF denotes Effluent from aeration tank

FIGURE NO. 14

PLAIN SKETCH WITH OVERALL DENSITY PER GRID



* denotes overall diffuser density per grid based on number of domes per grid and mid-depth plan area per grid (actual grid density is greater than values shown). Density = sq.ft./dome

new filters, 95 percent of all particles 0.3 microns and larger would be removed from the air supply.

4.7 AIRFLOW MEASUREMENT AND DISTRIBUTION

The original airflow measurement and control system would remain in operation with modifications to the measurement and control instrumentation to adjust for the significant reduction of airflow throughout the system. The original airflow measurement equipment consisted of a 12-inch venturi meter on the head end of each aeration pass air supply line and one, 60-inch venturi meter on the main air supply pipe located between the blower building and the aeration tanks.

Airflow distribution modification would be accomplished by designing the fine pore diffuser system to operate with equal airflow rate to all diffusers under normal operating conditions and to distribute the diffusers (tapering) according to the oxygen demand throughout the aeration tank. Airflow adjustment from pass to pass would be accomplished by adjusting the 12-inch control valves on the air line to each aeration pass. Further fine tuning of air distribution within a pass would be possible by adjusting the 4-inch control valves on each of the seven drop pipes feeding the fine pore diffuser grids.

4.8 DISSOLVED OXYGEN/AERATION CONTROL SCHEME

The original design in 1968 provided for dissolved oxygen measurement and airflow control instrumentation. This mode of control would be continued for the fine pore retrofit as well. DO probes and meters manufactured by the pHOX Co. were installed at the half-way point along the length of each aeration pass with a submergence of about 3 feet. This instrumentation was linked to the airflow control instrumentation.

Calibration of the continuously recording DO instrumentation would be accomplished by MDC laboratory personnel on an unscheduled basis as deemed necessary. A laboratory calibrated portable DO probe and meter would be used to measure mixed liquor dissolved oxygen at the location of the in-place DO probe. The in-place DO meter would then be adjusted as necessary to agree with the reading from the portable unit.

4.9 CONTRACT DOCUMENTS AND BID

MDC staff performed the detailed final design and preparation of the contract specifications and drawings. The contract documents required the bid to be made by the aeration equipment manufacture and not by general contractors. The purpose of this requirement was to place total responsibility for the retrofit contract squarely upon the aeration equipment manufacturer. The scope of work included:

1. all in-tank aeration equipment and piping,
2. air filtration equipment,
3. removal of the old existing coarse bubble system,
4. cleaning of the aeration tanks, and
5. installation of all the new equipment.

Bids were advertised in February 1982. The three bidders were: The Norton Co., Worcester, MA; Sanitaire, Milwaukee, WI; and The Gray Engineering Group, Toronto, Canada. The successful bidder was the Norton Co. Installation work began in the summer of 1982. Aeration Tank No. 1 was completed in August, Aeration Tank No. 2 in September, and Aeration Tank Nos. 3 and 4 were completed in November 1982.

4.10 DESCRIPTION OF FINE PORE DIFFUSER EQUIPMENT PURCHASED

The fine pore dome diffuser equipment installed in Aeration Tank Nos. 1 through 4 is the Norton Dome Diffuser Aeration System (DDAS). Each diffuser is a 7-inch diameter porous ceramic dome which is secured to a UPVC plastic pipe saddle by a dome orifice bolt. Air emerges from the 4-inch grid piping network at each saddle location up through a hollow plastic dome bolt which contains a 13/64-inch diameter orifice in the bolt side wall. Air then fills the cavity between the saddle and under side of the ceramic dome where it disperses through the wall of the dome. Neoprene gaskets seal the dome at the dome bolt location and saddle. The dome saddle is cemented to the 4-inch diameter UPVC grid pipe. Figure No. 7 contains a sketch of the diffuser and pipe support assemblies.

The pipe grid system is supported and anchored to the aeration tank floor by a Norton designed stainless steel bracket which allows for 1/8-inch vertical increments of adjustment. The support bracket is secured to the concrete floor slab with two

1/4-inch diameter stainless steel expansion anchor bolts. The 4-inch UPVC air piping is attached to the support bracket by a standard commercially available stainless steel gear clamp.

Although 3,100 diffusers were specified for each aeration tank, the actual number of diffusers installed in each tank is 3,329. The distribution of diffusers by grid and aeration pass is contained on Figure No. 13.

4.11 INSPECTION AND TESTING

During all phases of the installation, MDC personnel continuously inspected the completed work on a grid-by-grid basis. Alignment of piping and diffuser elevation were checked and verified for proper location and elevation. All diffusers were installed and leveled to tolerance of +/- 1/8-inch. The 7-inch ceramic dome diffusers were inspected after installation for proper gasket placement and bolt torque. Bolt torque was especially important because of the limited allowance for torque load error associated with the plastic dome bolts (25 inch-pounds maximum torque).

Upon completion of the installation in each tank, clean water was introduced to a level 3 inches above the top of the dome diffusers. Grid levelness was checked and verified, and a system air distribution and leak test was performed. After all corrections were made to assure uniform air distribution and no leaks at pipe fittings, saddle assemblies and around gaskets, the water level was slowly increased to full depth while observing the air distribution pattern. The aeration tank was then placed in operation.

5.0 OPERATIONAL PERFORMANCE AND EVALUATION

5.1 SYSTEM STARTUP

Prior to the startup of Aeration Tank No. 1 with new fine pore aeration equipment in mid-August 1982, the average air usage over the previous 2 months was 64 MCFD (Mil. Cu. Ft./Day), and the blower power usage over the same period averaged 31,000 KWH/day. During the same period MLSS ranged from 2,500 to 4,000 mg/l, and blower discharge pressure ranged from 7.5 to 7.7 psig. Air supply was controlled automatically during this period, with air valves controlled by signals from DO probes in each pass. An average dissolved oxygen concentration of 1 mg/l was usually maintained in each pass.

Upon startup of the new fine pore aeration system in Aeration Tank No. 1, air usage immediately dropped to 54 MCFD, and blower power usage dropped to 28,000 KWH/day.

Aeration Tank No. 2 was placed on-line with the new equipment at the first of September. During late August MLSS concentrations had been increasing, and air supply was intentionally increased over the preretrofit baseline levels. As the MLSS concentration increased to over 5,000 mg/l, the greater air requirements began to affect the different pressure requirements of the coarse and fine pore systems which were on-line concurrently and being controlled by the same automatic airflow control system.

The fine pore systems in Aeration Tank Nos. 1 and 2 received less air than required, and anaerobic conditions occurred causing sludge bulking and subsequent loss of solids in the final effluent. Air supply to the entire four-tank system was increased until a solution to the air distribution problems could be found. Sludge wasting was increased to lower the MLSS concentration to the 2,500 mg/l design range and, thereby, lower the total oxygen demand requirements.

By the first of November 1982 the installation of the entire project was complete. With all four aeration tanks on-line with the new fine pore aeration equipment, air usage dropped to 36 MCFD, and power fell to a level of 22,000 KWH/day. (These levels are approximately 60% and 70% of preretrofit conditions, respectively.) For the remainder of 1982 the system was operated at these levels. During this period the automatic air control instrumentation was adjusted, and an economical operating range was investigated.

During the first week of 1983 an unexpected increase in MLSS concentration caused air distribution problems and a large increase in blower power usage. At the same time the automatic control system did not perform as planned. Blower discharge pressure was greater than necessary to deliver air to all the passes, and air supply to some passes was reduced to levels lower than the minimum recommended values required for solids suspension and to prevent water-side fouling of the ceramic diffusers.

In mid-January 1983 the aeration system was placed in the manual mode of operation, with DO probes used for monitoring purposes only. In the automatic air control mode the blower discharge pressure varied from 7.1 to 7.4 psig. After switching to manual air control operation, the blower discharge pressure was adjusted to 6.8 psig and all 12-inch air control valves on aeration pass lines were locked fully open. Air usage dropped slightly, but power consumption fell by over 10 percent. Further adjustment to the blower inlet guide vane positioning resulted in an additional 10 percent reduction in power draw at the blowers.

During April 1983 influent channel air usage was reduced by one-half the previous rate of use. These reductions brought the total air usage to 22 MCFD and power consumption to 15,000 KWH/day.

As was noted in the pilot testing of fine pore diffusers in 1979, foaming of the aeration tanks became worse after the start-up of the new fine pore system. It was determined that high MCRT's (greater than 3-5 days) caused foaming to increase above an acceptable level. Short-term remedial action to reduce foam consisted of reducing the mixed liquor dissolved oxygen concentration to zero or near zero.

5.2 OPERATING CONDITIONS

Average operating conditions for the period from retrofit implementation through the off-gas testing program are contained in Table Nos. 2, 3, 4, 5, and 6, and also in Appendix I-C. The design BOD loading was estimated to be about 30,000 lbs./day to the secondary treatment system in 1982 and about 33,000 lbs./day in 1985. Average daily wastewater flows for these years were projected to be 46.4 MGD for 1982 and 48.5 MGD for 1985. Generally, wastewater flow rates have exceeded the design projections by a small amount, but BOD loading has lagged behind the projections by a greater amount.

MLSS concentration, which was assigned a design criteria range from 2,000 mg/l to 2,500 mg/l, has varied widely over the years since the retrofit started up. Concentrations as high as 6,000 mg/l have been measured, and the average MLSS concentration was much greater than the upper limit design value of 2,500 mg/l. This high solids inventory in the aeration system has caused oxygen demand to increase and aeration efficiency to lower, thus keeping energy costs up. In addition, high MLSS concentrations mean longer MCRT values. Foaming becomes a problem under these conditions and oxygen transfer efficiency is adversely affected as well.

5.3 OPERATIONAL CONTROL

The primary control used in the operation of the aeration system is dissolved oxygen concentration. This control is accomplished manually by observing the dissolved oxygen concentration in the fourth pass of each of two aeration tanks twice daily and adjusting blower output to achieve a positive DO in the fourth aeration pass for at least 12 hours per day. The positive dissolved oxygen concentration usually occurs between 12 midnight and 12 noon each day. Generally, the entire aeration system operates at a mixed liquor dissolved oxygen concentration of less than 0.5 mg/l.

Diffuser air sparge rates vary within the design range as the demand for oxygen changes. The established mode of operation is to leave all aeration pass control values fully open, allowing all diffusers to sparge at approximately equal rates throughout the system. Should dissolved oxygen concentrations increase in some aeration passes or tanks, air supply throttling is initiated at the individual aeration pass or passes having the greater DO concentration. Throttling is not continued to a point below which airflow to a pass would be less than the minimum airflow to achieve mixing and solids suspension (0.12 SCFM/sq. ft.) or less than 0.5 SCFM per dome.

5.4 TREATMENT PERFORMANCE

The water quality of the plant effluent remains consistently high after the implementation of fine pore aeration. Effluent BOD and suspended solids concentrations nearly always remain below 10 mg/l. No specific qualitative or quantitative information is available concerning before and after retrofit effluent characteristics and treatment performance.

5.5 AERATION PERFORMANCE EVALUATION

5.5.1 General

An extensive aeration system performance evaluation has been undertaken at the MDC treatment facility as part of the ASCE/EPA Oxygen Transfer Study. From September 1985 through August 1987 Aeration Technologies, Inc., conducted off-gas testing during eleven separate site visits. Over 340 individual off-gas tests were performed in Aeration Tank No. 2 to measure and record aeration performance over time. The results of the field off-gas measurements were compared with plant water quality data and operating conditions for the periods in which testing was performed.

Table No. 7 contains a listing of the eleven site test visits together with a brief description of the type of testing performed. The eleven site visits are graphed chronologically on Figure No. 15.

The first two site visits were for the purpose of equipment and facility checkout. Only specific points in the aeration system were tested during these visits. The first full test of Aeration Tank No. 2 began on November 12, 1985. A total of seven full-tank tests were performed over the two-year period. The initial full tank test in November 1985, and the second full-tank test in March 1986 used a sampling plan consisting of four replicate tests at each of the influent, middle, and effluent thirds of each aeration pass. (This sampling plan, designated as Sampling Plan "A", is shown graphically on Figure No. 16). For the remaining five full-tank tests, a sampling plan using one replicate at each third point, but with three sets of tests for each site visit was adopted. It was believed that the reduced time necessary to test the total tank on a once-through basis would be more representative of

Table 7

OFF-GAS TEST CHRONOLOGICAL SUMMARY

Start Date	Test Description	Test Designation
09-14-85	Preliminary Checkout of Equipment	P1
10-15-85	Start Cleaning of Aeration Tank	--
10-21-85*	Preliminary Checkout of Equipment	P2
11-12-85**	Full Testing	1A
12-19-85	Influent Point Testing	S1
03-24-86**	Full Testing	2A
04-01-86	Diurnal Testing	S2
07-14-86***	Full Testing	3B
02-04-87***	Full Testing	4B
04-22-87***	Full Testing	5B
05-01-87	Starting Cleaning of Aeration Tank	--
06-18-87***	Full Testing	6B
08-13-87***	Full Testing	7B

*Conducted in Aeration Tank No. 1 (Aeration Tank No. 2 down for cleanining).
**Four replicate tests per sample location and one excursion through the aeration tank.
***One test per sample location and three excursions through the aeration tank.

FIGURE NO. 15

TESTING AND TANK CLEANING TIME SUMMARY

LEGEND: 1A - "A" designates full test with four replicate tests per sample location and one pass through the aeration tank.

3B - "B" designates full test with one test per sample location and three passes through the aeration tank.

P1 - Preliminary tests.

S1, S2 - special testing (influent point and diurnal, respectively).

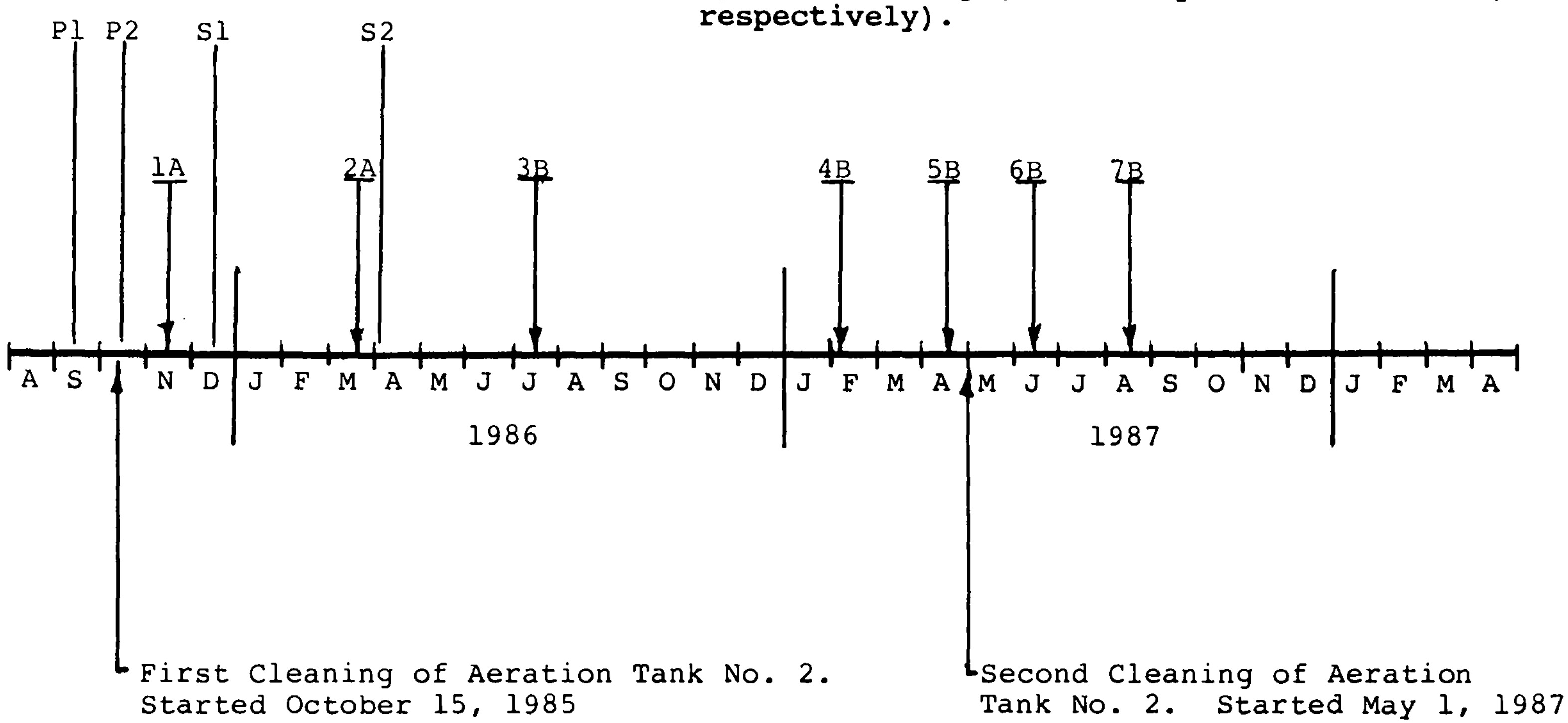
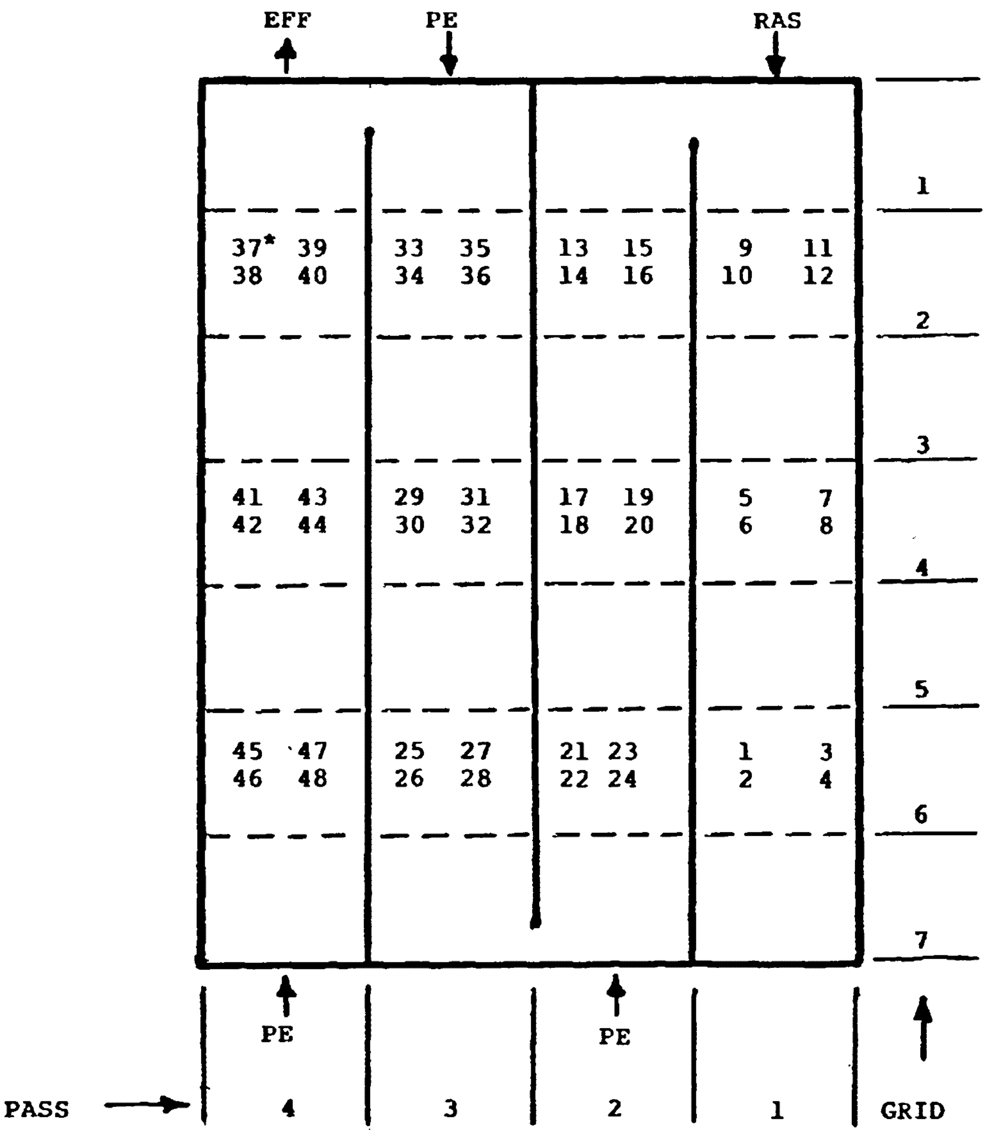


FIGURE NO. 16

OFF-GAS SAMPLING PLAN "A"



* Denotes test number and sample location for tests conducted on November 12, 13, 14, 1985 and on March 24 and 25, 1986. Four replicate tests at each sample location (one excursion through the aeration tank per site visit).

actual performance conditions in the aeration tank. (This second sampling plan, designated as Sampling Plan "B" is shown graphically on Figure No. 17).

Two special tank tests were conducted on Aeration Tank No. 2 as part of the overall study. These tests consisted of an influent point test at each pass within 2 months after the first tank cleaning, and a diurnal test at one point in the aeration tank to determine the variation in performance over a twenty-four hour period.

The off-gas test equipment and analysis procedures were in accordance with the project "Manual of Methods for Fine Bubble Diffused Aeration Field Studies." Photo Plate P-1, Appendix I-B, contains photographs of the off-gas analyzer apparatus and the off-gas collection hood. Only one hood was used for the "A" sampling plan, while two identical hoods were used for the "B" sampling plan.

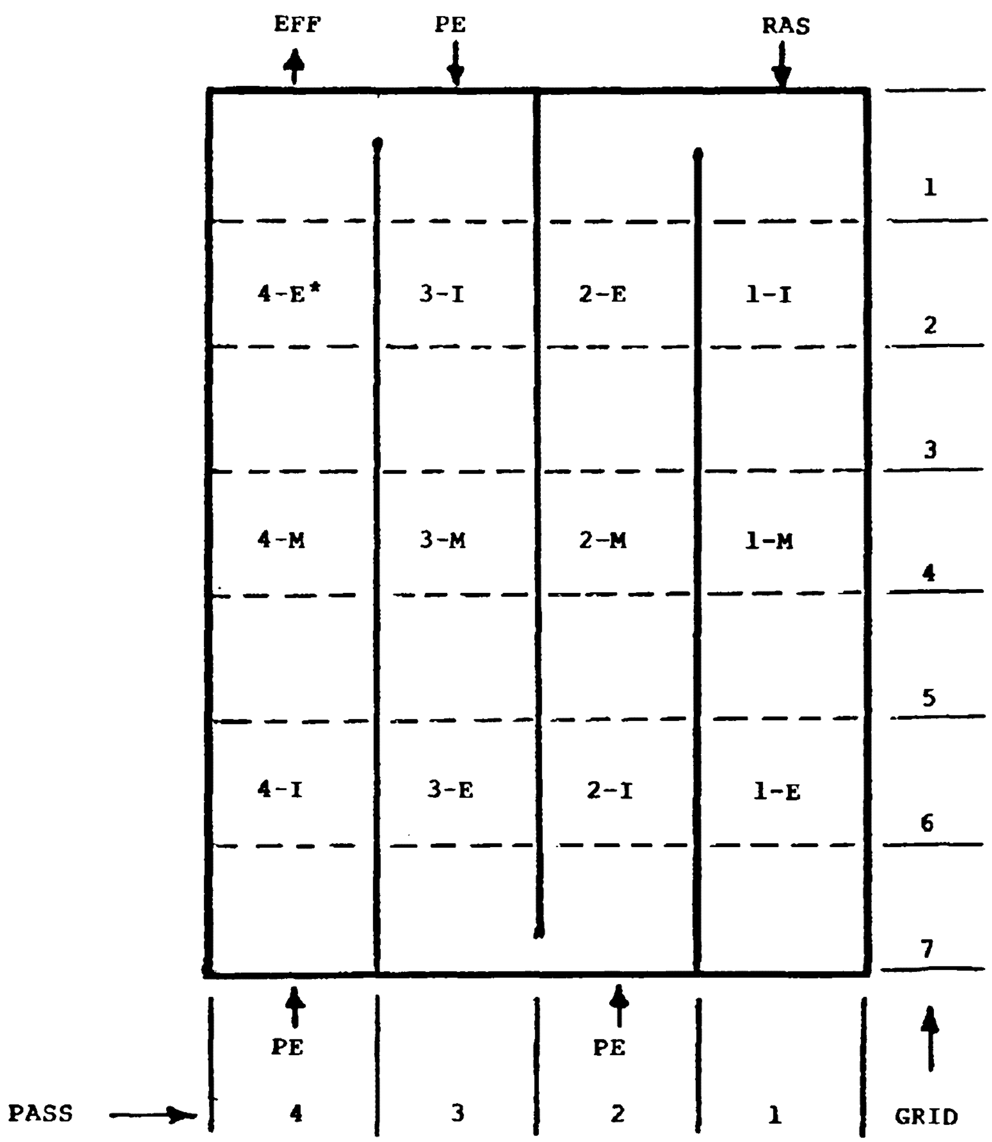
The results of all off-gas testing are summarized in the tables and figures at the end of this report. Appendix I-A contains a summary of individual test run results plus the whole tank and pass airflow weighted results and the average weighted results by pass and whole tank. Appendix I-D contains the complete report of dynamic wet pressure (DWP) testing conducted on several sample diffusers sent to the University of Wisconsin for evaluation.

Plant wastewater and process characteristics for the off-gas test site visits are contained in Table Nos. 5 and 6. These data are plotted on Figure Nos. 18 through 21 versus elasped study time, starting with the site visit in September 1985.

The results of oxygen transfer performance tests are summarized in Table Nos. 8, 9, 10, and 11. Table No. 8 contains the overall performance data by site visit for the whole tank based on airflow weight averaged results from 36 to 48 individual test runs per site visit. Table Nos. 9 and 10 contain individual test run and average alpha×SOTE and apparent alpha values for sampling points 2-I and 2-M (Aeration Pass 2, influent end and middle). Table No. 11 contains the results of the diurnal test conducted at sampling point 2-M in April 1986. Figure Nos. 22 through 31 contain plots of the data contained in Table Nos. 8 through 11. The information is plotted versus elapsed time from the beginning of the study. Tank cleaning dates are indicated on the elapsed time graph.

FIGURE NO. 17

OFF-GAS SAMPLING PLAN "B"



* Denotes samples location for all tests conducted after April 2, 1986. One replicate test at each sample location (three excursions through the aeration tank per site visit).

FIGURE NO. 18

PLANT PERFORMANCE DATA

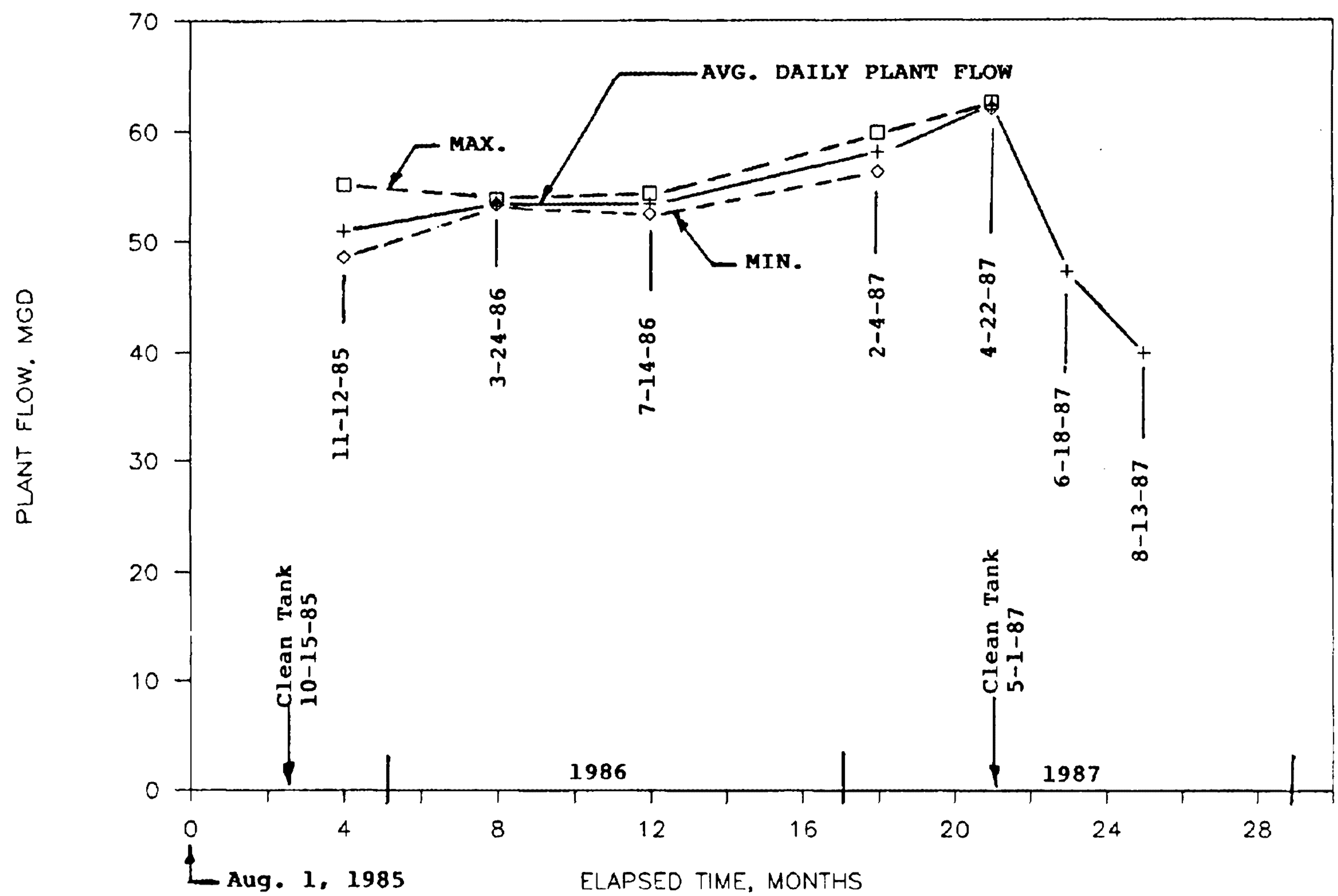


FIGURE NO. 19

PLANT PERFORMANCE DATA

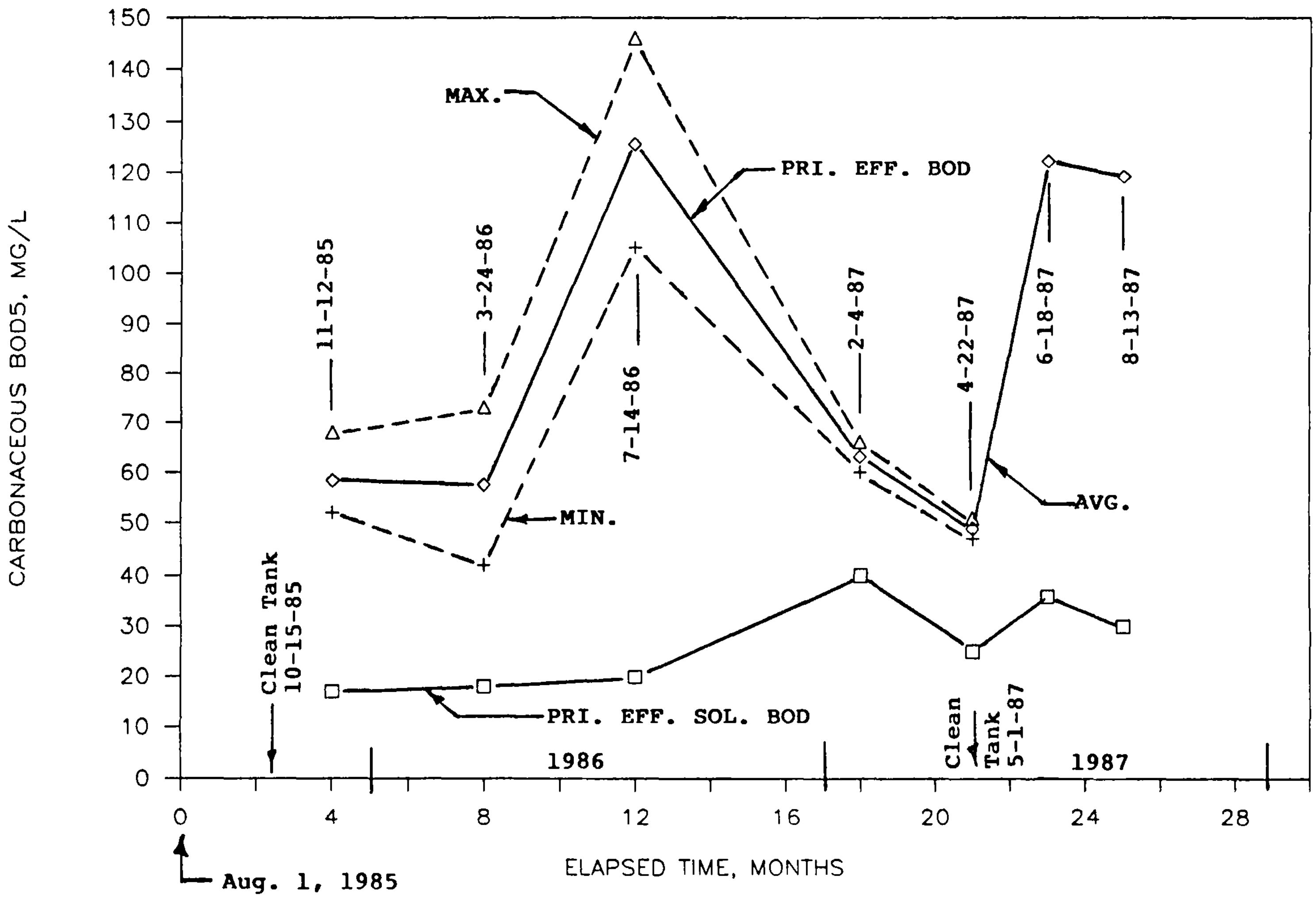


FIGURE NO. 20

PLANT PERFORMANCE DATA

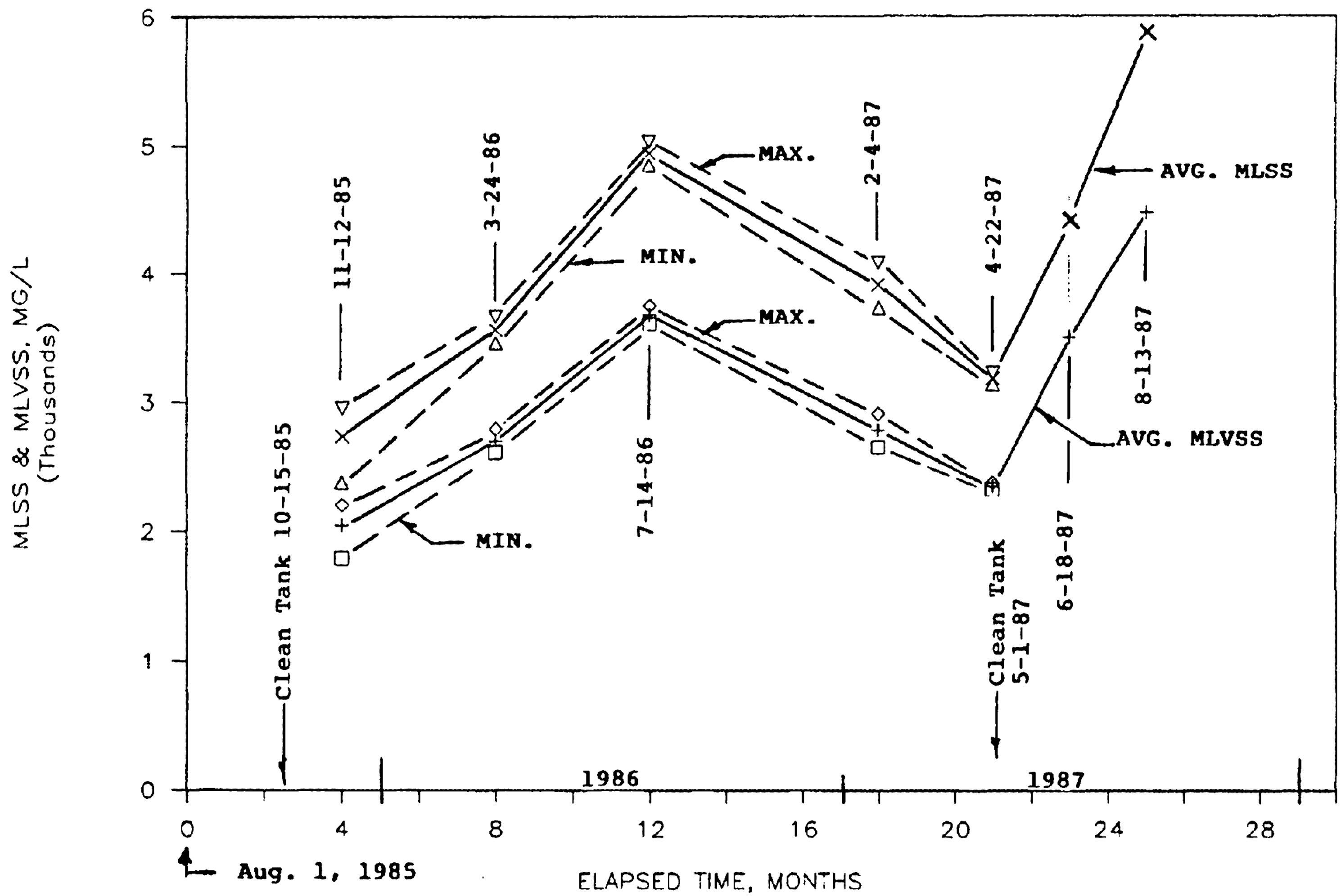


FIGURE NO. 21

PLANT PERFORMANCE DATA

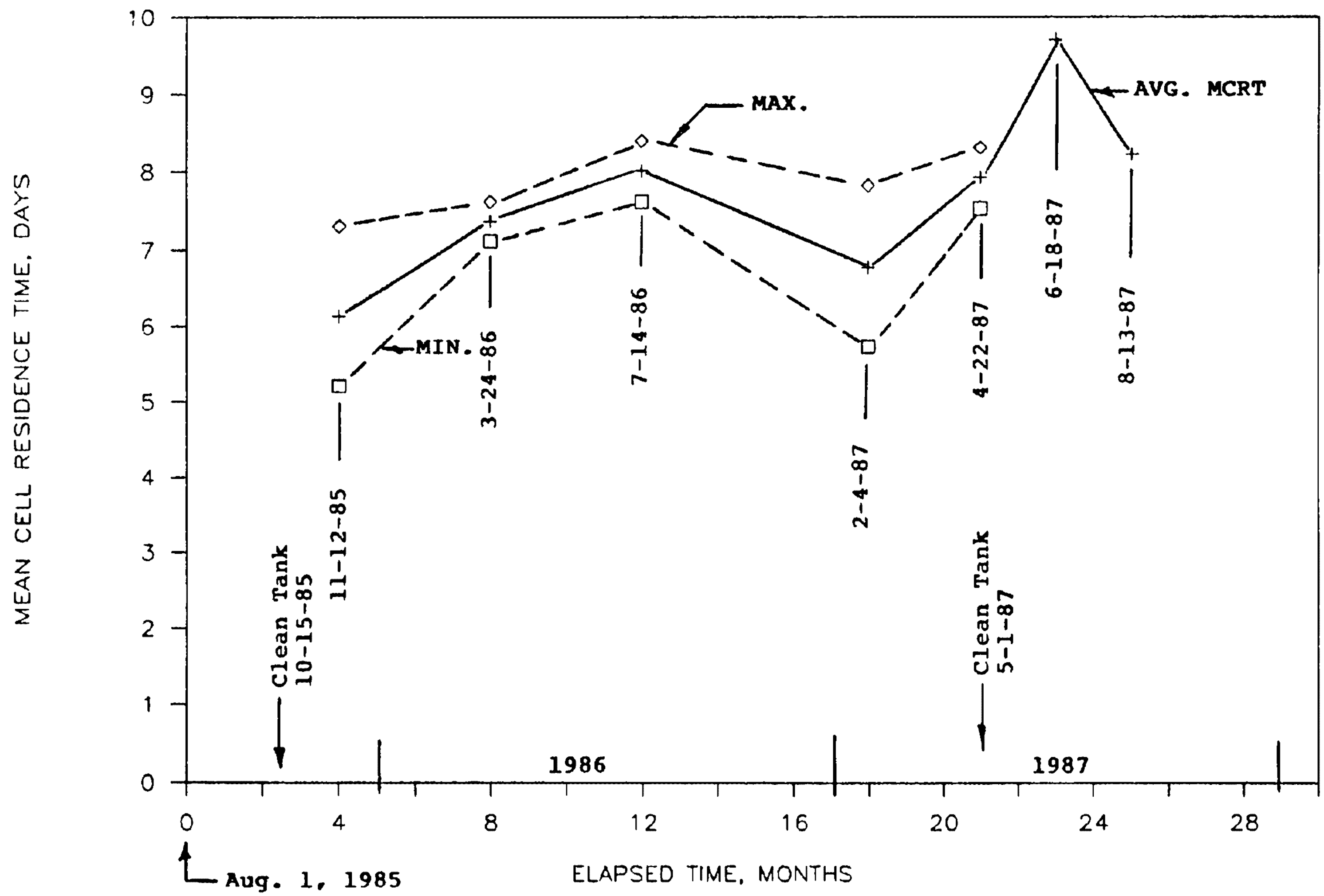


Table 8

OVERALL AERATION PERFORMANCE FOR THE WHOLE TANK

DATE	TEST NO.	ML TEMP., DEG C	ALPHA x SOTE, %	AIRFLOW/ DOME, SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA x SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
OCTOBER 1985 - FIRST CLEANING									
11-12-85	1A	18.9	12.60	0.96	3194.9	28.2	0.45	417.28	932.25
03-24-86	2A	13.9	8.18	1.28	4260.8	28.2	0.29	361.24	1247.52
07-14-86	3B	22.5	9.40	2.40	7994.3	25.4	0.37	778.46	2107.14
02-04-87	4B	13.1	9.00	1.49	4952.6	27.3	0.33	461.65	1400.87
04-22-87	5B	14.7	11.36	1.41	4673.8	27.5	0.41	550.22	1331.89
MAY 1987 - SECOND CLEANING									
06-18-87	6B	21.6	9.35	0.85	2819.2	28.6	0.33	273.22	836.46
08-13-87	7B	24.7	9.88	2.20	7309.3	25.6	0.39	748.21	1942.09
AVERAGE		18.5	10.0	1.5	5029.3	27.3	0.4	512.9	1399.7

NOTES: 1A - "A" TESTS DESIGNATE FOUR REPLICATE TESTS PER SAMPLE LOCATION AND ONE EXCURSION THROUGH THE AERATION TANK

3b - "B" TESTS DESIGNATE ONE TEST PER SAMPLE LOCATION AND THREE EXCURSIONS THROUGH THE AERATION TANK.

Table 9

SAMPLE LOCATION: PASS 2, INFLUENT (2-1)

START DATE	ALPHA X SOTE	APPARENT ALPHA	REPLICATE MODE
09-14-85	5.41	0.18	
	5.23	0.17	A
	7.00	0.23	
AVG.	5.88	0.20	
11-12-85	14.59	0.47	
	14.80	0.48	A
	13.75	0.44	
	13.79	0.44	
AVG.	14.23	0.46	
12-19-85	4.71	0.18	
	4.22	0.16	A
	4.17	0.16	
	5.29	0.20	
AVG.	4.60	0.17	
3-24-86	8.58	0.32	
	8.17	0.30	A
	8.07	0.30	
	9.14	0.34	
AVG.	8.49	0.31	
07-14-86	13.51	0.53	
	10.06	0.39	B
	10.06	0.39	
AVG.	11.21	0.44	
02-04-87	9.16	0.33	
	8.82	0.32	B
	9.22	0.33	
AVG.	9.07	0.33	
04-22-87	10.00	0.33	
	9.38	0.34	B
	11.04	0.40	
AVG.	10.14	0.36	
06-18-87	13.48	0.45	
	12.09	0.40	B
	11.74	0.39	
AVG.	12.44	0.41	
08-13-87	11.67	0.45	
	9.79	0.38	B
	9.43	0.36	
AVG.	10.29	0.40	

Table 10

SAMPLE LOCATION: PASS NO. 2, MIDDLE (2-M)

START DATE	ALPHA X SOTE	APPARENT ALPHA	REPLICATE MODE
11-12-85	15.63	0.52	
	16.77	0.55	A
	16.82	0.56	
	16.24	0.54	
AVG.	16.37	0.54	
3-24-86	7.17	0.25	
	8.24	0.29	A
	6.86	0.24	
	7.63	0.27	
AVG.	7.48	0.26	
4-1-86*			
MAX.	11.25	0.41	
MIN.	6.43	0.23	A
AVG.	8.27	0.30	
7-14-86	11.42	0.46	
	9.08	0.37	B
	11.38	0.46	
AVG.	10.63	0.43	
2-4-87	7.71	0.29	
	9.02	0.34	B
	8.30	0.31	
AVG.	8.34	0.31	
4-22-87	10.40	0.36	
	8.10	0.30	B
	7.88	0.30	
AVG.	8.79	0.32	
6-18-87	11.46	0.40	
	9.88	0.34	B
	11.83	0.41	
AVG.	11.06	0.38	
8-13-87	10.84	0.43	
	11.14	0.44	B
	11.45	0.45	
AVG.	11.14	0.44	

* TOTAL OF 40 TESTS CONDUCTED

Table 11

OFF-GAS TEST RESULTS FOR APRIL 1 AND 2, 1986 (DIURNAL STUDY)

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
2-M	2	4-1-86	1130	1	7.50	0.18	15.2	7.81	245	1.10	269.5	28.3	0.28	21.81	79.03
2-M	2	4-1-86	1145	2	8.45	0.18	15.2	8.80	245	1.10	269.5	28.3	0.31	24.58	79.03
2-M	2	4-1-86	1230	3	8.50	0.18	15.2	8.85	245	1.10	269.5	28.3	0.31	24.72	79.03
2-M	2	4-1-86	1245	4	7.96	0.14	15.1	8.26	245	1.10	269.5	28.3	0.29	23.07	79.03
2-M	2	4-1-86	1330	5	8.11	0.13	15.2	8.41	245	1.10	269.5	28.3	0.30	23.49	79.03
2-M	2	4-1-86	1345	6	7.76	0.13	15.2	8.04	245	1.10	269.5	28.3	0.28	22.45	79.03
2-M	2	4-1-86	1430	7	7.07	0.12	15.2	7.32	245	1.10	269.5	28.3	0.26	20.44	79.03
2-M	2	4-1-86	1445	8	7.77	0.12	15.2	8.05	245	1.10	269.5	28.3	0.28	22.48	79.03
2-M	2	4-1-86	1530	9	7.49	0.07	15.4	7.72	245	1.10	269.5	28.3	0.27	21.56	79.03
2-M	2	4-1-86	1545	10	8.40	0.07	15.4	8.66	245	1.10	269.5	28.3	0.31	24.19	79.03
2-M	2	4-1-86	1630	11	6.67	0.06	15.4	6.87	245	1.10	269.5	28.3	0.24	19.19	79.03
2-M	2	4-1-86	1645	12	7.27	0.06	15.4	7.49	245	1.10	269.5	28.3	0.26	20.92	79.03
2-M	2	4-1-86	1730	13	7.48	0.06	15.3	7.70	245	1.10	269.5	28.3	0.27	21.50	79.03
2-M	2	4-1-86	1745	14	6.83	0.06	15.3	7.04	245	1.10	269.5	28.3	0.25	19.66	79.03
2-M	2	4-1-86	1830	15	6.72	0.06	15.3	6.92	245	1.10	269.5	28.3	0.24	19.33	79.03
2-M	2	4-1-86	1845	16	7.05	0.06	15.3	7.26	245	1.10	269.5	28.3	0.26	20.28	79.03
2-M	2	4-1-86	1930	17	6.90	0.06	15.4	7.11	245	1.10	269.5	28.3	0.25	19.86	79.03
2-M	2	4-1-86	1945	18	6.24	0.06	15.4	6.43	245	1.10	269.5	28.3	0.23	17.96	79.03
2-M	2	4-1-86	2030	19	7.38	0.06	15.3	7.60	245	1.10	269.5	28.3	0.27	21.22	79.03
2-M	2	4-1-86	2045	20	7.76	0.06	15.3	7.99	245	1.10	269.5	28.3	0.28	22.31	79.03
2-M	2	4-1-86	2230	21	7.06	0.06	15.2	7.27	245	1.10	269.5	28.3	0.26	20.30	79.03
2-M	2	4-1-86	2245	22	7.33	0.06	15.2	7.55	245	1.10	269.5	28.3	0.27	21.09	79.03
2-M	2	4-2-86	0030	23	7.50	0.06	15.1	7.73	245	1.30	318.5	27.4	0.28	25.51	90.43
2-M	2	4-2-86	0045	24	7.45	0.06	15.1	7.68	245	1.30	318.5	27.4	0.28	25.35	90.43
2-M	2	4-2-86	0230	25	7.44	0.05	15.1	7.66	245	1.30	318.5	27.4	0.28	25.28	90.43
2-M	2	4-2-86	0245	26	7.39	0.05	15.1	7.61	245	1.30	318.5	27.4	0.28	25.12	90.43
2-M	2	4-2-86	0430	27	8.51	0.06	15.1	8.77	245	1.30	318.5	27.4	0.32	28.95	90.43
2-M	2	4-2-86	0445	28	8.19	0.06	15.1	8.44	245	1.30	318.5	27.4	0.31	27.86	90.43
2-M	2	4-2-86	0630	29	8.00	0.08	15.0	8.26	245	1.30	318.5	27.4	0.30	27.26	90.43
2-M	2	4-2-86	0645	30	7.88	0.08	15.0	8.14	245	1.30	318.5	27.4	0.30	26.87	90.43
2-M	2	4-2-86	0730	31	8.41	0.07	14.9	8.68	245	1.30	318.5	27.4	0.32	28.65	90.43
2-M	2	4-2-86	0745	32	8.65	0.07	14.9	8.93	245	1.30	318.5	27.4	0.33	29.47	90.43
2-M	2	4-2-86	0830	33	7.48	0.09	14.9	7.73	245	1.20	294.0	27.6	0.28	23.55	84.09
2-M	2	4-2-86	0845	34	8.59	0.09	14.9	8.88	245	1.20	294.0	27.6	0.32	27.05	84.09
2-M	2	4-2-86	0930	35	10.83	0.15	14.8	11.25	245	1.20	294.0	27.6	0.41	34.27	84.09
2-M	2	4-2-86	0945	36	9.02	0.15	14.8	9.37	245	1.20	294.0	27.6	0.34	28.55	84.09
2-M	2	4-2-86	1030	37	9.86	0.25	14.8	10.33	245	1.20	294.0	27.6	0.37	31.47	84.09
2-M	2	4-2-86	1045	38	10.67	0.25	14.8	11.18	245	1.20	294.0	27.6	0.41	34.06	84.09
2-M	2	4-2-86	1130	39	9.83	0.13	14.8	10.20	245	1.20	294.0	27.6	0.37	31.08	84.09
2-M	2	4-2-86	1145	40	9.49	0.13	14.8	9.84	245	1.20	294.0	27.6	0.36	29.98	84.09
2-M AVG.		-	-	-	-	-	15.1	8.27	245	1.17	286.7	27.9	0.30	24.57	82.89

FIGURE NO. 22

OVERALL PERFORMANCE FOR TOTAL TANK

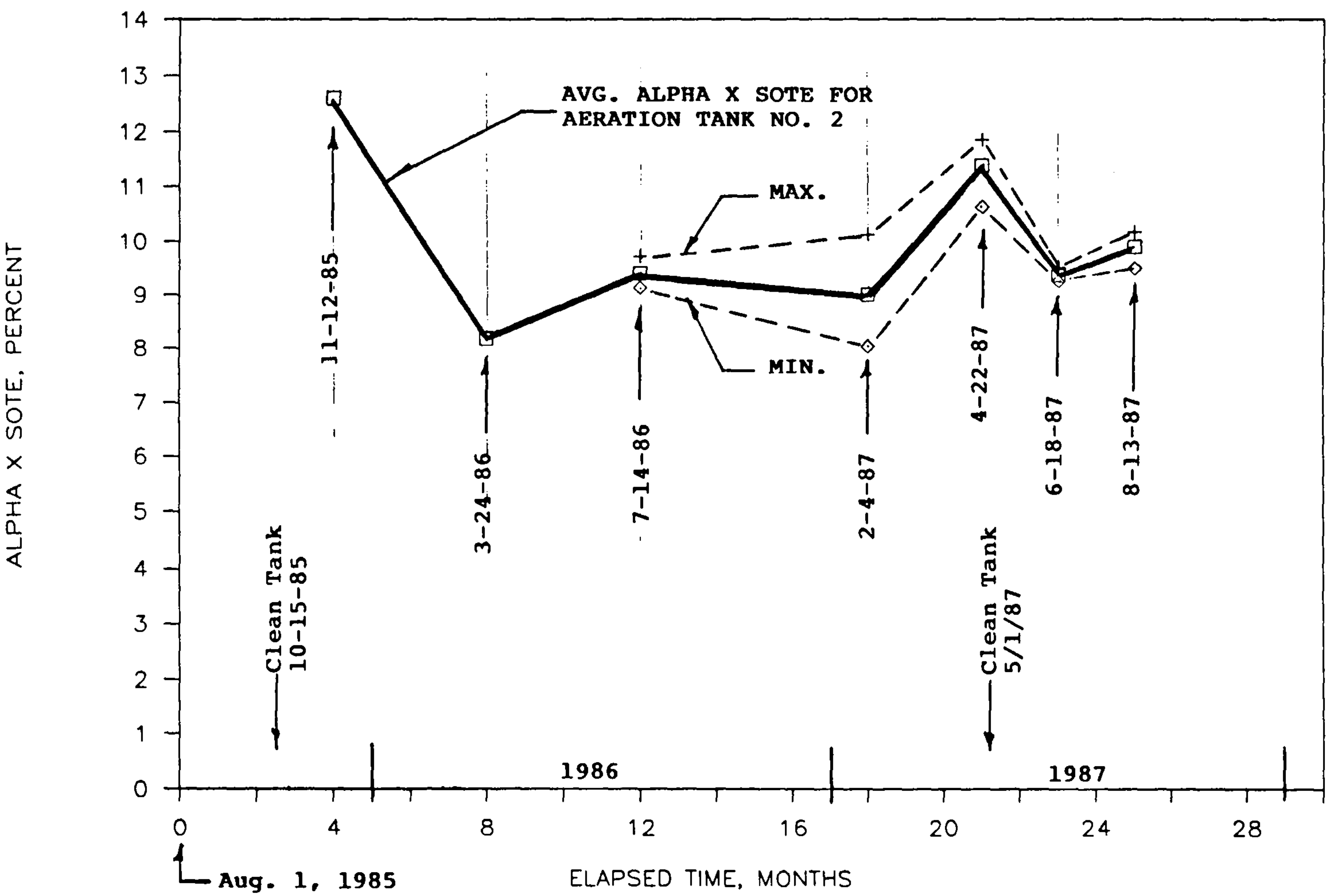


FIGURE NO. 23

OVERALL PERFORMANCE FOR TOTAL TANK

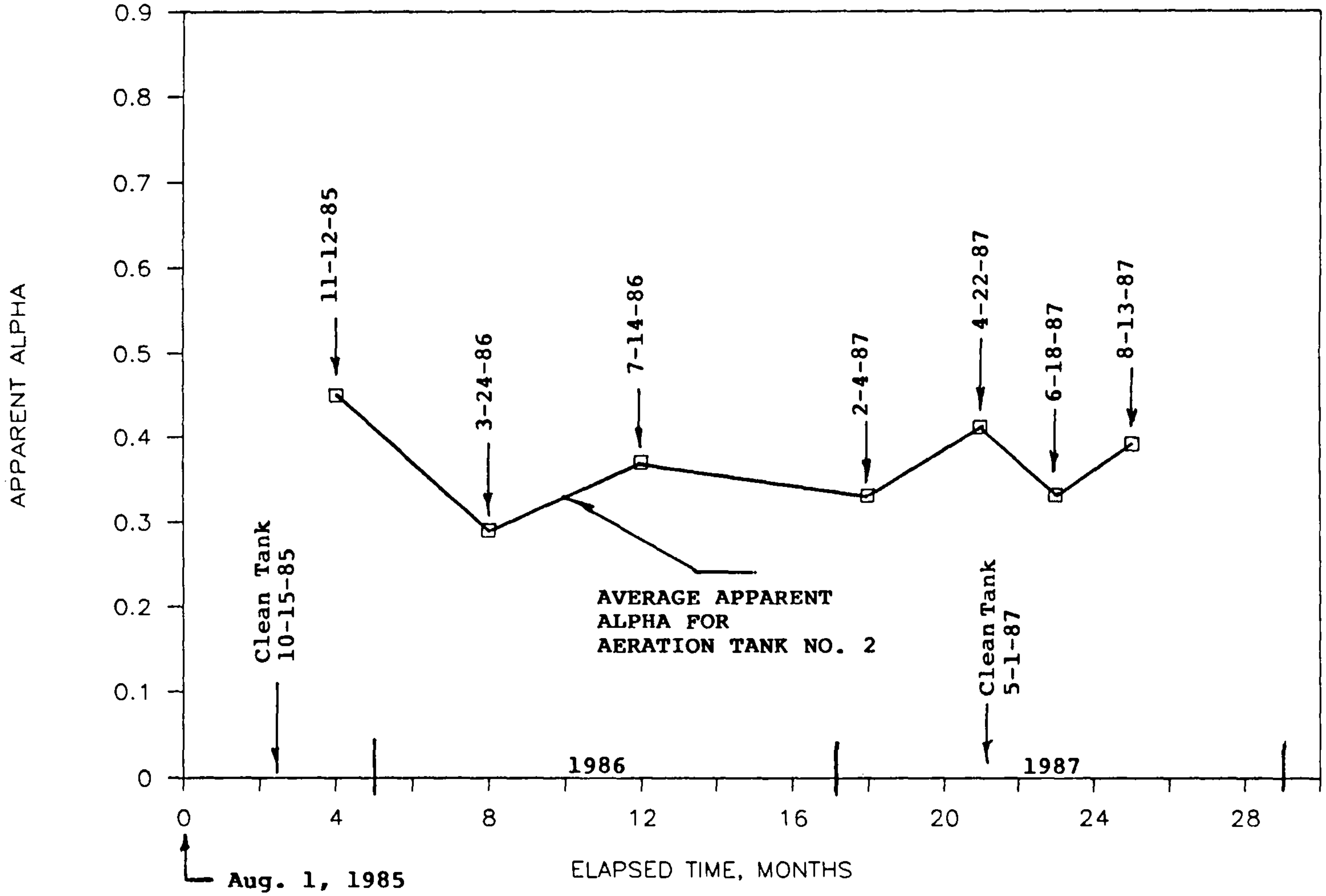


FIGURE NO. 24

OVERALL PERFORMANCE FOR TOTAL TANK

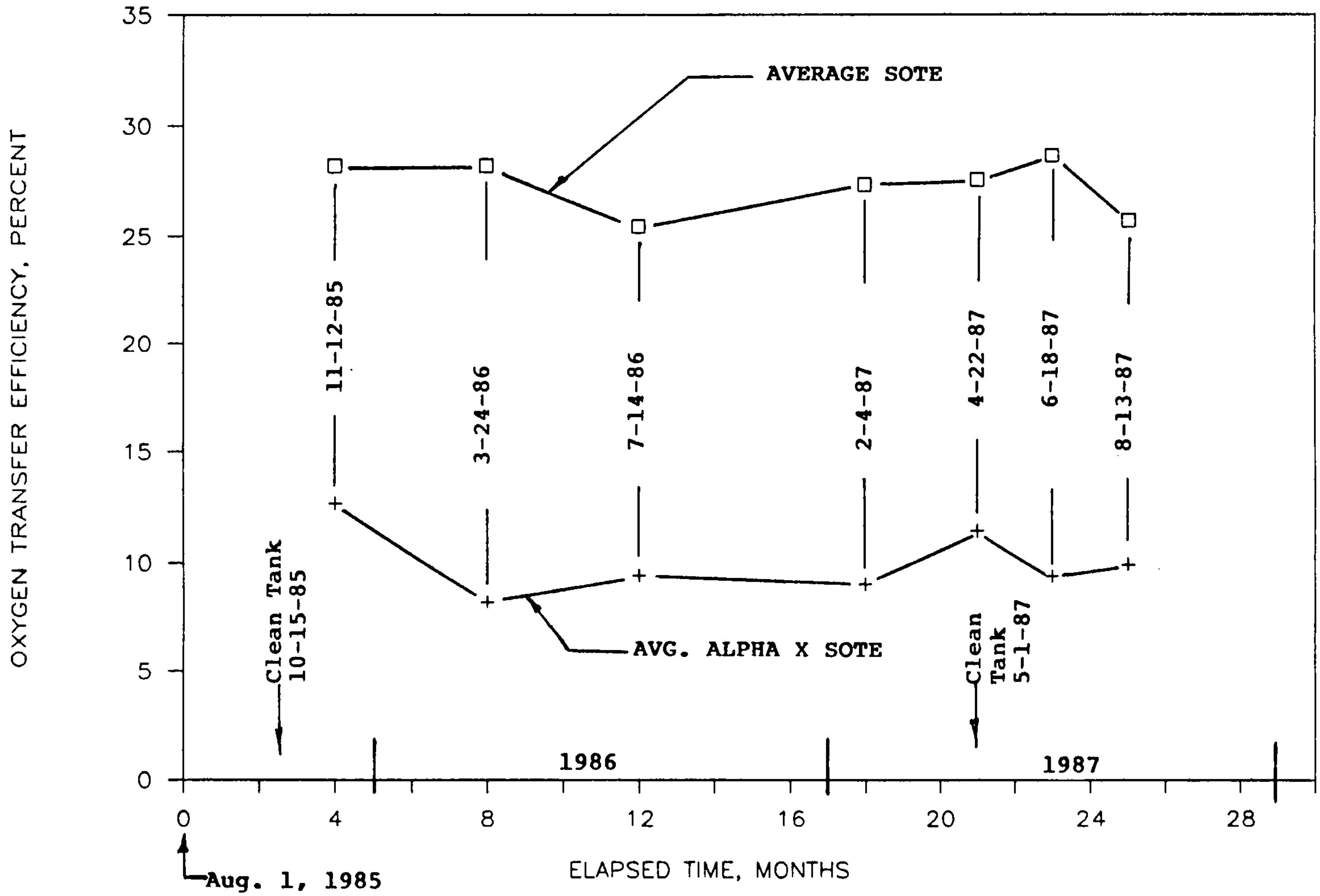


FIGURE NO. 25

OVERALL PERFORMANCE FOR TOTAL TANK

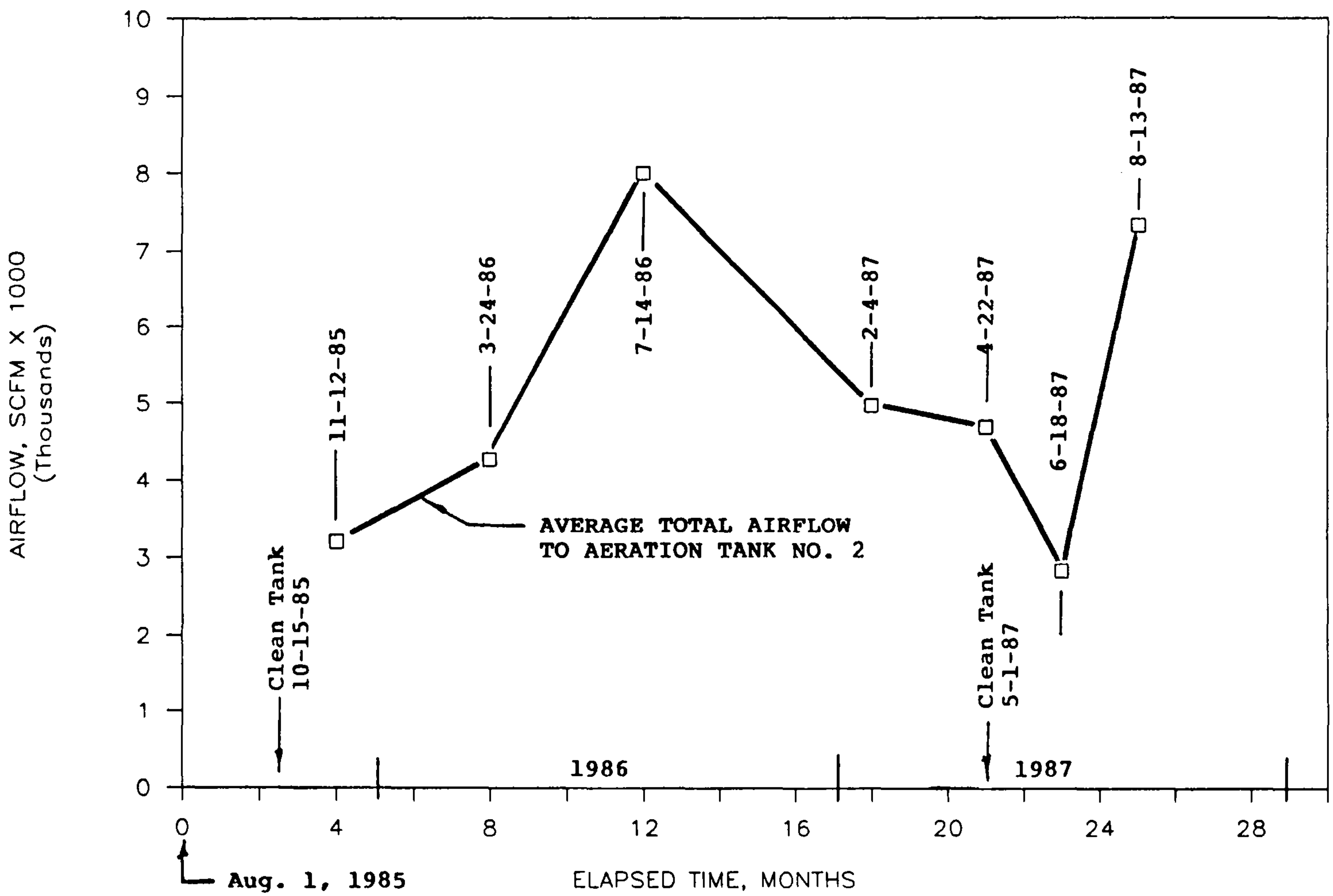


FIGURE NO. 26

ALPHA × SOTE - PASS NO. 2 - INFLUENT

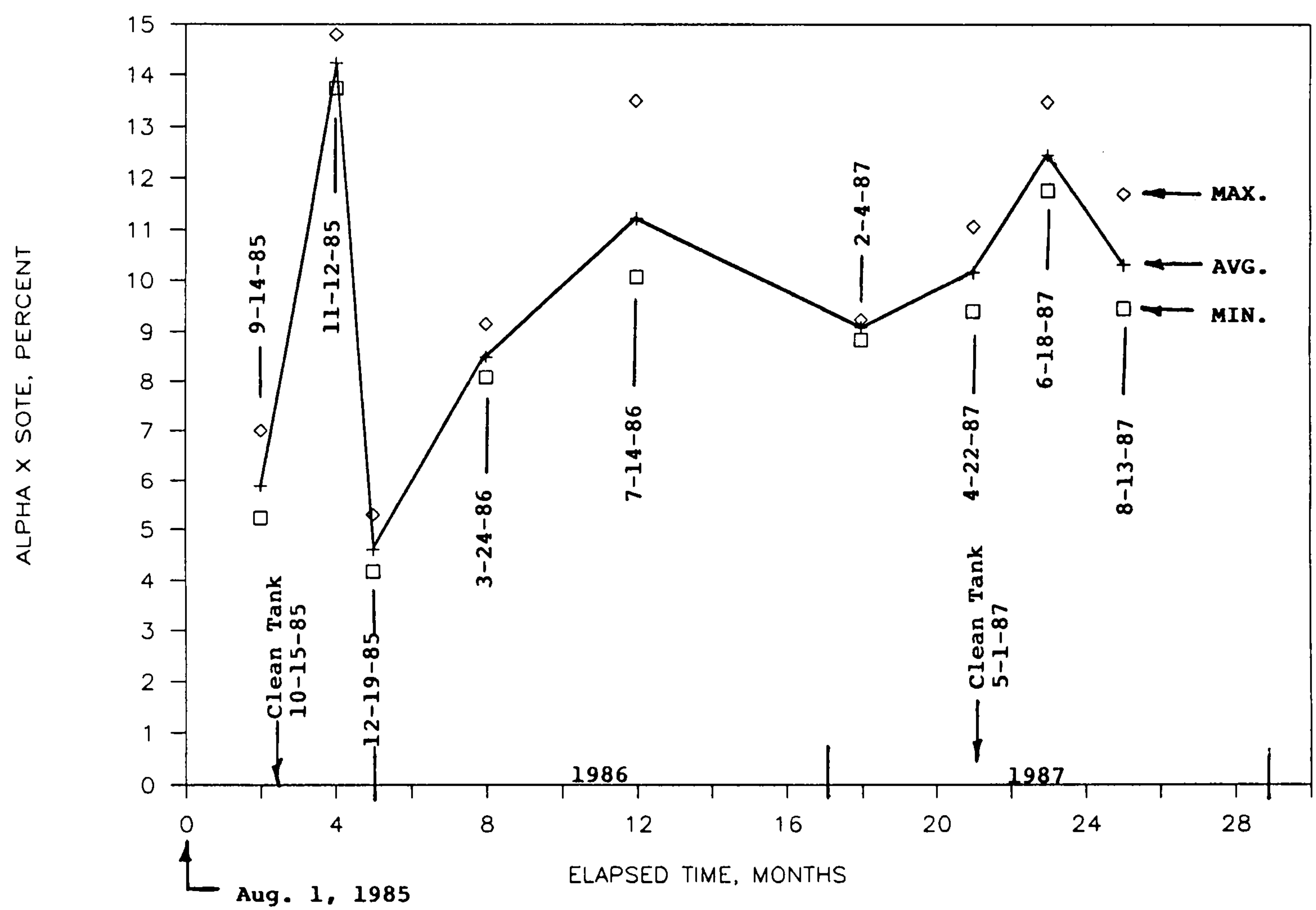


FIGURE NO. 27

APPARENT ALPHA - PASS NO. 2 - INFLUENT

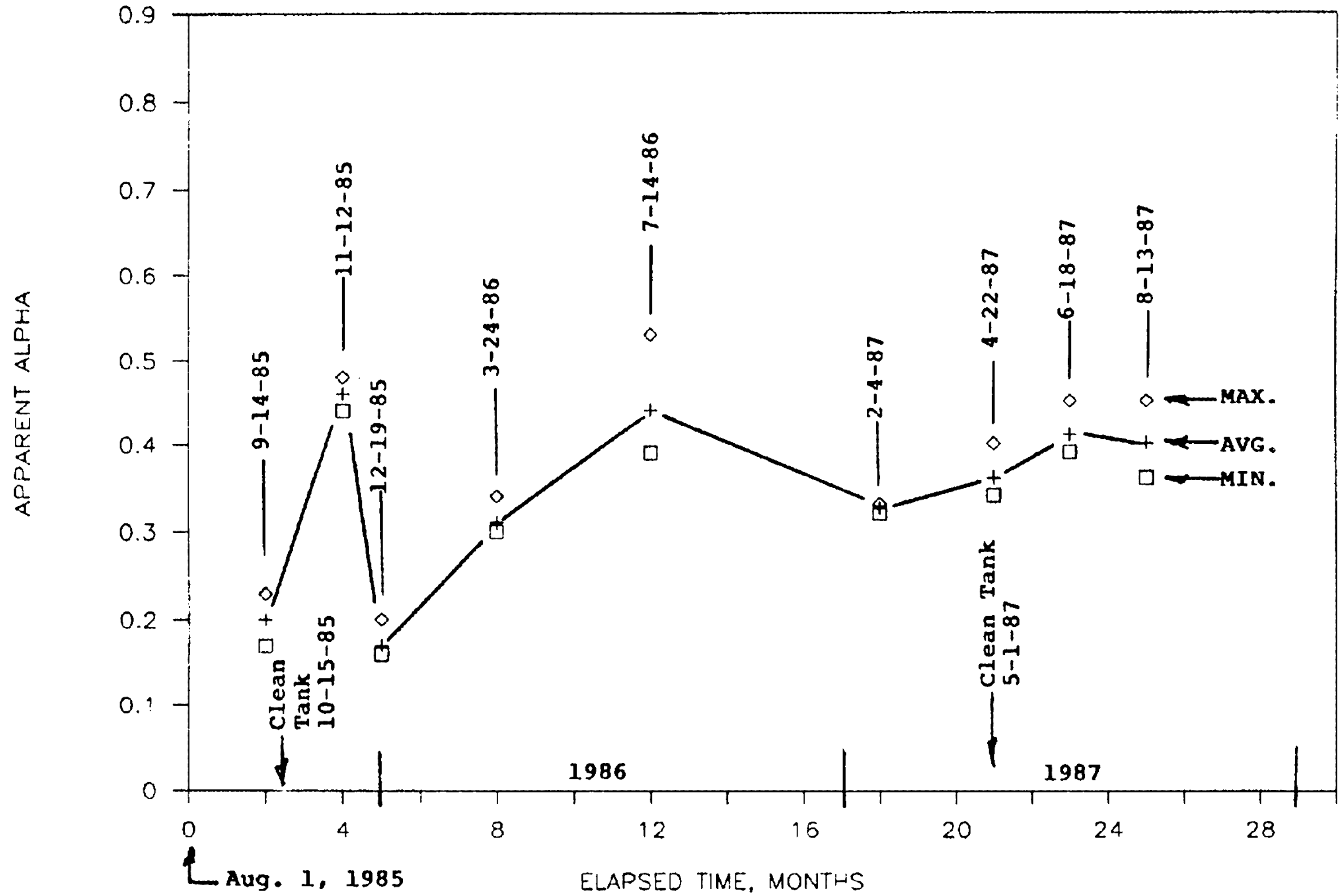


FIGURE NO. 28

ALPHA × SOTE - PASS NO. 2 - MIDDLE

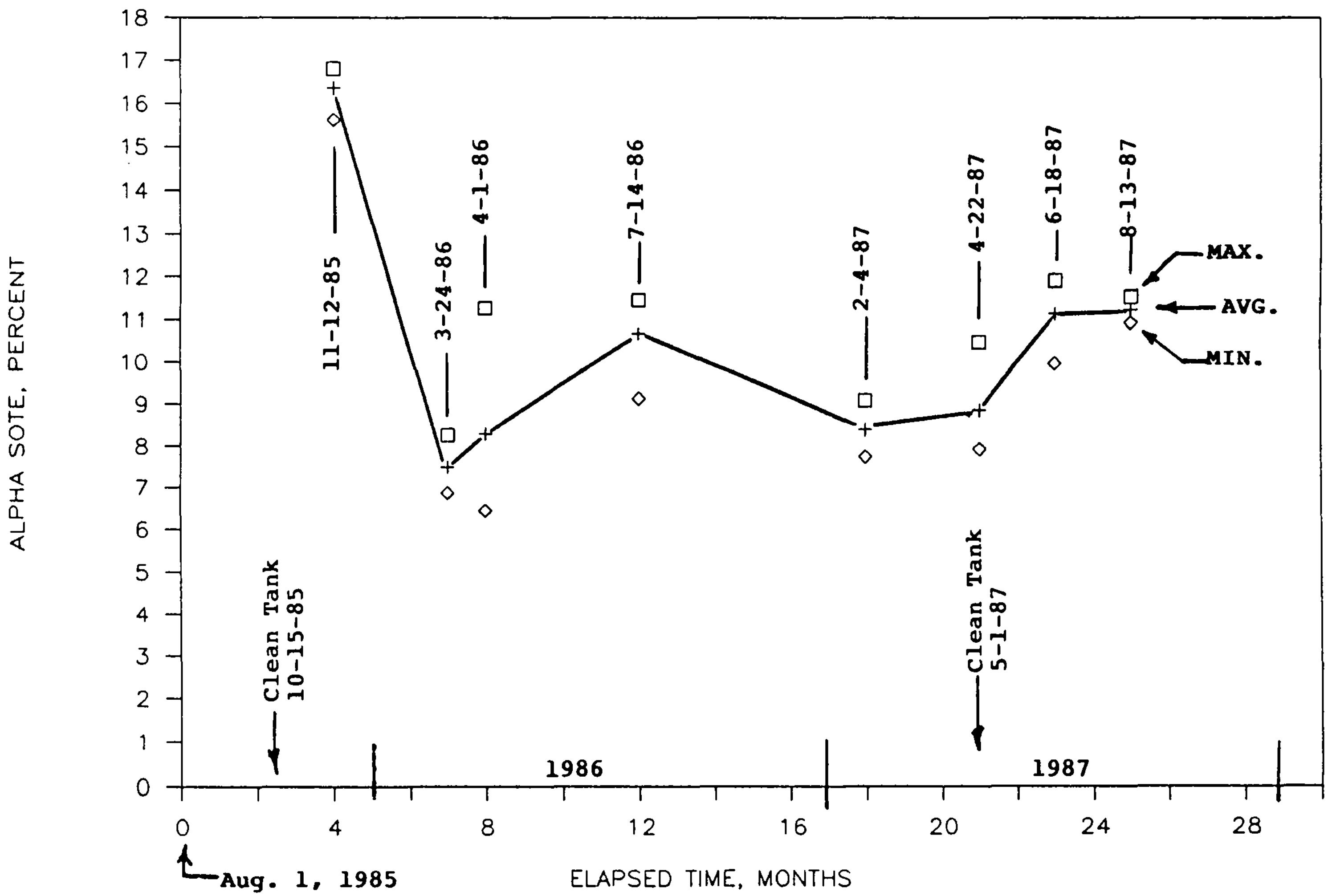


FIGURE NO. 29

APPARENT ALPHA - PASS NO. 2 - MIDDLE

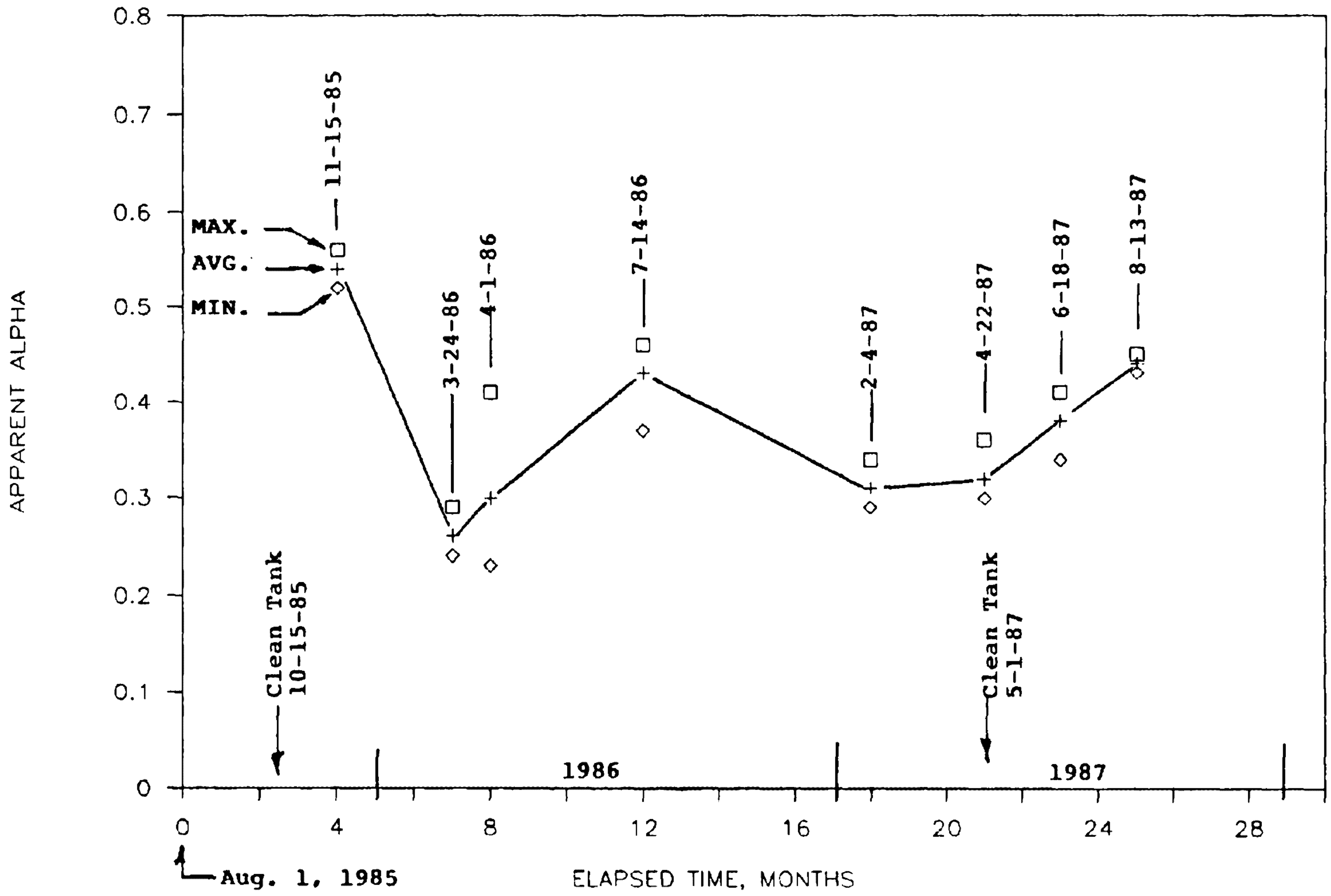


FIGURE NO. 30

OFF-GAS TEST RESULTS FOR APRIL 1 AND 2, 1986 (DIURNAL STUDY)

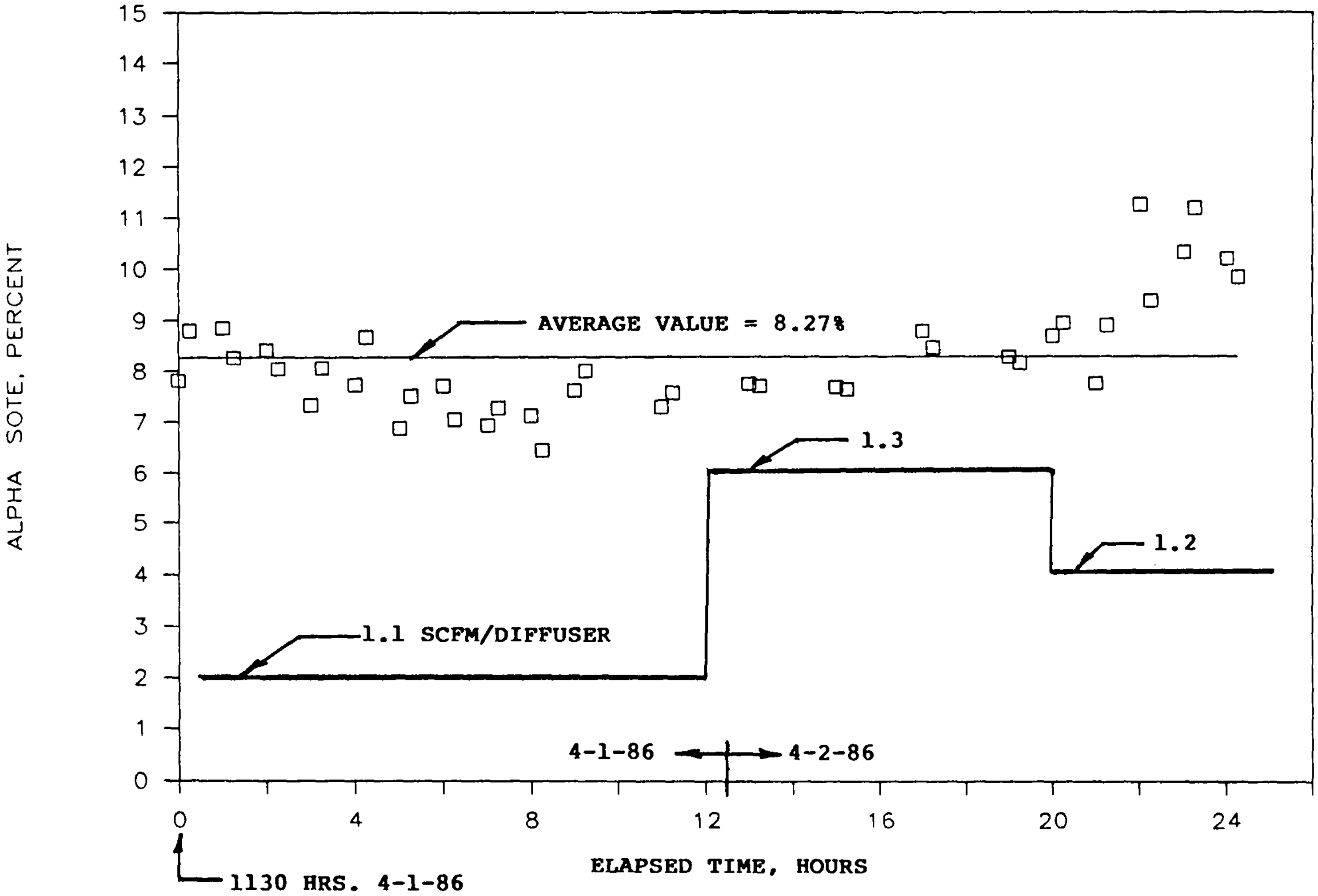
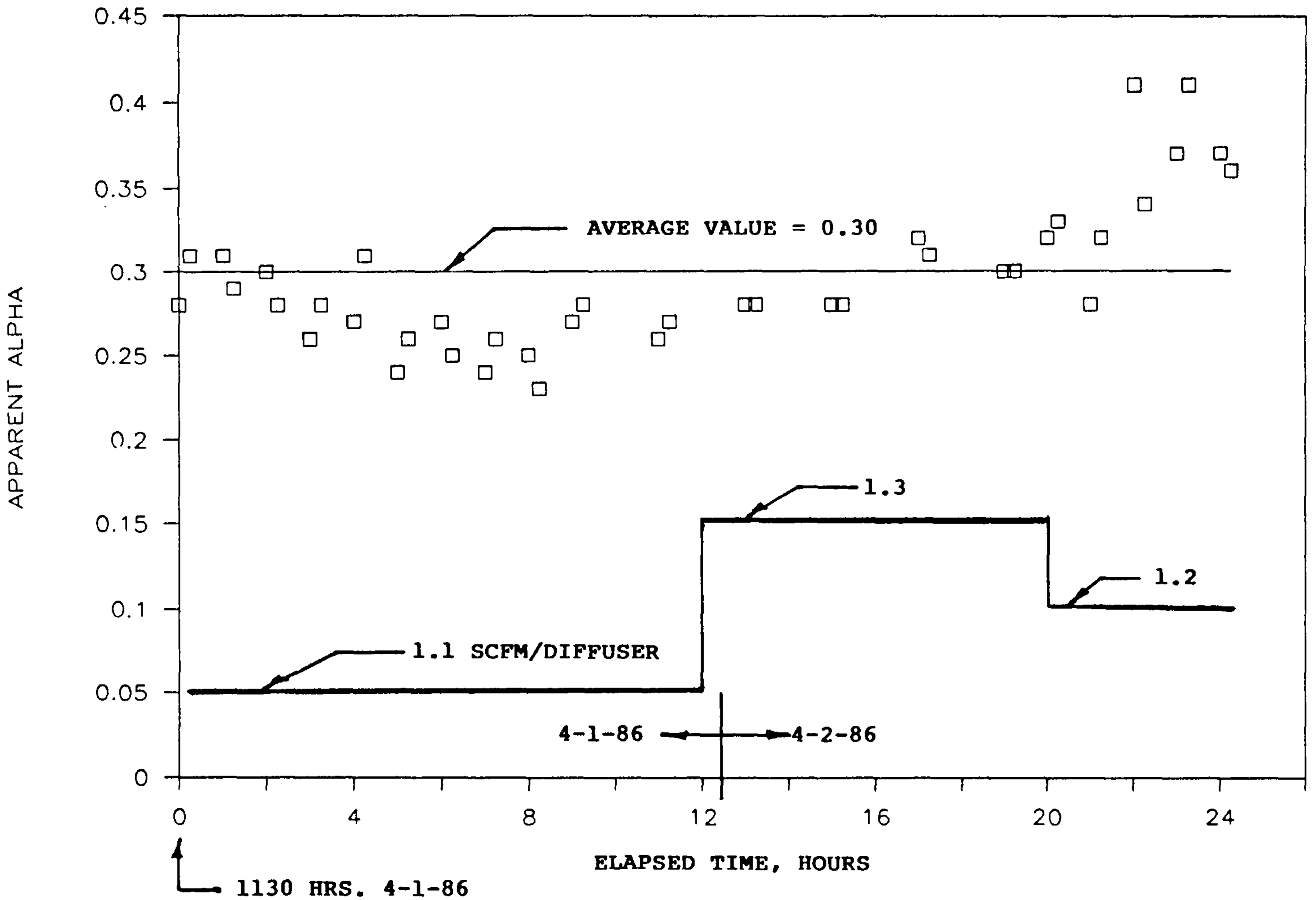


FIGURE NO. 31

OFF-GAS TEST RESULTS FOR APRIL 1 AND 2, 1986 (DIURNAL STUDY)



5.5.2 Oxygen Transfer Efficiency

The overall whole-tank oxygen transfer efficiency, expressed as alpha x SOTE, averaged 10.0 percent for the two-year study period. The average whole-tank alpha×SOTE test results varied from a high of 12.6 percent to a low of 8.2 percent throughout the study. The whole-tank average values are based on seven site visits from November 1985 to August 1987 and represent the summary of over 340 individual test runs. During each site visit each aeration pass was tested at the influent, middle, and effluent third points. Sampling Plan "A" replicated each sample location four times consecutively, and Sampling Plan "B" replicated overall whole-tank off-gas results three times for each site visit.

Evaluation and comparison of all test results by specific parameter indicates that oxygen transfer efficiency varies in an unexplainable trend over time, from test to test, and from sample location to sample location. This varability is consistent with the variation in wastewater characteristics and process operating parameters throughout the study period. Also, diffuser air leaks caused changes in air distribution and special oxygen transfer efficiency.

An example of the variation in alpha×SOTE at various times and points is illustrated as follows:

Sampling Criteria	alpha×SOTE, Percent Avg.	Min.	Max.
♦ average whole-tank weighted results for seven site visits	9.97	8.18	12.60
♦ average whole-tank weighted results for February 1987 site visit	9.00	8.04	10.11

Sampling Criteria	alpha×SOTE, Percent Avg.	Min.	Max.
♦ average sample location 2-I results for nine site visits	9.57	4.60	14.23
♦ average sample location 2-I results for February 1987 site visit	9.07	8.82	9.16
♦ average sample location 2-M results for eight site visits	10.26	7.48	16.37
♦ average sample location 2-M results for February 1987 site visit	8.34	7.71	9.02
♦ average sample location 2-M results for April 1986 diurnal study	8.27	6.43	11.25

From the above data it can be shown that the range in oxygen transfer efficiency varies over a wide range depending upon the time frame and number of sample points and tests used for comparison. Replicate test-run results at one sample location and for one site visit were relatively close (ranged within +/- 5 to 10 percent of the average), while average whole tank weighted results for a site visit were also relatively close (+/- 2 to 12 percent of the average). However, diurnal variations in a twenty-four hour period at one sample location varied as much +/- 30 percent of the average alpha×SOTE. The overall whole-tank weighted average results for the two- year study period ranged from +/- 22 percent of the average, while the range in results at specific sample locations over the same period was up to +/- 50 percent of the average value.

With this variability, a large number of tests and wide time base are necessary factors in estimating overall average performance characteristics which are representative of the general system performance.

5.5.3 Clean Water and Mixed Liquor Performance Comparison

Each off-gas test result is compared with the expected clean water performance value based on Standard Oxygen Transfer test data. These data are plotted on Figure No. 24 for the average whole-tank test results by site visit. Figure No. 9 also contains a plot of clean water and alphaxSOTE performance versus airflow per diffuser for the average whole-tank test results. Reported clean water test data are also plotted on the Figure. The expected average SOTE value for the Hartford design is 27.5 percent, and the average whole-tank alphaxSOTE as measured by off-gas testing is 10.0 percent.

5.5.4 Measured Alpha

The measured alpha factor value for the average whole-tank test results is 0.37 with a range of 0.29 to 0.45. Individual sample point alpha values ranged from less than 0.2 to up to about 0.6. Usually the very low alpha values were measured at influent feed point sample locations in any of the aeration passes.

5.5.5 Physical Observations

The photographs contained in Appendix I-B indicate observations made during routine operation and tank cleaning. Photo Plate P-2 contains photographs of Nocardia foaming conditions experienced from time to time during the study period as well as surface bubble patterns at the tank inlets.

Observations made during the tank cleaning operations were very informative. Photo Plates P-3, P-4, and P-6 illustrate the degree of external slime buildup on the diffusers. Even after initial hosing (Photo P-3.2), significant amounts of foulant remained on the diffusers.

The wet, slimy deposits, which appeared to be mostly organic, uniformly covered the exterior surface of the diffusers. After initial hosing, patchy deposits, which appeared to be inorganic, remained on the surface of most of the diffusers. Also, these deposits covered the vertical sides of most diffusers, and acid cleaning did not appear to be effective in removing the materials from the sides of the diffusers.

Much of the deposited material on the outside of the diffusers was inorganic, and significant amount of grit and silt were present at the inlet points of Pass Nos. 2, 3, and 4 (primary effluent feed points). These deposits can be seen in the photographs (Photo P-5.1 and P-6.2).

The inside (air side) surface of diffusers removed for laboratory testing at a later date contained small amounts of dried-on scale which probably originated from mixed liquor intrusion into the air pipe grid system through openings caused by broken dome bolts, cracked gaskets and other leaks in the air piping system. The air side deposits did not appear to be significant, particularly when compared to the outside (liquid side) deposits on the diffuser.

5.5.6 Laboratory Testing

Several diffuser domes were removed from the aeration tank during the cleaning period in May 1987. Uncleaned and acid cleaned samples were shipped to the University of Wisconsin for testing and evaluation. A new, unused dome was also included with the used domes.

The results of the laboratory testing are contained in Appendix I-D. Testing of the uncleaned diffusers indicated that the Dynamic Wet Pressure (DWP) at points of deposited materials was extremely high. Acid cleaning reduced DWP values greatly, but to values still twice as high as for new diffusers.

5.6 EFFECT OF CLEANING ON PERFORMANCE

5.6.1 Cleaning Frequency

There is no routine cleaning program for, or a basis for cleaning the fine pore diffuser equipment at the Hartford facility. Approximately one year after being placed in service, all four aeration tanks were dewatered one at a time and the aeration equipment inspected. No cleaning was performed during this inspection program. Prior to the beginning of off-gas testing in Aeration Tank No. 2 in the fall of 1985, the tank was dewatered and the aeration equipment cleaned. Photo Plates P-3, P-4, and P-5, Appendix I-B, depict the condition of the dome diffusers after three years of continuous service. The other three aeration tanks were also cleaned in the fall of 1985 for the first time.

Only Aeration Tank No. 2 was cleaned a second time in May 1987. The reason for cleaning the tank was to develop before and after cleaning oxygen transfer efficiency data for the ASCE/EPA Oxygen Transfer Study. There was no performance basis used to initiate cleaning in May 1987 rather than at some other time. Photo Plates P-6 through P-10 contain unclean and cleaned diffuser photographs for the May 1987 cleaning.

5.6.2 Cleaning Method

The cleaning method used both times is known as the "Milwaukee Method" which uses hosing and acid application. This method has been used at the Milwaukee wastewater treatment plants for several years. A high pressure water jet is applied to the diffuser surface followed by acid spraying and hosing. The rational is to first hose off the easily removable foulants 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 used for this method are: high or low pressure water hosing equipment, acid spray applicator, and acid solution.

The cleaning procedure is as follows:

1. dewater the aeration tank with the air supply on while dewatering.
2. clean the diffuser grid system by high pressure hosing with water (either tap or final effluent) while the air supply is on and at a sparge rate of approximately 1 SCFM per diffuser.
3. apply approximately 50 ml of acid to the surface of the diffuser using the spray applicator. No air is discharged through the diffuser during the acid application period.
4. let the acid remain on the diffusers for 30 minutes.

5. scrub the diffuser with a cleaning brush as necessary.
6. hose the diffusers off again for one minute or as long as necessary to remove all of the residual acid and solubilized materials with the air supply remaining on throughout the final hosing.

The acid solution used for cleaning is a commercially available cleaning compound known as "ZEP." The active ingredient is 22 percent HCl with surfactants added to aid the cleaning process. This cleaner was found to be much more effective than using straight 14 percent HCl solution on diffuser samples cleaned in the laboratory. Photo Plates P-7 and P-8, Appendix I-B, contain photographs of the cleaning process.

5.6.3 Air Distribution and Leak Testing

Immediately after cleaning the aeration equipment as described above, air distribution and leak testing was conducted prior to placing the aeration tank back on-line. Plant effluent was introduced to the aeration tank until the diffuser grid was submerged by 2 to 3 inches of liquid. Airflow was adjusted to approximately 0.5 SCFM per diffuser, and observations were made for air distributions and leaks.

All gaskets, dome bolts, and other air leaks were repaired throughout the tank, and any leveling of, or repairs to pipe supports was accomplished at that time.

Photo Plates P-9 and P-10, Appendix I-B, show the effect of gasket leaks at individual diffusers. Photo Plate P-10.1 shows the effect of a broken pipe support on levelness of the diffuser grid.

Diffuser leaks were identified by the bubble pattern generated at each diffuser (Photo Plate P-9.1). Fixing of the leaks consisted of the following procedure:

1. loosen dome bolt and rotate dome and gasket on saddle about 15 degrees.
2. tighten dome bolt to 25 inch-pounds of torque with torque wrench.
3. repeat step no. 2 with further rotating of dome as necessary if first attempt was not successful.
4. install new gaskets if rotation of dome does not stop leak after three or four attempts.

Photo Plate P-11 contains two photos of used dome gaskets which were replaced because of air leaks caused by the cracks in the gaskets. These gaskets could not be prevented from leaking by following the above procedure.

In the course of cleaning an aeration tank and repairing leaks, several gaskets required replacement, and several plastic dome bolts were broken during the repair work. During the first cleaning in October 1985, several dome bolts were inadvertently overtightened by mistake. Some bolts failed before the tank was filled and placed in service. However, several bolts failed after the tank was placed on-line. In Aeration Tank No. 4 the number of bolt failures was significant enough to require that the tank be taken off line, dewatered, and the broken bolts replaced within a few days of cleaning and start-up.

5.6.4 Post Study Period Cleaning Observations

Aeration Tank No. 2 was out of service from September 25 through October 19, 1988 for cleaning and repairs to the dome diffuser aeration equipment. After dewatering the tank, the following were noted:

1. over 400 domes were missing from the dome saddles due to broken plastic dome hold-down bolts.

2. over 500 domes were on the dome saddles, but the plastic dome hold-down bolts had broken.

3. the pipe grid hold-down gear clamp supports on one grid were broken, and the plastic grid piping had separated.

The broken plastic dome bolts were replaced with stainless steel bolts, and over 250 new dome gaskets were installed where old, defective gaskets could not be reused.

Between October 19, 1988 and November 14, 1988, coarse bubbling began in Aeration Tank No. 2. Approximately 75 coarse bubble locations were identified. The cause of coarse bubbling was probably due to additional plastic dome bolt breakage.

The cost to clean and repair Aeration Tank No. 2 was over 3 times more than for earlier individual cleanings.

5.7 BEFORE AND AFTER CLEANING OTE RESULTS

Prior to the initial tank cleaning in October 1985, only preliminary influent sample point off-gas tests were performed on Aeration Tank No. 2. Full-tank testing was conducted about three weeks after the aeration tank was placed back in service. Influent point off-gas testing was again conducted about a month later in Aeration Tank No. 2.

The second diffuser cleaning was bracketed by full-tank off-gas tests before and after cleaning in May 1987. These whole-tank aeration performance tests provide the most complete information on oxygen transfer performance for the whole tank before and after cleaning.

The overall weighted tank alpha×SOTE value based on tests conducted in November 1985 was 12.6 percent. These tests were conducted within a month after tank cleaning. The apparent alpha value for the overall tank performance was computed to be 0.45. Based on tests conducted on the Aeration Pass No. 2 influent sample point in September 1985 (alpha×SOTE = 5.9 and apparent alpha = 0.2), it appeared that the cleaning was very beneficial. However, further influent sample point testing in December 1985 resulted in an alpha×SOTE value of 4.6 and an apparent alpha of 0.17.

Noticeable coarse bubbling was observed at the inlet feed points of all passes within the first month after cleaning. Organic loading remained relatively constant throughout the period from September through December 1985, and the average soluble BOD was 38 percent of the primary effluent BOD for this period. From plant wastewater quality data and observations of coarse bubbling, it was assumed that the diffusers were fouling quickly after cleaning due to the buildup of biological slime on the surface of the diffusers, particularly at the influent points of each pass.

Just prior to the second tank cleaning in May 1987, off-gas testing was conducted at the end of April. After cleaning and start-up of Aeration Tank No. 2 in the first week of May 1987, organic loading to the aeration system increased and solids inventory began to rise. Post-tank cleaning off-gas testing was delayed until the middle of June 1987 due to process upsets from the higher loading conditions.

The before and after results of off-gas testing for the May 1987 cleaning are summarized as follows:

Parameter	Before	After
Pri. Eff. BOD, mg/l	49	112
Final Eff. BOD, mg/l	4	9
Plant Flow, MGD	62.3	47.2
MLSS, mg/l	3200	4500
MCRT, Days	7.9	9.7
Avg. alpha×SOTE, %	11.36	9.35
Apparent Alpha	0.41	0.33
Pass 2-I, alpha×SOTE, %	10.14	12.44
Pass 2-I, Apparent Alpha	0.36	0.41
Pass 2-M, alpha×SOTE, %	8.79	11.06
Pass 2-M, Apparent Alpha	0.32	0.38

Low transfer efficiency results in Aeration Pass Nos. 1 and 4 for the June 1987 tests lowered the total average tank performance results for the after cleaning tests to below those for before cleaning. Also, the before cleaning results were the highest measured results of the entire test period since the initial tests conducted in November 1985.

Organic loading, MLSS, and MCRT increased significantly between the before and after testing. These wastewater and process changes certainly effected the oxygen transfer performance in an adverse manner in the after cleaning tests versus the before cleaning tests.

Due to the wide range in values for wastewater characteristics, process parameters, and off-gas results by sample location and by test, a strong conclusion cannot be drawn regarding quantitative changes in oxygen transfer efficiency as a result of diffuser cleaning.

Although diffuser cleaning may have little effect upon changes in oxygen transfer efficiency, the cleaning of diffusers on a routine basis is beneficial. Diffuser cleaning removes built-up deposits of both inorganic and organic materials which cause increased back pressure through the diffuser. Secondly, diffuser cleaning provides for an inspection of the aeration equipment and the undertaking of air distribution and leak tests. Any necessary repairs to limit gasket and other leaks and perform any other repairs constitutes good maintenance practice at the time of tank cleaning.

5.8 COST OF CLEANING

The cost of cleaning one aeration tank is based on cost data for two cleanings of Aeration Tank No. 2 and one cleaning of the other three aeration tanks. If cleaning frequency in the future would be once per year, then the estimated costs presented herein would represent annual cleaning costs.

The estimated costs by category, are as follows for one aeration tank:

♦ Labor for hosing, acid cleaning, and leak repair (100 man-hours using 2 to 3 laborers with some overtime)	$ 2,000.00
♦ Cleaning Chemical (55 gallon drum of ZEP)	250.00
♦ Cleaning equipment and protective clothing	750.00
♦ Spare parts for repair of equipment (gaskets, bolts, domes, pipe supports, etc.)	1,500.00
TOTAL COST	$ 4,500.00

The total cost per tank represents a per diffuser unit cleaning cost of $1.35 for each diffuser cleaned. The unit cost would be less than $1.00 per diffuser when the miscellaneous costs for maintaining the equipment are excluded from the total cost estimate.

The cleaning cost estimates do not include any allowance for the expense of grit removal from the aeration tank. At some point in the future significant deposits of grit will have to be removed from the aeration tanks.

Maintenance work to repair leaks and diffusers and piping will increase as the aeration equipment gets older. At the time cleaning was performed at Hartford, the aeration equipment was 3 years old. Leak repairs to diffusers involved between 5 and 10 percent of all diffusers. Cleaning at a future time may well involve repair work to a larger percentage of the diffusers.

From the condition of the gaskets removed during tank cleaning, it is conceivable that all gaskets may require replacement with new gaskets in the near future. Plastic dome bolts should be replaced with stainless steel bolts at the same time. Also, the effectiveness of acid cleaning should be evaluated in terms of diffuser headloss. As the aeration equipment becomes older, diffuser headloss may increase to unacceptable levels, even with acid cleaning.

The estimated equipment longevity, based on cleaning results and observation of equipment components removed at Hartford is:

♦ gaskets and plastic dome bolts	3 to 5 years until replacement with new components
♦ ceramic domes	5 to 8 years until thorough cleaning or replacement with new domes
♦ plastic grid piping system	over 10 years

The above longevity times are only estimates based on extrapolation of information and observations made after three to four years of operating experience at Hartford.

The average downtime required to clean each aeration tank was one week, including draining and filling time. Cleaning was scheduled for periods when total plant flow and organic loading were expected to be at average or below average values to minimize the effect of tank cleaning on plant operation and performance. With one tank out of operation, the remaining three tanks received a 33 percent increase in flow and organic loading. No adverse effects on plant effluent quality occurred during cleaning. However, if peak loading had occurred during cleaning, there could have been reduced effluent quality due to reduced retention time in the aeration process and possible diffuser air capacity limitations.

6.0 ECONOMIC CONSIDERATIONS FOR FINE PORE AERATION

6.1 POWER USE

The baseline period energy consumption for one 3,000 HP blower was 31,000 KWH/day with the original coarse bubble aeration equipment. Total aeration energy consumption dropped to 15,000 KWH/day after the retrofit project was completed and the new aeration system brought on line. Total plant electrical consumption was 54,000 KWH/day for the baseline period. (This value includes power for preliminary and primary treatment, effluent pumping, secondary treatment, and sludge processing). The total plant electrical consumption was reduced to 42,000 KWH/day after the retrofit. The reduction of 12,000 KWH/day represented a 22 percent decrease in total plant electrical consumption for 1983.

Power use data and trends based on wastewater flow and strength are presented in Table Nos. 2 and 4. Although ratios for power per unit BOD removed vary over time, the clear trend is that significantly less power is required per unit of BOD removed for the fine pore retrofit versus the original coarse bubble spiral-roll aeration system.

Significant fluctuations in this ratio could be caused by the wide range of MLSS in the aeration system over the period of record. The higher MLSS concentrations require greater amount of oxygen, and therefore power, per unit of BOD removed. In addition, the rate of change of power consumption for air delivery is not constant over the full range of airflow for the blowers at Hartford.

In August 1985 the Metropolitan District Commission retained Metcalf & Eddy to investigate the feasibility of upgrading the air delivery system by replacing are of the existing Brown-Boveri 3,000 HP blowers with a more efficient blower. In Metcalf & Eddy's report of January 1986, it was concluded that the existing original blowers were not as efficient as new, smaller blowers. The existing blowers had the following power consumption-air delivery characteristics:

Blower Air Delivery SCFM	Power Consumption KW/1000 SCFM
60,000	28.5
30,000	34.0
15,000	45.5

With post-retrofit air supply reduced to below 30,000 SCFM or over a 50 percent reduction, the resulting power consumption reduction was less than 40 percent due to the less efficient operation of the blower at the reduced airflow output.

The Metcalf & Eddy report recommended that a new blower system be installed for the channel aeration; its capacity being 7,500 SCFM; and that a new 25,000 SCFM blower be installed for activated sludge aeration, replacing one of the existing Brown-Boveri 3,000 HP units. The estimated payback of the recommendations was about 3 years.

6.2 OXYGEN TRANSFER EFFICIENCY COMPARISON

The original coarse bubble spiral-roll aeration system is estimated to have an SOTE performance of between 6 and 7 percent. A value of 6.25 has been selected based on test data from the manufacturer and test results from the L. A. County oxygen transfer study. The efficiency of this aeration equipment is reduced to 4.4 percent (alpha×SOTE) when an alpha of 0.7 is assumed. The resulting OTE in mixed liquor with a DO concentration of 2.0 mg/l is 3.2 percent for the coarse bubble system.

The average value for alpha×SOTE for all whole-tank tests conducted on the fine pore aeration system in Aeration Tank No. 2 is 10.0 percent transfer. This represents 2.25 times the transfer efficiency of the original equipment. The ratio of 2.25 is in general agreement with the ratio of airflows before and after retrofit.

The comparison of SOTE and alpha×SOTE for each system is presented graphically on Figure No. 11. Both specified and "expected" SOTE efficiencies are plotted for the fine pore dome diffusers. The "expected" efficiencies are based on full-scale clean water test results for fine pore dome diffusers tested and analyzed per the ASCE Standard Procedure.

6.3 INCREASE IN ACTUAL EFFICIENCY

It appears reasonable to assume that the fine pore average actual efficiency (alpha×SOTE) is in the range of 9 to 10 percent. The original coarse bubble spiral-roll system average operating efficiency is estimated to be in the range of 4 to 5 percent (alpha×SOTE). The increase in actual efficiency represents 200 to 225 percent of the original system efficiency.

The retrofit design assumption was for an actual fine pore efficiency of about 17.5 percent (Figure No. 9), but this value was based on a very unrealistic (by today's standards) alpha value of 0.75. Even with an alpha of 0.5 the actual efficiency would be approximately 15 percent for the fine pore system, or over 3 times more efficient than the original system.

A doubling of transfer efficiency for this retrofit seems to be reasonable based on the reported values for both power consumption and airflow before and after the retrofit. Also, the alpha×SOTE values measured in this system agree reasonably well with the results from several other fine pore dome diffuser systems tested using the off-gas method in the recent past. (See EPA final report for specific results at other locations.)

6.4 COST CONSIDERATIONS

The estimated capital cost of the retrofit based on the consultant's estimate was between $1,115,000 and $1,830,000. The actual total capital cost for the project was less than $600,000, completely installed.

The installed cost on a per diffuser basis was less than $50.00/diffuser including modifications to the instrumentation, additional air filtration, and all installation costs. In-tank diffuser equipment and piping costs, alone, probably represented half of the total cost of the project.

Annual operating savings were estimated to be over $200,000 for the first year of operation. A daily power reduction of about 12,000 KWH was realized, and the electrical rate in 1983 was about $0.05 per KWH. Similar savings in the cost of electricity have been observed for the following years.

Annual maintenance costs for the fine pore system have not increased significantly over maintenance costs for the coarse bubble system. All four aeration tanks were cleaned in late 1985 in preparation for the ASCE/EPA Oxygen Transfer Study. Up until that time, no cleaning or other maintenance had been performed on the fine pore system.

The cost to clean each aeration tank in 1985 was approximately $4,500, or $18,000 for all four tanks. The breakdown for cleaning each tank is as follows:

Labor (100 man hours including overtime)	$2,000.00
Chemicals (ZEP cleaner)	250.00
Cleaning Equipment and Protective Clothing	750.00
Spare Parts (domes, bolts, gaskets, pipe hangers, etc.)	1,500.00
TOTAL TANK	$4,500.00

The total downtime for cleaning a single four-pass aeration tank was approximately one week, including draining and refilling.

The cost of replacing domes, gaskets, and bolts with new equipment would be approximately $35,000 for an entire aeration tank. In addition, the removal of grit, debris, and sludge could cost an additional $15,000. Total rehabilitation of the fine pore diffuser system should not be required more often than once every 5 to 8 years. However, gaskets and plastic bolts may require replacement as often as every 3 years.

Payback periods of less than 3 years can be expected for replacement of spiral-roll coarse bubble aeration equipment with full-floor coverage fine pore dome/disc aeration equipment. This payback is predicated upon the ability to reduce blower power usage through turndown and/or shutdown of blower units after retrofitting with the new equipment.

7.0 RECOMMENDATIONS

7.1 GENERAL

As a result of a thorough review of the Hartford Water Pollution Control Plant retrofit history and evaluation of over 2 years operating and oxygen transfer performance data as part of the ASCE/EPA Oxygen Transfer Study, several recommendations can be made regarding retrofit considerations for other similar facilities. These recommendations are categorized as follows:

1. Engineering Design
2. Equipment Design
3. Operation
4. Maintenance
5. Efficiency Considerations
6. Clogging Potential
7. Mechanical Reliability
8. Overall Advantages and Disadvantages

7.2 ENGINEERING DESIGN

Diffuser grid system and other in-tank air piping should be designed for operational flexibility for delivery of oxygen as required to specific sections of the aeration tank or process. Spare diffuser saddle capacity should always be provided in the design. Other methods of tapering air supply should be provided in the design as well. Grid system layout should include a specified minimum number of grids to ensure tapering capability and operational flexibility. Also, the grid system design should facilitate easy cleaning of the aeration tank when removal of bottom deposits becomes necessary.

Consideration should be given to the inlet or feed point design. Adequate distribution and mixing of the influent are necessary. If very low alpha values and the possibility of heavy fouling occur at the influent points, the aeration equipment design should address these conditions. the use of a full-floor coverage coarse bubble grid at the influent point might be more feasible than the use of a fine pore diffuser grid.

Dissolved oxygen measurement and control instrumentation design should be kept as simple as possible. Only proven technologies with a history of low maintenance should be considered.

Air supply piping should be sized for capacity considerations throughout the design life period (usually 20 years). Piping should provide for operational flexibility and tapering of the air supply.

Air distribution considerations should include an understanding of the oxygen demand profile in the system and methods for accomplishing necessary tapering, either by grid number and size selection or by control valves, or a combination of both.

Blower design or modification must be considered whenever changing from coarse bubble to fine pore aeration. Airflow, discharge pressure, and power consumption relationships must be evaluated and understood with regard to the new operating conditions. Net operating savings will be a direct result of reduced electrical power draw of the blower system and not as a result of increased oxygen transfer efficiency of the new aeration equipment.

7.3 EQUIPMENT DESIGN

The fine pore diffuser equipment should be durable and functionally simple. Systems using gaskets and plastic bolts should be evaluated carefully. Currently available gasketing systems are prone to leak and do not hold up for long periods of time. Plastic dome bolts are subject to total failure if overtightened or if temperature stresses develop after installation. Problems with either gaskets or dome bolts lead to coarse bubbling (loss of oxygen transfer efficiency), maldistribution of air, and intrusion of mixed liquor into the diffuser grid system.

In-tank air piping should be totally corrosion resistant. Pipe supports should be manufactured of stainless steel and designed for easy and precise leveling of the diffuser grid.

All piping grids should contain moisture blow-off units.

7.4 OPERATION

The fine pore diffused aeration system should be operated within the airflow range of the design. Minimum airflow rates for solids suspension and mixing of the mixed liquor and minimum airflow rates per diffuser to assure uniform distribution of air throughout a grid must be maintained.

Minimum dissolved oxygen concentrations should be established based on process and effluent quality considerations. Monitoring of dissolved oxygen should be based upon maintaining accurately measuring DO equipment.

MLSS concentrations should be maintained within design ranges insofar as possible. Increases in MLSS inventories in the aeration system increase oxygen demand and probably lower the apparent alpha values.

7.5 MAINTENANCE

All fine pore aeration systems must be properly maintained to ensure high operational efficiency. Routine inspection, cleaning, and repair must be carried out as necessary. Diffuser headloss, or dynamic wet pressure, and oxygen transfer efficiency measurements provide useful information for cleaning frequency requirements. Observation of surface patterns can provide information concerning coarse bubbling (possibly due to biofouling of the diffusers or from gasket leaks) and obvious air leaks. Major coarse bubbling problems should be checked out immediately and repairs made as soon as possible. Not only is oxygen transfer efficiency reduced as a result of coarse bubbling, but diffuser system clogging is possible from mixed liquor backflow into the air system.

7.6 EFFICIENCY CONSIDERATIONS

Retrofit design should be predicated upon sound performance data. Valid Standard Oxygen Transfer information should only be used in the design. Diffuser airflow rates, water depth, and diffuser density should be the same for test result information as for the proposed design conditions.

Alpha factors in the range of 0.3 to 0.4 should be used for fine pore diffuser systems. Higher values of the alpha factor should not be used unless specific alpha factor testing has been carried out, and the results verify that less conservative values could be used. Any alpha factor testing should include results for fouled or dirty diffusers as well as results for the new, clean diffusers.

For plug-flow systems where diffuser tapering is required to match changing oxygen demand, both clean water transfer efficiency and alpha factor value selection must take into consideration the need to select different values for SOTE and alpha at different points along the taper.

In many fine pore aeration systems oxygen transfer efficiency will diminish from a high value immediately after cleaning to lower values as operating time increases. These changes in oxygen transfer efficiency should be taken into consideration for determining cleaning frequency and assessing overall operating cost.

7.7 CLOGGING POTENTIAL

Regardless of operating mode, fine pore diffusers may clog or foul over time. Both operating mode and wastewater characteristics effect the degree and frequency of clogging. Fine silt and other inorganic materials carried in the primary effluent stream can and do end up on the diffusers, causing an increase in diffuser headloss. Biological materials which develop on the surface of the diffusers also cause clogging problems to exist. At Hartford, the high concentration of soluble BOD in the primary effluent probably causes rapid biofouling at the inlet ends of the aeration passes.

Air-side fouling can occur from particles in the air supply or from backflow of mixed liquor into the diffuser grid piping through leaking gaskets and bolts, broken bolts, and leaks in the air piping. The major air-side fouling potential is from leaks in equipment components and not from particles in the air supply.

7.8 MECHANICAL RELIABILITY

Mechanical reliability is always a concern when using plastic components in severe duty applications such as aeration. Materials must be handled more carefully during installation. Temperature variations must be accounted for with the thermal expansion and contraction of the plastic components.

Diffuser attachment to the pipe grid system should be simple and positive. Plastic dome bolts should not be used because of high potential for bolt failure. Gaskets should be manufactured of materials which will have long service life and not leak shortly after installation. Gaskets can be replaced as required and plastic bolts can be replaced with stainless steel bolts. However, replacement and repair of the diffuser attachment is costly.

7.9 OVERALL ADVANTAGES AND DISADVANTAGES

The most significant advantage of any fine pore retrofit is increased oxygen transfer efficiency. In some cases the increased efficiency allows for reduction of power consumption, and in other cases, additional aeration capacity is achieved without additional power consumption.

The disadvantages of fine pore aeration are not significant as long as the overall objectives of power savings or additional aeration capacity are being achieved. These disadvantages include:

1. need for higher level of maintenance of the aeration equipment,
2. shorter equipment life-cycle,
3. more limited tank accessibility for cleaning, and
4. possibility of tank downtime effecting process and plant effluent quality.

In spite of higher levels of maintenance and operational care, fine pore aeration retrofit systems which are properly operated and maintained will have life-cycle costs which are significantly less than continuing with the existing coarse bubble equipment.

8.0 REFERENCES

1. Manual of Methods for Fine Bubble Diffused Aeration Field Studies, ASCE/EPA Project, July 1985.

2. "Coarse Bubble to Fine Bubble Aeration Retrofit," Paul F. Gilbedrt and James H. Chase, Presented at the Ninth U.S.-Japan Conference on Sewage Treatment Technology, Tokyo, Japan, Sept. 1983.

3. "Report to the Metropolitan District Hartford, CT on Cost-Effectiveness Analysis of Using Fine Bubble Diffusers at Hartford WPCP," Metcalf & Eddy, Sept. 1981

4. "Report to Hartford, CT Metropolitan District Commission on Evaluation of New Variable Speed Drives for the Primary Effluent Pumps and New Blowers for the Aeration System," Metcalf & Eddy, Jan. 1986.

APPENDIX I-A

SUMMARY OF INDIVIDUAL OFF-GAS FIELD TESTS AND COMPUTATIONS FOR AIRFLOW-WEIGHT AVERAGING

OFF-GAS TEST RESULTS FOR SEPTEMBER 14, 1985

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-E	1	9-14-85	1400	1	8.88	0.20	25.3	8.94	223	1.00	223.0	28.2	0.32	20.66	65.17
1-E	1	9-14-85	1430	2	7.87	0.20	25.3	7.92	223	1.00	223.0	28.2	0.28	18.30	65.17
1-E	1	9-14-85	1445	3	8.33	0.20	25.3	8.39	223	1.00	223.0	28.2	0.30	19.39	65.17
1-E AVG.		-	-	-	-	-	25.3	8.42	223	1.00	223.0	28.2	0.30	19.45	65.17
2-I	2	9-14-85	1530	4	5.37	0.20	25.2	5.41	338	0.70	236.6	30.1	0.18	13.26	73.80
2-I	2	9-14-85	1600	5	5.19	0.20	25.2	5.23	338	0.70	236.6	30.1	0.17	12.82	73.80
2-I	2	9-14-85	1730	6	6.95	0.20	25.2	7.00	338	0.70	236.6	30.1	0.23	17.16	73.80
2-I AVG.		-	-	-	-	-	25.2	5.88	338	0.70	236.6	30.1	0.20	14.41	73.80

OFF-GAS TEST RESULTS FOR NOVEMBER 12, 13 & 14, 1985

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
2-I	2	11-13-85	1359	21	14.15	0.19	19.0	14.59	338	0.70	236.6	31.0	0.47	35.77	76.01
2-I	2	11-13-85	1415	22	14.35	0.18	18.8	14.80	338	0.70	236.6	31.0	0.48	36.29	76.01
2-I	2	11-13-85	1430	23	13.33	0.19	19.0	13.75	338	0.70	236.6	31.0	0.44	33.71	76.01
2-I	2	11-13-85	1445	24	13.37	0.19	19.0	13.79	338	0.70	236.6	31.0	0.44	33.81	76.01
2-I AVG.		-	-	-	-	-	19.0	14.23	338	0.70	236.6	31.0	0.46	34.90	76.01
2-M	2	11-13-85	1300	17	15.23	0.13	18.8	15.63	245	0.40	98.0	30.3	0.52	15.87	30.77
2-M	2	11-13-85	1315	18	16.34	0.13	18.8	16.77	245	0.40	98.0	30.3	0.55	17.03	30.77
2-M	2	11-13-85	1330	19	16.37	0.14	18.7	16.82	245	0.40	98.0	30.3	0.56	17.08	30.77
2-M	2	11-13-85	1345	20	15.81	0.14	18.7	16.24	245	0.40	98.0	30.3	0.54	16.49	30.77
2-M AVG.		-	-	-	-	-	18.8	16.37	245	0.40	98.0	30.3	0.54	16.62	30.77
2-E	2	11-13-85	1159	13	13.05	0.15	18.5	13.43	210	0.40	84.0	30.3	0.44	11.69	26.38
2-E	2	11-13-85	1215	14	12.75	0.15	18.5	13.12	210	0.40	84.0	30.3	0.43	11.42	26.38
2-E	2	11-13-85	1230	15	13.14	0.13	18.6	13.49	210	0.40	84.0	30.3	0.45	11.74	26.38
2-E	2	11-13-85	1245	16	14.92	0.13	18.6	15.32	210	0.40	84.0	30.3	0.51	13.34	26.38
2-E AVG.		-	-	-	-	-	18.6	13.84	210	0.40	84.0	30.3	0.46	12.05	26.38
PASS 2 SUMMARY		-	-	-	-	-	18.8	14.65	793	0.53	418.6	30.7	0.48	63.56	133.16

OFF-GAS TEST RESULTS FOR OCTOBER 21, 1985

TEST * LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-E	1	10-21-85	1145	1	4.82	0.10	21.3	4.89	223	1.00	223.0	28.2	0.17	11.30	65.17
1-E	1	10-21-85	1230	2	4.94	0.10	21.3	5.01	223	1.00	223.0	28.2	0.18	11.58	65.17
1-E	1	10-21-85	1300	3	5.06	0.10	21.3	5.14	223	1.00	223.0	28.2	0.18	11.88	65.17
1-E	1	10-21-85	1430	4	5.39	0.10	21.3	5.47	223	1.00	223.0	28.2	0.19	12.64	65.17
1-E	1	10-21-85	1530	5	4.26	0.10	21.3	4.32	223	1.00	223.0	28.2	0.15	9.98	65.17
1-E AVG.		-	-	-	-	-	21.3	4.97	223	1.00	223	28.2	0.18	11.48	65.17

* ALL TESTS CONDUCTED IN AERATION TANK NO. 1.

OFF-GAS TEST RESULTS FOR NOVEMBER 12, 13 & 14, 1985

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-I	1	11-13-85	1001	9	10.25	2.20	18.2	13.04	489	0.50	244.5	33.5	0.39	33.04	84.88
1-I	1	11-13-85	1015	10	9.56	2.20	18.2	12.16	489	0.50	244.5	33.5	0.36	30.81	84.88
1-I	1	11-13-85	1030	11	9.31	2.20	18.3	11.84	489	0.50	244.5	33.5	0.35	30.00	84.88
1-I	1	11-13-85	1045	12	10.87	2.20	18.3	13.83	489	0.50	244.5	33.5	0.41	35.04	84.88
1-I AVG.		-	-	-	-	-	18.3	12.72	489	0.50	244.5	33.5	0.38	32.22	84.88
1-M	1	11-12-85	1515	5	9.21	5.50	17.1	18.47	352	0.71	249.9	31.5	0.59	47.83	81.58
1-M	1	11-12-85	1545	6	11.62	5.40	17.1	22.90	352	0.71	249.9	31.5	0.73	59.31	81.58
1-M	1	11-13-85	1059	7	11.12	2.20	18.3	14.15	352	0.50	176.0	32.5	0.44	25.81	59.27
1-M	1	11-13-85	1115	8	13.70	2.20	18.3	17.43	352	0.50	176.0	32.5	0.54	31.79	59.27
1-M AVG.		-	-	-	-	-	17.7	18.66	352	0.61	213.0	31.9	0.58	41.19	70.43
1-E	1	11-12-85	1330	1	15.28	1.40	17.7	17.80	223	0.71	158.3	29.0	0.61	29.20	47.58
1-E	1	11-12-85	1400	2	12.70	1.40	17.7	14.80	223	0.71	158.3	29.0	0.51	24.28	47.58
1-E	1	11-12-85	1430	3	16.35	1.70	17.3	19.66	223	0.71	158.3	29.0	0.68	32.26	47.58
1-E	1	11-12-85	1445	4	11.96	2.30	17.3	15.35	223	0.71	158.3	29.0	0.53	25.19	47.58
1-E AVG.		-	-	-	-	-	17.5	16.90	223	0.71	158.3	29.0	0.58	27.73	47.58
PASS 1	SUMMARY	-	-	-	-	-	17.8	15.85	1064	0.58	615.8	31.8	0.50	101.14	202.89

OFF-GAS TEST RESULTS FOR NOVEMBER 12, 13 & 14, 1985

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
3-I	3	11-14-85	1255	33	9.49	0.62	19.7	10.19	325	1.80	585.0	27.2	0.37	61.77	164.89
3-I	3	11-14-85	1315	34	10.97	0.62	19.7	11.78	325	1.80	585.0	27.2	0.43	71.41	164.89
3-I	3	11-14-85	1330	35	8.14	0.20	19.8	8.39	325	1.80	585.0	27.2	0.31	50.86	164.89
3-I	3	11-14-85	1345	36	8.54	0.20	19.8	8.80	325	1.80	585.0	27.2	0.32	53.35	164.89
3-I AVG.		-	-	-	-	-	19.8	9.79	325	1.80	585.0	27.2	0.36	59.35	164.89
3-M	3	11-13-85	1615	29	13.55	0.19	19.1	13.97	245	0.90	220.5	28.9	0.48	31.92	66.04
3-M	3	11-13-85	1630	30	13.36	0.19	19.1	13.78	245	0.90	220.5	28.9	0.48	31.49	66.04
3-M	3	11-13-85	1645	31	13.30	0.15	19.3	13.65	245	0.90	220.5	28.9	0.47	31.19	66.04
3-M	3	11-13-85	1715	32	13.23	0.15	19.3	13.58	245	0.90	220.5	28.9	0.47	31.03	66.04
3-M AVG.		-	-	-	-	-	19.2	13.75	245	0.90	220.5	28.9	0.48	31.41	66.04
3-E	3	11-13-85	1500	25	15.99	0.19	19.0	16.49	223	0.90	200.7	28.9	0.57	34.30	60.11
3-E	3	11-13-85	1535	26	17.30	0.19	19.0	17.84	223	0.90	200.7	28.9	0.62	37.10	60.11
3-E	3	11-13-85	1540	27	16.48	0.19	19.1	16.99	223	0.90	200.7	28.9	0.59	35.34	60.11
3-E	3	11-13-85	1555	28	17.08	0.19	19.1	17.61	223	0.90	200.7	28.9	0.61	36.63	60.11
3-E AVG.		-	-	-	-	-	19.1	17.23	223	0.90	200.7	28.9	0.60	35.84	60.11
PASS 3	SUMMARY	-	-	-	-	-	19.3	12.14	793	1.27	1006.2	27.9	0.43	126.60	291.04

OFF-GAS TEST RESULTS FOR NOVEMBER 12, 13 & 14, 1985

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O /HR	NEW SOTR, LBS. O /HR
4-I	4	11-14-85	1610	45	8.29	0.11	19.7	8.47	293	1.70	498.1	26.8	0.32	43.72	138.33
4-I	4	11-14-85	1625	46	7.44	0.11	19.7	7.60	293	1.70	498.1	26.8	0.28	39.23	138.33
4-I	4	11-14-85	1640	47	8.12	0.11	19.7	8.30	293	1.70	498.1	26.8	0.31	42.84	138.33
4-I	4	11-14-85	1655	48	7.74	0.11	19.7	7.91	293	1.70	498.1	26.8	0.30	40.83	138.33
4-I AVG.		-	-	-	-	-	19.7	8.07	293	1.70	498.1	26.8	0.30	41.66	138.33
4-M	4	11-14-85	1510	41	11.90	0.25	19.7	12.32	210	1.70	357.0	25.4	0.49	45.58	93.97
4-M	4	11-14-85	1525	42	12.37	0.25	19.7	12.81	210	1.70	357.0	25.4	0.50	47.39	93.97
4-M	4	11-14-85	1540	43	11.72	0.25	19.7	12.13	210	1.70	357.0	25.4	0.48	44.87	93.97
4-M	4	11-14-85	1555	44	11.83	0.25	19.7	12.25	210	1.70	357.0	25.4	0.48	45.32	93.97
4-M AVG.		-	-	-	-	-	19.7	12.38	210	1.70	357.0	25.4	0.49	45.79	93.97
4-E	4	11-14-85	1410	37	11.69	0.54	19.6	12.46	176	1.70	299.2	23.5	0.53	38.63	72.86
4-E	4	11-14-85	1425	38	11.26	0.54	19.6	12.00	176	1.70	299.2	23.5	0.51	37.21	72.86
4-E	4	11-14-85	1440	39	12.24	0.21	19.6	12.63	176	1.70	299.2	23.5	0.54	39.16	72.86
4-E	4	11-14-85	1455	40	12.23	0.21	19.6	12.62	176	1.70	299.2	23.5	0.54	39.13	72.86
4-E AVG.		-	-	-	-	-	19.6	12.43	176	1.70	299.2	23.5	0.53	38.53	72.86
PASS 4 SUMMARY		-	-	-	-	-	19.7	10.53	679	1.70	1154.3	25.5	0.41	125.98	305.16

OFF-GAS TEST RESULTS FOR DECEMBER 19 AND 20, 1985

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
4-I	4	12-19-85	1415	1	5.87	0.33	16.1	6.18	293	1.75	512.8	26.8	0.23	32.84	142.40
4-I	4	12-19-85	1430	2	7.60	0.33	16.1	8.00	293	1.75	512.8	26.8	0.30	42.51	142.40
4-I	4	12-19-85	1440	3	6.48	0.20	16.2	6.74	293	1.75	512.8	26.8	0.25	35.81	142.40
4-I	4	12-19-85	1515	4	5.45	0.20	16.2	5.67	293	1.75	512.8	26.8	0.21	30.13	142.40
4-I AVG.		-	-	-	-	-	16.2	6.65	293	1.75	512.8	26.8	0.25	35.32	142.40
2-I	2	12-19-85	1540	5	4.58	0.07	16.2	4.71	338	1.40	473.2	26.5	0.18	23.10	129.95
2-I	2	12-19-85	1600	6	4.10	0.07	16.2	4.22	338	1.40	473.2	26.5	0.16	20.69	129.95
2-I	2	12-19-85	1630	7	4.05	0.07	16.2	4.17	338	1.40	473.2	26.5	0.16	20.45	129.95
2-I	2	12-19-85	1710	8	5.14	0.07	16.2	5.29	338	1.40	473.2	26.5	0.20	25.94	129.95
2-I AVG.		-	-	-	-	-	16.2	4.60	338	1.40	473.2	26.5	0.17	22.55	129.95
1-I	1	12-20-85	805	9	5.61	2.48	16.2	7.33	489	1.30	635.7	30.5	0.24	48.29	200.92
1-I	1	12-20-85	830	10	7.32	2.48	16.4	9.57	489	1.30	635.7	30.5	0.31	63.04	200.92
1-I	1	12-20-85	850	11	5.76	2.41	16.4	7.47	489	1.30	635.7	30.5	0.24	49.21	200.92
1-I	1	12-20-85	915	12	6.29	2.41	16.4	8.16	489	1.30	635.7	30.5	0.27	53.75	200.92
1-I AVG.		-	-	-	-	-	16.4	8.13	489	1.30	635.7	30.5	0.27	53.57	200.92
3-I	3	12-20-85	945	13	7.19	0.54	16.1	7.72	325	1.60	520.0	27.5	0.28	41.60	148.19
3-I	3	12-20-85	1015	14	6.51	0.54	16.1	6.99	325	1.60	520.0	27.5	0.25	37.67	148.19
3-I	3	12-20-85	1050	15	7.82	0.39	16.1	8.28	325	1.60	520.0	27.5	0.30	44.62	148.19
3-I	3	12-20-85	1130	16	7.85	39	16.1	8.31	325	1.60	520.0	27.5	0.30	44.78	148.19
3-I AVG.		-	-	-	-	-	16.1	7.83	325	1.60	520.0	27.5	0.28	42.17	148.19

OFF-GAS TEST RESULTS FOR MARCH 24 AND 25, 1986

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-I	1	3-24-86	1230	9	8.11	0.15	13.7	8.44	489	1.10	537.9	31.5	0.27	47.05	175.58
1-I	1	3-24-86	1245	10	8.26	0.15	13.7	8.59	489	1.10	537.9	31.5	0.27	47.88	175.58
1-I	1	3-24-86	1300	11	9.70	0.11	13.7	10.06	489	1.10	537.9	31.5	0.32	56.08	175.58
1-I	1	3-24-86	1315	12	8.30	0.11	13.7	8.60	489	1.10	537.9	31.5	0.27	47.94	175.58
1-I AVG.		-	-	-	-	-	13.7	8.92	489	1.10	537.9	31.5	0.28	49.73	175.58
1-M	1	3-24-86	1130	5	7.81	0.08	13.6	8.08	352	1.10	387.2	30.1	0.27	32.42	120.77
1-M	1	3-24-86	1145	6	7.79	0.08	13.6	8.06	352	1.10	387.2	30.1	0.27	32.34	120.77
1-M	1	3-24-86	1200	7	7.47	0.08	13.6	7.73	352	1.10	387.2	30.1	0.26	31.02	120.77
1-M	1	3-24-86	1215	8	7.70	0.08	13.6	7.96	352	1.10	387.2	30.1	0.26	31.94	120.77
1-M AVG.		-	-	-	-	-	13.6	7.96	352	1.10	387.2	30.1	0.26	31.93	120.77
1-E	1	3-24-86	1030	1	9.10	0.11	13.4	9.44	223	1.10	245.3	28.1	0.34	24.00	71.43
1-E	1	3-24-86	1045	2	8.23	0.11	13.4	8.54	223	1.10	245.3	28.1	0.30	21.71	71.43
1-E	1	3-24-86	1100	3	8.12	0.09	13.5	8.41	223	1.10	245.3	28.1	0.30	21.38	71.43
1-E	1	3-24-86	1115	4	7.13	0.09	13.5	7.38	223	1.10	245.3	28.1	0.26	18.76	71.43
1-E AVG.		-	-	-	-	-	13.5	8.44	223	1.10	245.3	28.1	0.30	21.46	71.43
PASS 1 SUMMARY		-	-	-	-	-	13.6	8.50	1064	1.10	1170.4	30.3	0.28	103.12	367.78

OFF-GAS TEST RESULTS FOR MARCH 24 AND 25, 1986

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
2-I	2	3-24-86	1615	21	8.31	0.07	13.8	8.58	338	1.80	608.4	27.1	0.32	54.09	170.86
2-I	2	3-24-86	1630	22	7.91	0.07	13.8	8.17	338	1.80	608.4	27.1	0.30	51.51	170.86
2-I	2	3-24-86	1645	23	7.81	0.07	13.8	8.07	338	1.80	608.4	27.1	0.30	50.88	170.86
2-I	2	3-24-86	1730	24	8.85	0.07	13.8	9.14	338	1.80	608.4	27.1	0.34	57.62	170.86
2-I AVG.		-	-	-	-	-	13.8	8.49	338	1.80	608.4	27.1	0.31	53.53	170.86
2-M	2	3-24-86	1430	17	6.94	0.07	13.8	7.17	245	1.10	269.5	28.3	0.25	20.02	79.03
2-M	2	3-24-86	1445	18	7.98	0.07	13.8	8.24	245	1.10	269.5	28.3	0.29	23.01	79.03
2-M	2	3-24-86	1500	19	6.64	0.07	13.8	6.86	245	1.10	269.5	28.3	0.24	19.16	79.03
2-M	2	3-24-86	1530	20	7.39	0.07	13.8	7.63	245	1.10	269.5	28.3	0.27	21.31	79.03
2-M AVG.		-	-	-	-	-	13.8	7.48	245	1.10	269.5	28.3	0.26	20.88	79.03
2-E	2	3-24-86	1330	13	7.78	0.14	13.7	8.09	210	1.10	231.0	28.1	0.29	19.37	67.27
2-E	2	3-24-86	1345	14	7.29	0.14	13.7	7.58	210	1.10	231.0	28.1	0.27	18.14	67.27
2-E	2	3-24-86	1400	15	7.01	0.14	13.7	7.29	210	1.10	231.0	28.1	0.26	17.45	67.27
2-E	2	3-24-86	1415	16	7.22	0.14	13.7	7.50	210	1.10	231.0	28.1	0.27	17.95	67.27
2-E AVG.		-	-	-	-	-	13.7	7.62	210	1.10	231.0	28.1	0.27	18.23	67.27
PASS 2 SUMMARY		-	-	-	-	-	13.8	8.06	793	1.40	1108.9	27.6	0.29	92.64	317.16

OFF-GAS TEST RESULTS FOR MARCH 24 AND 25, 1986

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
3-I	3	3-25-86	1200	33	6.59	0.03	14.1	6.78	325	1.30	422.5	28.5	0.24	29.68	124.78
3-I	3	3-25-86	1245	34	6.61	0.03	14.1	6.80	325	1.30	422.5	28.5	0.24	29.77	124.78
3-I	3	3-25-86	1300	35	7.69	0.03	14.1	7.91	325	1.30	422.5	28.5	0.28	34.63	124.78
3-I	3	3-25-86	1315	36	7.04	0.03	14.1	7.25	325	1.30	422.5	28.5	0.25	31.74	124.78
3-I AVG.		-	-	-	-	-	14.1	7.19	325	1.30	422.5	28.5	0.25	31.46	124.78
3-M	3	3-25-86	1045	29	7.73	0.04	14.0	7.96	245	1.30	318.5	27.6	0.29	26.27	91.09
3-M	3	3-25-86	1100	30	8.37	0.04	14.0	8.62	245	1.30	318.5	27.6	0.31	28.45	91.09
3-M	3	3-25-86	1115	31	7.07	0.04	14.0	7.28	245	1.30	318.5	27.6	0.26	24.03	91.09
3-M	3	3-25-86	1130	32	6.96	0.04	14.0	7.17	245	1.30	318.5	27.6	0.26	23.66	91.09
3-M AVG.		-	-	-	-	-	14.0	7.76	245	1.30	318.5	27.6	0.28	25.60	91.09
3-E	3	3-25-86	915	25	9.04	0.07	14.0	9.34	223	1.30	289.9	27.1	0.34	28.06	81.41
3-E	3	3-25-86	945	26	10.18	0.07	14.0	10.51	223	1.30	289.9	27.1	0.39	31.57	81.41
3-E	3	3-25-86	1000	27	9.01	0.07	14.0	9.31	223	1.30	289.9	27.1	0.34	27.97	81.41
3-E	3	3-25-86	1030	28	8.54	0.07	14.0	8.82	223	1.30	289.9	27.1	0.33	26.50	81.41
3-E AVG.		-	-	-	-	-	14.0	9.50	223	1.30	289.9	27.1	0.35	28.53	81.41
PASS 3 SUMMARY		-	-	-	-	-	14.0	8.01	793	1.30	1030.9	27.8	0.29	85.60	297.28

OFF-GAS TEST RESULTS FOR MARCH 24 AND 25, 1986

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
4-I	4	3-25-86	1630	45	7.83	0.09	14.4	8.10	293	1.40	410.2	28.1	0.29	34.43	119.45
4-I	4	3-25-86	1645	46	7.60	0.09	14.4	7.86	293	1.40	410.2	28.1	0.28	33.41	119.45
4-I	4	3-25-86	1700	47	7.78	0.07	14.4	8.03	293	1.40	410.2	28.1	0.29	34.13	119.45
4-I	4	3-25-86	1730	48	7.82	0.07	14.4	8.07	293	1.40	410.2	28.1	0.29	34.30	119.45
4-I AVG.		-	-	-	-	-	14.4	8.02	293	1.40	410.2	28.1	0.29	34.07	119.45
4-M	4	3-25-86	1445	41	8.25	0.08	14.3	8.52	210	1.40	294.0	26.5	0.32	25.96	80.74
4-M	4	3-25-86	1515	42	7.44	0.08	14.3	7.69	210	1.40	294.0	26.5	0.29	23.43	80.74
4-M	4	3-25-86	1530	43	9.24	0.08	14.3	9.55	210	1.40	294.0	26.5	0.36	29.10	80.74
4-M	4	3-25-86	1600	44	8.69	0.08	14.3	8.98	210	1.40	294.0	26.5	0.34	27.36	80.74
4-M AVG.		-	-	-	-	-	14.3	8.69	210	1.40	294.0	26.5	0.33	26.46	80.74
4-E	4	3-25-86	1345	37	7.59	0.12	14.2	7.87	176	1.40	246.4	25.5	0.31	20.10	65.11
4-E	4	3-25-86	1400	38	6.74	0.12	14.2	6.99	176	1.40	246.4	25.5	0.27	17.85	65.11
4-E	4	3-25-86	1415	39	7.24	0.12	14.2	7.51	176	1.40	246.4	25.5	0.29	19.18	65.11
4-E	4	3-25-86	1430	40	7.64	0.12	14.2	7.92	176	1.40	246.4	25.5	0.31	20.22	65.11
4-E AVG.		-	-	-	-	-	14.2	7.57	176	1.40	246.4	25.5	0.30	19.34	65.11
PASS 4 SUMMARY		-	-	-	-	-	14.3	8.11	679	1.40	950.6	26.9	0.30	79.87	265.30

OFF-GAS TEST RESULTS FOR APRIL 1 AND 2, 1986 (DIURNAL STUDY)

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
2-M	2	4-1-86	1130	1	7.50	0.18	15.2	7.81	245	1.10	269.5	28.3	0.28	21.81	79.03
2-M	2	4-1-86	1145	2	8.45	0.18	15.2	8.80	245	1.10	269.5	28.3	0.31	24.58	79.03
2-M	2	4-1-86	1230	3	8.50	0.18	15.2	8.85	245	1.10	269.5	28.3	0.31	24.72	79.03
2-M	2	4-1-86	1245	4	7.96	0.14	15.1	8.26	245	1.10	269.5	28.3	0.29	23.07	79.03
2-M	2	4-1-86	1330	5	8.11	0.13	15.2	8.41	245	1.10	269.5	28.3	0.30	23.49	79.03
2-M	2	4-1-86	1345	6	7.76	0.13	15.2	8.04	245	1.10	269.5	28.3	0.28	22.45	79.03
2-M	2	4-1-86	1430	7	7.07	0.12	15.2	7.32	245	1.10	269.5	28.3	0.26	20.44	79.03
2-M	2	4-1-86	1445	8	7.77	0.12	15.2	8.05	245	1.10	269.5	28.3	0.28	22.48	79.03
2-M	2	4-1-86	1530	9	7.49	0.07	15.4	7.72	245	1.10	269.5	28.3	0.27	21.56	79.03
2-M	2	4-1-86	1545	10	8.40	0.07	15.4	8.66	245	1.10	269.5	28.3	0.31	24.19	79.03
2-M	2	4-1-86	1630	11	6.67	0.06	15.4	6.87	245	1.10	269.5	28.3	0.24	19.19	79.03
2-M	2	4-1-86	1645	12	7.27	0.06	15.4	7.49	245	1.10	269.5	28.3	0.26	20.92	79.03
2-M	2	4-1-86	1730	13	7.48	0.06	15.3	7.70	245	1.10	269.5	28.3	0.27	21.50	79.03
2-M	2	4-1-86	1745	14	6.83	0.06	15.3	7.04	245	1.10	269.5	28.3	0.25	19.66	79.03
2-M	2	4-1-86	1830	15	6.72	0.06	15.3	6.92	245	1.10	269.5	28.3	0.24	19.33	79.03
2-M	2	4-1-86	1845	16	7.05	0.06	15.3	7.26	245	1.10	269.5	28.3	0.26	20.28	79.03
2-M	2	4-1-86	1930	17	6.90	0.06	15.4	7.11	245	1.10	269.5	28.3	0.25	19.86	79.03
2-M	2	4-1-86	1945	18	6.24	0.06	15.4	6.43	245	1.10	269.5	28.3	0.23	17.96	79.03
2-M	2	4-1-86	2030	19	7.38	0.06	15.3	7.60	245	1.10	269.5	28.3	0.27	21.22	79.03
2-M	2	4-1-86	2045	20	7.76	0.06	15.3	7.99	245	1.10	269.5	28.3	0.28	22.31	79.03
2-M	2	4-1-86	2230	21	7.06	0.06	15.2	7.27	245	1.10	269.5	28.3	0.26	20.30	79.03
2-M	2	4-1-86	2245	22	7.33	0.06	15.2	7.55	245	1.10	269.5	28.3	0.27	21.09	79.03
2-M	2	4-2-86	0030	23	7.50	0.06	15.1	7.73	245	1.30	318.5	27.4	0.28	25.51	90.43
2-M	2	4-2-86	0045	24	7.45	0.06	15.1	7.68	245	1.30	318.5	27.4	0.28	25.35	90.43
2-M	2	4-2-86	0230	25	7.44	0.05	15.1	7.66	245	1.30	318.5	27.4	0.28	25.28	90.43
2-M	2	4-2-86	0245	26	7.39	0.05	15.1	7.61	245	1.30	318.5	27.4	0.28	25.12	90.43
2-M	2	4-2-86	0430	27	8.51	0.06	15.1	8.77	245	1.30	318.5	27.4	0.32	28.95	90.43
2-M	2	4-2-86	0445	28	8.19	0.06	15.1	8.44	245	1.30	318.5	27.4	0.31	27.86	90.43
2-M	2	4-2-86	0630	29	8.00	0.08	15.0	8.26	245	1.30	318.5	27.4	0.30	27.26	90.43
2-M	2	4-2-86	0645	30	7.88	0.08	15.0	8.14	245	1.30	318.5	27.4	0.30	26.87	90.43
2-M	2	4-2-86	0730	31	8.41	0.07	14.9	8.68	245	1.30	318.5	27.4	0.32	28.65	90.43
2-M	2	4-2-86	0745	32	8.65	0.07	14.9	8.93	245	1.30	318.5	27.4	0.33	29.47	90.43
2-M	2	4-2-86	0830	33	7.48	0.09	14.9	7.73	245	1.20	294.0	27.6	0.28	23.55	84.09
2-M	2	4-2-86	0845	34	8.59	0.09	14.9	8.88	245	1.20	294.0	27.6	0.32	27.05	84.09
2-M	2	4-2-86	0930	35	10.83	0.15	14.8	11.25	245	1.20	294.0	27.6	0.41	34.27	84.09
2-M	2	4-2-86	0945	36	9.02	0.15	14.8	9.37	245	1.20	294.0	27.6	0.34	28.55	84.09
2-M	2	4-2-86	1030	37	9.86	0.25	14.8	10.33	245	1.20	294.0	27.6	0.37	31.47	84.09
2-M	2	4-2-86	1045	38	10.67	0.25	14.8	11.18	245	1.20	294.0	27.6	0.41	34.06	84.09
2-M	2	4-2-86	1130	39	9.83	0.13	14.8	10.20	245	1.20	294.0	27.6	0.37	31.08	84.09
2-M	2	4-2-86	1145	40	9.49	0.13	14.8	9.84	245	1.20	294.0	27.6	0.36	29.98	84.09
2-M AVG.		-	-	-	-	-	15.1	8.27	245	1.17	286.7	27.9	0.30	24.57	82.89

OFF-GAS TEST RESULTS FOR JULY 14 AND 15, 1986

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-I	1	7-14-86	1503	5	7.86	1.35	21.8	9.23	489	2.10	1026.9	27.8	0.33	98.22	295.83
1-M	1	7-14-86	1423	3	8.57	0.85	21.7	9.44	352	2.10	739.2	26.7	0.35	72.31	204.52
1-E	1	7-14-86	1345	1	10.93	0.25	21.6	11.21	223	2.10	468.3	25.3	0.44	54.40	122.78
PASS 1	SUMMARY	-	-	-	-	-	21.7	9.71	1064	2.10	2234.4	26.9	0.36	224.93	623.13
2-I	2	7-14-86	1402	2	11.64	1.25	21.7	13.51	338	2.40	811.2	25.5	0.53	113.57	214.36
2-M	2	7-14-86	1435	4	10.90	0.35	21.0	11.42	245	2.40	588.0	24.7	0.46	69.59	150.50
2-E	2	7-14-86	1514	6	9.83	0.25	21.8	10.05	210	2.40	504.0	24.5	0.41	52.49	127.96
PASS 2	SUMMARY	-	-	-	-	-	21.5	11.95	793	2.40	1903.2	25.0	0.48	235.64	492.82
3-I	3	7-14-86	1557	7	6.57	0.18	22.0	6.64	325	2.50	812.5	25.5	0.26	55.91	214.70
3-M	3	7-14-86	1615	9	7.62	0.18	22.2	7.72	245	2.50	612.5	24.7	0.31	49.00	156.77
3-E	3	7-14-86	1637	11	9.83	0.35	22.2	10.16	223	2.50	557.5	24.5	0.41	58.70	141.54
PASS 3	SUMMARY	-	-	-	-	-	22.1	7.96	793	2.50	1982.5	25.0	0.32	163.60	513.02
4-I	4	7-14-86	1644	12	7.12	0.18	22.3	7.21	293	2.50	732.5	25.2	0.29	54.73	191.28
4-M	4	7-14-86	1625	10	7.71	0.20	22.2	7.83	210	2.50	525.0	24.2	0.32	42.60	131.66
4-E	4	7-14-86	1607	8	7.69	0.18	22.1	7.78	176	2.50	440.0	23.7	0.33	35.47	108.06
PASS 4	SUMMARY	-	-	-	-	-	22.2	7.55	679	2.50	1697.5	24.5	0.31	132.80	431.01
TANK 2	SUMMARY	-	-	-	-	-	21.9	9.34	3329	2.35	7817.6	25.4	0.37	756.98	2059.98

OFF-GAS TEST RESULTS FOR JULY 14 AND 15, 1986

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-I	1	7-15-86	1237	20	8.62	0.70	22.6	9.33	489	2.20	1075.8	27.8	0.34	104.01	309.92
1-M	1	7-15-86	1317	22	9.35	0.30	22.7	9.64	352	2.20	774.4	26.7	0.36	77.36	214.26
1-E	1	7-15-86	1408	24	9.21	0.10	22.9	9.28	223	2.20	490.6	25.3	0.37	47.18	128.62
PASS 1	SUMMARY	-	-	-	-	-	22.7	9.42	1064	2.20	2340.8	26.9	0.35	228.55	652.81
2-I	2	7-15-86	1358	23	9.62	0.40	23.0	10.06	338	2.60	878.8	25.5	0.39	91.61	232.22
2-M	2	7-15-86	1300	21	8.90	0.20	23.1	9.08	245	2.60	637.0	24.7	0.37	59.94	163.05
2-E	2	7-15-86	1214	19	10.81	0.20	23.3	11.02	210	2.60	546.0	24.5	0.45	62.35	138.62
PASS 2	SUMMARY	-	-	-	-	-	23.1	10.01	793	2.60	2061.8	25.0	0.40	213.90	533.89
3-I	3	7-15-86	1139	18	8.60	0.10	22.7	8.66	325	2.50	812.5	25.5	0.34	72.91	214.70
3-M	3	7-15-86	1105	16	11.57	0.50	22.6	12.21	245	2.50	612.5	24.7	0.49	77.50	156.77
3-E	3	7-15-86	1042	14	10.64	1.30	22.6	12.46	223	2.50	557.5	24.5	0.51	71.98	141.54
PASS 3	SUMMARY	-	-	-	-	-	22.6	10.83	793	2.50	1982.5	25.0	0.43	222.40	513.02
4-I	4	7-15-86	1028	13	6.16	0.30	22.2	6.33	293	2.50	732.5	25.2	0.25	48.05	191.28
4-M	4	7-15-86	1054	15	8.03	0.80	22.3	8.78	210	2.50	525.0	24.2	0.36	47.77	131.66
4-E	4	7-15-86	1124	17	10.02	1.20	22.4	11.55	176	2.50	440.0	23.7	0.49	52.66	108.06
PASS 4	SUMMARY	-	-	-	-	-	22.3	8.44	679	2.50	1697.5	24.5	0.34	148.48	431.01
TANK 2	SUMMARY	-	-	-	-	-	22.7	9.71	3329	2.43	8082.6	25.4	0.38	813.33	2130.72

OFF-GAS TEST RESULTS FOR JULY 14 AND 15, 1986

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-I	1	7-15-86	1519	30	8.58	0.25	22.9	8.80	489	2.20	1075.8	27.8	0.32	98.10	309.92
1-M	1	7-15-86	1451	28	8.83	0.30	22.9	9.12	352	2.20	774.4	26.7	0.34	73.19	214.26
1-E	1	7-15-86	1408	26	9.21	0.10	22.9	9.28	223	2.20	490.6	25.3	0.37	47.18	128.62
PASS 1	SUMMARY	-	-	-	-	-	22.9	9.01	1064	2.20	2340.8	26.9	0.33	218.47	652.81
2-I	2	7-15-86	1358	25	9.62	0.40	23.0	10.06	338	2.60	878.8	25.5	0.39	91.61	232.22
2-M	2	7-15-86	1416	27	11.15	0.20	23.1	11.38	245	2.60	637.0	24.7	0.46	75.12	163.05
2-E	2	7-15-86	1504	29	13.27	0.15	23.1	13.46	210	2.60	546.0	24.5	0.55	76.16	138.62
PASS 2	SUMMARY	-	-	-	-	-	23.1	11.37	793	2.60	2061.8	25.0	0.45	242.89	533.89
3-I	3	7-15-86	1557	31	6.15	0.10	22.9	6.20	325	2.50	812.5	25.5	0.24	52.20	214.70
3-M	3	7-15-86	1616	33	7.83	0.15	23.0	7.94	245	2.50	612.5	24.7	0.32	50.40	156.77
3-E	3	7-15-86	1639	35	10.43	0.40	23.1	10.90	223	2.50	557.5	24.5	0.45	62.97	141.54
PASS 3	SUMMARY	-	-	-	-	-	23.0	8.06	793	2.50	1982.5	25.0	0.32	165.57	513.02
4-I	4	7-15-86	1653	36	8.57	0.10	23.0	8.64	293	2.50	732.5	25.2	0.34	65.58	191.28
4-M	4	7-15-86	1623	34	6.02	0.10	22.9	6.07	210	2.50	525.0	24.2	0.25	33.02	131.66
4-E	4	7-15-86	1610	32	8.50	0.20	22.9	8.67	176	2.50	440.0	23.7	0.37	39.53	108.06
PASS 4	SUMMARY	-	-	-	-	-	22.9	7.85	679	2.50	1697.5	24.5	0.32	138.14	431.01
TANK 2	SUMMARY	-	-	-	-	-	23.0	9.13	3329	2.43	8082.6	25.4	0.36	765.07	2130.72

OFF-GAS TEST RESULTS FOR FEBRUARY 4 AND 5, 1987

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-I	1	2-4-87	1515	5	6.70	3.44	13.4	10.32	489	1.50	733.5	29.5	0.35	78.44	224.23
1-M	1	2-4-87	1445	3	5.27	3.08	13.3	7.71	352	1.50	528.0	28.2	0.27	42.19	154.30
1-E	1	2-4-87	1420	1	9.44	0.18	13.3	9.87	223	1.50	334.5	26.3	0.38	34.21	91.16
PASS 1	SUMMARY	-	-	-	-	-	13.3	9.36	1064	1.50	1596.0	28.4	0.33	154.84	469.69
2-I	2	2-4-87	1430	2	8.59	0.37	13.3	9.16	338	1.40	473.2	28.0	0.33	44.92	137.30
2-M	2	2-4-87	1500	4	7.37	0.18	13.3	7.71	245	1.40	343.0	26.9	0.29	27.40	95.61
2-E	2	2-4-87	1545	6	6.61	0.13	13.4	6.88	210	1.40	294.0	26.7	0.26	20.96	81.35
PASS 2	SUMMARY	-	-	-	-	-	13.3	8.11	793	1.40	1110.2	27.3	0.30	93.28	314.26
3-I	3	2-4-87	1610	7	5.59	0.20	13.4	5.86	325	1.60	520.0	27.6	0.21	31.58	148.73
3-M	3	2-4-87	1650	10	7.44	0.37	13.4	7.93	245	1.60	392.0	26.4	0.30	32.21	107.24
3-E	3	2-4-87	1725	12	8.00	0.99	13.4	9.09	223	1.60	356.8	26.1	0.35	33.61	96.50
PASS 3	SUMMARY	-	-	-	-	-	13.4	7.41	793	1.60	1268.8	26.8	0.28	97.40	352.47
4-I	4	2-4-87	1715	11	4.85	0.94	13.4	5.48	293	1.70	498.1	26.8	0.20	28.29	138.33
4-M	4	2-4-87	1645	9	6.44	1.11	13.4	7.41	210	1.70	357.0	25.5	0.29	27.41	94.34
4-E	4	2-4-87	1630	8	6.75	1.82	13.4	8.42	176	1.70	299.2	24.9	0.34	26.11	77.20
PASS 4	SUMMARY	-	-	-	-	-	13.4	6.84	679	1.70	1154.3	25.9	0.26	81.81	309.87
TANK 2	SUMMARY	-	-	-	-	-	13.4	8.04	3329	1.54	5129.3	27.2	0.30	427.33	1446.29

OFF-GAS TEST RESULTS FOR FEBRUARY 4 AND 5, 1987

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-I	1	2-5-87	1050	20	6.48	4.40	12.8	11.49	489	1.40	684.6	29.7	0.39	81.51	210.70
1-M	1	2-5-87	1115	22	7.22	3.90	12.8	11.83	352	1.40	492.8	28.4	0.42	60.41	145.03
1-E	1	2-5-87	1125	23	7.61	0.40	12.9	8.14	223	1.40	312.2	26.5	0.31	26.33	85.73
PASS 1	SUMMARY	-	-	-	-	-	12.8	10.90	1064	1.40	1489.6	28.6	0.38	168.26	441.47
2-I	2	2-5-87	1135	24	7.51	1.30	12.9	8.82	338	1.40	473.2	27.9	0.32	43.25	136.81
2-M	2	2-5-87	1100	21	7.51	1.50	12.8	9.02	245	1.40	343.0	26.8	0.34	32.06	95.26
2-E	2	2-5-87	1020	19	6.05	1.20	12.8	7.03	210	1.40	294.0	26.5	0.27	21.42	80.74
PASS 2	SUMMARY	-	-	-	-	-	12.8	8.41	793	1.40	1110.2	27.2	0.31	96.73	312.80
3-I	3	2-5-87	950	17	6.07	2.80	12.7	8.51	325	1.50	487.5	27.7	0.31	42.99	139.94
3-M	3	2-5-87	915	15	4.71	2.85	12.7	6.65	245	1.50	367.5	26.6	0.25	25.33	101.30
3-E	3	2-5-87	850	13	8.48	2.90	12.8	12.06	223	1.50	334.5	26.3	0.46	41.80	91.16
PASS 3	SUMMARY	-	-	-	-	-	12.7	8.93	793	1.50	1189.5	27.0	0.33	110.12	332.40
4-I	4	2-5-87	905	14	6.74	4.30	12.7	11.74	293	1.70	498.1	26.8	0.44	60.60	138.33
4-M	4	2-5-87	925	16	7.54	4.90	12.6	14.51	210	1.70	357.0	25.5	0.57	53.68	94.34
4-E	4	2-5-87	1005	18	4.69	5.00	12.6	9.19	176	1.70	299.2	24.9	0.37	28.49	77.20
PASS 4	SUMMARY	-	-	-	-	-	12.6	11.94	679	1.70	1154.3	25.9	0.46	142.77	309.87
TANK 2	SUMMARY	-	-	-	-	-	12.8	10.11	3329	1.49	4943.6	27.3	0.37	517.88	1396.54

OFF-GAS TEST RESULTS FOR FEBRUARY 4 AND 5, 1987

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-I	1	2-5-87	1210	29	4.86	4.10	12.8	8.21	489	1.40	684.6	29.7	0.28	58.24	210.70
1-M	1	2-5-87	1150	27	5.81	3.90	12.7	9.51	352	1.40	492.8	28.4	0.33	48.57	145.03
1-E	1	2-5-87	1145	26	8.16	0.50	12.9	8.81	223	1.40	312.2	26.5	0.33	28.50	85.73
PASS 1	SUMMARY	-	-	-	-	-	12.8	8.77	1064	1.40	1489.6	28.6	0.31	135.31	441.47
2-I	2	2-5-87	1140	25	8.02	1.10	12.8	9.22	338	1.40	473.2	27.9	0.33	45.21	136.81
2-M	2	2-5-87	1200	28	7.49	0.75	12.9	8.30	245	1.40	343.0	26.8	0.31	29.50	95.26
2-E	2	2-5-87	1220	30	7.36	0.40	12.9	7.87	210	1.40	294.0	26.5	0.30	23.98	80.74
PASS 2	SUMMARY	-	-	-	-	-	12.9	8.58	793	1.40	1110.2	27.2	0.32	98.69	312.80
3-I	3	2-5-87	1305	32	7.38	0.93	13.1	8.33	325	1.30	422.5	28.5	0.29	36.47	124.78
3-M	3	2-5-87	1325	34	7.87	0.80	13.1	8.77	245	1.30	318.5	27.1	0.32	28.95	89.44
3-E	3	2-5-87	1345	35	10.96	1.40	13.1	13.02	223	1.30	289.9	27.1	0.48	39.11	81.41
PASS 3	SUMMARY	-	-	-	-	-	13.1	9.78	793	1.30	1030.9	27.7	0.35	104.53	295.64
4-I	4	2-5-87	1400	36	5.84	1.40	13.2	6.94	293	1.70	498.1	26.8	0.26	35.82	138.33
4-M	4	2-5-87	1320	33	6.71	2.60	13.1	9.20	210	1.70	357.0	25.5	0.36	34.04	94.34
4-E	4	2-5-87	1250	31	6.29	3.75	13.1	10.11	176	1.70	299.2	24.9	0.41	31.35	77.20
PASS 4	SUMMARY	-	-	-	-	-	13.1	8.46	679	1.70	1154.3	25.9	0.33	101.20	309.87
TANK 2	SUMMARY	-	-	-	-	-	13.0	8.87	3329	1.44	4785.0	27.4	0.32	439.74	1359.78

OFF-GAS TEST RESULTS FOR APRIL 22 AND 23, 1987

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-I	1	4-22-87	1405	5	9.03	1.50	15.1	10.63	489	1.28	625.9	31.0	0.34	68.95	201.07
1-M	1	4-22-87	1345	3	12.01	1.10	15.0	13.60	352	1.28	450.6	29.2	0.47	63.50	136.34
1-E	1	4-22-87	1250	1	11.86	0.20	14.9	12.38	223	1.28	285.4	27.3	0.45	36.62	80.75
PASS 1	SUMMARY	-	-	-	-	-	15.0	11.98	1064	1.28	1361.9	29.6	0.40	169.07	418.16
2-I	2	4-22-87	1330	2	9.33	0.50	15.0	10.00	338	1.08	365.0	29.9	0.33	37.83	113.11
2-M	2	4-22-87	1355	4	9.93	0.25	15.1	10.40	245	1.08	264.6	28.7	0.36	28.52	78.69
2-E	2	4-22-87	1410	6	10.35	0.30	15.1	10.89	210	1.08	226.8	28.3	0.38	25.59	66.51
PASS 2	SUMMARY	-	-	-	-	-	15.1	10.36	793	1.08	856.4	29.1	0.36	91.94	258.31
3-I	3	4-22-87	1445	8	8.39	0.30	15.2	8.83	325	1.28	416.0	28.9	0.31	38.07	124.58
3-M	3	4-22-87	1500	10	8.42	0.30	15.2	8.86	245	1.28	313.6	27.7	0.32	28.79	90.02
3-E	3	4-22-87	1520	12	12.11	0.60	15.2	13.09	223	1.28	285.4	27.3	0.48	38.72	80.75
PASS 3	SUMMARY	-	-	-	-	-	15.2	10.04	793	1.28	1015.0	28.1	0.36	105.58	295.35
4-I	4	4-22-87	1510	11	6.90	0.30	15.2	7.26	293	1.43	419.0	27.5	0.26	31.52	119.40
4-M	4	4-22-87	1450	9	9.47	0.40	15.2	10.05	210	1.43	300.3	25.9	0.39	31.27	80.60
4-E	4	4-22-87	1430	7	11.81	0.50	15.2	12.65	176	1.43	251.7	25.5	0.50	32.99	66.51
PASS 4	SUMMARY	-	-	-	-	-	15.2	9.52	679	1.43	971.0	26.5	0.36	95.79	266.51
TANK 2	SUMMARY	-	-	-	-	-	15.1	10.61	3329	1.26	4204.4	28.4	0.37	462.37	1238.33

OFF-GAS TEST RESULTS FOR APRIL 22 AND 23, 1987

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-I	1	4-23-87	1140	20	7.28	3.80	14.5	11.01	489	1.45	709.1	26.3	0.42	80.90	193.24
1-M	1	4-23-87	1200	22	7.38	3.75	14.5	11.09	352	1.45	510.4	28.2	0.39	58.66	149.15
1-E	1	4-23-87	1215	24	9.67	0.35	14.7	10.22	223	1.45	323.4	26.3	0.39	34.24	88.13
PASS 1	SUMMARY	-	-	-	-	-	14.6	10.87	1064	1.45	1542.8	26.9	0.40	173.80	430.52
2-I	2	4-23-87	1210	23	8.68	0.60	14.5	9.38	338	1.41	476.6	27.7	0.34	46.32	136.80
2-M	2	4-23-87	1150	21	7.46	0.65	14.6	8.10	245	1.41	345.5	26.6	0.30	29.00	95.22
2-E	2	4-23-87	1130	19	8.35	0.65	14.5	9.07	210	1.41	296.1	26.3	0.34	27.83	80.70
PASS 2	SUMMARY	-	-	-	-	-	14.5	8.90	793	1.41	1118.1	27.0	0.33	103.15	312.72
3-I	3	4-23-87	1105	18	9.69	1.30	14.4	11.17	325	1.52	494.0	27.7	0.40	57.18	141.80
3-M	3	4-23-87	1030	15	8.79	3.70	13.7	13.04	245	1.52	372.4	26.6	0.49	50.32	102.65
3-E	3	4-23-87	1010	13	11.23	5.20	13.7	20.32	223	1.52	339.0	26.3	0.77	71.37	92.38
PASS 3	SUMMARY	-	-	-	-	-	13.9	14.32	793	1.52	1205.4	27.0	0.53	178.88	336.83
4-I	4	4-23-87	1020	14	7.92	4.50	13.7	13.00	293	1.59	465.9	27.5	0.47	62.76	132.76
4-M	4	4-23-87	1040	16	8.00	4.20	13.9	12.65	210	1.59	333.9	25.9	0.49	43.77	89.62
4-E	4	4-23-87	1100	17	9.76	4.00	14.5	15.14	176	1.59	279.8	25.2	0.60	43.90	73.08
PASS 4	SUMMARY	-	-	-	-	-	14.0	13.45	679	1.59	1079.6	26.4	0.51	150.43	295.45
TANK 2	SUMMARY	-	-	-	-	-	14.3	11.83	3329	1.49	4945.9	26.8	0.44	606.26	1375.53

OFF-GAS TEST RESULTS FOR APRIL 22 AND 23, 1987

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-I	1	4-23-87	1300	30	7.55	3.70	14.8	11.31	489	1.45	709.1	29.5	0.38	83.10	216.76
1-M	1	4-23-87	1240	28	8.71	3.00	14.7	12.00	352	1.45	510.4	28.2	0.43	63.47	149.15
1-E	1	4-23-87	1230	26	10.15	0.50	14.7	10.87	223	1.45	323.4	26.3	0.41	36.42	88.13
PASS 1	SUMMARY	-	-	-	-	-	14.7	11.45	1064	1.45	1542.8	28.4	0.40	182.99	454.03
2-I	2	4-23-87	1220	25	10.21	0.60	14.7	11.04	338	1.41	476.6	27.7	0.40	54.52	136.80
2-M	2	4-23-87	1235	27	7.35	0.50	14.5	7.88	245	1.41	345.5	26.6	0.30	28.21	95.22
2-E	2	4-23-87	1250	29	10.67	0.40	14.9	11.33	210	1.41	296.1	26.3	0.43	34.76	80.70
PASS 2	SUMMARY	-	-	-	-	-	14.7	10.14	793	1.41	1118.1	27.0	0.38	117.50	312.72
3-I	3	4-23-87	1320	31	7.52	1.00	15.0	8.43	325	1.46	474.5	27.7	0.30	41.45	136.20
3-M	3	4-23-87	1405	33	9.48	0.50	14.9	10.16	245	1.46	357.7	26.6	0.38	37.66	98.60
3-E	3	4-23-87	1425	35	12.58	0.90	14.9	13.98	223	1.46	325.6	26.3	0.53	47.17	88.73
PASS 3	SUMMARY	-	-	-	-	-	14.9	10.53	793	1.46	1157.8	27.0	0.39	126.28	323.54
4-I	4	4-23-87	1435	36	7.41	0.80	15.0	8.16	293	1.55	454.2	27.5	0.30	38.40	129.42
4-M	4	4-23-87	1415	34	9.02	0.95	14.9	10.07	210	1.55	325.5	25.9	0.39	33.97	87.36
4-E	4	4-23-87	1345	32	9.70	1.70	14.9	11.64	176	1.55	272.8	25.2	0.46	32.91	71.24
PASS 4	SUMMARY	-	-	-	-	-	14.9	9.65	679	1.55	1052.5	26.4	0.37	105.28	288.02
TANK 2	SUMMARY	-	-	-	-	-	14.8	10.54	3329	1.46	4871.2	27.3	0.39	532.04	1378.31

OFF-GAS TEST RESULTS FOR JUNE 18, 1987

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-I	1	6-18-87	1115	5	5.24	2.20	21.5	6.66	489	1.50	733.5	29.5	0.23	50.62	224.23
1-M	1	6-18-87	1050	3	7.67	1.50	22.0	8.90	352	1.50	528.0	28.2	0.32	48.70	154.30
1-E	1	6-18-87	1030	1	9.86	1.20	22.0	11.06	223	1.50	334.5	26.3	0.42	38.34	91.16
PASS 1	SUMMARY	-	-	-	-	-	21.8	8.32	1064	1.50	1596.0	28.4	0.29	137.66	469.69
2-I	2	6-18-87	1040	2	10.35	2.45	22.0	13.48	338	0.60	202.8	29.9	0.45	28.33	62.84
2-M	2	6-18-87	1100	4	9.71	1.65	22.0	11.46	245	0.60	147.0	28.7	0.40	17.46	43.72
2-E	2	6-18-87	1125	6	9.76	1.50	22.0	11.33	210	0.60	126.0	28.3	0.40	14.79	36.95
PASS 2	SUMMARY	-	-	-	-	-	22.0	12.29	793	0.60	475.8	29.1	0.42	60.58	143.51
3-I	3	6-18-87	1200	7	4.38	4.70	22.5	8.14	325	0.60	195.0	29.9	0.27	16.45	60.42
3-M	3	6-18-87	1240	10	7.69	2.70	22.0	10.34	245	0.60	147.0	28.7	0.36	15.75	43.72
3-E	3	6-18-87	1250	11	9.63	2.70	22.0	12.95	223	0.60	133.8	28.3	0.46	17.96	39.24
PASS 3	SUMMARY	-	-	-	-	-	22.2	10.17	793	0.60	475.8	29.1	0.35	50.16	143.38
4-I	4	6-18-87	1300	12	5.83	0.70	21.0	6.29	293	0.40	117.2	29.5	0.21	7.64	35.83
4-M	4	6-18-87	1230	9	8.04	0.25	21.0	8.29	210	0.40	84.0	27.9	0.30	7.22	24.29
4-E	4	6-18-87	1210	8	8.92	0.50	22.0	9.29	176	0.40	70.4	27.1	0.34	6.78	19.77
PASS 4	SUMMARY	-	-	-	-	-	21.3	7.69	679	0.40	271.6	28.4	0.27	21.63	79.88
TANK 2	SUMMARY	-	-	-	-	-	21.8	9.24	3329	0.85	2819.2	28.6	0.32	270.02	836.46

OFF-GAS TEST RESULTS FOR JUNE 18, 1987

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-I	1	6-18-87	1415	19	6.19	1.20	22.0	6.95	489	1.50	733.5	29.5	0.24	52.83	224.23
1-M	1	6-18-87	1445	22	8.22	0.80	21.5	8.90	352	1.50	528.0	28.2	0.32	48.70	154.30
1-E	1	6-18-87	1505	24	11.32	0.60	21.5	12.00	223	1.50	334.5	26.3	0.46	41.60	91.16
PASS 1	SUMMARY	-	-	-	-	-	21.7	8.65	1064	1.50	1596.0	28.4	0.30	143.12	469.69
2-I	2	6-18-87	1455	23	10.46	1.40	21.5	12.09	338	0.60	202.8	29.9	0.40	25.41	62.84
2-M	2	6-18-87	1435	21	8.36	1.60	21.5	9.88	245	0.60	147.0	28.7	0.34	15.05	43.72
2-E	2	6-18-87	1425	20	9.24	1.20	21.5	10.44	210	0.60	126.0	28.3	0.37	13.63	36.95
PASS 2	SUMMARY	-	-	-	-	-	21.5	10.97	793	0.60	475.8	29.1	0.38	54.09	143.51
3-I	3	6-18-87	1350	17	5.88	4.20	22.0	9.87	325	0.60	195.0	29.9	0.33	19.94	60.42
3-M	3	6-18-87	1330	15	7.71	3.00	22.0	10.80	245	0.60	147.0	28.7	0.38	16.45	43.72
3-E	3	6-18-87	1310	13	9.41	2.70	22.0	12.66	223	0.60	133.8	28.3	0.45	17.55	39.24
PASS 3	SUMMARY	-	-	-	-	-	22.0	10.94	793	0.60	475.8	29.1	0.38	53.95	143.38
4-I	4	6-18-87	1320	14	6.03	0.70	21.0	6.51	293	0.40	117.2	29.5	0.22	7.91	35.83
4-M	4	6-18-87	1340	16	7.3	0.40	21.0	7.64	210	0.40	84.0	27.9	0.27	6.65	24.29
4-E	4	6-18-87	1400	18	8.27	0.50	21.0	8.75	176	0.40	70.4	27.1	0.32	6.38	19.77
PASS 4	SUMMARY	-	-	-	-	-	21.0	7.44	679	0.40	271.6	28.4	0.26	20.94	79.88
TANK 2	SUMMARY	-	-	-	-	-	21.5	9.31	3329	0.85	2819.2	28.6	0.33	272.10	836.46

OFF-GAS TEST RESULTS FOR JUNE 18, 1987

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-I	1	6-18-87	1605	30	6.93	1.15	21.5	7.79	489	1.50	733.5	29.5	0.26	59.21	224.23
1-M	1	6-18-87	1545	28	8.13	1.20	21.5	9.19	352	1.50	528.0	28.2	0.33	50.28	154.30
1-E	1	6-18-87	1525	26	10.76	0.60	21.5	11.41	223	1.50	334.5	26.3	0.43	39.55	91.16
PASS 1	SUMMARY	-	-	-	-	-	21.5	9.01	1064	1.50	1596.0	28.4	0.32	149.05	469.69
2-I	2	6-18-87	1515	25	10.27	1.30	21.5	11.74	338	0.60	202.8	29.9	0.39	24.67	62.84
2-M	2	6-18-87	1535	27	10.12	1.50	21.5	11.83	245	0.60	147.0	28.7	0.41	18.02	43.72
2-E	2	6-18-87	1555	29	10.10	1.20	21.5	11.42	210	0.60	126.0	28.3	0.40	14.91	36.95
PASS 2	SUMMARY	-	-	-	-	-	21.5	11.68	793	0.60	475.8	29.1	0.40	57.60	143.51
3-I	3	6-18-87	1620	31	5.57	4.00	22.0	9.05	325	0.60	195.0	29.9	0.30	18.29	60.42
3-M	3	6-18-87	1650	34	7.21	2.40	22.0	9.33	245	0.60	147.0	28.7	0.32	14.21	43.72
3-E	3	6-18-87	1710	36	9.95	2.10	22.0	12.40	223	0.60	133.8	28.3	0.44	17.19	39.24
PASS 3	SUMMARY	-	-	-	-	-	22.0	10.08	793	0.60	475.8	29.1	0.35	49.69	143.38
4-I	4	6-18-87	1700	35	5.76	0.20	21.5	5.86	293	0.40	117.2	29.5	0.20	7.12	35.83
4-M	4	6-18-87	1640	33	8.22	0.15	21.5	8.33	210	0.40	84.0	27.9	0.30	7.25	24.29
4-E	4	6-18-87	1630	32	9.20	0.20	21.5	9.37	176	0.40	70.4	27.1	0.35	6.84	19.77
PASS 4	SUMMARY	-	-	-	-	-	21.5	7.53	679	0.40	271.6	28.4	0.27	21.20	79.88
TANK 2	SUMMARY	-	-	-	-	-	21.6	9.50	3329	0.85	2819.2	28.6	0.33	277.55	836.46

OFF-GAS TEST RESULTS FOR AUGUST 13, 1987

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-I	1	8-13-87	1220	6	8.87	0.21	24.8	8.96	489	2.10	1026.9	27.8	0.32	95.35	295.83
1-M	1	8-13-87	1200	4	9.51	0.30	24.8	9.70	352	2.10	739.2	26.7	0.36	74.30	204.52
1-E	1	8-13-87	1140	2	8.15	0.31	24.9	8.32	223	2.10	468.3	25.3	0.33	40.38	122.78
PASS 1	SUMMARY	-	-	-	-	-	24.8	9.07	1064	2.10	2234.4	26.9	0.34	210.03	623.13
2-I	2	8-13-87	1130	1	11.62	0.38	24.7	11.67	338	2.20	743.6	26.0	0.45	89.93	200.35
2-M	2	8-13-87	1150	3	10.40	0.50	24.7	10.84	245	2.20	539.0	25.2	0.43	60.55	140.75
2-E	2	8-13-87	1210	5	11.92	0.38	24.8	12.26	210	2.20	462.0	25.0	0.49	58.70	119.69
PASS 2	SUMMARY	-	-	-	-	-	24.7	11.57	793	2.20	1744.6	25.5	0.45	209.17	460.79
3-I	3	8-13-87	1235	7	9.17	0.12	24.6	9.18	325	2.20	715.0	26.0	0.35	68.02	192.64
3-M	3	8-13-87	1255	9	11.52	0.61	24.6	12.16	245	2.20	539.0	25.2	0.48	67.92	140.75
3-E	3	8-13-87	1325	12	12.52	0.81	24.7	13.51	223	2.20	490.6	25.0	0.54	68.68	127.10
PASS 3	SUMMARY	-	-	-	-	-	24.6	11.32	793	2.20	1744.6	25.5	0.44	204.62	460.50
4-I	4	8-13-87	1315	11	6.21	0.35	24.6	6.37	293	2.60	761.8	25.0	0.25	50.29	197.36
4-M	4	8-13-87	1305	10	7.69	0.73	24.6	8.23	210	2.60	546.0	24.0	0.34	46.57	135.79
4-E	4	8-13-87	1245	8	10.36	0.86	24.5	11.25	176	2.60	457.6	23.5	0.48	53.35	111.44
PASS 4	SUMMARY	-	-	-	-	-	24.6	8.21	679	2.60	1765.4	24.3	0.34	150.20	444.59
TANK 2	SUMMARY	-	-	-	-	-	24.7	9.97	3329	2.25	7489.0	25.6	0.39	774.01	1989.01

OFF-GAS TEST RESULTS FOR AUGUST 13, 1987

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-I	1	8-13-87	1450	20	9.41	0.36	24.7	9.66	489	2.10	1026.9	27.8	0.35	102.80	295.83
1-M	1	8-13-87	1510	22	9.56	0.21	24.8	9.66	352	2.10	739.2	26.7	0.36	74.00	204.52
1-E	1	8-13-87	1520	23	9.69	0.12	24.9	9.69	223	2.10	468.3	25.3	0.38	47.02	122.78
PASS 1	SUMMARY	-	-	-	-	-	24.8	9.67	1064	2.10	2234.4	26.9	0.36	223.82	623.13
2-I	2	8-13-87	1540	24	9.76	0.14	24.8	9.79	338	2.20	743.6	26.0	0.38	75.44	200.35
2-M	2	8-13-87	1500	21	10.73	0.46	24.8	11.14	245	2.20	539.0	25.2	0.44	62.22	140.75
2-E	2	8-13-87	1440	19	9.77	0.36	24.6	10.04	210	2.20	462.0	25.0	0.40	48.07	119.69
PASS 2	SUMMARY	-	-	-	-	-	24.7	10.27	793	2.20	1744.6	25.5	0.40	185.73	460.79
3-I	3	8-13-87	1425	18	7.85	0.14	24.7	7.88	325	2.20	715.0	26.0	0.30	58.39	192.64
3-M	3	8-13-87		16	not performed		-	-	245	-	-	-	-	-	-
3-E	3	8-13-87	1345	14	12.29	0.72	24.7	13.13	223	2.20	490.6	25.0	0.53	66.75	127.10
PASS 3	SUMMARY	-	-	-	-	-	24.7	10.02	793	2.20	1205.6	25.6	0.39	125.14	319.74
4-I	4	8-13-87	1335	13	5.94	0.41	24.6	6.14	293	2.60	761.8	25.0	0.25	48.47	197.36
4-M	4	8-13-87	1355	15	7.54	0.57	24.6	7.93	210	2.60	546.0	24.0	0.33	44.87	135.79
4-E	4	8-13-87	1415	17	10.76	0.79	24.6	11.59	176	2.60	457.6	23.5	0.49	54.96	111.44
PASS 4	SUMMARY	-	-	-	-	-	24.6	8.11	679	2.60	1765.4	24.3	0.33	148.30	444.59
TANK 2	SUMMARY	-	-	-	-	-	24.7	9.48	3329	2.09	6950.0	25.7	0.37	682.98	1848.25

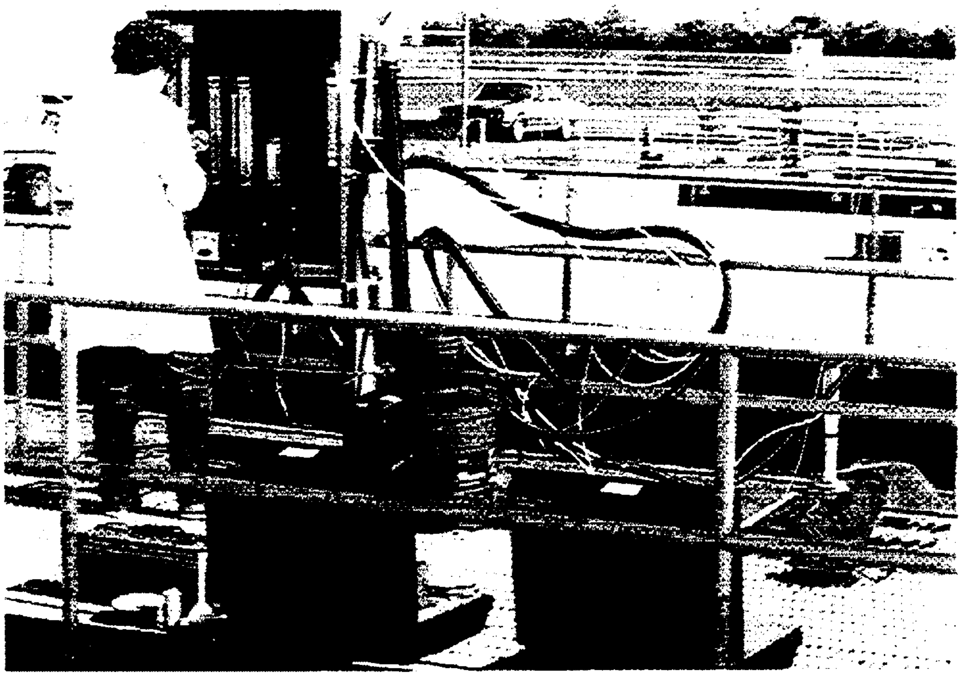
OFF-GAS TEST RESULTS FOR AUGUST 13, 1987

TEST LOCATION	PASS NO.	DATE	TIME	RUN NO.	MEAS. OTE,%	DO, MG/L	ML TEMP, DEG C	ALPHA X SOTE, %	NO. OF DOMES	AIRFLOW SCFM	TOTAL AIRFLOW, SCFM	NEW SOTE, %	APPARENT ALPHA	ALPHA X SOTR, LBS. O2/HR	NEW SOTR, LBS. O2/HR
1-I	1	8-13-87	1630	29	8.83	0.25	24.9	8.96	489	2.10	1026.9	27.8	0.32	95.35	295.83
1-M	1	8-13-87	1610	27	8.56	0.35	24.9	8.78	352	2.10	739.2	26.7	0.33	67.26	204.52
1-E	1	8-13-87	1550	25	9.88	0.21	24.9	9.98	223	2.10	468.3	25.3	0.39	48.43	122.78
PASS 1	SUMMARY	-	-	-	-	-	24.9	9.11	1064	2.10	2234.4	26.9	0.34	211.03	623.13
2-I	2	8-13-87	1600	26	9.28	0.26	24.8	9.43	338	2.20	743.6	26.0	0.36	72.66	200.35
2-M	2	8-13-87	1620	28	11.38	0.17	24.8	11.45	245	2.20	539.0	25.2	0.45	63.95	140.75
2-E	2	8-13-87	1640	30	9.14	0.34	24.9	9.36	210	2.20	462.0	25.0	0.37	44.81	119.69
PASS 2	SUMMARY	-	-	-	-	-	24.8	10.04	793	2.20	1744.6	25.5	0.39	181.43	460.79
3-I	3	8-13-87	1710	32	9.16	0.22	24.8	9.26	325	2.20	715.0	26.0	0.36	68.61	192.64
3-M	3	8-13-87	1730	34	12.73	0.54	24.8	13.33	245	2.20	539.0	25.2	0.53	74.45	140.75
3-E	3	8-13-87	1750	36	13.49	0.61	24.8	14.23	223	2.20	490.6	25.0	0.57	72.34	127.10
PASS 3	SUMMARY	-	-	-	-	-	24.8	11.92	793	2.20	1744.6	25.5	0.47	215.41	460.50
4-I	4	8-13-87	1740	35	4.72	0.19	24.8	4.76	293	2.60	761.8	25.0	0.19	37.58	197.36
4-M	4	8-13-87	1720	33	8.15	0.25	24.8	8.27	210	2.60	546.0	24.0	0.34	46.79	135.79
4-E	4	8-13-87	1700	31	10.63	0.60	24.7	11.22	176	2.60	457.6	23.5	0.48	53.20	111.44
PASS 4	SUMMARY	-	-	-	-	-	24.8	7.52	679	2.60	1765.4	24.3	0.31	137.57	444.59
TANK 2	SUMMARY	-	-	-	-	-	24.8	9.61	3329	2.25	7489.0	25.6	0.37	745.45	1989.01

APPENDIX I-B

PHOTO PLATES OF AERATION DIFFUSERS, CLEANING, AND OFF-GAS EQUIPMENT

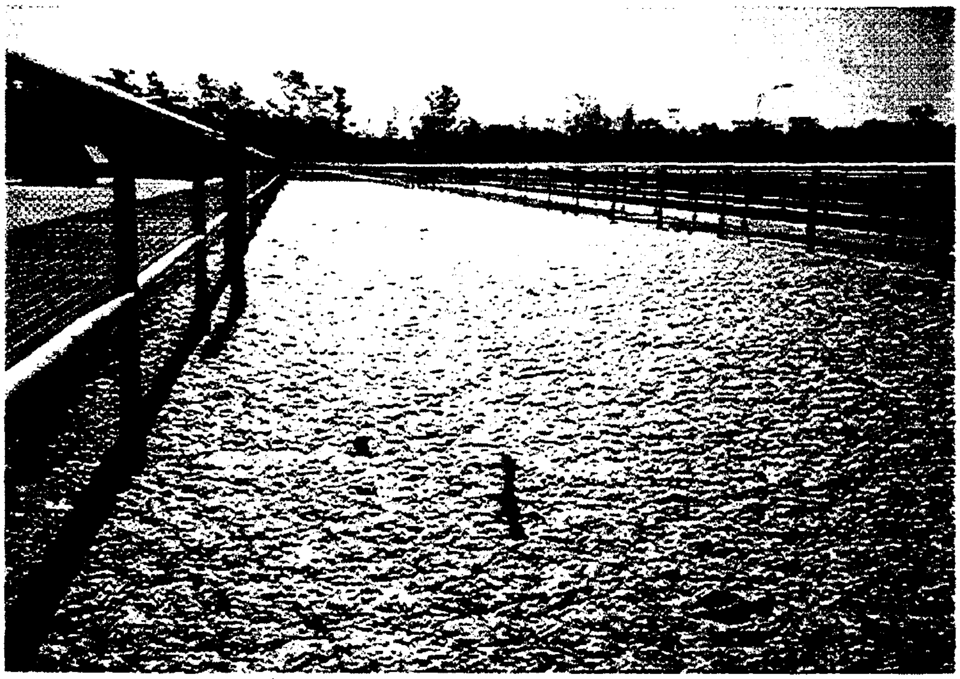
PHOTO PLATE P-1 OFF-GAS EQUIPMENT



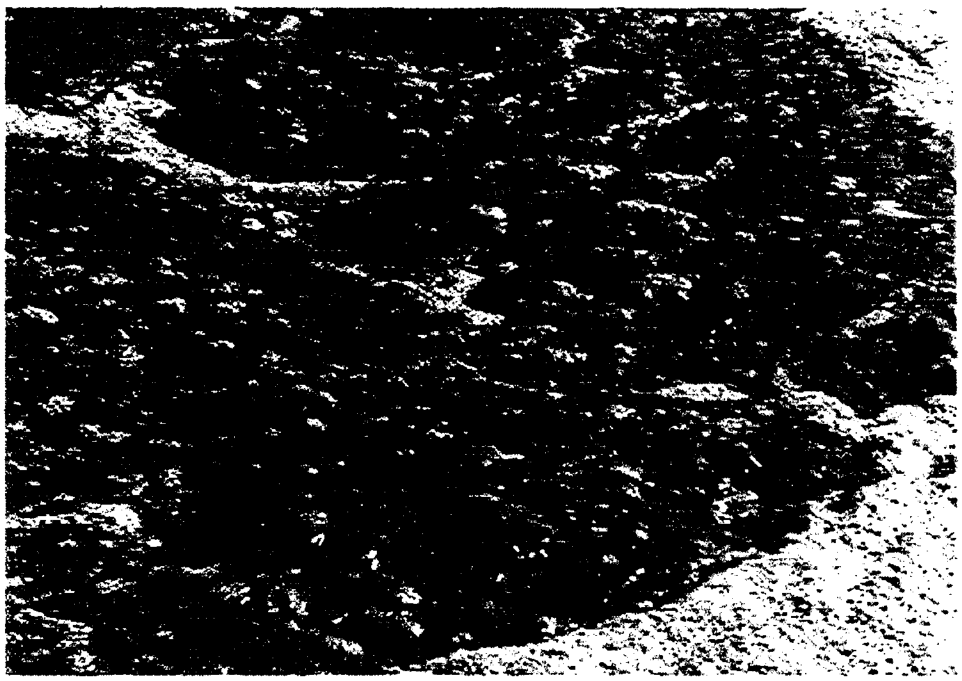
P-1.1 OFF-GAS ANALYZER APPARATUS

P-1.2 FLEXIBLE MEMBRANE OFF-GAS COLLECTION HOOD

PHOTO PLATE P-2 AERATION SYSTEM

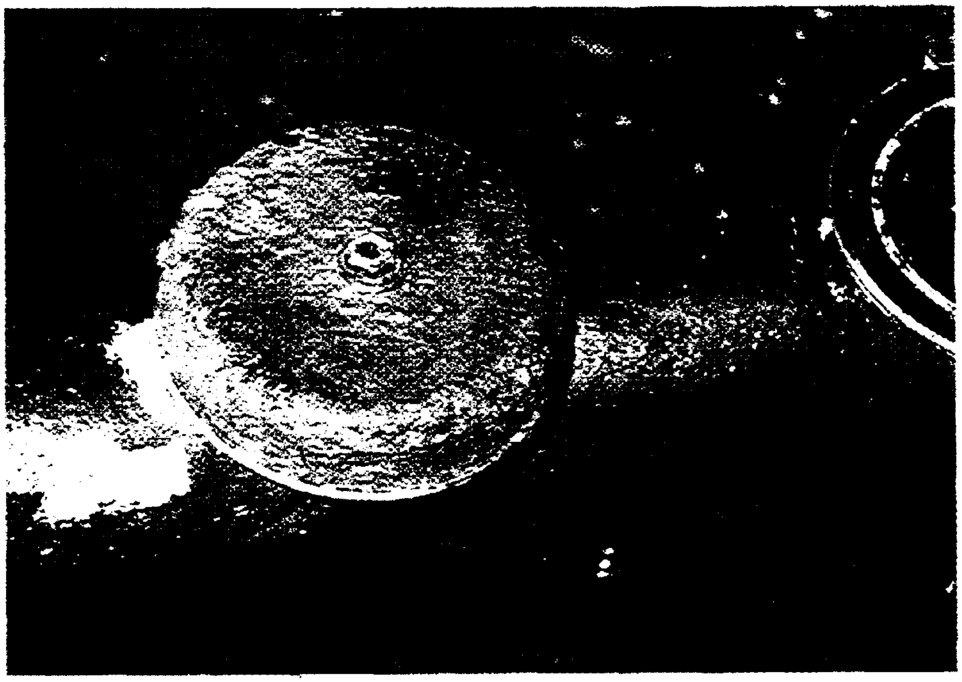


P-2.1 NOCARDIA FOAM PROBLEM AT DISSOLVED OXYGEN CONCENTRATION GREATER THAN 1.0 MG/L

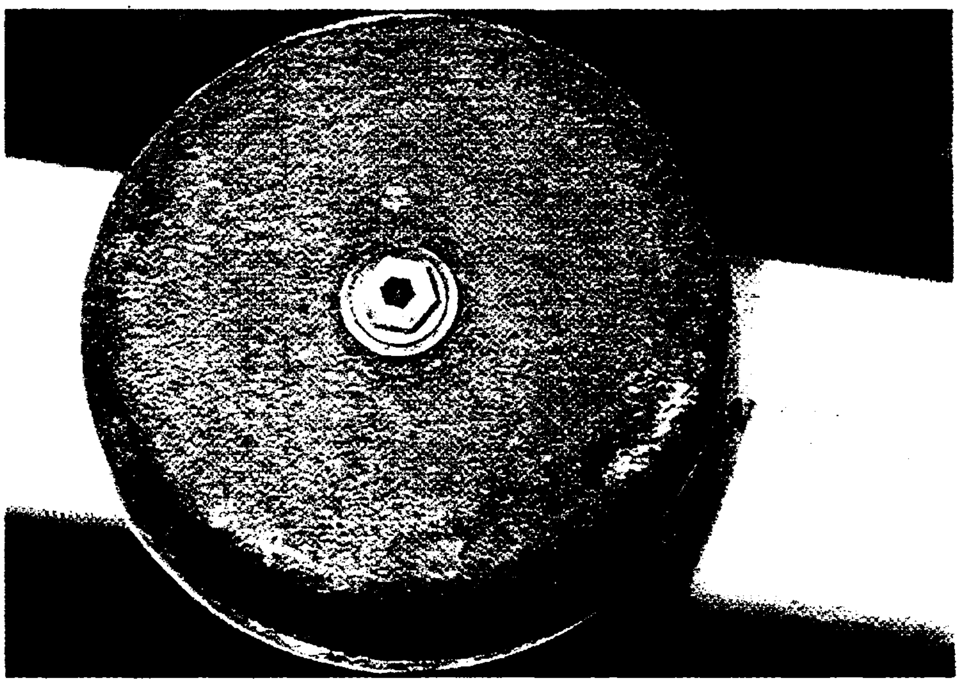


P-2.2 COARSE BUBBLES AT SURFACE (COARSING CONDITION) MOST PREVALENT AT AERATION TANK INFLUENT POINTS

PHOTO PLATE P-3 DIRTY DOMES

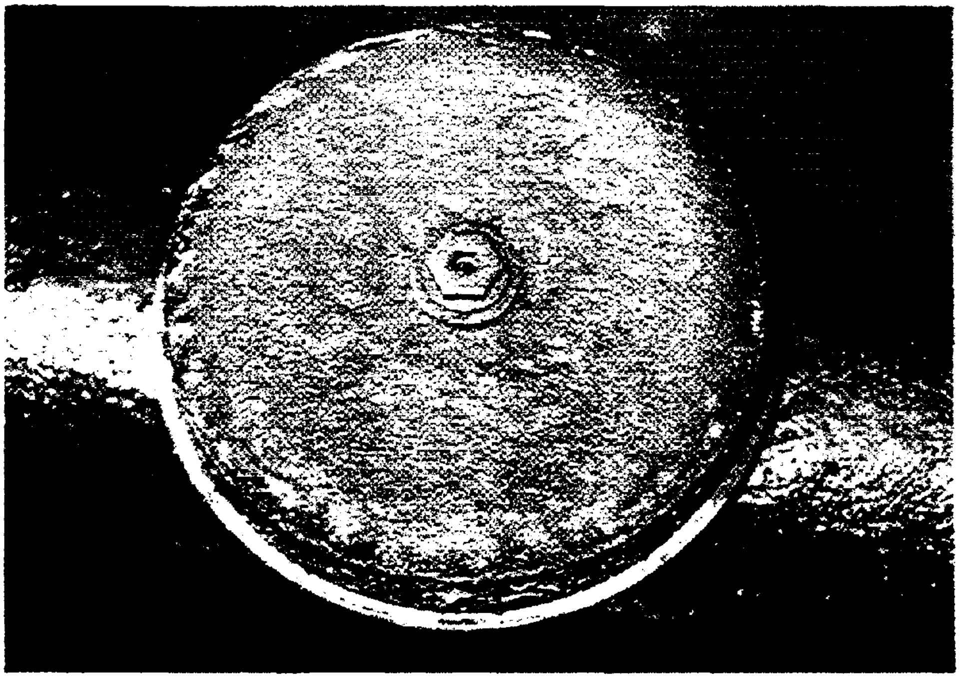


P-3.1 BEFORE CLEANING ON OCTOBER 21, 1985 (AFTER 3 YEARS OF CONTINUOUS OPERATION)

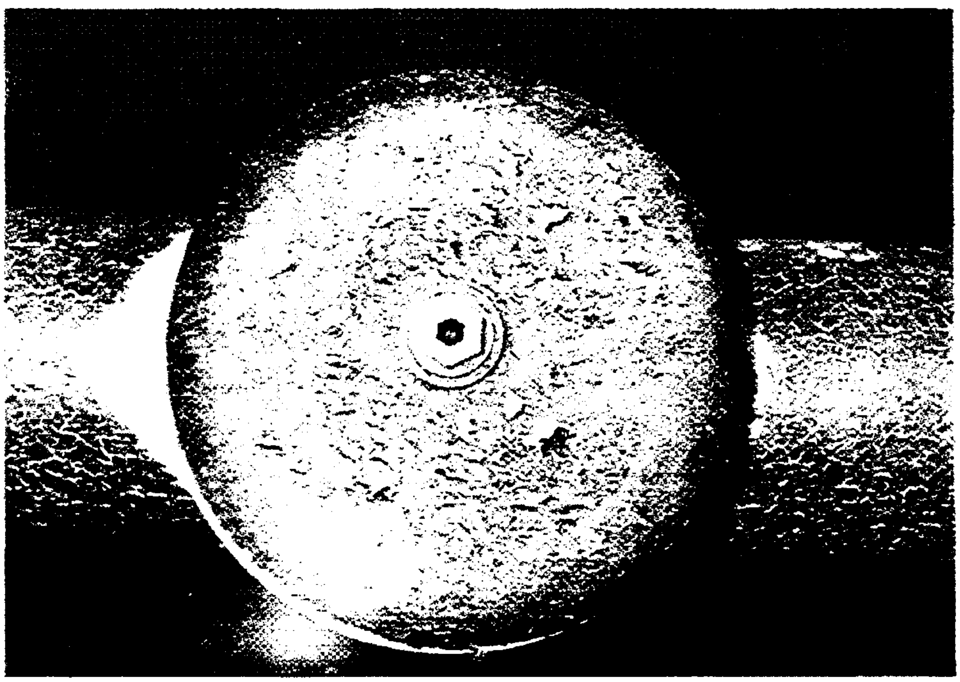


P-3.2 AFTER HIGH PRESSURE HOSING ON OCTOBER 21, 1985 (CERAMIC DOME DID NOT CLEAN OFF)

PHOTO PLATE P-4 DIRTY DOMES

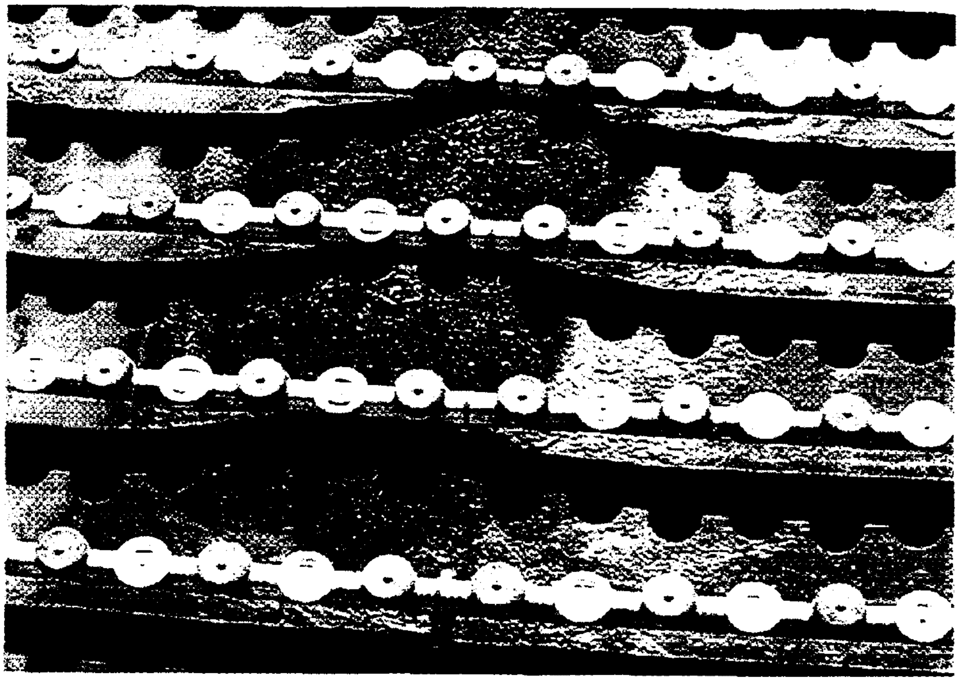


P-4.1 AFTER DEWATERING AERATION TANK AND BEFORE CLEANING (OCTOBER 21, 1985)

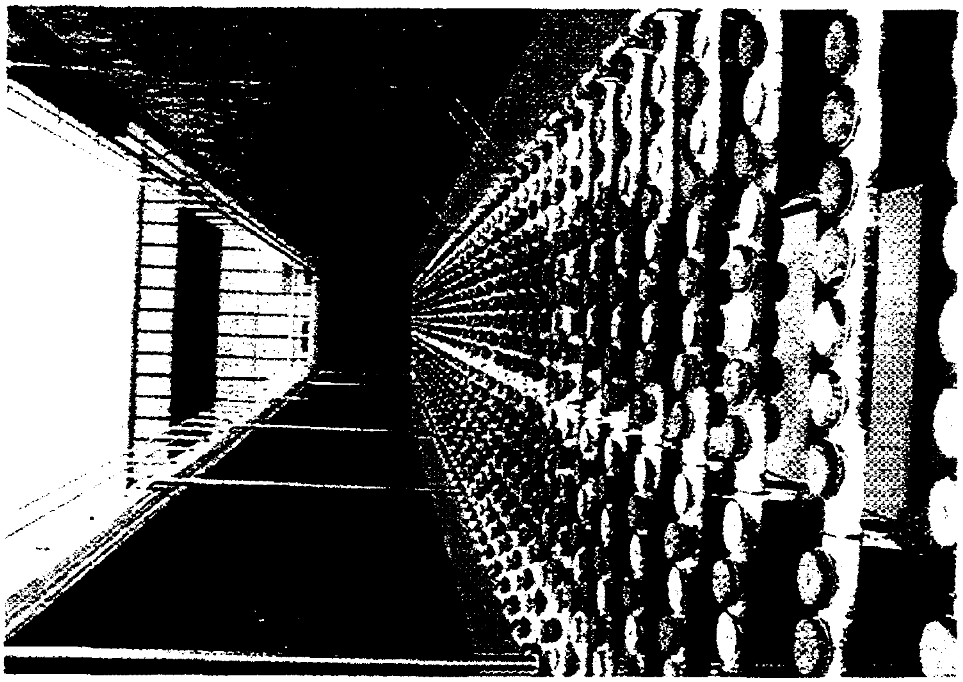


P-4.2 AFTER DEWATERING AERATION TANK AND BEFORE CLEANING (AIR WAS NOT SHUT OFF AFTER DEWATERING--SLUDGE HAS DRIED ON)

PHOTO PLATE P-5 INITIAL CLEANING

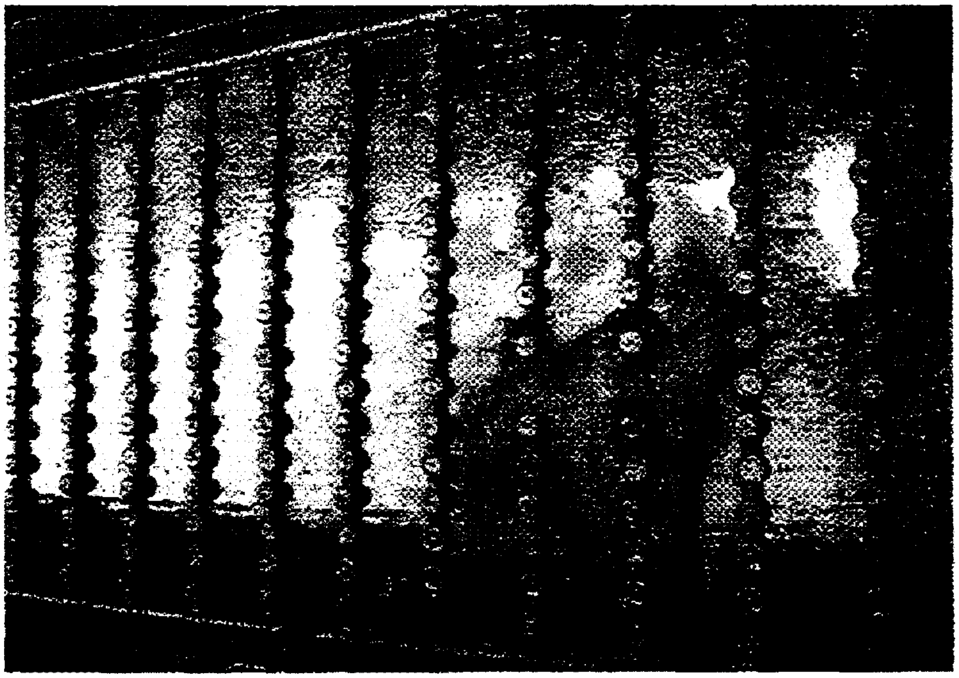


P-5.1 AFTER HIGH PRESSURE HOSING AND ACID CLEANING (OCTOBER 21, 1985)

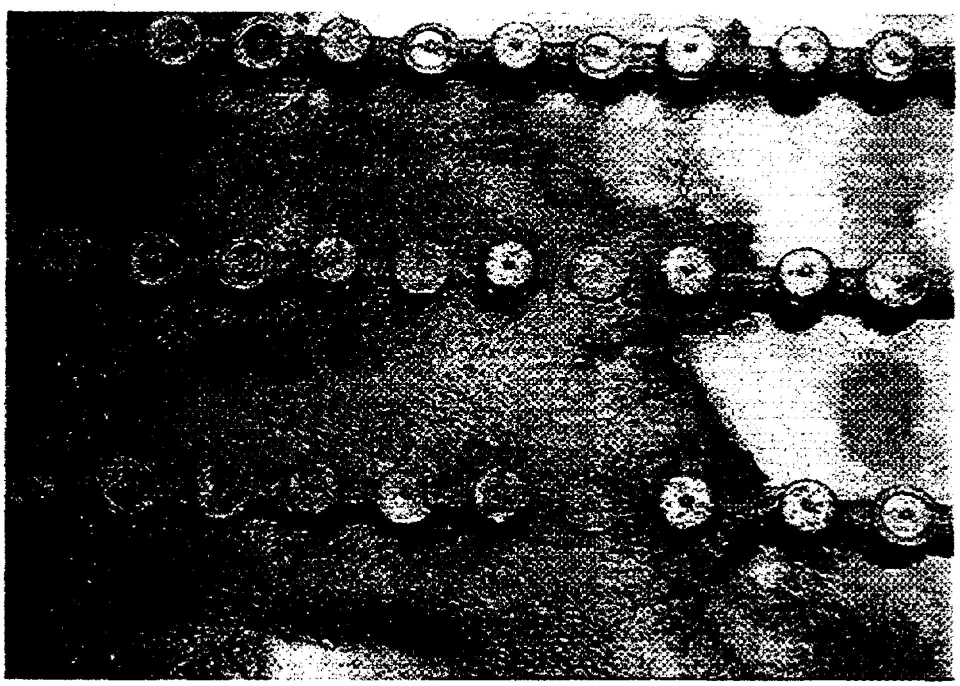


P-5.2 COMPLETELY CLEANED AERATION TANK PASS (OCTOBER 21, 1985)

PHOTO PLATE P-6 DIRTY DOMES

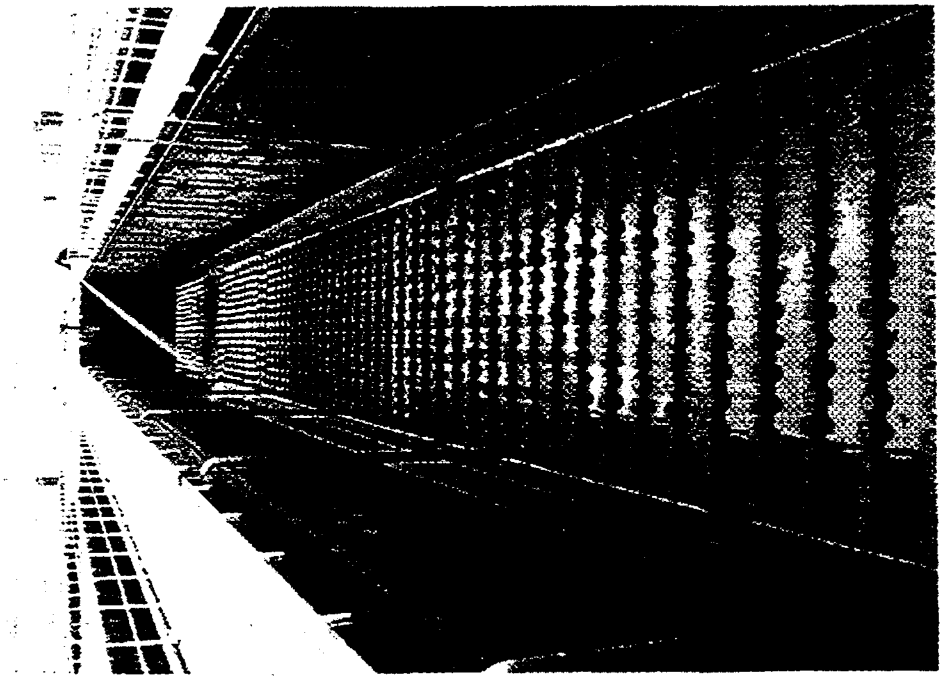


P-6.1 IMMEDIATELY AFTER DEWATERING ON MAY 1, 1987

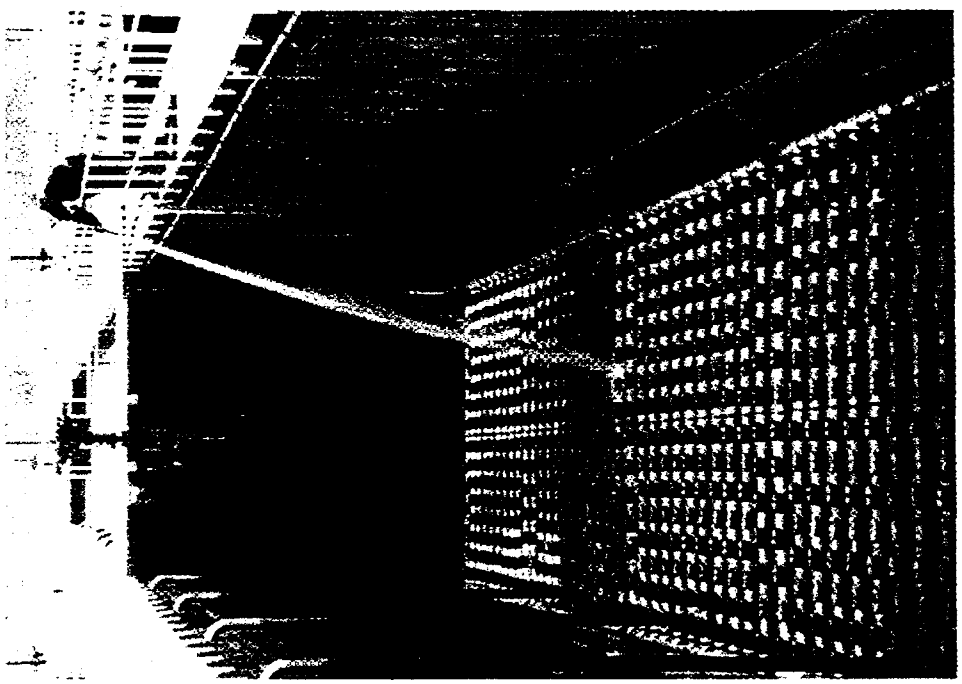


P-6.2 CLOSEUP OF INLET END OF AERATION PASS ON MAY 1, 1987

PHOTO PLATE P-7 HIGH PRESSURE HOSING

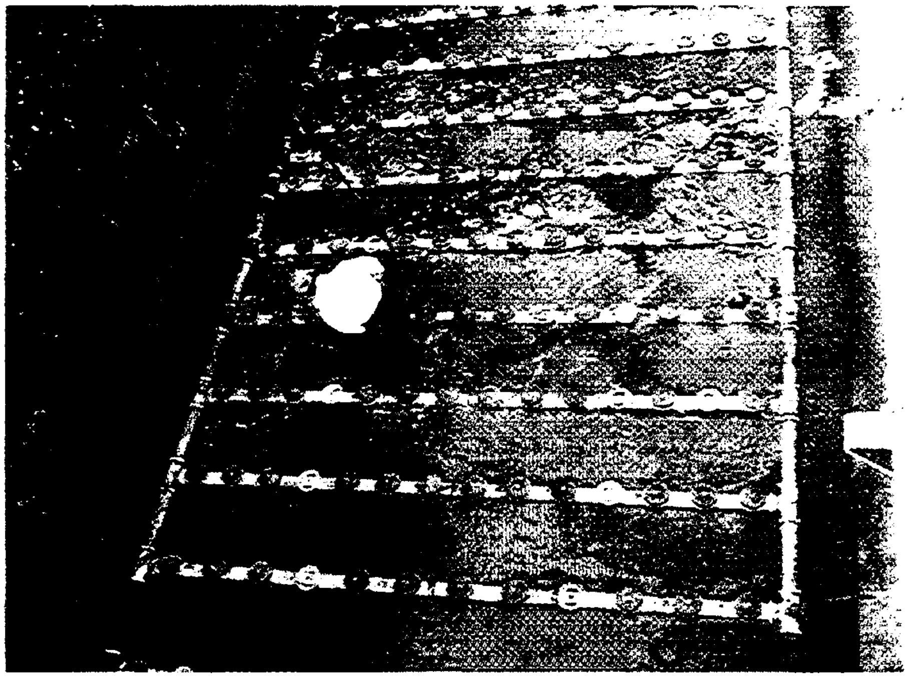


P-7.1 HIGH PRESSURE HOSING OF GRID SYSTEM IMMEDIATELY AFTER DEWATERING (MAY 1, 1987)

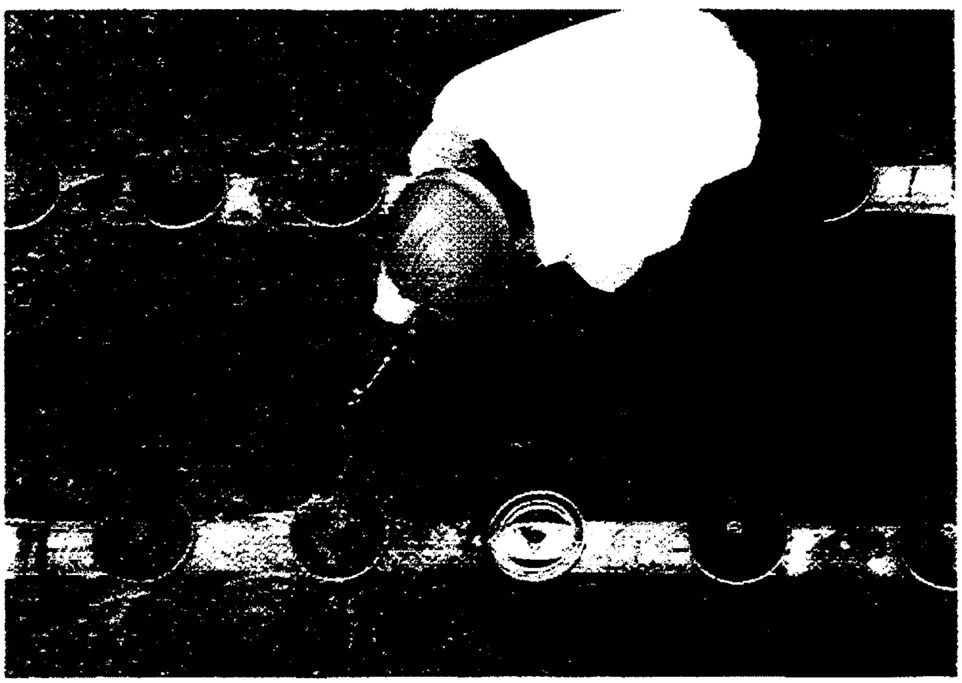


P-7.2 HIGH PRESSURE HOSING OF GRID SYSTEM IMMEDIATELY AFTER DEWATERING (MAY 1, 1987)

PHOTO PLATE P-8 ACID CLEANING



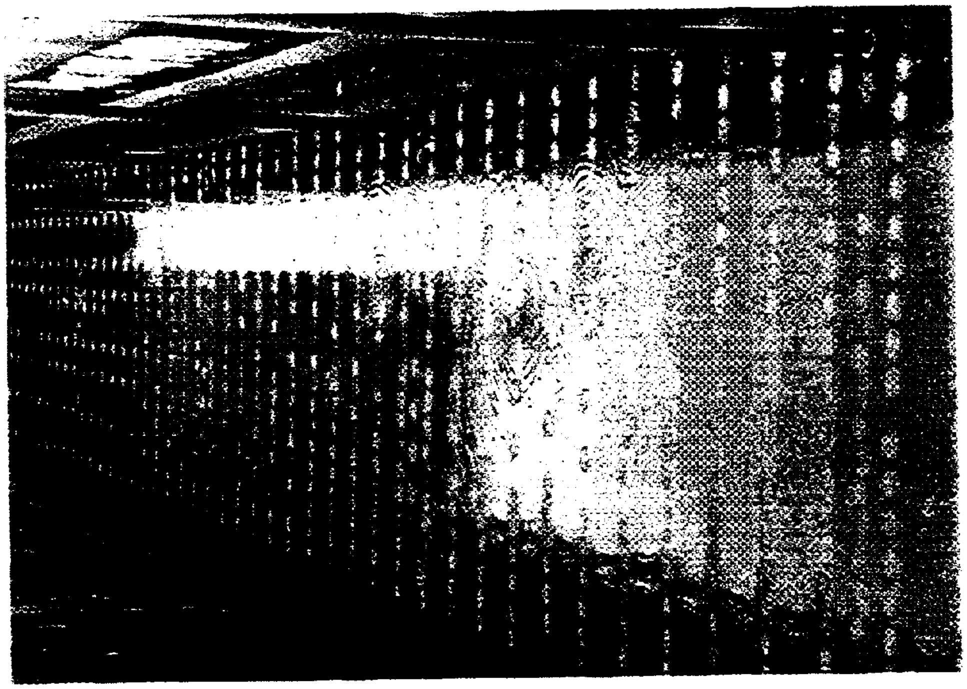
P-8.1 APPLYING ACID TO DOMES (MAY 1, 1987)



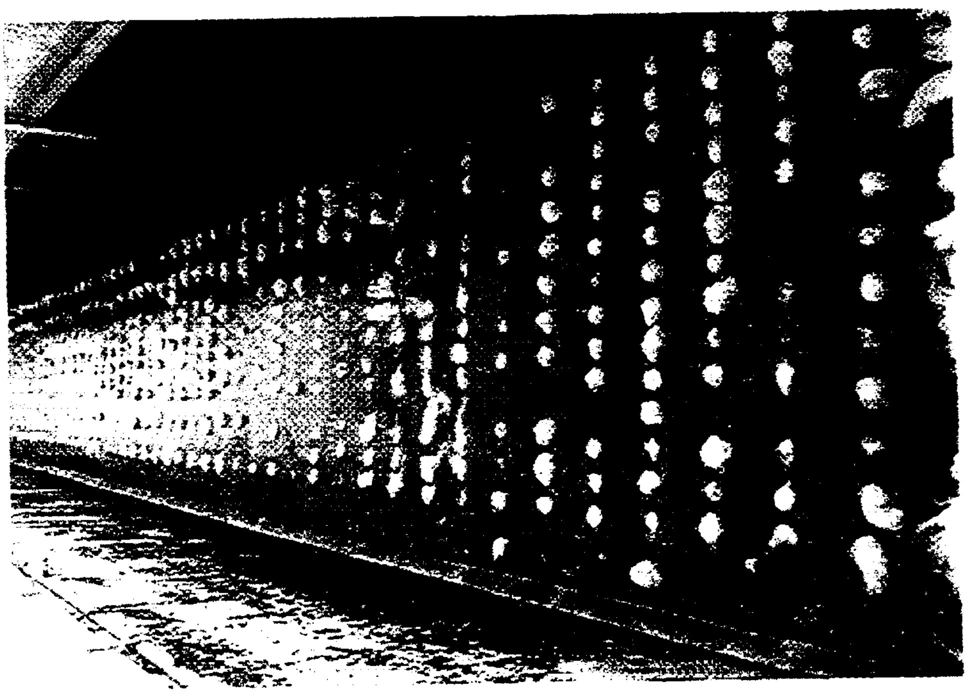
P-8.2 APPLYING ACID TO DOMES (MAY 1, 1987)

ASCE/EPA OXYGEN TRANSFER STUDY
HARTFORD, CT MDC FACILITY
AERATION TANK NO. 2

PHOTO PLATE P-9 ACID CLEANING



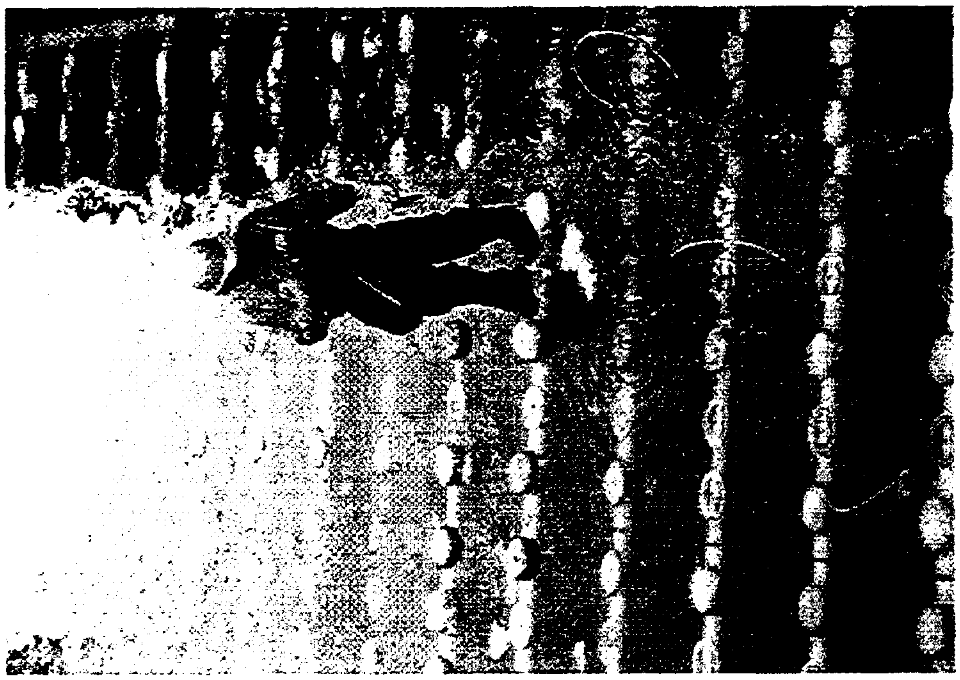
P-9.1 LOW AIRFLOW GASSING TO CHECK FOR LEAKS (MAY 1, 1987)
NOTE SURFACE RIPPLES AT LEAK POINTS



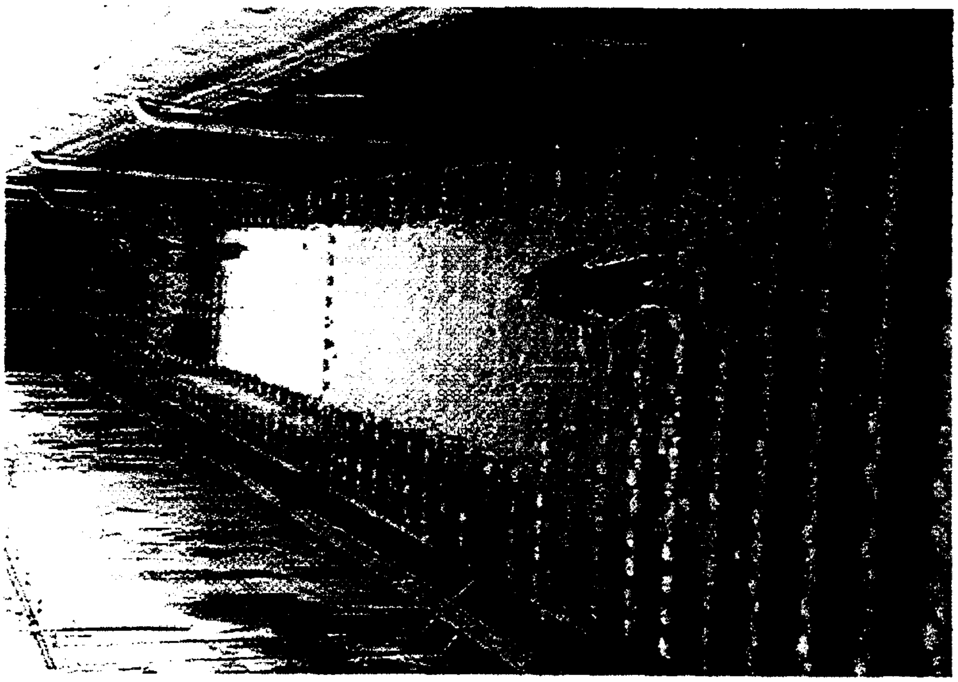
P-9.2 "AIRING" DOMES AFTER ACID APPLICATION (MAY 1, 1987)

ASCE/EPA OXYGEN TRANSFER STUDY
HARTFORD, CT MDC FACILITY
AERATION TANK NO. 2

PHOTO PLATE P-10 LEAK REPAIR



P-10.1 LEAK DETECTION AND REPAIR (NOTE RAISED AIR LATERAL IN FRONT OF WORKER (PIPE SUPPORT STRAP BROKEN)

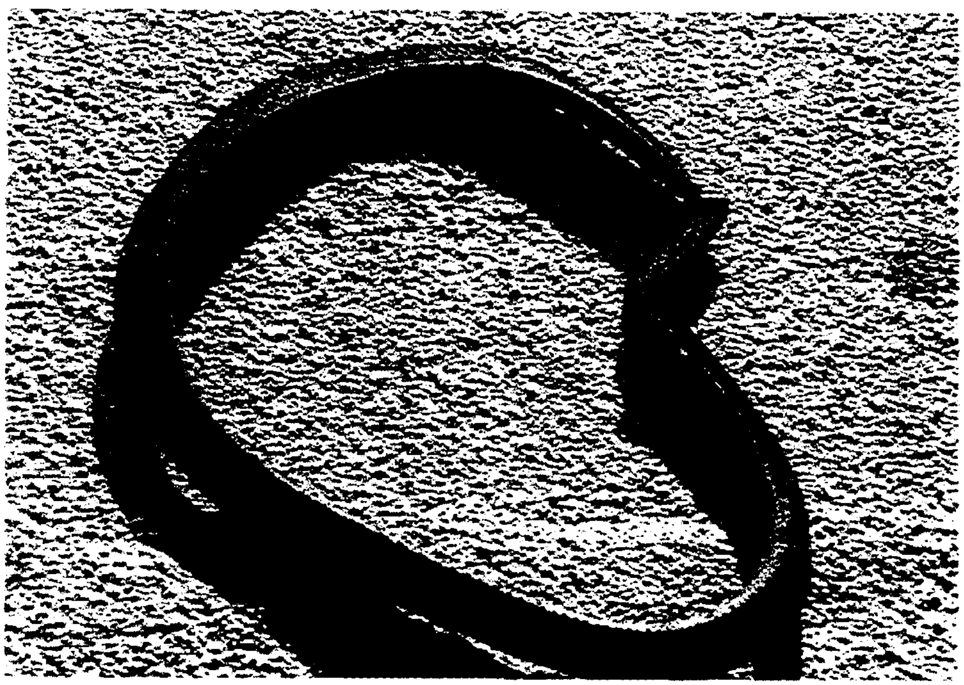


P-10.2 CHECKING FOR LEAKS AT DOME SEAT GASKETS AND AT DOME BOLT LOCATIONS (MAY 1, 1987)

ASCE/EPA OXYGEN TRANSFER STUDY
HARTFORD, CT MDC FACILITY
AERATION TANK NO. 2

PHOTO PLATE P-11 WORN OUT GASKETS

P-11.1 DISCARDED DOME SEAT GASKETS - AGE ABOUT 5.5 YRS. (MAY 1, 1987)



P-11.2 BROKEN DOME SEAT GASKET. NO PLASTICITY OR ELASTICITY LEFT; MANY CRACKS IN GASKET

APPENDIX I-C

OVERALL PLANT DATA SHEET
BASED ON
PREVIOUS YEAR OF RECORD
AND
SUPPLEMENTAL INFORMATION

EXHIBIT A.1: OVERALL PLANT DATA SHEET
BASED ON PREVIOUS YEAR OF RECORD

Plant Name: HARTFORD WATER POLLUTION CONTROL PLANT

Location: HARTFORD, CT

Flow Through Secondary Treatment:

Average: 47.6 MGD
Maximum: 58.1 MGD

1. WASTEWATER CHARACTERISTICS - BASED ON MONTHLY AVERAGES

Temperature, Deg. C:

Average: 19
Minimum: 14
Maximum: 23

	Raw Influent, mg/l			Sec. Eff., mg/l		
Parameter	Avg.	Min.	Max.	Avg.	Min.	Max.
BOD_5 [1]	133	77	172	11	6	16
COD	*	*	*	*	*	*
TSS	152	115	216	18	8	33
TDS	*	*	*	*	*	*
TKN	*	*	*	*	*	*
Total P	*	*	*	*	*	*
pH (units)	7.2	7.1	7.3	7.2	7.1	7.3
Alk	*	*	*	*	*	*
Hardness	*	*	*	*	*	*
Nitrate - N	*	*	*	*	*	*

---

* not available and/or not determined
(1) see monthly average data at end of this Appendix.

2. PROCESS FLOW DIAGRAM INCLUDING TANK SIZES AND RETURN FLOWS FROM SLUDGE PROCESSING

Process Flow Diagram: See Figure No. 1 of report.

Primary Sed. Area:

Each tank, east side 4 @ 5,040 sq. ft.
Each tank, west side 8 @ 6,750 sq. ft.

Final Clar. Area:

Each of 6 @ 12,237 sq. ft.

Aeration Tank Vol.:

Each tank of 4 @ 232,000 cu. ft.

Aeration Tank Water Depth:

Nominal: 15.5 ft.

3. MAJOR INDUSTRIAL WASTES

- no major industrial streams
- 7 to 10 percent of flow is industrial and commercial

4. RETURN FLOWS FROM SLUDGE PROCESSING - AVERAGES

Source	Flow, MGD	BOD,mg/l	TSS,mg/l	TKN,mg/l	pH
Dewatering Filtrate	0.478	*	1,750	*	6.2
D.A.F. Thickener Overflow	1.58 - 3.46	*	500	*	7.0

* not available and/or not determined

5. PRIMARY EFFLUENT CHARACTERISTICS

Average Including Return Flows

Flow:	47.6 MGD
BOD:	95 mg/l
TSS:	98 mg/l
TKN:	*
TDS:	*
Oil and Grease:	*

* not available and/or not determined

6. PROCESS PARAMETERS - BASED ON AVERAGE CONDITIONS

Parameter			+/- percent variability max. no. to min. no.
Primary Overflow Rate, gpd/sf	East West	794 593	East +/- 10.0 West +/- 10.0
Aeration Detention Time, V/Q		4.5	+47, -24
MLSS Conc., mg/l		3,342[1]	+67, -36
Ratio, MLVSS/MLSS		0.759	+/- 5.0
Solids Wasting Rate, lbs., MLSS/day		44,590	+/- 34
Sludge Volume Index		166	+98, -48
Recycle Ratio, R/Q		40	+20, -33
Sludge Age, Days[2]		6.5[3]	-
F/M Ratio, per day[2] (based on MLVSS)		0.26	-

[1] see monthly average data at end of this Appendix.

[2] estimated clarifier holdup included in solids inventory.

[3] MCRT (see equation in Report Table No. 6 for calculation method).

7. AIR DIFFUSION SYSTEM

Tank Designation: Aeration Tank No. 2

Diffusers, Type and Number: Norton

Ceramic 7-in. diameter Dome Diffusers (See Figure Nos. 2,3,4,5 & 6 of Report).

For number and distribution see Figure No. 7 of Report.

Recommended Air Rates for this Diffuser, SCFM:

Grids with > 133 domes
min. 0.5 SCFM max. 2.5 SCFM

Grids with < 133 domes
min. 0.5 SCFM max. 2.5 SCFM
plus min. mixing airflow of 0.12 SCFM per sq. ft. of tank floor area.

Typical Wet Resistance for this Diffuser over the Rec. Air Rate Range:

	at Min. Rate	at Max. Rate
Orifice Resistance, in. H_2O	0.5*	13.5*
Clean Diffusers, in. H_2O	5.0*	20.5*
Dirty Diffuser, in. H_2O	**	**

Year Installed: Fall 1982

Submergence, ft.: 14.5

Water Dept, ft.: 15.5

Cleaning Practice and History: Acid cleaned by the "Modified Milwaukee Method" in October 1985 and May 1987.

Sketch of Diffuser Arrangement in Tank:

See Figure Nos. 4,5,6 and 7 of Report

---

* See Report Figure No. 12

** See Appendix I-D, Dome Diffuser Characterization Tests

8. BLOWERS AND AIR SUPPLY PIPING

Blower No.	Type, Brand, Model	Yr.	HP	RPM	SCFM	Op. Tim, Hr/Year
1	Multistage Centrifugal Brown-Boveri V11 22VdV1	1972	3000	3583	60,000	2920(est.)
2	"	"	"	"	"	"
3	"	"	"	"	"	"

Total Installed Blower HP: 9,000
Total Installed Blower SCFM: 180,000

Description of Air Filtration System:

Disposable, fiberglass "Biocell" filters installed ahead of oil bath coarse filters.

Supplemental Information on Blower Drives:

Drive No.	Drive Type	Brand	Model	Yr.	Design RPM	HP at Design RPM
1	Squirrel Cage Induction	Brown Boveri	MQGyn 222KO	1972	3583	3000
2	"	"	"	"	"	"
3	"	"	"	"	"	"

Typical Blowers Used at Average Operating Conditions:

Blower Numbers: 1
Total Horsepower: 3,000
Measured Pressure at Blower Discharge, psi: 7.2 +/-
Measured Dynamic Wet Pressure at Diffuser, psi: NA
Nominal Airflow per Diffuser, SCFM: 1.0 to 2.0

Typical Blowers Used at Maximum Operating Conditions:

Blower Numbers: 1
Total Horsepower: 3,000
Measured Pressure at Blower Discharge, psi: 7.5 +/-
Nominal Airflow per Diffuser, SCFM: 3.0

Blower Turndown Capability:

Excluding Channel Airflow	9,000 SCFM
with Channel Airflow	19,000 SCFM

Strategy Used to Manage Blowers:

Manual control, maintaining a positive DO in the fourth pass for at least 12 hours per day. Adjustments in airflow made by guide Vane control. Airflow and KW monthly average data is contained at the end of this Appendix.

Arrangement of Blowers and Transmission Piping:

Air piping is under the floor slab in blower building, and the main air piping runs in a utility tunnel between the aeration tanks.

Data Base for Aeration Tank Dissolved Oxygen:

Frequency of Measurement: All passes of two tanks twice daily. The fourth pass of some tanks - continuous chart recorders in use.

Number of Locations:	8
Length of Record:	2+ years

Typical Aeration Tank DO Values:

Quarter	Average	Minimum
1st	0.8	0
2nd	0.7	0
3rd	1.1	0
4th	1.6	0

(no maximum values available)

9. RESULTS OF PREVIOUS OXYGEN TRANSFER TESTS AT THIS PLANT:

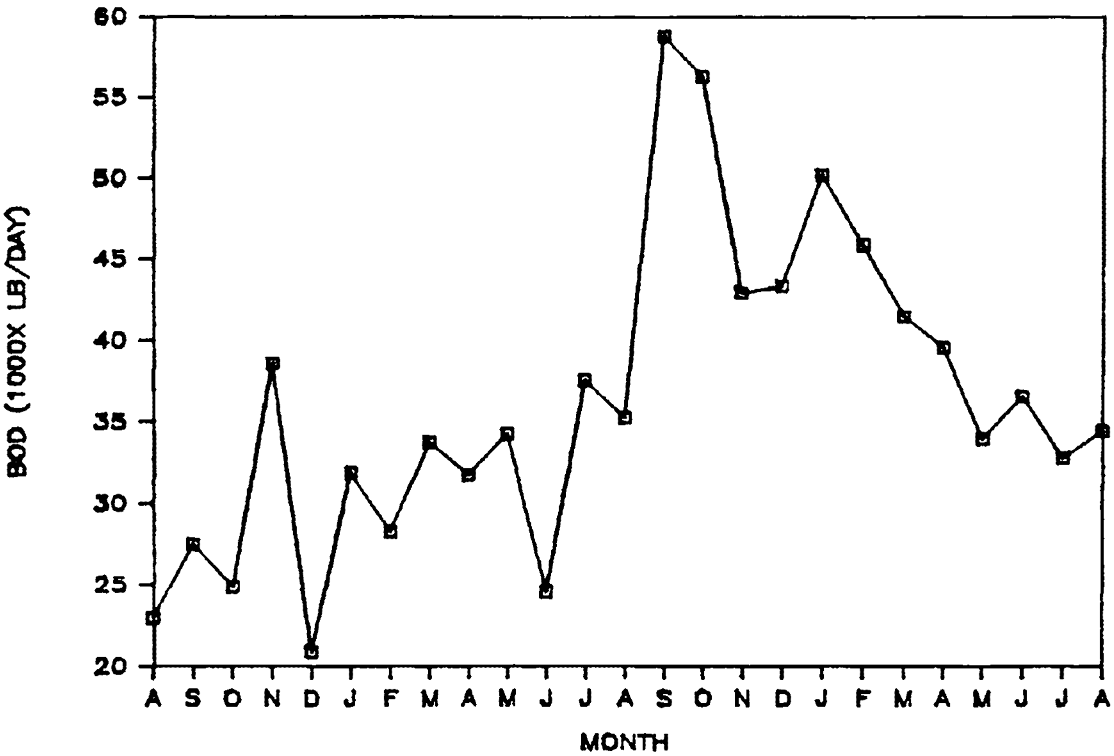
- none conducted -

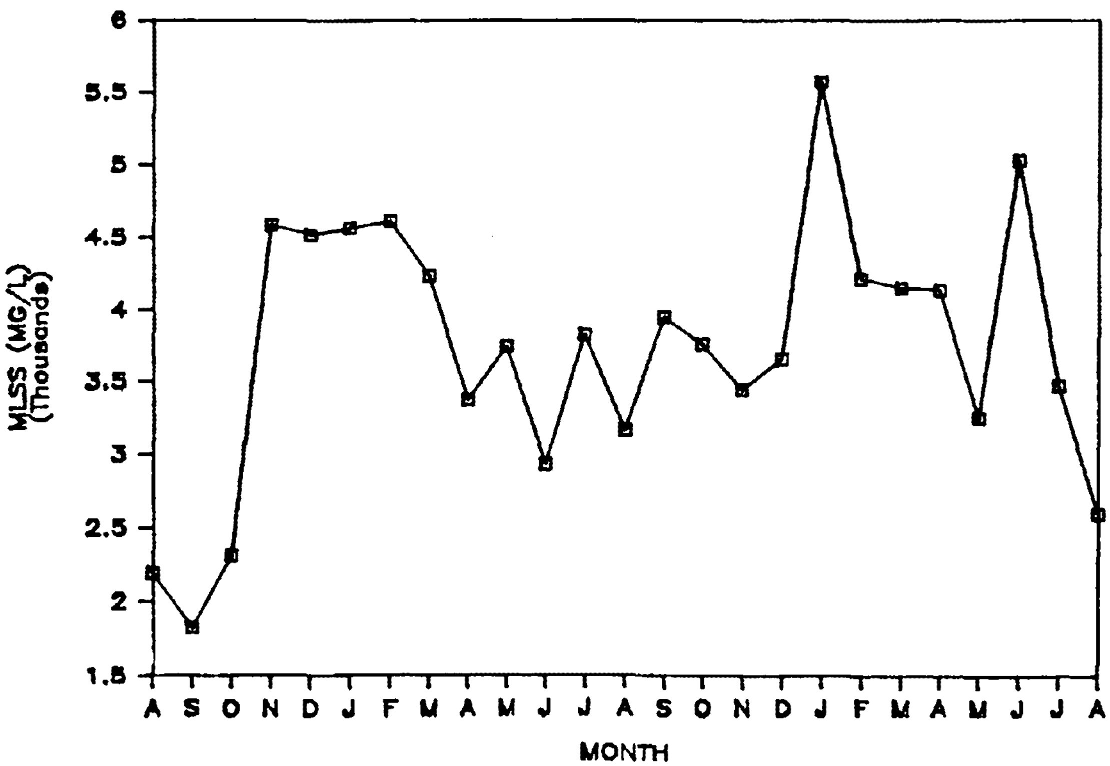
L. A. County work by Yunt and dome diffuser development testing conducted by AERTEC used for establishment of SOTE values.

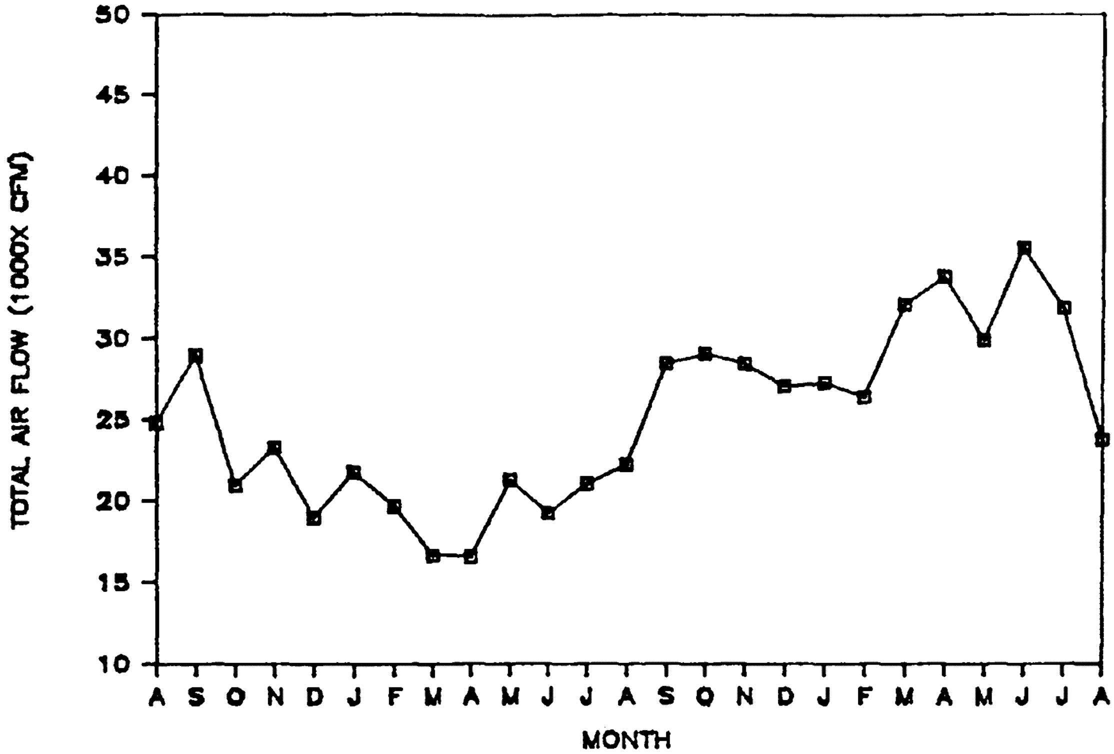
10. ADDITIONAL COMMENTS

- See attached supplemental information -

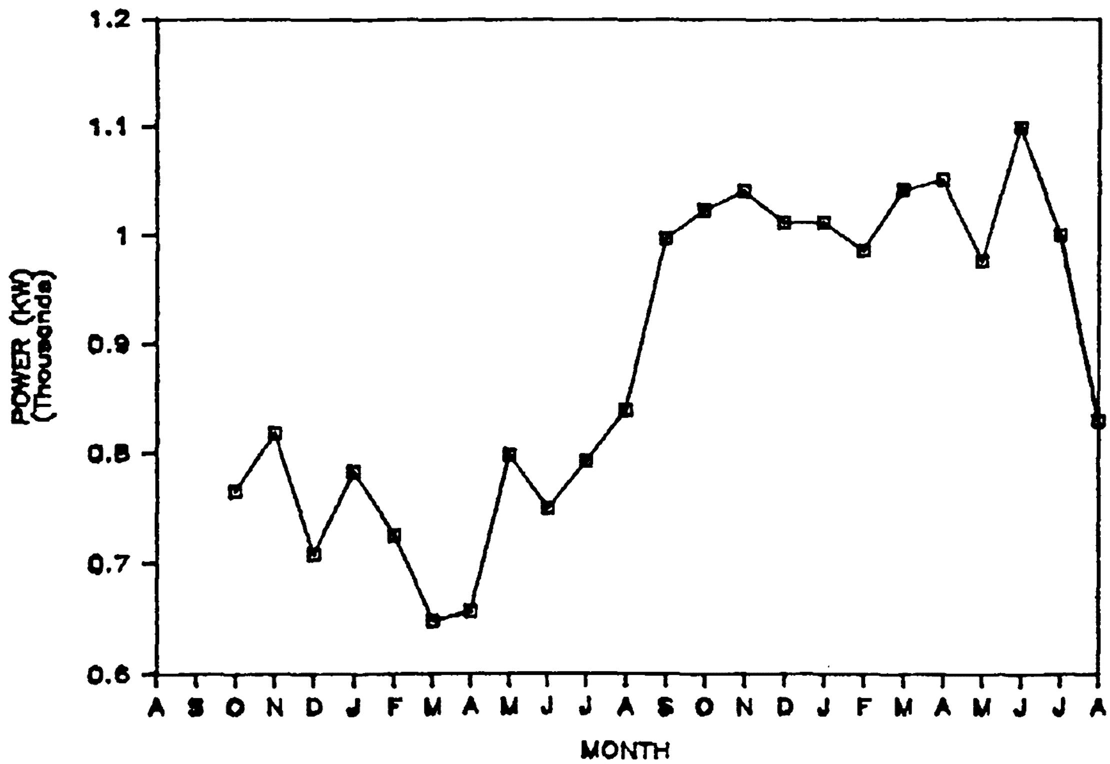
Month	Total Air Flow (1000xCFM)	Power (KW)	BOD (1000xlb/day)	MLSS (mg/l)
A '83	24.8		23.0	2197
S	29.0		27.5	1825
O	21.0	766	24.9	2314
N	23.3	819	38.6	4589
D	19.0	709	20.9	4521
J '84	21.8	784	31.9	4566
F	19.7	726	28.3	4614
M	16.7	649	33.8	4232
A	16.6	657	31.8	3377
M	21.3	800	34.3	3746
J	19.3	751	24.6	2939
J	21.1	794	37.6	3831
A	22.3	841	35.3	3172
S	28.5	998	58.8	3950
O	29.1	1024	56.3	3763
N	28.5	1042	43.0	3450
D	27.1	1013	43.4	3665
J '85	27.3	1013	50.2	5575
F	26.4	987	45.9	4215
M	32.1	1043	41.5	4152
A	33.8	1052	39.6	4137
M	29.9	977	34.0	3259
J	35.6	1100	36.6	5033
J	31.9	1001	32.8	3480
A	23.8	831	34.5	2606


BOD (1000X LB/DAY)
60
55
50
45
40
35
30
25
20
A S O N D J F M A M J J A S O N D J F M A M J J A
MONTH

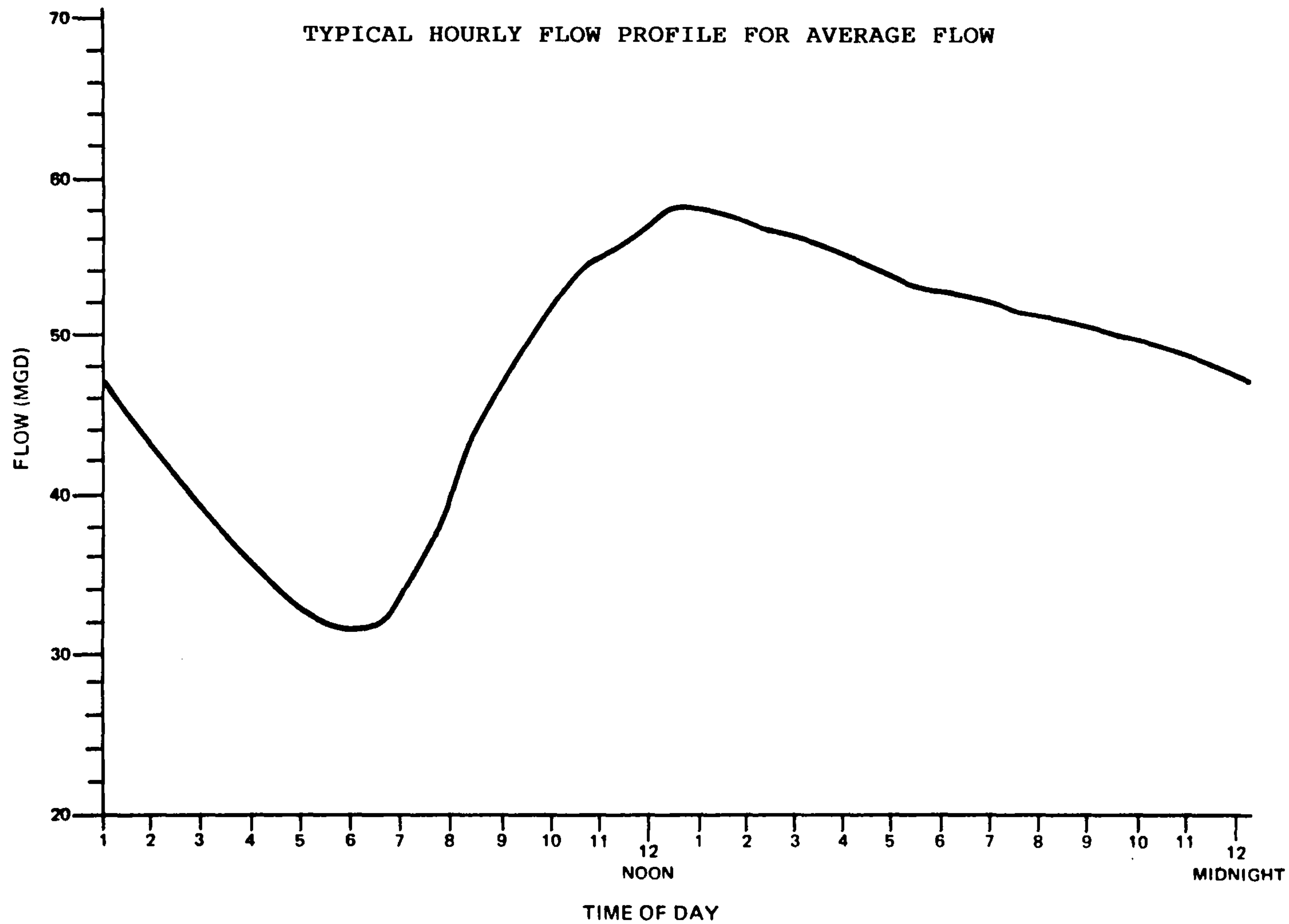

MLSS (MG/L)
(Thousands)
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
A S O N D J F M A M J J A S O N D J F M A M J J A
MONTH



50
45
40
35
30
25
20
15
10
TOTAL AIR FLOW (1000X CFM)
A S O N D J F M A M J J A S O N D J F M A M J J A
MONTH



1.2
1.1
1
0.9
0.8
0.7
0.6
POWER (KW)
(Thousands)
A S O N D J F M A M J J A S O N D J F M A M J J A
MONTH


TYPICAL HOURLY FLOW PROFILE FOR AVERAGE FLOW
FLOW (MGD)
70
60
50
40
30
20
1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
NOON
MIDNIGHT
TIME OF DAY

APPENDIX I-D

DOME DIFFUSER CHARACTERIZATION TESTS

BEFORE AND AFTER CLEANING

(APRIL AND MAY 1987)

UNIVERSITY OF WISCONSIN–MADISON

DEPARTMENT OF CIVIL AND
ENVIRONMENTAL ENGINEERING

Engineering Building
1415 Johnson Drive
Madison, Wisconsin 53706
Telephone: 608/262-

July 8, 1987

Gary Gilbert
Aeration Technologies Inc.
P.O. Box 488
N. Andover, MA 01845

Dear Gary:

Enclosed are the test results that we performed on the Norton dome diffusers at Hartford, Connecticut, before and after cleaning.

I think the data pretty much speaks for itself. The "dirty" diffusers were very fouled producing high BRV values (range - 19 to 75 in. wg). You may note that at several points on the diffuser, it was totally clogged (BRV value in the raw tables of 7.5 in. Hg means no flow - in excess of 200 in. wg). Distribution of foulant was uneven, thereby resulting in most of the flow (a) through the lightly fouled portions of the stone, (b) through the gasket, and (c) around the bolt hole. This is clearly demonstrated by the high flux rates at the "inner" and "outer" circle. DWP values were low because much of the air leaked around the gaskets! Net result of this would be coarse bubbles, low SOTE.

Cleaning greatly improved uniformity of fouled areas, and flux was therefore more uniform as well. Bubble patterns were not bad. BRV values in two cases were above 14 in. wg, which is a little high for cleaned diffusers (clean stones are about 6-7 in. wg).

Foulant on the stones was high (~30 mg/cm^2) but not unusual for long periods between cleaning. The percent volatiles were typical of so many of the plants we have studied (usually under 10%).

I would expect that cleaning should improve SOTE at Hartford if gaskets are good and diffusers are properly tightened down and level. Please let me know if there is further information you need.

Sincerely,

Bill

William C. Boyle
Professor

WCB/jle

SUMMARY OF DIFFUSER CHARACTERIZATION DATA

Diffusers Received From: Hartford, CT
Date Received: 5/09/87 Tank 2, Pass 2, Inf.

Date Tested	Diffuser Type	Diffuser Condition and Identification	Avg. BRV	S / x
5/09/87	Norton	# 9,11	75.313	0.743
5/09/87	Norton	# 6,?	19.048	0.527
5/09/87	Norton	# 3,3	57.799	0.902

		DWP (in wg.) .5 cfm	.75 cfm	1.0 cfm	2.0 cfm	Ratio DWP@.75 BRV
5/09/87	# 9,11	10.0	11.6	12.3	24.2	0.154
5/09/87	# 6,?	7.8	8.7	9.3	13.5	0.457
5/09/87	# 3,3	7.2	7.6	8.2	11.2	0.131

	Air Flow Profile Flux Rate Inner (cfm/sqft)	Flux Rate Middle (cfm/sqft)	Flux Rate Outer (cfm/sqft
# 9,11	1.94	0.26	6.10
# 6,?	1.95	0.81	5.61
# 3,3	0.28	0.02	6.97

FOULANT SUMMARY SHEET
FOR
FINE BUBBLE DIFFUSERS

Diffusers Recieved From: Hartford, CT
Tank 2, Pass 2, Inf.

Date Received: 5/09/87

Date Tested	Diffuser Type	Total Solids (g/sq in)	Volatile solids (g/sq in)	Percent Volatiles	Fixed Solids (g/sq in)
5/09/87	Norton * # 9,11	0.196	0.013	6.5%	0.184
5/09/87	Norton * # 6,7 : F22	0.194	0.019	9.8%	0.175
5/09/87	Norton * # 6,7 : E26	0.229	0.017	7.5%	0.212
5/09/87	Norton * # 3,3	0.044	0.006	12.6%	0.038

Acid Insoluble

Diffuser Type	Total Solids (g/sq in)	Volatile solids (g/sq in)	Percent Volatiles	Fixed Solids (g/sq in)
* Norton # 9,11	0.160	0.00637	4.0%	0.153
Norton # 6,7 :F22	0.150	0.00252	1.7%	0.148
Norton # 6,7 :E26	0.191	0.00686	3.6%	0.184
Norton # 3,3	0.020	0.00137	6.7%	0.019

* Indicates diffuser was analyzed for acid solubles

Diffuser ID: Hartford, CT

9,11

Description:

FOULANT: There is a blackish material present underneath a dark brown material across the stone. The black foulant is hard, dry, and crusty. The brown is slimy and wet. The black is present mainly around the edges. The brown is spread fairly evenly across the stone.

FLOW: The flow is EXTREMELY uneven and mainly comes from the edges in large bubbles. There are some leaks present at the points of contact.

MISC.: The DWP varied during testing and would mot stabilize.
A BRV value of 7.50* indicates that the point is completely clogged. The points vary a lot, but are a good representation of the stones characteristics.

*inches Hg

Diffuser ID: Hartford, CT

6,7

Description:

FOULANT: There is a blackish material present underneath a dark brown material across the stone. The black foulant is hard, dry, and crusty. The brown is slimy and wet. The black is present mainly around the edges. The brown is spread fairly evenly across the stone.

FLOW: The flow is EXTREMELY uneven and mainly comes from the edges in large bubbles. There are some leaks present at the points of contact.

MISC.: The DWP varied during testing, but did finally stabilize.
Many points were taken during BRV testing to come up with the averages shown.

Diffuser ID: Hartford, CT

3,3

Description:

FOULANT: There is a blackish material present underneath a dark brown material across the stone. The black foulant is hard, dry, and crusty. The brown is slimy and wet. The black is present mainly around the edges. The brown is spread unevenly across the stone.

FLOW: The flow is EXTREMELY uneven and mainly comes from the edges in large bubbles. There are some leaks present at the points of contact.

MISC.: The DWP varied during testing, but did finally stabilize.
A BRV value of 7.50* indicates that the point is completely clogged. The values vary a lot, but are a good representation of the stones characteristics. Alternate points were tested on all stones, the best values were recorded.

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*inches Hg

NORTON/GRAY DOME DIFFUSER CHARACTERIZATION SHEET

DIFFUSER IDENTIFICATION-- Hartford, CT / Tank #2 Pass #2, Inf. #9,11 / Removed 5/05/87

DATE-- 5/09/87

LOCATION #	BRV (in HG)	H2O Height (in H2O)	BRV TOTAL (in H2O)
1	0.50	1.50	12.07
2	1.50	1.50	39.21
3	3.80	1.60	101.53
4	0.90	1.50	22.93
5	2.00	1.70	52.58
6	4.95	1.60	132.74
7	3.60	1.50	96.20
8	2.40	1.50	63.64
1S	4.10	1.75	109.52
4S	2.20	1.55	58.16
5S	7.50	1.60	201.95
8S	0.55	1.70	13.23

$\bar{x}$ = 65.113 TOP
s/x = 0.644

$\bar{x}$ = 75.313 OVERALL
s/x = 0.743

$\bar{x}$ = 95.715 SIDES
s/x = 0.846

DWP vs FLOW

ROTO RDG	FLOW (cfm)	DWP (in wg)	DWP(actual) (in wg)
91	2.08	30.3	25.3
21	0.50	29.2	24.2
33	0.75	17.3	12.3
43	1.00	16.6	11.6
87	2.00	15.0	10.0

Height of water above diffuser = 5.0 in.

FLOW PROFILE (3 bucket catch)

	VOLUME (cc)	TIME (sec)	TOTAL FLOW (cc/sec)	ANNULAR FLOW per sq ft (cfm/sq ft)	TOTAL ANN FLOW (cfm)
OUTER	10320	28.80	358.3	6.10	0.643
MIDDLE	600	10.90	55.0	0.26	0.028
INNER	400	9.60	41.7	1.94	0.088

Total Flow (cfm) = 0.759

NOTES--

NORTON/GRAY DOME DIFFUSER CHARACTERIZATION SHEET

DIFFUSER IDENTIFICATION-- Hartford, CT / Tank #2 Pass #2, Inf. #6,? / Removed 5/05/87

DATE-- 5/09/87

LOCATION #	BRV (in HG)		H2O Height (in H2O)	BRV TOTAL (in H2O)
1	0.50		1.50	12.07
2	0.50		1.55	12.02
3	0.60		1.50	14.78
4	0.90		1.55	22.88
5	0.60		1.50	14.78
6	0.60		1.50	14.78
7	0.50		1.55	12.02
8	1.80		1.55	47.30
1S	0.50		1.55	12.02
4S	0.80		1.55	20.16
5S	0.80		1.50	20.21
8S	1.00		1.60	25.54
	$\bar{x}$ =	18.830	TOP	
	s/x =	0.639		
	$\bar{x}$ =	19.048	OVERALL	
	s/x =	0.527		
	$\bar{x}$ =	19.484	SIDES	
	s/x =	0.286		

DWP vs FLOW

ROTO RDG	FLOW (cfm)	DWP (in wg)	DWP(actual) (in wg)
91	2.08	18.8	13.8
21	0.50	18.5	13.5
33	0.75	14.3	9.3
43	1.00	13.7	8.7
87	2.00	12.8	7.8

Height of water above diffuser = 5.0 in.

FLOW PROFILE (3 bucket catch)

	VOLUME (cc)	TIME (sec)	TOTAL FLOW (cc/sec)	ANNULAR FLOW per sq ft (cfm/sq ft)	TOTAL ANN FLOW (cfm)
OUTER	10320	28.50	362.1	5.61	0.591
MIDDLE	600	7.20	83.3	0.81	0.088
INNER	400	9.55	41.9	1.95	0.089
				Total Flow (cfm) =	0.767

NOTES-- ______________________________

NORTON/GRAY DOME DIFFUSER CHARACTERIZATION SHEET

DIFFUSER IDENTIFICATION-- Hartford, CT / Tank #2 Pass #2, Inf. #3,3 / Removed 5/05/87

DATE-- 5/09/87

LOCATION #	BRV (in HG)	H2O Height (in H2O)	BRV TOTAL (in H2O)
1	2.10	1.50	55.49
2	1.90	1.50	50.07
3	1.80	1.60	47.25
4	1.10	1.60	28.25
5	3.30	1.55	88.01
6	7.50	1.50	202.05
7	3.10	1.70	82.43
8	2.40	1.75	63.39
1S	0.45	1.80	10.41
4S	0.58	1.75	13.99
5S	0.55	1.70	13.23
8S	1.50	1.70	39.01

$\bar{x}$ = 77.119 TOP
s/x = 0.700

$\bar{x}$ = 57.799 OVERALL
s/x = 0.902

$\bar{x}$ = 19.160 SIDES
s/x = 0.695

DWP vs FLOW

ROTO RDG	FLOW (cfm)	DWP (in wg)	DWP(actual) (in wg)
91	2.08	16.3	11.3
21	0.50	16.2	11.2
33	0.75	13.2	8.2
43	1.00	12.6	7.6
87	2.00	12.2	7.2

Height of water above diffuser = 5.0 in.

FLOW PROFILE (3 bucket catch)

	VOLUME (cc)	TIME (sec)	TOTAL FLOW (cc/sec)	ANNULAR FLOW per sq ft (cfm/sq ft)	TOTAL ANN FLOW (cfm)
OUTER	10320	29.20	353.4	6.97	0.734
MIDDLE	100	14.50	6.9	0.02	0.002
INNER	100	16.54	6.0	0.28	0.013

Total Flow (cfm) = 0.749

NOTES-- ____

FOULANT ANALYSIS FOR FINE BUBBLE DIFFUSERS

DIFFUSER TYPE: Norton
DIFFUSER IDENTIFICATION: Hartford, CT
Diffuser Tank 2 Pass 2 #9,11
Removed 5/05/87
Date Tested: 5/09/87

Area Scraped: 38.5 sq in

Note - All weights are in grams

Dry weight of dish =	44.8957	Dish # - G22
Dish + Foulant(moist) =	57.3425	
Wet Foulant Weight =	12.4468	
Dry Weight(Dish + Foulant) =	52.4544	
Dry Foulant Weight =	7.5587	
Weight After 550 degC =	51.9665	
Non-Volatile Foulant Weight =	7.0708	
Percent Moisture =	39.3%	
Percent Volatiles =	6.5%	
Non-Volatile Weight / Unit Area =	0.184 grams/sq in	
Volatile Weight / Unit Area =	0.013 grams/sq in	

FOULANT ANALYSIS FOR FINE BUBBLE DIFFUSERS

DIFFUSER TYPE: Norton
DIFFUSER IDENTIFICATION: Hartford, CT
Diffuser Tank 2 Pass 2 #6,7
Removed 5/05/87
Date Tested: 5/09/87

Area Scraped: 19.2 sq in (1/2 of the total stone area)

Note - All weights are in grams

Dry weight of dish =	43.5532	Dish # - F22
Dish + Foulant(moist) =	50.9934	
Wet Foulant Weight =	7.4402	
Dry Weight(Dish + Foulant) =	47.2787	
Dry Foulant Weight =	3.7255	
Weight After 550 degC =	46.9154	
Non-Volatile Foulant Weight =	3.3622	
Percent Moisture =	49.9%	
Percent Volatiles =	9.8%	
Non-Volatile Weight / Unit Area =	0.175 grams/sq in	
Volatile Weight / Unit Area =	0.019 grams/sq in	

FOULANT ANALYSIS FOR FINE BUBBLE DIFFUSERS

DIFFUSER TYPE: Norton
DIFFUSER IDENTIFICATION: Hartford, CT
Diffuser Tank 2 Pass 2 #6,?
Removed 5/05/87
Date Tested: 5/09/87

Area Scraped: 19.2 sq in (1/2 of the total stone area)

Note - All weights are in grams

Dry weight of dish =	42.6883	Dish # - E26
Dish + Foulant(moist) =	50.7024	
Wet Foulant Weight =	8.0141	
Dry Weight(Dish + Foulant) =	47.0970	
Dry Foulant Weight =	4.4087	
Weight After 550 degC =	46.7643	
Non-Volatile Foulant Weight =	4.0760	
Percent Moisture =	45.0%	
Percent Volatiles =	7.5%	
Non-Volatile Weight / Unit Area =	0.212 grams/sq in	
Volatile Weight / Unit Area =	0.017 grams/sq in	

FOULANT ANALYSIS FOR FINE BUBBLE DIFFUSERS

DIFFUSER TYPE: Norton
DIFFUSER IDENTIFICATION: Hartford, CT
Diffuser Tank 2 Pass 2 #3,3
Removed 5/05/87
Date Tested: 5/09/87

Area Scraped: 38.5 sq in

Note - All weights are in grams

Dry weight of dish =	42.0200	Dish # - D12
Dish + Foulant(moist) =	45.3332	
Wet Foulant Weight =	3.3132	
Dry Weight(Dish + Foulant) =	43.7080	
Dry Foulant Weight =	1.6880	
Weight After 550 degC =	43.4953	
Non-Volatile Foulant Weight =	1.4753	
Percent Moisture =	49.1%	
Percent Volatiles =	12.6%	
Non-Volatile Weight / Unit Area =	0.038 grams/sq in	
Volatile Weight / Unit Area =	0.006 grams/sq in	

FOULANT ANALYSIS FOR FINE BUBBLE DIFFUSERS

DIFFUSER TYPE: Norton
DIFFUSER IDENTIFICATION: Hartford, CT
Acid applied.
Diffuser Tk.2, Ps.2, #9,11 This sheet lists values for the final analysis, after acid was applied.
Removed 5/05/87
Date Tested: 5/09/87

Area Scraped: 38.5 sq in

Note - All weights are in grams

Dry weight of dish =	44.8957	Dish # - G22
Dry Weight(Dish + Foulant) =	51.0446	
Dry Foulant Weight =	6.1489	
Weight After 550 degC = (Dish + Foulant)	50.7996	
Non-Volatile Foulant Weight =	5.9039	
Percent Volatiles = (after acid addition)	4.0%	
Non-Volatile Weight / Unit Area =	0.153 grams/sq in	
Volatile Weight / Unit Area =	0.00637 grams/sq in	

Acid Soluble Analysis

Dry foulant weight before acid addition =	7.5587
Dry foulant weight after acid addition =	6.1489
Acid Soluble Weight =	1.4098
Acid Soluble Percentage =	18.65%

FOULANT ANALYSIS FOR FINE BUBBLE DIFFUSERS

DIFFUSER TYPE: Norton
DIFFUSER IDENTIFICATION: Hartford, CT
Acid applied.
Diffuser Tk.2, Ps.2, #6,7 This sheet lists values for the final analysis, after acid was applied.
Removed 5/05/87
Date Tested: 5/09/87

Area Scraped: 19.2 sq in (1/2 of the total stone area)

Note - All weights are in grams

Dry weight of dish =	43.5532	Dish # - F22
Dry Weight(Dish + Foulant) =	46.4422	
Dry Foulant Weight =	2.8890	
Weight After 550 degC = (Dish + Foulant)	46.3937	
Non-Volatile Foulant Weight =	2.8405	
Percent Volatiles = (after acid addition)	1.7%	
Non-Volatile Weight / Unit Area =	0.148 grams/sq in	
Volatile Weight / Unit Area =	0.00252 grams/sq in	

Acid Soluble Analysis

Dry foulant weight before acid addition =	3.7255
Dry foulant weight after acid addition =	2.889
Acid Soluble Weight =	0.8365
Acid Soluble Percentage =	22.45%

FOULANT ANALYSIS FOR FINE BUBBLE DIFFUSERS

DIFFUSER TYPE: Norton
DIFFUSER IDENTIFICATION: Hartford, CT
Acid applied.
Diffuser Tk.2, Ps.2, #6,7 This sheet lists values for the final analysis, after acid was applied.
Removed 5/05/87
Date Tested: 5/09/87

Area Scraped: 19.2 sq in (1/2 of the total stone area)

Note - All weights are in grams

Dry weight of dish =	42.6883	Dish # - E26
Dry Weight(Dish + Foulant) =	46.3559	
Dry Foulant Weight =	3.6676	
Weight After 550 degC = (Dish + Foulant)	46.2239	
Non-Volatile Foulant Weight =	3.5356	
Percent Volatiles = (after acid addition)	3.6%	
Non-Volatile Weight / Unit Area =	0.184 grams/sq in	
Volatile Weight / Unit Area =	0.00686 grams/sq in	

Acid Soluble Analysis

Dry foulant weight before acid addition =	4.4087
Dry foulant weight after acid addition =	3.6676
Acid Soluble Weight =	0.7411
Acid Soluble Percentage =	16.81%

FOULANT ANALYSIS FOR FINE BUBBLE DIFFUSERS

DIFFUSER TYPE: Norton
DIFFUSER IDENTIFICATION: Hartford, CT
Acid applied.
Diffuser Tk.2, Ps.2, #3,3 This sheet lists values for the final analysis, after acid was applied.
Removed 5/05/87
Date Tested: 5/09/87

Area Scraped: 38.5 sq in

Note - All weights are in grams

Dry weight of dish =	42.0200	Dish # - D12
Dry Weight(Dish + Foulant) =	42.8057	
Dry Foulant Weight =	0.7857	
Weight After 550 degC = (Dish + Foulant)	42.7530	
Non-Volatile Foulant Weight =	0.7330	
Percent Volatiles = (after acid addition)	6.7%	
Non-Volatile Weight / Unit Area =	0.019 grams/sq in	
Volatile Weight / Unit Area =	0.00137 grams/sq in	

Acid Soluble Analysis

Dry foulant weight before acid addition =	1.688
Dry foulant weight after acid addition =	0.7857
Acid Soluble Weight =	0.9023
Acid Soluble Percentage =	53.45%

SUMMARY OF DIFFUSER CHARACTERIZATION DATA

Diffusers Received From: Hartford, MDC
Date Received: 5/26/87

Date Tested	Diffuser Type	Diffuser Condition and Identification	Avg. BRV	S / x
5/26/87	Norton	Cleaned #1	15.2	0.64
5/26/87	Norton	Cleaned #2	14.3	0.78
5/26/87	Norton	Cleaned #3	11.1	0.24
5/26/87	Norton	Clean #4	6.1	0.06

	DWP (in wg.) .5 cfm	.75 cfm	1.0 cfm	2.0 cfm	Ratio DWP@.75 BRV
Cleaned #1	7.8	8.3	8.8	10.6	0.546
Cleaned #2	6.5	6.7	6.9	7.7	0.467
Cleaned #3	7.1	7.5	7.8	9.4	0.676
Cleaned #4	5.6	5.8	5.8	6.4	0.959

	Air Flow Profile		
	Flux Rate Inner (cfm/sqft)	Flux Rate Middle (cfm/sqft)	Flux Rate Outer (cfm/sqft
Cleaned #1	4.89	3.41	1.50
Cleaned #2	4.32	2.24	3.05
Cleaned #3	2.27	1.81	4.35
Cleaned #4	3.65	1.83	3.61

No foulant, so none analyzed.

DIFFUSER DESCRIPTIONS

The diffusers were originally tested on 5/26/87. Retesting was done on 7/01/87, after the diffusers were soaked 20 hrs. The tops of the stones were relatively clean with only a few fouled areas. The foulant was hard, dry, and crusty.

When doing BRV's, the readings were constant until a fouled area was reached. These areas produced a variety of values. A good average was put on the data sheets.

The flow on the cleaned stones was uneven. Most of the flow came from the center or from the seal in the edges.

Diffuser ID: Hartford, MDC

Diffuser #1

Description:

FOULANT: The stone was fairly clean. There was some foulant present in sparsely located, dark brown patches. Some lighter brown material was also present near the edges.

FLOW: The flow was good, but uneven.

MISC.: The stone was retested on 7/01/87. It was soaked for 20 hrs. before retesting.

Diffuser ID: Hartford, MDC

Diffuser #2

Description:

FOULANT: The top of the stone was fairly clean. A brown material covered the edges of the stone. Some was dark and crusty and some was a lighter brown.

FLOW: The flow was good. On the edges and on the top the flow was rather sparse.

MISC.: The stone was soaked 20 hrs. before retesting.

Diffuser ID: Hartford, MDC

Diffuser #3

Description:

FOULANT: The top of the stone was fairly clean. A black sooty material covered the edges of the stone.

FLOW: The flow was good near the center of the stone. On the edges and outer edge of the top the flow was rather sparse.

MISC.: The stone was soaked 20 hrs. before retesting.

Diffuser ID: Hartford, MDC

Diffuser #4

Description:

FOULANT: The stone was new.

FLOW: Flow was good and uniform.

MISC.: The stone was soaked 20 hrs. before retesting.

NORTON/GRAY DOME DIFFUSER CHARACTERIZATION SHEET

DIFFUSER IDENTIFICATION-- Hartford, MDC

Diffuser #1

DATE-- 5/26/87

LOCATION #	BRV (in H2O)	H2O Height (in H2O)	BRV TOTAL (in H2O)
1	13.80	2.50	11.30
2	10.50	2.70	7.80
3	11.95	3.25	8.70
4	15.80	2.15	13.65
5	10.10	2.75	7.35
6	12.90	3.00	9.90
7	18.00	3.40	14.60
8	14.95	3.00	11.95
1S	31.00	2.00	29.00
4S	18.60	2.25	16.35
5S	13.75	2.00	11.75
8S	40.00	0.00	40.00

$\bar{x}$ = 10.656 TOP
s/x = 0.251

$\bar{x}$ = 15.196 OVERALL
s/x = 0.638

$\bar{x}$ = 24.275 SIDES
s/x = 0.526

DWP vs FLOW

ROTO RDG	FLOW (cfm)	DWP (in wg)	DWP(actual) (in wg)
91	2.08	15.7	10.7
21	0.50	12.8	7.8
33	0.75	13.3	8.3
43	1.00	13.8	8.8
87	2.00	15.6	10.6

Height of water above diffuser = 5.0 in.

FLOW PROFILE (3 bucket catch)

	VOLUME (cc)	TIME (sec)	TOTAL FLOW (cc/sec)	ANNULAR FLOW per sq ft (cfm/sq ft)	TOTAL ANN FLOW (cfm)
OUTER	10320	29.20	353.4	1.50	0.158
MIDDLE	600	2.15	279.1	3.41	0.368
INNER	400	3.80	105.3	4.89	0.223

Total Flow (cfm) = 0.749

NOTES-- ____________________

NORTON/GRAY DOME DIFFUSER CHARACTERIZATION SHEET

DIFFUSER IDENTIFICATION-- Hartford, MDC

Diffuser #2

DATE-- 5/26/87

LOCATION #	BRV (in H2O)	H2O Height (in H2O)	BRV TOTAL (in H2O)
1	10.70	2.25	8.45
2	11.60	3.50	8.10
3	24.00	4.00	20.00
4	17.20	3.50	13.70
5	14.55	3.25	11.30
6	12.00	3.75	8.25
7	10.00	3.60	6.40
8	10.85	3.00	7.85
1S	8.55	2.00	6.55
4S	40.00	0.00	40.00
5S	9.75	1.75	8.00
8S	35.30	1.75	33.55

$\bar{x}$ = 10.506 TOP
s/x = 0.426

$\bar{x}$ = 14.346 OVERALL
s/x = 0.782

$\bar{x}$ = 22.025 SIDES
s/x = 0.783

DWP vs FLOW

ROTO RDG	FLOW (cfm)	DWP (in wg)	DWP (actual) (in wg)
91	2.08	12.8	7.8
21	0.50	11.5	6.5
33	0.75	11.7	6.7
43	1.00	11.9	6.9
87	2.00	12.7	7.7

Height of water above diffuser = 5.0 in.

FLOW PROFILE (3 bucket catch)

	VOLUME (cc)	TIME (sec)	TOTAL FLOW (cc/sec)	ANNULAR FLOW per sq ft (cfm/sq ft)	TOTAL ANN FLOW (cfm)
OUTER	10320	28.80	358.3	3.05	0.321
MIDDLE	600	2.90	206.9	2.24	0.241
INNER	400	4.30	93.0	4.32	0.197

Total Flow (cfm) = 0.759

NOTES-- ____________________

NORTON/GRAY DOME DIFFUSER CHARACTERIZATION SHEET

DIFFUSER IDENTIFICATION-- Hartford, MDC

Diffuser #3

DATE-- 5/26/87

LOCATION #	BRV (in H2O)	H2O Height (in H2O)	BRV TOTAL (in H2O)
1	8.80	1.85	6.95
2	14.95	2.00	12.95
3	13.60	3.25	10.35
4	16.80	3.00	13.80
5	14.50	2.00	12.50
6	16.15	2.25	13.90
7	14.20	2.25	11.95
8	10.95	2.50	8.45
1S	9.65	2.00	7.65
4S	17.10	2.00	15.10
5S	11.50	1.85	9.65
8S	11.90	2.00	9.90

$\bar{x}$ = 11.356 TOP
s/x = 0.225

$\bar{x}$ = 11.096 OVERALL
s/x = 0.239

$\bar{x}$ = 10.575 SIDES
s/x = 0.301

DWP vs FLOW

ROTO RDG	FLOW (cfm)	DWP (in wg)	DWP(actual) (in wg)
91	2.08	14.5	9.5
21	0.50	12.1	7.1
33	0.75	12.5	7.5
43	1.00	12.8	7.8
87	2.00	14.4	9.4

Height of water above diffuser = 5.0 in.

FLOW PROFILE (3 bucket catch)

	VOLUME (cc)	TIME (sec)	TOTAL FLOW (cc/sec)	ANNULAR FLOW per sq ft (cfm/sq ft)	TOTAL ANN FLOW (cfm)
OUTER	10320	28.90	357.1	4.35	0.458
MIDDLE	600	4.25	141.2	1.81	0.196
INNER	400	8.20	48.8	2.27	0.103

Total Flow (cfm) = 0.757

NOTES-- ______________________________

NORTON/GRAY DOME DIFFUSER CHARACTERIZATION SHEET

DIFFUSER IDENTIFICATION-- Hartford, MDC

Diffuser #4

DATE-- 5/26/87

LOCATION #	BRV (in H2O)	H20 Height (in H2O)	BRV TOTAL (in H2O)
1	10.40	4.25	6.15
2	11.00	4.75	6.25
3	10.90	4.50	6.40
4	11.00	4.75	6.25
5	10.35	4.50	5.85
6	11.20	4.75	6.45
7	11.00	4.70	6.30
8	11.15	4.75	6.40
1S	8.80	3.25	5.55
4S	8.00	2.25	5.75
5S	8.15	2.50	5.65
8S	7.95	2.35	5.60

$\bar{x}$ = 6.256 TOP
s/x = 0.031

$\bar{x}$ = 6.050 OVERALL
s/x = 0.057

$\bar{x}$ = 5.638 SIDES
s/x = 0.015

DWP vs FLOW

ROTO RDG	FLOW (cfm)	DWP (in wg)	DWP(actual) (in wg)
91	2.08	11.5	6.5
21	0.50	10.6	5.6
33	0.75	10.8	5.8
43	1.00	10.8	5.8
87	2.00	11.4	6.4

Height of water above diffuser = 5.0 in.

FLOW PROFILE (3 bucket catch)

	VOLUME (cc)	TIME (sec)	TOTAL FLOW (cc/sec)	ANNULAR FLOW per sq ft (cfm/sq ft)	TOTAL ANN FLOW (cfm)
OUTER	10320	29.40	351.0	3.61	0.381
MIDDLE	600	3.50	171.4	1.83	0.197
INNER	400	5.10	78.4	3.65	0.166
				Total Flow (cfm) =	0.744

NOTES--