OXYGEN TRANSFER EFFICIENCY SURVEYS AT THE JONES ISLAND TREATMENT PLANTS 1985 - 1988

by

Read Warriner
Milwaukee Metropolitan Sewerage District
Milwaukee, Wisconsin 53204

Cooperative Agreement No. CR812167

Project Officer

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

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

DISCLAIMER

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

FOREWORD

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

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

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

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

PREFACE

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

ABSTRACT

Ceramic plate diffusers were among the earliest forms of fine pore diffusers used for oxygen transfer in activated sludge treatment. They have been successfully used for over 60 years in the Jones Island West Plant of the Milwaukee Metropolitan Sewerage District and, since initial start-up, in the Jones Island East Plant and the South Shore Plant. Surveys of performance of these diffusers in all three plants were included in the EPA/ASCE Fine Pore Aeration Project. This report presents the results of off-gas sampling surveys carried our at the original Jones Island West Plant and in the newly rehabilitated East Plant. The West Plant basins were scheduled for rehabilitation in 1989-90.

Twenty-one (21) basin surveys were carried out in the West Plant and 30 in the East Plant. For the West Plant basins, which contained the original ceramic diffusers with 15 feet of submergence, installed in 1923 and 1924, the median value of standardized oxygen transfer efficiency, alphaF(SOTE), was 11.8%. For the East Plant basins, which contained diffusers with 14 feet of submergence, installed in 1983, the median value of alphaF(SOTE) WAS 15.3%.

Cleaning history was noted for each basin at the time of each off-gas survey. An effect of time-in-service since cleaning on oxygen transfer efficiency was not documented by these surveys; however, there was an indication that short-term improvement occurred in the East Plant. Since alpha is unknown and varies widely between surveys, and possibly during surveys, it is difficult to separate alpha effects from fouling (F) effects on oxygen transfer efficiency. For the most part, extended periods of basin operation have no measurable effect on performance.

This report was submitted in partial fulfillment of Cooperative Agreement No. CR812167 by the American Society of Civil Engineers under subcontract to the Milwaukee Metropolitan Sewerage District under the partial sponsorship of the U.S. Environmental Protection Agency. The work reported herein was conducted over the period of 1985-1988.

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ACKNOWLEDGEMENTS

The involvement of engineering co-op students from Marquette University and the University of Wisconsin - Milwaukee was indispensable for this project. They are (in chronological order of participation): Robert Dumke, Michael Mitchell, Tom Raasch, Rockne Elgin, Robert Harley, Robert Carroll and Mark Wang. Their eagerness, excellent suggestions, and unflagging interest are gratefully acknowledged.

Larry Ernest, who was at that time Manager of Central Laboratory Services, was principal investigator at the inception of this project and a provider of encouragement and valuable advice throughout its course.

Operations and Maintenance staff of the Jones Island Wastewater Treatment Plant provided valuable guidance and logistical support from start to finish. Thanks are also in order to Lloyd Ewing and Dave Redmon of Ewing Engineering Company for their continuing support and guidance.

INTRODUCTION

Ceramic plate diffusers were among the earliest forms of fine pore diffusers used for oxygen transfer in activated sludge treatment. They have been successfully used for over sixty years in the Jones Island West Plant of the Milwaukee Metropolitan Sewerage District (MMSD) and, since initial start-up, in the Jones Island East Plant and the South Shore Plant. Because of this record, surveys of current performance of these diffusers in all three activated sludge plants were included in the EPA/ASCE Fine Pore Diffuser Project. This report presents the results of off-gas sampling surveys carried out in the original Jones Island West Plant and in the newly rehabilitated East Plant. The West Plant basins are scheduled for rehabilitation in 1989-90.

The present Jones Island Plant treats a dry weather flow of approximately 100 MGD with 70 MGD going to the East Plant and 30 MGD to the original West Plant. Aeration basins in both plants are equipped with one foot square diffuser plates assembled in 9-plate containers. However, the diffusers in the West Plant are the original fused silica plates installed in 1923 and 1924. They are one and a half inches thick, and the containers are placed across the direction of basin flow in a ridge and furrow configuration. In the East Plant the diffuser material is a mixture of alumina and silica, and the diffusers are one-inch thick with the containers arranged in a longitudinal, full floor coverage pattern. These diffusers were installed when the plant was rehabilitated in 1983. Diffuser submergence for the West Plant was 15 feet, and for the rehabilitated East Plant it is 14 feet.

SURVEY PROGRAM

Oxygen transfer efficiency surveys in the East Plant were made on 15 test days between August 30, 1985 and June 1, 1988. Both north and south passes of the basin were surveyed on each test date. Since the East Plant aeration basins were not included in the original EPA/ASCE Fine Pore diffuser Project, a testing program was not laid out in advance. Instead, surveys were conducted in response to requests from Operations staff. In 1985 and 1986, surveys were conducted in four different basins. However, Basin 6 was tested on 10 of the 15 survey days. Since Basin 6 was cleaned only in June, 1985 and June, 1988, the survey record provided an opportunity to monitor diffuser performance as a function of time in service. In addition to full basin surveys, special studies were carried out in Basin 6 on the influence of air flow rate on zero-DO OTE under process conditions. This normalized value for basin efficiency is known as alphaF(SOTE).

In the West Plant a program was planned to include twenty surveys of West Plant basins. Originally, five basins were to be tested four times each over a two-year period; however, due to a cleaning program in progress when off-gas surveys were scheduled, only five or six basins were normally available for testing. Since different basins were available at different times, the off-gas survey program had to be changed to include those basins that could be tested at the times equipment and personnel were available. None of the basins could be tested in all four of the test periods.

Following the April, 1986 Contractors' meeting, two additional surveys in the West Plant were added to the program. The first was a one-time investigation of the effects of collection hood placement patterns on observed oxygen transfer efficiency. The second was a 24-hour survey with hourly OTE observations for two hood stations in basin No. 16.

CONCLUSIONS

Overall average values of alphaF(SOTE) were higher in the East Plant than in the West Plant. The difference was probably due in part to the fact that all the West Plant basins tested were equipped with the original diffuser plates that had been installed in 1923-24. The East Plant diffusers were installed in 1983. Since the West Plant is scheduled for complete rehabilitation with installation of new diffuser plates, much maintenance has been deferred. The tank surface revealed boiling, indicative of damaged or poorly maintained diffusers. Another difference between the plants was in the layout of diffusers, a ridge and furrow pattern in the West Plant and a longitudinal pattern in the East Plant.

While many factors potentially contributed to differences in oxygen transfer efficiency between the two plants, the mean values for alphaF(SOTE) of 3.6% per meter of depth for the East Plant and 2.7% per meter for the West Plant were both considered representative of excellent fine pore diffuser performance for highly loaded municipal activated sludge plants (1). It is noteworthy that data obtained in 1964, for East Plant basins equipped with square diffusers in a similar longitudinal grid, showed almost the same average zero DO efficiency of 3.4% per meter of depth (2). Another conclusion applicable to both plants was tht time-in-service since diffuser cleaning had no discernible effect in alphaF(SOTE).

EAST PLANT

1. The flux weighted alphaF(SOTE) values obtained from 30 Jones Island East Plant aeration basin surveys on 15 test days ranged from 11.4% to 19.2% with a mean value of 15.4%. (The mean for 20 surveys in Basin 6 was 15.6%.)

2. The mean sludge age for the East Plant for the 15 test days was 3.8 days with a range of 2.3 to 5.3 days. The mean F/M ratio was 0.65 day^{-1}, with a range of 0.32 to 0.97 day^{-1}. No relationship was found between process OTE values and sludge age or F/M ratio.

3. During the second and third years following diffuser cleaning in Basin 6, with no primary sedimentation to reduce the waste load, the oxygen transfer capability, as measured by the off-gas method, was unchanged.

4. In two side-by-side trials, tapering the air supply had little effect on the overall rate of oxygen transfer.

5. At the basin inlet, under conditions of high potential oxygen uptake rate and very low dissolved oxygen, the oxygen transfer efficiency was constant over a large range of air flow rate.

WEST PLANT

1. The flux weighted alphaF(SOTE) values obtained from 21 West Plant aeration basin surveys ranged from 6.6% to 15.6% with a mean value of 11.7% (The median was 11.8%.)

2. The mean and the median sludge age for the West Plant for the 21 test days in the study period was 3.3 days. The mean F/M ratio was 0.82 $days^{-1}$. (The median was 0.63 $days^{-1}$.)

RECOMMENDATIONS

1. Since a prominent characteristic of the aeration basins in both treatment plants is large diffuser areas and low air flux rates, further attention should be directed to this variable. The effect of diffuser surface area on performance should be investigated and should be examined separately from the effect of air flux rate.

2. Since the effects of wastewater characteristics (alpha) and fouling (F) may have quite different effects on operating costs, an attempt should be made to separate these two phenomena. This could be done, for example, by comparing a freshly acid cleaned basin and a long time-in-service basin side-by-side, by comparing a week-end (low BOD loading) survey with a mid-week survey, and by surveying a basin with mixed liquor feed temporarily cut off.

TREATMENT PLANT DESCRIPTIONS

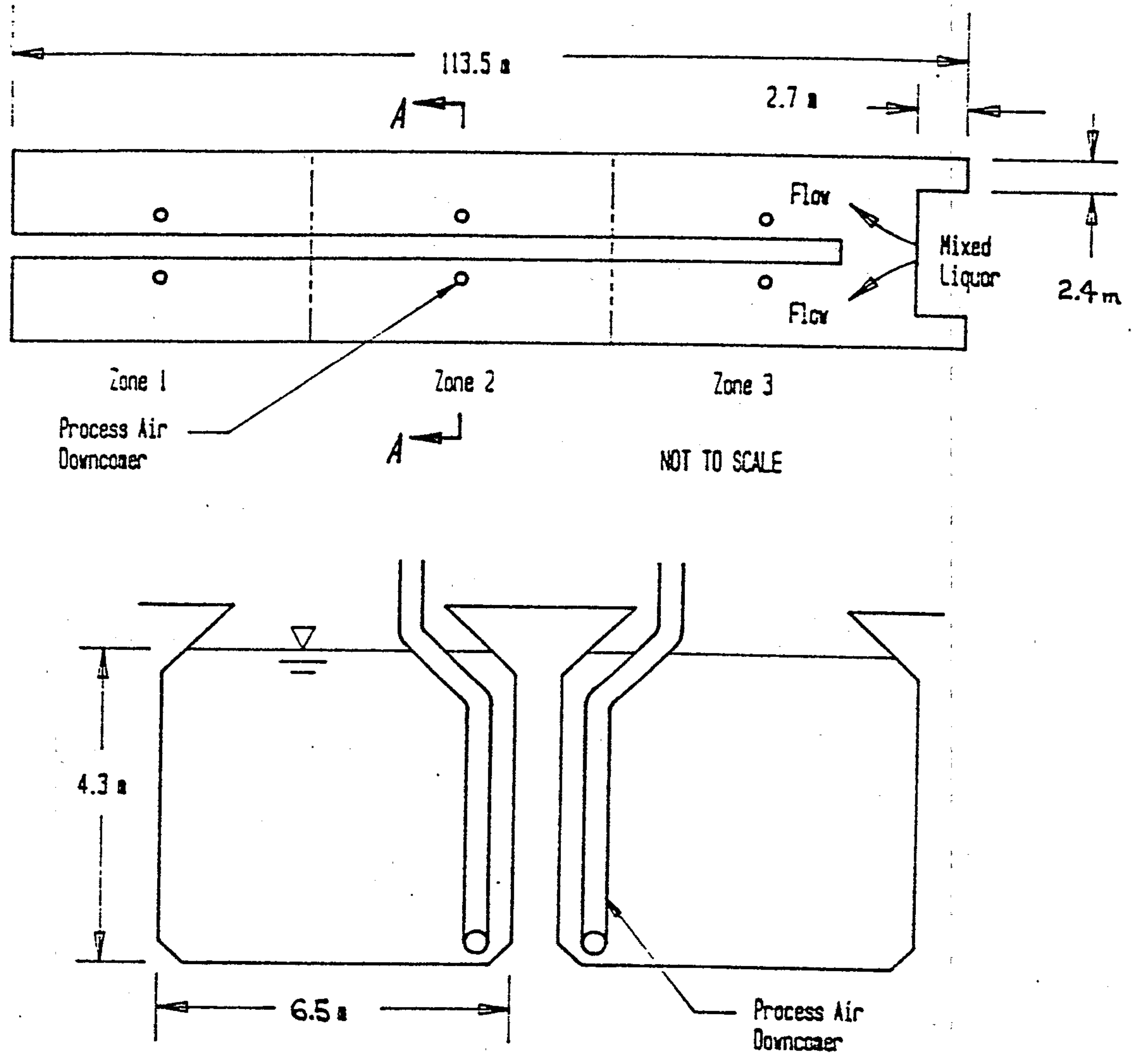
Detailed information concerning the historical records, aeration basin and process air supply designs, and the operation of both plants are presented in a report by Ernest (3) on the operating history of the Milwaukee Aeration Facilities as part of the same ASCE/EPA project.

EAST PLANT

The East Plant provides activated sludge treatment for approximately 75 MGD of screened municipal and industrial wastewater with 5-day BOD of 300 mg/L. Forty aeration basins are operated in pairs with the layout and dimensions shown in Figure 1. Part of the plant was constructed in 1935 and the remainder in 1952. Each pair of basins was operated as one 2-pass basin. Various fine bubble diffuser types and floor coverages were employed, and, at times, severe problems with aeration capacity were experienced. Extensive investigations in the 1960s (2) led to the longitudinal, full floor coverage patterns of diffusers still used today. In 1983, the basins were rehabilitated with new diffuser plates and piping and improvements in the distribution of air to downcomers and the tank drainage. The diffuser layout and the plate specifications were essentially unchanged. In June, 1985, the basins were converted to single pass operation.

The diffusers are square ceramic plates, mixtures of alumina and silca 12 inches square and 1 inch thick. The permeabilities range from 17 to 23. The plates are grouped by permeabilities in ranges of 17-19, 20-21, and 22-23. Each downcomer is fitted with plates of only one range. The plates are grouted into concrete containers placed flush with the bottom of the tank. Each container contains 9 plates and is connected at one end to a 1-inch diameter air pipe. The containers are placed end to end in the direction of the tank length, 32 containers in a row and 5 rows across the width of the basin. There are 1450 plates in each basin, 2900 plates in each pair.

As shown in Figure 1, air is supplied from downcomers to 3 separate zones in each basin. Air flow to each zone is set manually by a butterfly valve, but within each zone there are no orifices for control of air distribution. Each downcomer is equipped with an orifice meter and the air flow corresponding to the pressure drop is read from a portable flow indicator. A permanently mounted orifice meter and flow indicator for each pair of basins (6 zones) provides a check on the sum of the readings taken at the separate zones.



Section A - A

Figure 1. Layout and dimensions of the north and south passes of East Plant Tank No. 6.

WEST PLANT

The Jones Island West Plant comprised two batteries of 12 aeration basins each. All surveys for the fine pore diffuser project were carried out in the South Battery. Recycle sludge and screened sewage are combined to form the mixed liquor feeding both north and south batteries. The aeration basins are two-pass; each pass is 222 feet long and 22 feet wide. The water depth is 15 feet to the surface of the plates.

Figure 2 shows plan and cross-section views of Basin Number 6 which was also the location of a four unit disk diffuser test plenum that was installed and monitored during the course of these surveys.

The air supply to each tank is metered through a single main that divides into two downcomers, one feeding each pass as indicated in Figure 2. The air supply pipe runs along the center near the bottom of each pass with take-offs to diffuser containers on either side and along the center line. Each container holds nine plates. The containers are placed in the bottom of the tank in a ridge and furrow configuration, so that they lie across the direction of flow except for one row that runs longitudinally along the center of the tank floor parallel to the air supply line. All 12 aeration basins in the South Battery contain the original Filtros silica plates, 12 inches square by 1-1/2 inches thick with permeabilities of 9-10, that were installed in 1923 and 1924. The total number of plates in each two-pass tank is 2348.

The aeration basins in the South Pass of the West Plant are scheduled to be completely rehabilitated with new plates and air piping as well as conversion from two-pass to single pass operation before 1990. Therefore, a significant amount of maintenance has been deferred. During the 1985/86 testing periods, all of the tanks had one or more large boils representing damaged plates or piping. Furthermore, the operator frequently experienced difficulty in getting sufficient air flow to some of the tanks to keep a consistent positive dissolved oxygen measurement at the three-quarter point where the Zullig DO probe was located. In an effort to correct this apparent fouling problem, several tanks were taken out of service for acid cleaning in 1985 and 1986.

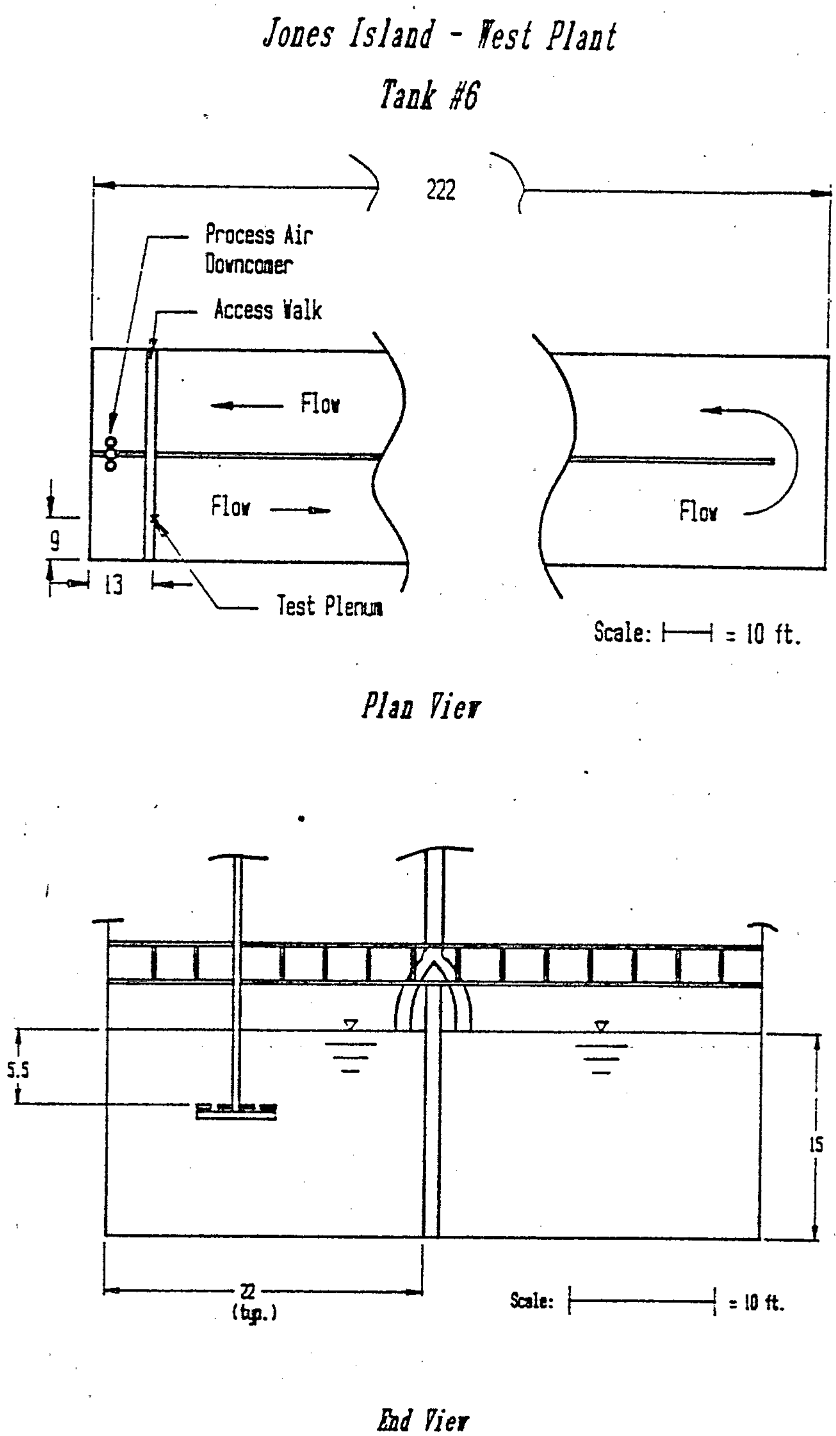


Figure 2. Layout and dimensions of West Plant Tank No. 6.

CONDUCT OF THE SURVEYS

OFF-GAS SURVEY METHODS

The MMSD purchased an "Aerator-Rator, Mark IV" off-gas analyzer from Ewing Engineering Company in June, 1985. This provided the opportunity to use the off-gas method for measurement of oxygen transfer efficiency as described by Redmon, et al. (4). The off-gas monitoring unit was used with two gas collection hoods, designed and built by Ewing Engineering Company. The hoods, constructed of fiber glass and PVC pipe reinforcing, each had a collection area of dimensions 2 feet by 16.5 feet or 33 square feet. The volume under the hood was approximately 30 cubic feet and depended on the hood position in the mixed liquor. The connection between each hood and the Aerator-Rator was made with 50 feet of 1-1/4 inch vacuum cleaner hose.

Carbon dioxide content in the off-gas was measured using a Dwyer CO_2 indicator. The Aerator-Rator came equipped with a drying column, so humidity data were not collected for either off-gas or reference air. At least two gas samples were collected for CO_2 determination for every collection hood position. Mixed liquor dissolved oxygen concentration was also measured at every collection hood station using YSI dissolved oxygen meters and field probes. Readings were taken at depths of approximately four feet and ten feet and averaged. These two readings rarely varied by more than 0.1 mg/l.

East Plant

Before an East Plant tank was surveyed, 12 test stations were located at equal distances along the length. With a hood collecting off-gas from 33 square feet at each station, the total area sampled was 396 square feet or five percent of tank surface area. For the East Plant surveys, north and south passes were tested on the same day with one collecting hood in each pass and the Aerator-Rator set up between the two passes. Stations were sampled in sequence from the inlet to the outlet, alternating between the north and south passes. At each station, the hood was positioned lengthwise across the width of the tank, approximately in the center, and secured with ropes. As soon as a station was sampled, the hood was moved to the next location while a measurement was completed for the adjacent tank.

The traverse from inlet to outlet for both passes usually required 6 hours. The average time on a station was 15 minutes, with the oxygen sensor millivolt output recorded for the latter half of that period. After data for a station were recorded, the hood was moved immediately to the next station where about 20 minutes elapsed before off-gas readings were started. These readings were recorded at one-minute intervals, and the data were accepted when 4 readings had been obtained within a range not exceeding 4 millivolts.

West Plant

For a West Plant survey, 15 test stations were located at approximately equal intervals along the length of the tank. With a hood collecting off-gas from 33 square feet at each station, the total area sampled was 495 square feet or five percent of tank surface area. The hoods were positioned lengthwise across the width of the tank, except at the turning point (Station 8) where the hood was halfway between the baffle and the endwall, along the direction of flow. The West Plant tanks are laid out in pairs with the second pass of one tank sharing a common wall with the first pass of the other tank. Therefore, the off-gas analyzer could be used from only one side of the tank. Hood placements in the pass away from the operator had to be made by a team member in a boat. Hooks that could be moved from position to position had to be constructed so that ropes from the hoods could be secured as required.

For the West Plant surveys, testing began in the morning at the turning point. One hood was then moved along each pass. The final readings were taken about six hours later at the furthest upstream and furthest downstream positions in the tanks (stations 1 and 15).

AERATION BASIN OPERATION

East Plant

Screened wastewater is combined with return sludge and conveyed in an aerated channel approximately 450 feet to the East Plant basins. Each of the 20 pairs of basins has a common headworks. The split in mixed liquor flow between the north pass and the south pass is partly controlled by weir elevations at the discharge end and is intended to be exactly even. A dye test carried out shortly after the start of single-pass operation in 1985 showed that the flow in the south pass of Basin 6 was about 10 percent higher than the flow in the north pass. The mixed liquor in the feed channel travels about 1200 feet from Basin 1 to Basin 20. Measurements of dissolved oxygen and oxygen uptake rate at intervals along the feed channel have shown that a fraction of the waste load is removed in the channel, but the extent of this treatment has not been measured.

The inlet zone of each pass is about 25 percent larger than the second or the third zone, but the density of diffuser plates is the same. Usually, during off-gas OTE surveys air flows to the zones were adjusted to provide the same air flow rate per diffuser throughout the tank; however, in some cases air flow was tapered (i.e., more air was added in the first zone). During a survey, air flow to the basin was kept constant. Mixed liquor flows varied only slightly (usually within plus or minus 10%).

West Plant

For West Plant tanks both air flow and mixed liquor flow were manually controlled. Mixed liquor flow varied diurnally, but variation did not exceed 25 percent of average flow during a test. Air flows varied even less and were manually adjusted to keep them within about 10 percent of the average for the test period.

TREATMENT PLANT OPERATION

Measurements of screened sewage 5-day BOD and mixed liquor suspended solids were obtained from plant monthly reports providing analytical data from 24-hour composite samples and operations data based on the same 24-hour periods. Nitrogen data were all compiled from plant monthly reports and based on 24-hour composite samples of screened sewage and final effluent.

Sludge is wasted at the Jones Island West Plant through separate gravity thickeners which are fed mixed liquor from aeration tanks isolated for this purpose. Sludge wasting from the East Plant is accomplished by pumping return sludge across to the West Plant return sludge line. This procedure probably did not affect the West Plant OTE surveys because none of the aeration basins used for sludge wasting was included in the study. However, the calculation of sludge age estimates for West Plant was complicated by the inflow of East Plant waste sludge which would have to be subtracted from the total sludge wasting for the entire Jones Island Plant. Since the former can vary widely over 24 hours, such a calculation is questionable. As an alternative, sludge age values reported for the West Plant are those calculated for the entire plant by plant operations staff for the monthly data summary. The calculation is based on the total solids inventory throughout the plant and the total solids wasting rate. For the East Plant surveys, on the other hand, the sludge ages reported are based on East Plant data including estimates of the solids in the clarifiers and feed channels.

PRESENTATION OF SURVEY DATA

Survey data were recorded on the "Off-Gas Field Data Sheet" (5). The value of beta, the ratio of the saturation oxygen concentration in process water to that in clean water, was assumed to be 0.99 for all of the surveys. The clean water saturation values selected were 10.5 mg/l for the 14-foot deep East Plant aeration basins and 10.6 mg/l for the West Plant basins where the submergence was 15 feet (6). An effective saturation depth of 43% of submergence was assumed in obtaining the pressure correction factor used to calculate the field dissolved oxygen saturation value and the deficit or driving force at each station.

A FORTRAN program was written to accept the data obtained from an off-gas survey, complete the required calculations, and print a report displaying the data and the calculated efficiencies for each station as well as flux weighted values for the field efficiency (FOTE) and the standard efficiency for a dissolved oxygen concentration of zero, i.e., alphaF(SOTE). Figure 3 is an illustration of a survey summary report for the East Plant and Figure 4 is an illustration for the West Plant.

OFF GAS SUMMARY

TEST SITE: JI EAST PLANT   TEST DATE: 7-14-87   AERATION TANK #: 6S   AERATION SYSTEM: CERAMIC PLATES   SUBMERGENCE(ft): 14

TANK VOL(MG): 0 95   AIR RATE(SCFM): 1770   WASTEWATER FLOW(MGD): 2.9   RETURN SLUDGE(MGD): 0.8   TOTAL FLOW(MGD): 3.7

RET. TIME(hrs): 6.0   MLSS(mg/l): 1500   EST LOAD(#BOD/#MLVSSday): 0.86   EST SLUDGE AGE(days): 2.5

TEST CREW: RW, TR   C*20(MG/L): 10.5   LOCAL AIR TEMP(DEG F): 75   HOOD NUMBER: OT-1

TIME	STA.	MOG	MVR	ML TEMP	DO	DEFICIT	ROTAM 1	ROTAM 2	FOTE	SPOTE	FLUX	STOTE	BAROM	ROT TEMP	ROT PRES	FCO2
10:58	1	907.	1001.	22.00	0.10	9.75	143.0	0.0	0.103	0.0100	0.112	0.104	29.35	74.00	7.00	.0120
11:19	2	847.	1000.	22.10	0.20	9.63	133.0	0.0	0.173	0.0171	0.104	0.178	29.36	81.00	7.00	.0125
11:39	3	898	1000.	22.10	0.15	9.68	204.0	0.0	0.112	0.0110	0.155	0.114	29.35	79.00	14.00	.0125
13.02	4	881.	999.	22.00	0.30	9.55	0.0	64.0	0.128	0.0128	0 228	0.133	29.35	73.00	7.00	.0155
13:18	5	852.	1000.	22.20	0.40	9.41	0.0	60.0	0.162	0.0164	0 217	0.170	29.35	72.00	7.00	.0175
13.38	6	881.	1000.	22.30	0.95	8.84	0.0	57.0	0.126	0.0135	0.208	0.140	29.35	73 00	7.00	.0185
14:08	7	894.	999.	22.50	2.10	7.66	0.0	64.0	0.110	0.0135	0.227	0.141	29.36	75.00	7.00	.0175
14:26	8	900.	999.	22.40	2.60	7.18	0.0	62 0	0.102	0.0134	0 221	0.139	29.36	76.00	7.00	.0185
14:47	9	883.	998.	22.40	3.50	7.16	0.0	67.0	0.134	0.0177	0.117	0.184	29.36	71.00	7.00	.0170
15:19	10	908.	998.	22.50	4.00	5.76	0.0	70.0	0.091	0.0148	0.244	0.154	29.36	75.00	8.00	.0185
15.38	11	916	999.	22.60	4.10	5.64	0.0	68.0	0.082	0.0137	0.236	0.143	29.36	84 00	7.00	.0180
16:00	12	908	1000.	22.60	4.10	5.64	0.0	80.0	0.096	0.0159	0.271	0.166	29.36	79.00	7.00	.0160
WEIGHTED AVERAGES :									0.115	0.0142	0.195					

EXPLANATION OF THE VARIABLES

STA: STATION NUMBER   MOG: MILLIVOLTS OFF GAS   MVR: MILLIVOLTS REFERENCE AIR   DO. DISSOLVED OXYGEN (mg/l)

ML TEMP: MIXED LIGUOR TEMPERATURE (deg C)   ROTAM 1 OR 2: ROTAMETER READING   FOTE: FIELD OXYGEN TRANSFER EFFICIENCY

SPOTE: OXYGEN TRANSFER EFFICIENCY AT 20 deg C PER mg/l OF DO DEFICIT   STOTE: OXYGEN TRANSFER EFFICIENCY AT 20 deg C AND ZERO DO

FLUX: AIR FLOW AT SURFACE (scfm/sq ft)   BAROM. BAROMETRIC PRESSURE (in of mercury)

ROT TEMP: AIR TEMPERATURE AT THE ROTAMETER (deg F)   ROT PRESS: PRESSURE AT THE ROTAMETER (in of water)

FCO2: FRACTION OF CO2 IN OFF-GAS

Figure 3. Sample report format used for East Plant off gas survey data.

OFF GAS SUMMARY

TEST SITE: JI WEST PLANT   TEST DATE: 8-12-85   AERATION TANK #: 6   AERATION SYSTEM: CERAMIC PLATES   SUBMERGENCE(ft): 15

TANK VOL(MG): 1.08   AIR RATE(SCFM): 2500   WASTEWATER FLOW(MGD): 3.0   RETURN SLUDGE(MGD): 1.3   TOTAL FLOW(MGD): 4.3

RET.TIME(hrs): 6.0   MLSS(mg/l): 2500   EST LOAD(#BOD/#MLVSSday): 0.43   EST SLUDGE AGE(days): 4.2

TEST CREW: LOCAL AIR TEMP(deg F): 80   C*20(mg/l): 10.6   SOURCE: EWING ENGINEERING CO

TIME	STA.	MOG	MVR	ML TEMP	DO	DEFICIT	ROTAM 1	ROTAM 2	FOTE	SPOTE	FLUX	STOTE	BAROM	ROT TEMP	ROT PRES	FCO2
16:35	1	935.	1001.	22.00	0.60	9.31	0.0	127.0	0.074	0.0080	0.397	0.079	29.32	94.00	11.50	.0070
16:06	2	896.	1000.	22.00	1.00	8.91	0.0	89.0	0.122	0.0130	0.292	0.135	29.32	94.00	9.00	.0060
15:35	3	902.	998.	22.00	1.15	8.76	0.0	116.0	0.110	0.0120	0.367	0.124	29.30	90.00	10.50	.0080
15:08	4	909.	997.	22.00	1.80	8.11	0.0	129.0	0.098	0.0120	0.403	0.120	29.30	93.00	12.00	.0100
14:39	5	929.	999.	22.00	2.55	7.36	0.0	107.0	0.074	0.0100	0.343	0.099	29.30	88.00	9.50	.0115
12:38	6	921.	1002.	22.00	2.60	7.30	0.0	104.0	0.088	0.0110	0.337	0.119	29.28	81.00	10.00	.0110
12:05	7	918.	998.	22.00	3.20	6.69	0.0	95.0	0.088	0.0130	0.311	0.130	29.25	86.00	10.00	.0100
10:32	8	892.	997.	21.00	1.25	8.85	123.0	0.0	0.115	0.0130	0.097	0.132	29.24	80.00	7.00	.0130
10:04	9	928.	1001.	21.00	2.75	7.35	0.0	44.0	0.077	0.0100	0.171	0.107	29.24	76.00	8.00	.0115
11:35	10	906.	997.	21.00	1.25	8.85	0.0	42.0	0.101	0.0110	0.165	0.116	29.24	80.00	7.00	.0105
12:27	11	905.	1000.	21.00	1.05	9.06	0.0	37.0	0.102	0.0110	0.151	0.114	29.28	80.00	6.50	.0140
14:26	12	903.	1000.	22.00	0.70	9.21	0.0	39.0	0.106	0.0110	0.156	0.114	29.30	85.00	7.00	.0125
15:00	13	889.	997.	22.00	1.00	8.91	0.0	58.0	0.116	0.0120	0.208	0.129	29.30	90.00	7.50	.0160
15:26	14	897.	998.	22.00	1.15	8.76	0.0	37.0	0.109	0.0120	0.150	0.124	29.30	91.00	7.00	.0140
15:56	15	887.	1000.	22.00	0.35	9.56	0.0	36.0	0.120	0.0120	0.147	0.124	29.32	91.00	4.50	.0175
								WEIGHTED AVERAGES :	0.097	0.0113	0.246					

EXPLANATION OF THE VARIABLES

STA: STATION NUMBER   MOG: MILLIVOLTS OFF GAS   MVR: MILLIVOLTS REFERENCE AIR   DO: DISSOLVED OXYGEN (mg/l)

ML TEMP: MIXED LIQUOR TEMPERATURE (deg C)   ROTAM 1 OR 2: ROTAMETER READING   FOTE: FIELD OXYGEN TRANSFER EFFICIENCY

SPOTE: OXYGEN TRANSFER EFFICIENCY AT 20 deg C PER mg/l OF DO DEFICIT   STOTE: OXYGEN TRANSFER EFFICIENCY AT 20 deg C AND ZERO DO

FLUX: AIR FLOW AT SURFACE (scfm/sq ft)   BAROM: BAROMETRIC PRESSURE (in of mercury)

ROT TEMP: AIR TEMPERATURE AT THE ROTAMETER (deg F)   ROT PRESS: PRESSURE AT THE ROTAMETER (in of water)

FCO2: FRACTION OF CO2 IN OFF-GAS

Figure 4. Sample report format used for West Plant off gas survey data.

SURVEY RESULTS

EAST PLANT

Fifteen pairs of surveys were completed for the Jones Island East Plant. Table 1 is an overall summary of test dates, test conditions and flux weighted average field and standard OTE values. Also shown are tank cleaning information and sludge age and loading estimates for the test dates. In addition to maintaining a constant air flow to the basin pair during an OTE survey, the survey team also monitored the air flows in the six downcomers (three in each pass). These zone air flows were also recorded and are shown in Table 2. Table 3 contains nitrogen related data taken from plant laboratory records for the 15 test dates. Detailed information concerning treatment plant facilities and operation is included in the East Plant Overall Plant Data Sheet (Appendix A).

Since 10 of the 15 surveys in the East Plant between August, 1985 and June, 1988, were conducted in Basin 6, Table 4 was prepared to show the trends in performance of this basin. Basin 6 was hosed and acid cleaned in June, 1985, the same month when the East Plant aeration basins were converted from 2-pass to single pass operation.

Tank 6 performance was evaluated in September, 1985, and subsequently in 1986-88, as shown in Table 4. AlphaF(SOTE) varied between 14 and 17 percent, but showed no decrease with the two years in service. The tank was hosed and acid cleaned in May, 1988. Values of alphaF(SOTE) of 19 and 17 percent were then obtained for the north and south passes, respectively. While these efficiencies were higher than average for the previous three years, one cannot, on the basis of this one survey, conclude the cleaning procedure produced significant improvement.

During May, 1987, two surveys were conducted in Basin 6 when the air flow was set at a uniform rate to all three zones in one pass but concentrated in the first zone in the other pass. For the higher air flow test (Fig. 5), the north pass with air flow at a uniform rate of about 1.3 scfm/diffuser had a flux weighted alphaF(SOTE) value of 17 percent. The south pass with a tapered air supply had a flux weighted alphaF(SOTE) value of 15 percent. However, the dissolved oxygen (DO) concentration in the South Pass rose more rapidly in the first zone which may at times be a desirable operating condition (e.g., as a possible means for control of the growth of filamentous bacteria).

For the test with lower air flow (Fig. 6), the DO concentration at the overflow from the basin with a uniform air supply was

TABLE 1. OXYGEN TRANSFER SURVEY DATA FOR THE JONES ISLAND EAST PLANT

Date	Basin Number	Time in Service (Mos.)	Cleaning Method	Airflow (scfm)	FOTE % North	FOTE % South	AlphaF(SOTE) % North	AlphaF(SOTE) % South	Sludge Age (Days)	Loading #BOD5 per #MLVSS - Day	Loading #BOD5 per 1000 Cu.Ft.-Day
8/30/85	18	4	A	2500	8.8	9.5	18.3	19.2	5.3	0.55	62.5
9/04/85	6	3	A	1750	15.7	13.0	18.2	13.6	3.5	1.14	119.2
9/19/85	6	4	A	2210	13.0	11.7	16.4	12.9	2.3	1.16	92.4
9/24/85	18	5	A	1750	12.7	12.1	15.3	14.3	3.5	0.99	95.5
4/22/86	3	8	W	1420	10.8	10.2	14.6	13.7	3.4	0.70	86.0
4/24/86	17	22	A-1	1800	9.5	10.9	11.4	12.3	4.5	0.38	46.8
10/07/86	6	16	A	1700	10.8	9.4	15.8	13.2	5.8	0.57	41.6
10/22/86	18	18	A	1600	10.6	9.2	16.2	15.4	2.4	0.69	44.7
10/27/86	6	17	A	1625	7.7	7.2	17.4	14.8	4.0	0.66	35.1
10/28/86	6	17	A	1250	11.6	12.0	14.6	13.8	4.8	0.76	62.7
5/22/87	6	24	A	1910	9.7	9.0	17.0	14.7	3.3	0.56	67.3
5/28/87	6	24	A	1390	16.1	15.3	17.3	17.6	4.9	0.59	85.5
7/14/87	6	26	A	1770	11.4	11.5	15.6	14.8	2.5	1.01	71.5
11/12/87	6	30	A	1500	12.4	12.6	14.0	13.9	2.4	1.00	90.7
6/1/88	6	1	A	1570	17.2	15.6	19.2	16.7	3.6	0.76	105.4

W Denotes washing with a high pressure (100 psi) hose.

A Denotes washing followed by acid cleaning.

A-1 Indicates acid cleaning in first quarter of the tank only.

TABLE 2. SUPPLEMENTARY AIR FLOW RATE DATA FOR EAST PLANT OXYGEN TRANSFER SURVEYS

Date	Tank	Air Rate (1) scfm Zone 1	scfm Zone 2	scfm Zone 3	scfm/diffuser Zone 1	scfm/diffuser Zone 2	scfm/diffuser Zone 3
8/30/85	18	1250	750	500	2.24	1.67	1.13
9/04/85	6	750	500	500	1.34	1.11	1.13
9/19/85	6	960	710	540	1.72	1.58	1.22
9/24/85	18	750	500	500	1.34	1.11	1.13
4/22/86	3	700	430	280	1.25	0.96	0.63
4/24/86	17	840	570	390	1.51	1.27	0.88
10/07/86	6	3400	(North and South)		1.17	(North and South)	
10/22/86	18	700	500	400	1.25	1.11	0.91
10/27/86	6	615	520	490	1.10	1.16	1.11
10/28/86	6	500	400	350	0.90	0.89	0.79
5/22/87	6N	740	590	580	1.33	1.31	1.31
	6S	1080	420	410	1.94	0.93	0.93
5/28/87	6N	820	290	280	1.47	0.64	0.63
	6S	540	430	420	0.97	0.96	0.95
7/14/87	6	675	550	545	1.21	1.22	1.23
11/12/87	6	570	470	460	1.02	1.04	1.04
6/1/88	6	600	490	480	1.08	1.09	1.09

(1) Unless otherwise indicated, zone air flows were the same for the North Pass and the South Pass. Numbers of plates per zone are as follows: Zone 1 - 558, Zone 2 - 450, Zone 3 - 442.

TABLE 3. SECONDARY TREATMENT NITROGEN DATA FOR EAST PLANT OXYGEN TRANSFER SURVEYS

Date	Screened Sewage	East Plant Effluent		
	TKN	TKN	NO2	NO3
8/30/85	37	5	0.6	3.4
9/14/85	40	7	1.4	4.1
9/19/85	38	7	1.9	2.2
9/24/85	43	8	1.3	2.7
4/22/86	--	10	0.2	0.2
4/24/86	39	12	0.2	0.2
10/07/86	24	5	0.5	3.7
10/22/86	--	5	0.4	2.2
10/27/86	24	7	0.4	2.4
10/28/86	25	8	0.4	1.2
5/22/87	41	6	0.1	0.2
5/28/87	50	8	0.1	0.1
7/14/87	38	9	0.5	0.9
11/12/87	48	12	0.1	0.1
6/01/88	47	12	0.1	0.1

All values in mg/l; (--) denotes missing value.

TABLE 4. OPERATING CONDITIONS AND OXYGEN TRANSFER EFFICIENCY SURVEY RESULTS FOR EAST PLANT BASIN 6

Time in Service, Mos.	AlphaF(SOTE) %	FOTE %	scfm/ Diffuser	BOD5 mg/l	Retention Time, Hrs.	MLVSS mg/l
3	16	14	1.2	360	3.5	1680
4	15	12	1.5	300	3.8	1270
16	15	10	1.2	210	4.1	1220
17	16	8	1.1	140	4.0	1000
17	14	12	0.9	220	4.1	1310
24	16	9	1.3	380	4.7	1700
24	17	16	1.0	370	4.1	1610
26	15	11	1.2	320	5.3	1100
30	14	13	1.0	380	4.9	1460

Air flows and efficiencies are the average values for both north and south passes.

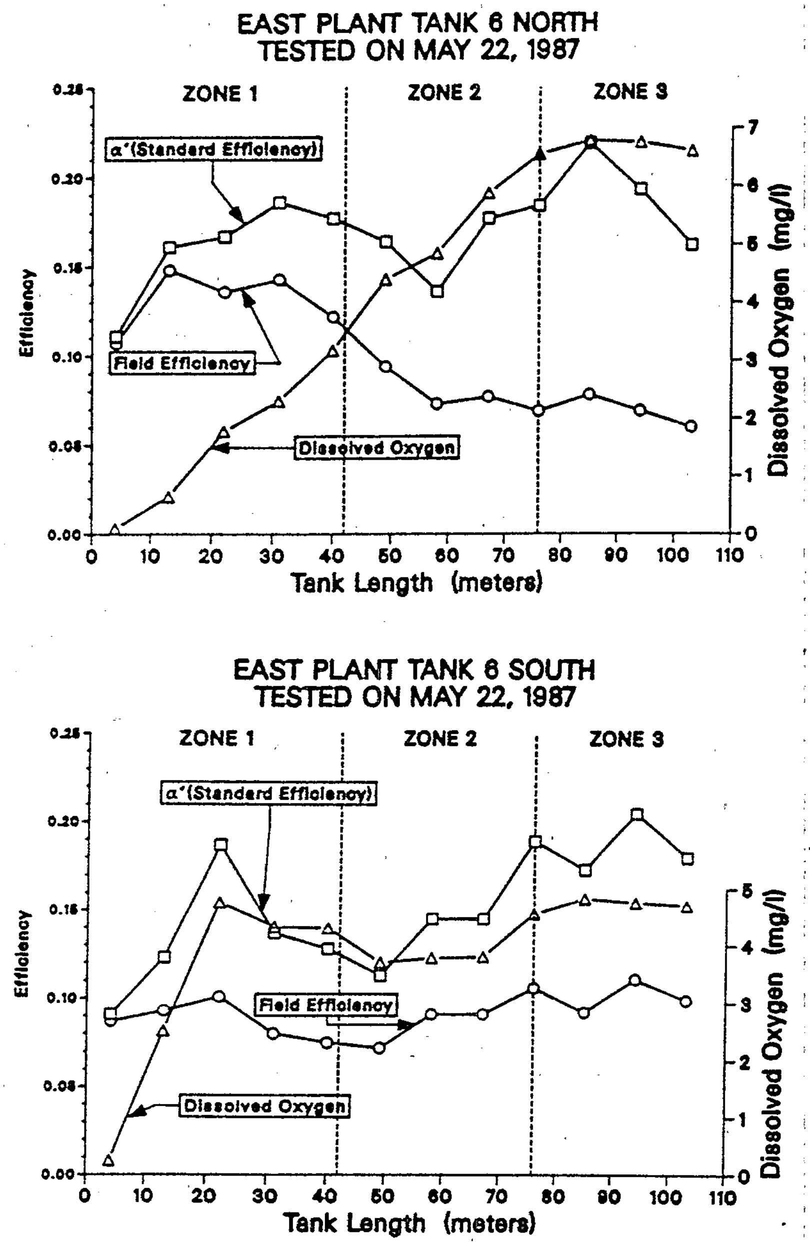


Figure 5. Oxygen transfer efficiency and dissolved oxygen concentration in Basin No. 6, May 22, 1987.

Note: Air flow to each pass was 1910 scfm, added uniformly in the north pass at 1.3 scfm per diffuser and at 1.94, 0.93 and 0.93 scfm per diffuser in the first, second and third zones of the south pass, respectively.

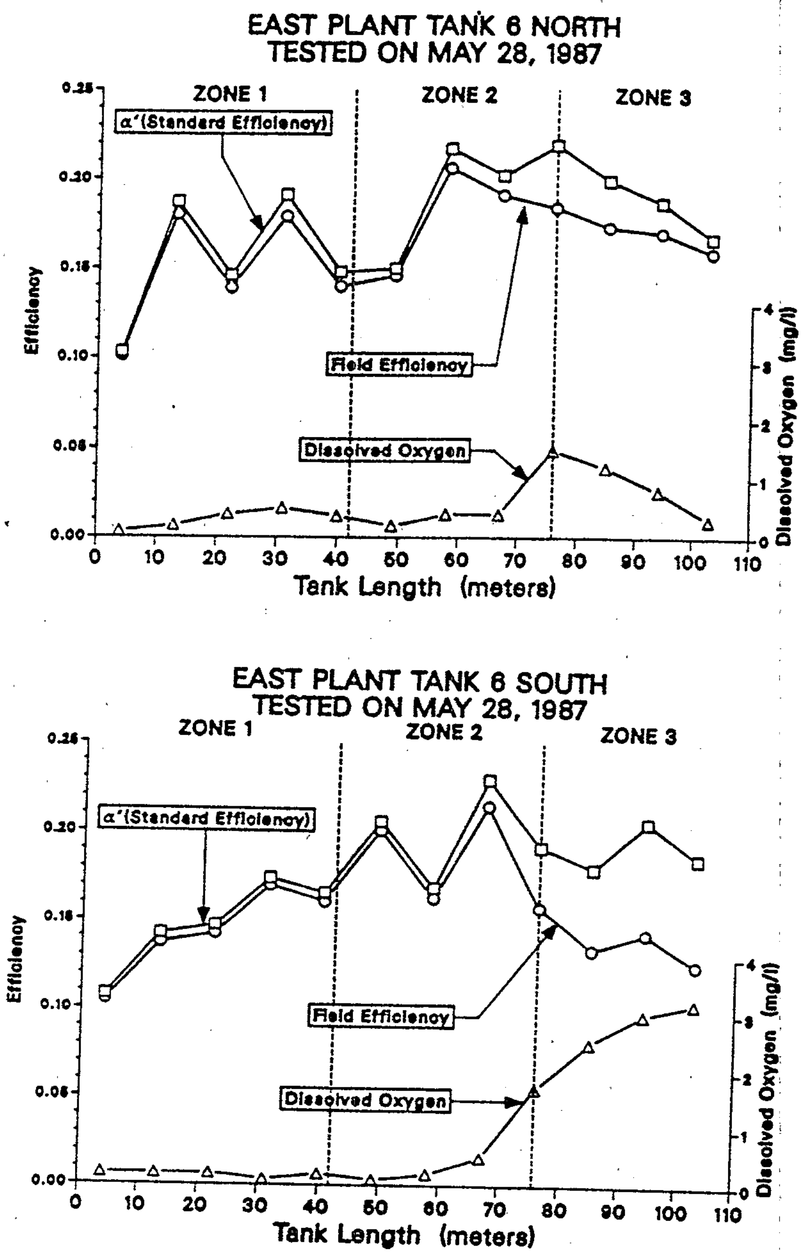


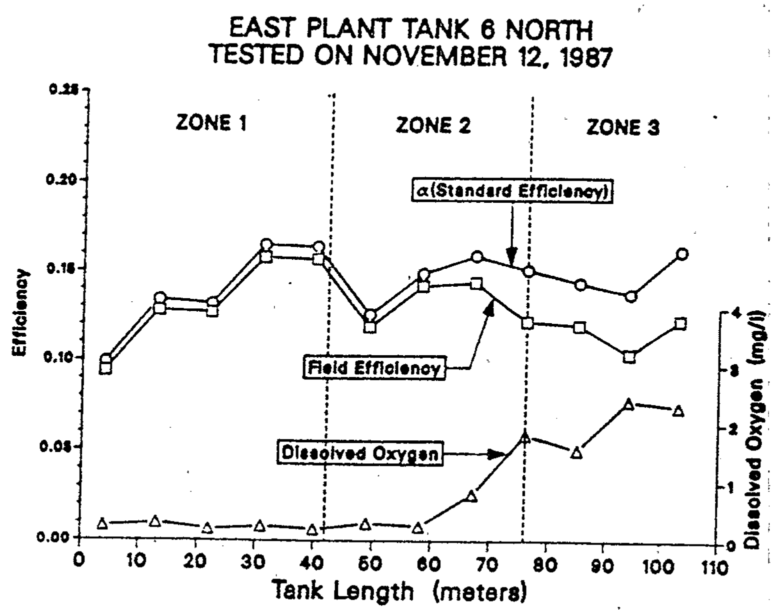
Figure 6. Oxygen transfer efficiency and dissolved oxygen concentration in Basin No. 6, May 28, 1987.

Note: Air flow to each pass was 1390 scfm, added uniformly in the south pass at 0.96 scfm per diffuser and at 1.47, 0.64 and 0.63 scfm per diffuser in the first, second and third zones of the north pass, respectively.

about 3 mg/L. For the basin with a tapered air supply it was close to zero. Several months later, when the same average air flow rate of about one scfm per diffuser was applied uniformly in both passes during a survey, the OTE and DO profiles were almost identical for both passes as shown in Figure 7.

Boyle (7) cited reports indicating decreased SOTE with increase in air flow per diffuser for various types of fine bubble diffusers. This effect was investigated for this diffuser system by measuring alphaF(SOTE) for a range of air flows at a location 4 meters from the basin inlet (where oxygen uptake rate would not limit oxygen transfer rate) and at a location 6 meters from the basin outlet (where oxygen uptake rate would probably limit oxygen transfer rate). The results of two tests at the basin inlet are shown in Tables 5 and 6. In both test series alphaF(SOTE) was constant as air flow per diffuser increased. There are several possible explanations for this finding. SOTE may have decreased at the same time as alpha increased. A more likely condition, given the absence of air flow control orifices to the individual containers, is that SOTE decreased for diffuser plates in service, but previously inactive diffuser plates were brought into service as air flow to the zone increased. This could produce the overall result that alphaF(SOTE) stayed constant.

At the basin outlet alphaF(SOTE) appeared to be constant for the range of air flows shown in Table 7. Field oxygen transfer rate and dissolved oxygen concentration also increased. While it is possible that oxygen uptake rate increased even with DO concentrations in the range of 3 to 6 mg/L, additional test runs will be needed to establish that test conditions were at steady state during the measurements.



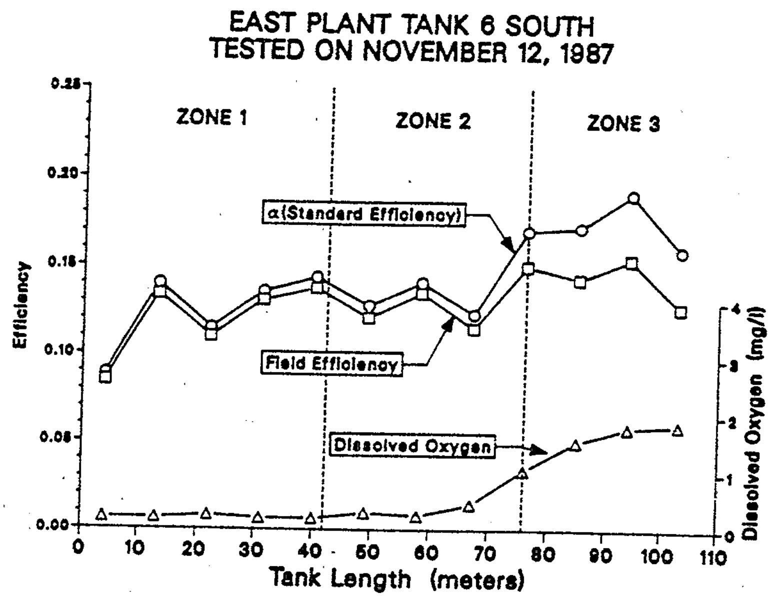


Figure 7. Oxygen transfer efficiency and dissolved oxygen concentration in Basin No. 6, November 12, 1987.

Note: Air flow to each pass was 1.09 scfm per diffuser to all three zones.

TABLE 5. OXYGEN TRANSFER MEASUREMENTS AT THE INLET, WITH A LOW OXYGEN UPTAKE RATE (1), IN EAST PLANT BASIN 6

Air Flow $scfm/ft^3$	FOTR(2) g/m^3-hr	AlphaF(SOTE) %	Dissolved Oxygen mg/l
0.34	7	8	0.2
0.68	15	8	0.3
1.02	22	10	2.0

(1) Wastewater 5-day BOD was 300 mg/l; mixed liquor volatile suspended solids concentration was 900 mg/l.

(2) FOTR = field oxygen transfer rate.

TABLE 6. OXYGEN TRANSFER MEASUREMENTS AT THE INLET, WITH A HIGH OXYGEN UPTAKE RATE (1), IN EAST PLANT BASIN 6

Air Flow $scfm/ft^3$	FOTR(2) g/m^3-hr	AlphaF(SOTE) %	Dissolved Oxygen mg/l
0.38	10	10	0.1
0.76	22	11	0.1
1.11	33	11	0.1
1.43	37	10	0.1
1.76	42	9	0.2

(1) Wastewater 5-day BOD was 290 mg/l; mixed liquor volatile suspended solids concentration was 1700 mg/l.

(2) FOTR = field oxygen transfer rate.

TABLE 7: OXYGEN TRANSFER MEASUREMENTS AT THE OUTLET (1) IN EAST PLANT BASIN 6

Air Flow scfm/ft^3	FOTR(2) g/m^3-hr	AlphaF(SOTE) %	Dissolved Oxygen mg/l
0.42	12	14	3.3
0.68	17	16	4.7
1.02	19	15	5.8

(1) Mixed liquor volatile suspended solids concentration was 1200 mg/l.

(2) FOTR = field oxygen transfer rate.

WEST PLANT

Twenty-one surveys were completed for the Jones Island West Plant. Table 8 is an overall summary of test dates, test conditions, and flux weighted average field and standard OTE values. Also shown are tank cleaning information and sludge age and loading estimates for the test dates. Table 9 contains nitrogen related data taken from plant laboratory records for the 21 test dates. Detailed information concerning treatment plant facilities and operation are included in the Overall Plant Data Sheet (Appendix B) and in the monthly averages of analytical data for Jones Island screened sewage and of operating data for the West Plant activated sludge basins. These latter data were compiled in connection with the EPA/ASCE Interplant Fouling Study (Appendix C).

Figure 8 shows two of the profiles obtained, one in August, 1985, and one in August, 1986. The first showed a DO concentration of one to three mg/L throughout most of the basin, while in the second the DO concentration never exceeded one mg/L. The flux-weighted standardized OTE values were nearly identical (11.9 and 11.8%). The form of the DO profile for the 1985 survey was quite unexpected for a tank designed for plug flow. In fact, many of the DO profiles observed were difficult to explain. Conditions that contributed to these results in many of the surveys included one or more of the following:

1. The survey schedule that sampled the middle of the basin early in the day and then moved both upstream and downstream as the load increased.

2. Operator determined changes in air flows and mixed liquor flows while surveys were in progress.

3. Severe boils or gushers where plates or pipes were damaged, starving the immediate vicinity for air and causing low OTE for the air escaping at the boil.

Diurnal Study

The results of a diurnal test at stations 2 and 14 are shown in Figure 9. The test ran from noon, September 2, to noon, September 3, 1986. The air flow to the basin was maintained at 3000 scfm. The dissolved oxygen profile was nearly flat at less than 0.2 mg/L throughout the 24 hours at station 2, while it varied between 1.0 and 2.5 mg/L, probably in response to plant loading, at station 14.

Since the collection hoods were kept at fixed locations, changes in alphaF(SOTE) were presumably the result of changes in mixed

TABLE 8. OXYGEN TRANSFER SURVEY DATA FOR THE JONES ISLAND WEST PLANT

Date	Basin Number	Time in Service (Mos.)	Cleaning Method	Airflow (scfm)	FOTE %	AlphaF(SOTE) %	Sludge Age (Days)	Loading: #BOD5 per #MLVSS - Day	Loading: #BOD5 per 1000 cu.ft.-Day
7/31/85	20	< 1	W	2200	10.4	10.9	3.1	0.60	55.8
9/12/85	6	49	W	2500	9.7	11.9	4.2	0.43	45.1
8/14/85	18	1	W	800	12.4	12.9	4.1	0.48	55.6
9/20/85	10	< 1	W	2200	12.7	13.8	4.1	0.44	46.8
8/23/85	12	1	W	2500	12.5	15.6	4.1	0.46	50.3
8/27/85	6	50	W	2500	9.8	10.7	3.4	0.63	52.7
10/14/85	8	51	W	2000	7.2	10.2	3.0	0.55	45.1
11/04/85	12	48	W	1600	8.0	12.4	2.3	0.43	28.5
11/05/85	8	52	W	2100	5.7	6.6	2.3	1.45	88.4
11/07/85	14	2	W	1300	10.3	11.3	3.2	1.00	93.4
11/14/85	16	2	W	1700	9.2	10.1	3.5	0.75	66.9
05/02/86	10	9	W	3200	9.3	10.6	4.5	0.55	80.5
05/08/86	12	10	W	3300	7.0	10.1	3.9	0.45	53.6
05/13/86	14	1	A-1	1300	12.3	13.8	3.2	0.95	93.6
06/23/86	16	2	A-1	2200	10.0	13.7	3.2	1.09	95.6
06/25/86	20	2	A-1	1400	11.6	12.3	3.4	0.76	83.8
08/11/86	6	60	W	2000	9.4	13.0	1.8	1.09	50.3
08/12/86	14	4	A-1	2200	9.4	11.2	2.2	1.97	113.3
08/13/86	16	4	A-1	2200	10.1	10.6	2.8	1.08	77.6
08/19/86	16	4	A-1	2200	11.0	11.8	3.2	0.93	73.3
08/20/86	20	4	A-1	2900	10.8	13.0	3.3	1.09	117.5

W Denotes washing with a high pressure (100 psi) hose.

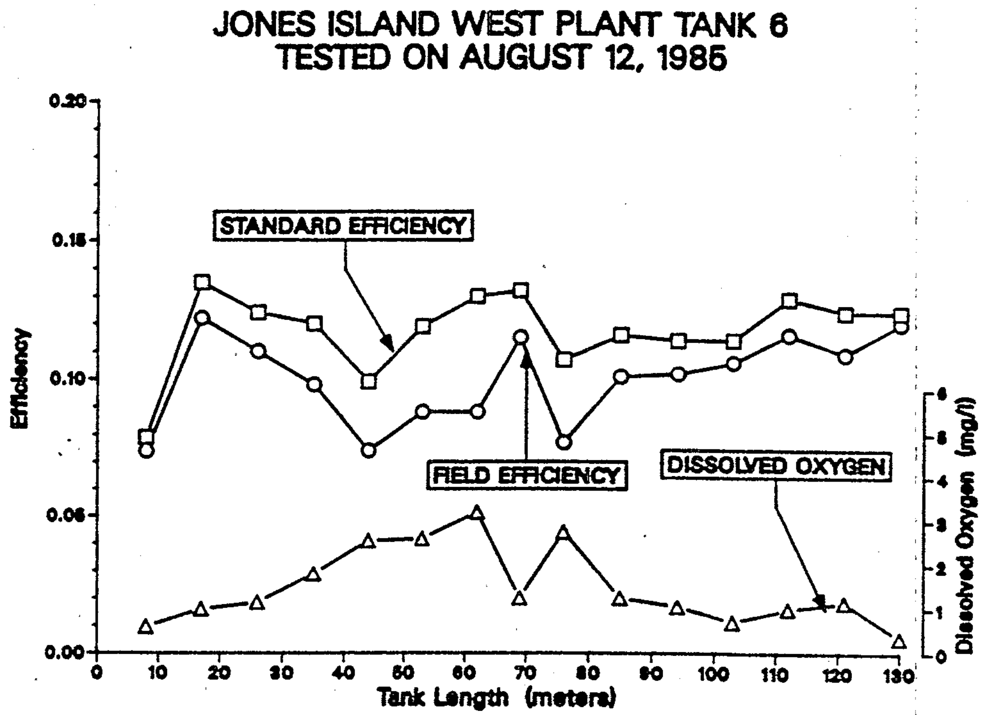
A Denotes washing followed by acid cleaning.

A-1 Indicates acid cleaning in first quarter of the tank only.

TABLE 9. SUPPLEMENTARY SECONDARY TREATMENT NITROGEN DATA FOR JONES ISLAND PLANT FOR THE WEST PLANT SURVEY DATES

Date	Screened Sewage TKN	Final Effluent TKN	NH_3	NO_2	NO_3
7/31/85	34	10	5	0.4	0.6
8/12/85	24	5	1	1.1	6.0
8/14/85	41	8	3	0.5	1.5
8/20/85	39	5	1	0.8	6.5
8/23/85	38	6	3	0.5	3.8
8/27/85	42	6	3	0.6	3.2
10/14/85	35	6	2	0.9	2.8
11/04/85	29	7	4	0.9	3.6
11/05/85	34	12	8	1.1	1.8
11/07/85	37	12	6	0.5	0.5
11/14/85	30	7	4	0.5	0.6
5/02/86	38	12	8	0.1	0.3
5/08/86	34	11	6	0.2	0.2
5/13/86	35	14	8	0.2	0.1
6/23/86	24	4	2	0.6	8.8
6/25/86	32	5	2	0.4	1.5
8/11/86	27	3	1	0.9	4.6
8/12/86	27	5	2	0.4	0.9
8/13/86	29	6	3	0.4	0.9
8/19/86	26	3	2	0.5	1.7
8/20/86	--	5	2	0.4	1.3

All values in mg/L; (-) denotes missing value; during the study period, no samples were collected for West Plant alone. Data in this table apply to the entire Jones Island Plant.



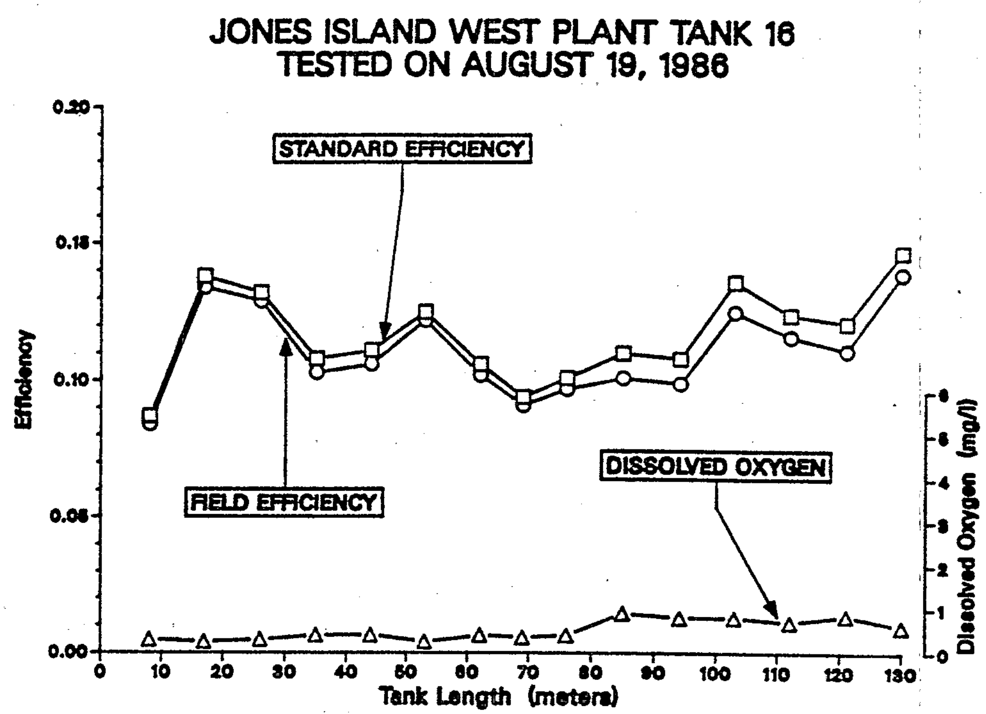
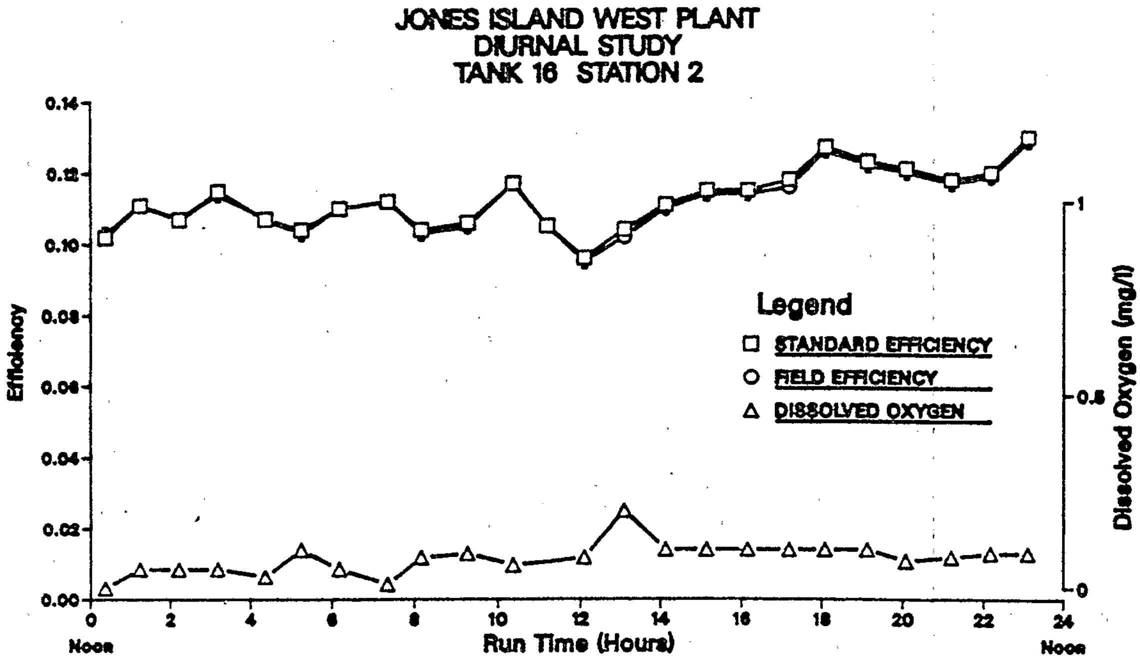


Figure 8. Oxygen transfer efficiency and dissolved oxygen concentration in West Plant Tanks 6 and 16.



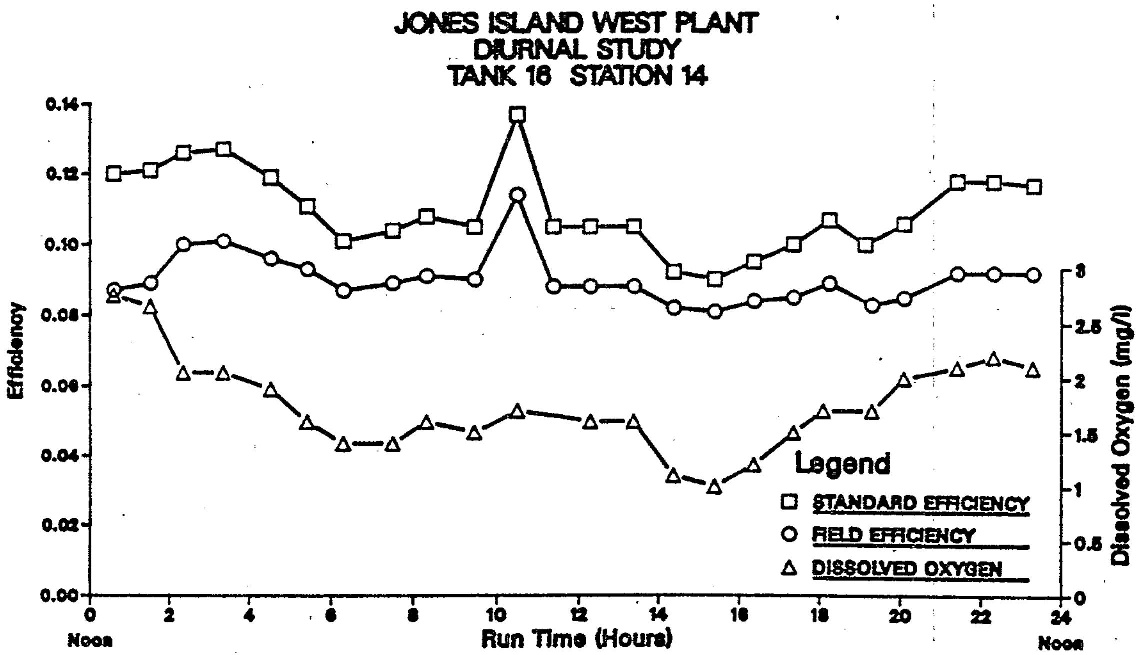


Figure 9. Diurnal test results for West Plant Tank 16 on September 2 and 3, 1986.

liquor characteristics, that is, alpha, in response to changes in plant organic loading. Although the swing was not dramatic, there was an increase in alphaF(SOTE) beginning about 6:00 a.m. at station 2 and 10:00 a.m. at station 14, a change that was consistent with the hydraulic residence time of about 4 hours during the survey.

Collection Hood Orientation

On July 3, 1986, the effect of the pattern used for the hood locations was tested in a separate set of OTE measurements in the downstream pass of Tank 20. The two hoods were moved in tandem in a "T" formation. The lead hood was positioned across the direction of mixed liquor flow (the pattern presently used) and the trailing hood was positioned in the center of the tank along the direction of flow. One hood was slightly ahead of, and the other slightly behind, the usual test locations for Tank 20 in the downstream pass.

Seven tank locations were tested in this manner. There was no significant difference ($P<0.05$) for OTE values, but the mean flux rate for the cross-tank position was nearly double the mean flux rate for the along-the-tank position. The results are shown in Table 10. The applied air rate was approximately 0.12 scfm/sq ft. The most likely explanation for the high flux rates measured in the cross-tank orientation was the presence of severe boils at two stations.

TABLE 10. HOOD POSITION TEST AVERAGE RESULTS FOR THE WEST PLANT

Hood Position	AlphaF(SOTE) %	Flux Rate scfm/sq ft.(1)
Across Tank	10.5	0.207
Along Tank	10.5	0.124

(1) The applied air flow rate was 0.122 scfm/sq ft.

DISCUSSION

The standardization of oxygen transfer efficiency under process conditions, alphaF(SOTE), has been proposed by the ASCE Oxygen Transfer Committee for characterizing performance of aeration basins equipped with fine pore diffusers (1). SOTE refers to clean water performance which is unknown in this case. Alpha is the ratio of oxygen transfer rate under process conditions to the rate in clean water. With time, diffusers operating under process conditions may suffer fouling and loss of efficiency. This effect is incorporated in the modified transfer efficiency term, alphaF(SOTE).

EAST PLANT

The average value of alphaF(SOTE) for all 30 East Plant surveys was 15.4% with a range of 11.4 to 19.2%. For the East Plant tanks the average efficiency per meter of depth was 3.6%, a very high value in comparison with the values in the interim data base presented by Brenner and Boyle (1).

Among the operating variables presented in Table 1, sludge age varied from 2.3 days to 5.8 days, air flow from 1250 scfm (0.86 scfm/diffuser) to 2500 scfm (1.72 scfm/diffuser), and time in service since previous cleaning from one month to two and a half years. The influence of these variables on efficiency was examined by applying stepwise multiple regression. With a 5% level of significance, no statistical relationship was found between any of these variables and alphaF(SOTE).

WEST PLANT

The average value of alphaF(SOTE) for 21 West Plant surveys was 11.7% with a range of 6.6 to 15.6%. For the West Plant tanks the average efficiency per meter of depth was 2.7% which, for a sludge age of 3.3 days, was quite a good value in comparison with the values in the interim data base presented by Brenner and Boyle. This performance is especially remarkable in view of the age of the diffusers of over 60 years.

Among the operating variables presented in Table 8, sludge age varied from 2.7 days to 12 days, air flow from 1300 scfm (0.55 scfm/diffuser) and 3300 scfm (1.41 scfm/diffuser), and time in service since previous cleaning from 6 months to nearly 5 years. The influence of these variables on alphaF(SOTE) was examined by applying stepwise multiple regression. With a 5% level of significance, no statistical relationship was found between any of these variables and alphaF(SOTE).

REFERENCES

1. Brenner, R.C., and Boyle, W.C., "Status of Fine Pore Aeration in the United States," In: Proceedings of the 11th United States/Japan Conference on Sewage Treatment Technology, EPA 600/9-88/010, NTIS No. PB88-214986, U.S. E.P.A. Cincinnati, Ohio, 1988.

2. Leary, R.D., Ernest, L.A. and Katz, W.J., "Full Scale Oxygen Transfer Studies of Seven Diffuser Systems," Journal WPCF, 41: 459-473, 1969.

3. Ernest, L.A. Case History Report on Milwaukee Ceramic Plate Aeration Facilities. Study conducted under Cooperative Agreement CR812167, Risk Reduction Engineering Laboratory, U.S. E.P.A., Cincinnati, Ohio (to be published).

4. Redmon, D.T., Boyle, W.C. and Ewing L., "Oxygen Transfer Efficiency Measurements in Mixed Liquor Using Off-Gass Techniques," Journal WPCF, 55:1338-1347, 1983.

5. Cooperative Agreement CR812167, Risk Reduction Laboratory, U.S. E.P.A., Cincinnati, Ohio, Manual of Methods for Fine Bubble Diffused Aeration Field Studies, Appendix A, July 1985.

6. Personal communication from David T. Redmon, Ewing Engineering Co., Milwaukee, WI September 27, 1985.

7. Boyle, W.C. (Ed.) Summary Report: Fine Pore (Fine Bubble) Aeration Systems, EPA/625/8/85/010. Prepared by the American Society of Civil Engineers (ASCE), Committee on Oxygen Transfer, New York, 1985.

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

Plant Name... Jones Island East Plant ... Location... Milwaukee, Wisconsin ...

Flow Through Secondary Treatment: Average... 82 ...MGD Max.Day... 145 ...MGD

WASTEWATER CHARACTERISTICS- BASED ON MONTHLY AVERAGES

Temperature, deg. C: Average... 17.7 ... Min... 15.3 ... Max... 19.3 ...

	Raw Influent mg/1			Sec. Effl. mg/1		
	Ave	Min	Max	Ave	Min	Max
5 day BOD	293	216	372	19.3	9.5	17.2
COD (opt)						
TSS	212	163	304	13.2	9.6	17.6
TDS	772	642	928	752	628	923
TKN	31	23	36.9	7.7	3.7	11.7
Total P	4.9	2.9	7.0	.41	.23	.83
pH (not mg/1)	7.3	6.9	7.6	7.2	6.8	7.6
Alkalinity*						
Hardness*						
Nitrate-N	--	--	--	2.3	.3	4.7

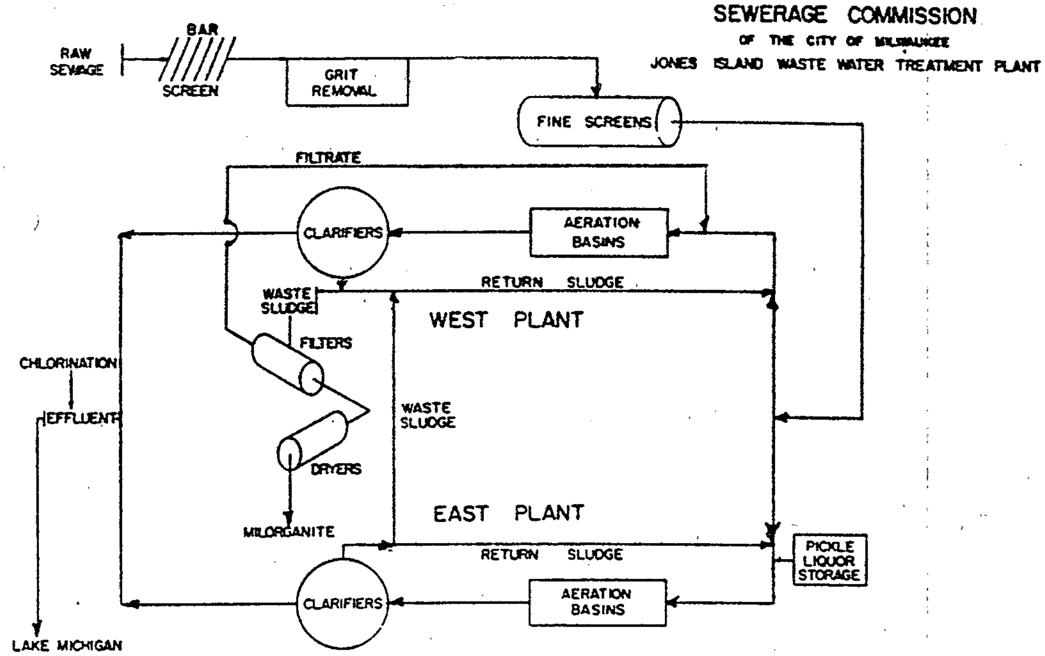
*as calcium carbonate equivalent

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

Primary Sed. Area, sq ft...--........ Final Clar. Area, sq ft...90,000.....

Aeration Tank Vol. cu ft...**........ Aeration Tank Water Depth ft...15....

** During 1985/86, the number of West Plant aeration basins in service varied from 10 to 20, depending on total plant loading and the fraction taken by the East Plant.



MAJOR INDUSTRIAL WASTES- Averages

Brewing	Flow....5.9....MGD	BOD....1655....mg/l
Machinery (including plating)	Flow....2.8....MGD	BOD....42....mg/l
Food	Flow....2.9....MGD	BOD....880....mg/l
Tanning	Flow....2.0....MGD	BOD....750....mg/l
Paper (recycled)	Flow....4....MGD	BOD....1860....mg/l

RETURN FLOWS FROM SLUDGE PROCESSING— Averages

Source	Flow MGD	BOD mg/1	TSS mg/1	TKN mg/1	pH	...
Vacuum Filter Filtrate	2.6	220	450	--	3.5-4.5	
Scrubber Water from Dryers	3	220	1200	--	6.8	

Notes: Overflow from gravity thickeners is discharged with plant effluent.

SCREENED SEWAGE
~~PRIMARY EFFLUENT~~ CHARACTERISTICS— AVERAGE INCLUDING RETURN FLOWS

Flow 57.6 MGD BOD 277 mg/1 TSS 224 mg/1 TKN 30 mg/1

TDS -- mg/1 Oil and Grease -- mg/1

PROCESS PARAMETERS— Based on Average Conditions

		+/- percent variability max. month to min. month Min.	Max.
Primary Overflow Rate, gpd/sf	--	--	--
Aeration Detention Time, V/Q	5.9	4.3	7.2
MLSS Concentration mg/1	2480	2000	3300
Ratio, MLVSS/MLSS	.70	.66	.77
MLSS Inventory 1b*			
Solids Wasting Rate, 1b MLSS/day	Cannot be calculated for West Plant alone.		
Sludge Volume Index	106	69	203
Recycle Ratio, R/Q	.42	.32	.48

Sludge Age, Days*.(Entire Jones Island Plant).3.5 2.7(min.)--4.6(max.)

F/M Ratio, per day*(West Plant) 0.51 .... 0.37(min.)--0.68(max.)
(based on MLVSS)

*estimated clarifier holdup included in solids inventory

AIR DIFFUSION SYSTEM: For Each Tank Studied. Tank Designation. South pass tanks in the West Plant

Diffusers, Type and Number. Ceramic plates (Filtros) -- 9-10 permeability, 2348 per basin.

Recommended Air Rates for this Diffuser, SCFM Min..0.9...... Max..1.95......

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

	at Min Rate	at Max Rate
Orifice Resistance, inches water	Orifice size is 1.5 inches	
Clean Diffuser, inches water	These data unavailable for West Plant.	
Dirty Diffuser, inches water (if available)		

Year Installed 1923/24 Submergence, ft..15....... Water Depth, ft.15...

Cleaning Practice and History: ....

Please see the plant history report by Larry Ernest.

Sketch of Diffuser Arrangement in Tank. Give Essential Dimensions for Diffuser Spacing and Air Distribution Piping. Indicate Tapering. Begin with Downcomer.

Please see the plant history report by Larry Ernest.

BLOWERS AND AIR SUPPLY PIPING

Blower Number	Type, Brand, Model Four stage axial vane	Year	HP	RPM	SCFM	Op. Time Hr/Year
1	Allis-Chalmers, VA904	1972	5500	4,882	110,000	46
2	Allis-Chalmers, VA904	1972	5500	4,882	110,000	5126
3	Allis-Chalmers, VA904	1972	5500	4,882	110,000	2682
4	Allis-Chalmers, VA904	1972	5500	4,882	110,000	939
5						
6						

Total Installed Blower HP 22,000 **SCFM**

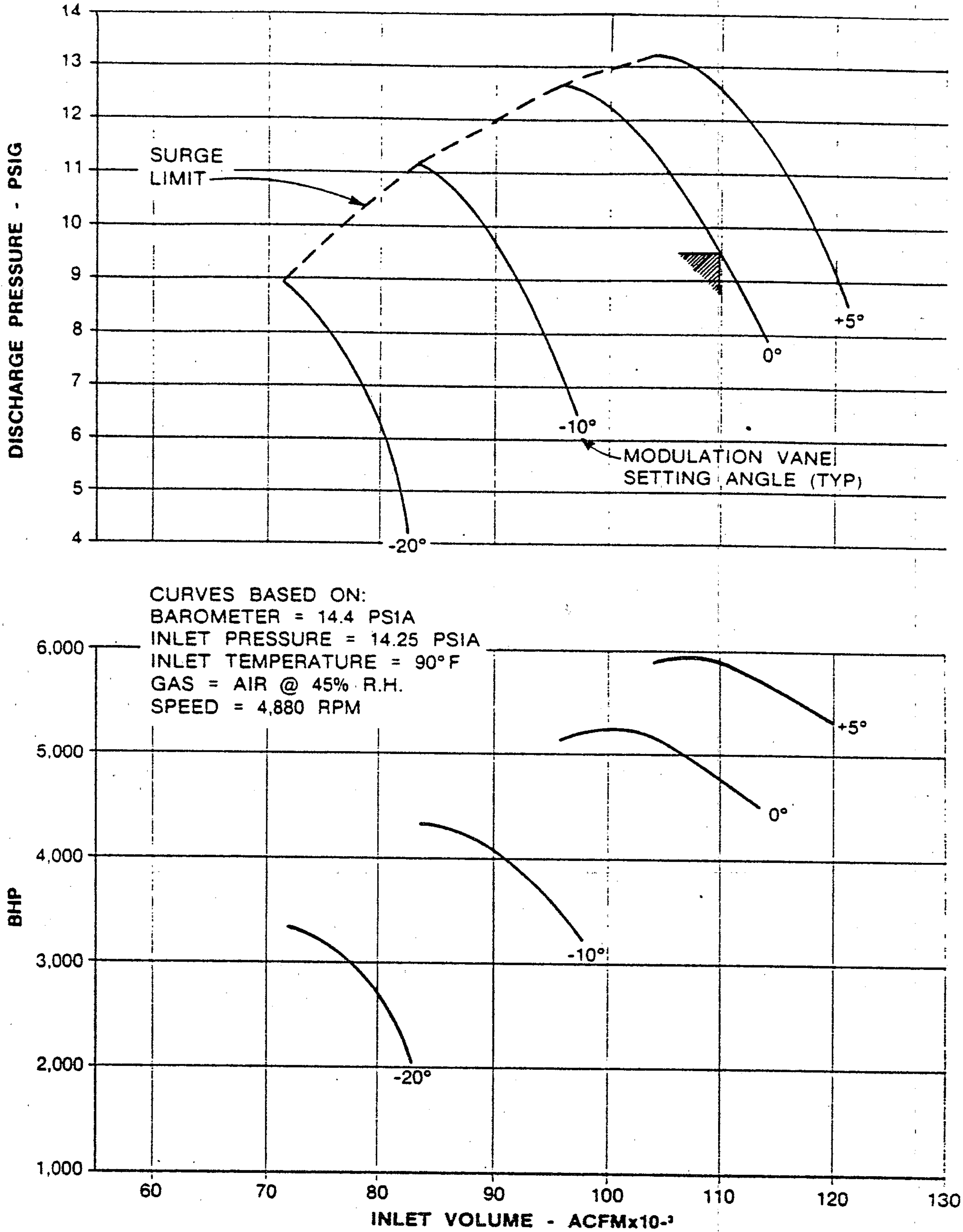
Include the Rating Curve for Each Blower if Available
SEE ATTACHED

Describe the Air Filtration System:

Air flow first goes through a media type roll filter then goes through a agglomerator followed by a bag and cartridge system before reaching compressor inlet.

Supplemental Information on Blower Drives

Drive Number	Drive Type, Brand, Model Synchronous Motor	Year	Design RPM	HP at Design RPM
1	Allis-Chalmers	1972	1,200	5500
2	Allis-Chalmers	1972	1,200	5500
3	Allis-Chalmers	1972	1,200	5500
4	Allis-Chalmers	1972	1,200	5500
5				
6				



Note: Curves based on shop test data.

FIGURE 1
ALLIS-CHALMERS PAC CURVES

Typical Blowers Used at Average Operating Conditions:

Blower Numbers..... 1 .....Total Horsepower..... 4244 .....

Measured Pressure at Blower Discharge, psi..... 7.4 .....

Measured Dynamic Wet Pressure at Diffuser, psi.............

Nominal SCFM per Diffuser....................

Typical Blowers Used at Maximum Operating Conditions:

Blower Numbers..... 1 ..... Total Horsepower..... 5180 .....

Measured Pressure at Blower Discharge, psi..... 8.2 .....

Nominal SCFM per Diffuser....................

Describe Blower Turndown Capability..............

..... 66520 scfm minimum output per blower .....

....

....

Describe Strategy Used to Manage Blowers..............

....

....

Provide a Sketch Showing the Arrangement of Blowers and Transmission Piping. If possible, Show Sufficient Detail so that Friction Loss Calculations Could be Made. Show Pipe Sizes, Lengths, Control Valves and Number of Bends from the Blowers to the Aeration Tanks.

SEE ATTACHED

Describe the Data Base for Aeration Tank Dissolved Oxygen:

Frequency of Measurement...Two or three times per shift.................

Number of Locations..Middle of second pass in alternate tanks...........

Length of Record.....Six years...

Typical Aeration Tank D.O. Values

	Maximum	Minimum
First Quarter	.....2.....	....0.....
Second Quarter	.....3.....	....0.....
Third Quarter	.....4.....	....1.....
Fourth Quarter	.....5.....	....1.....

RESULTS OF PREVIOUS OXYGEN TRANSFER TESTS AT THIS PLANT

....

....

....

....

ADDITIONAL COMMENTS

Describe the Data Base for Aeration Tank Dissolved Oxygen:

Frequency of Measurement... two or three times per shift.

Number of Locations........ one per basin (North pass only)

Length of Record........... six years

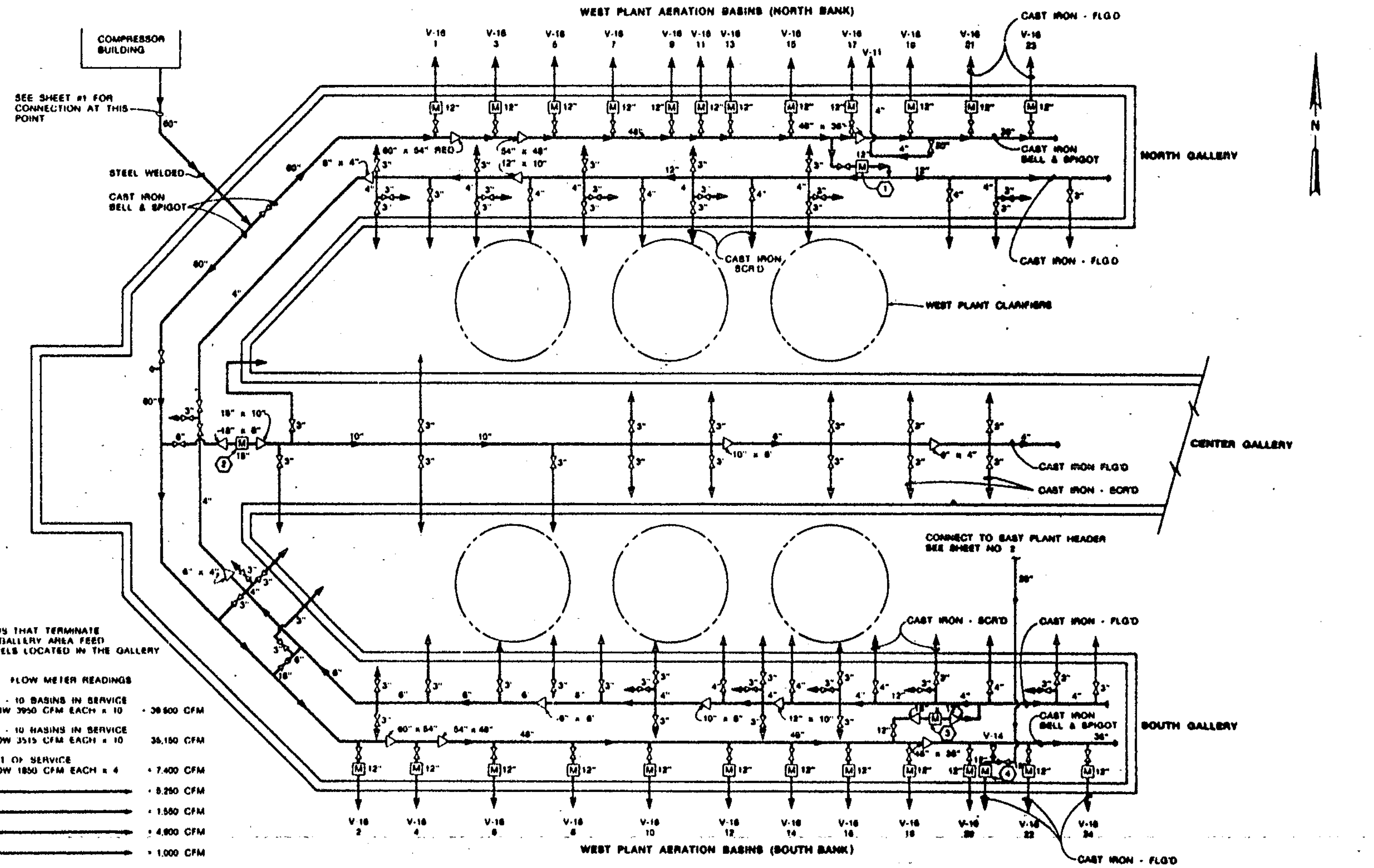
Typical Aeration Tank D.O. Values

	Maximum mg/l	Minimum mg/l
First Quarter	3	0
Second Quarter	6	0
Third Quarter	9	2
Fourth Quarter	9	3

RESULTS OF PREVIOUS OXYGEN TRANSFER TESTS AT THIS PLANT

....

ADDITIONAL COMMENTS



NOTE
FLOW ARROWS THAT TERMINATE WITHIN THE GALLERY AREA FEED FLOW CHANNELS LOCATED IN THE GALLERY

FLOW METER READINGS

NORTH BANK - 10 BASINS IN SERVICE AVERAGE FLOW 3950 CFM EACH x 10	= 39,500 CFM
SOUTH BANK - 10 BASINS IN SERVICE AVERAGE FLOW 3515 CFM EACH x 10	35,150 CFM
4 BASINS OUT OF SERVICE AVERAGE FLOW 1850 CFM EACH x 4	= 7,400 CFM
METER (1) ⟶	= 5,250 CFM
METER (2) ⟶	= 1,550 CFM
METER (3) ⟶	= 4,900 CFM
METER (4) ⟶	= 1,000 CFM
TOTAL	= 94,750 CFM

FIGURE 3
WEST PLANT PROCESS AIR DISTRIBUTION SYSTEM

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

Plant Name Jones Island West Plant Location Milwaukee, Wisconsin

Flow Through Secondary Treatment: Average 52 MGD Max.Day 107 MGD

WASTEWATER CHARACTERISTICS- BASED ON MONTHLY AVERAGES

Temperature, deg. C: Average 17.7 Min 15.3 Max 19.3

	Raw Influent mg/1			Sec. Effl. mg/1		
	Ave	Min	Max	Ave	Min	Max
5 day BOD	293	216	372	18.2	11	32.3
COD (opt)						
TSS	212	16.3	304	22.3	14.4	34.7
TDS ***	772	642	928	828	693	1005
TKN	31	23	36.9	8.8	4.2	12.7
Total P	4.9	2.9	7.0	.48	.31	.87
pH (not mg/1)	7.3	6.9	7.6	7.2	6.8	7.6
Alkalinity*	--	--	--	240	--	--
Hardness*	--	--	--	240	210	270
Nitrate-N	--	--	--	1.8	.2	4.6

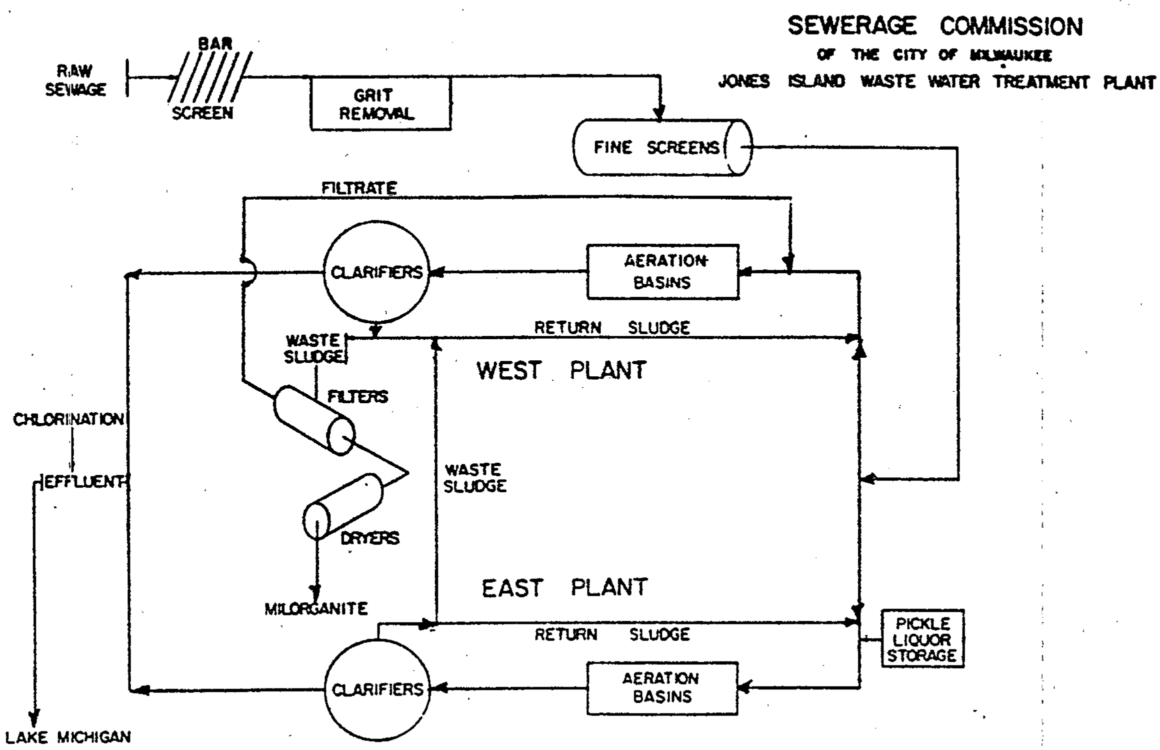
*as calcium carbonate equivalent

*** for the dates of January 1979 to November 1981

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

Primary Sed. Area, sq ft..... -- ..... **Final Clar. Area, sq ft**..... 111,000

Aeration Tank Vol. cu ft..... 5,000,000 ..... **Aeration Tank Water Depth ft**.. 14 ...



MAJOR INDUSTRIAL WASTES- Averages

Brewing	**Flow** 5.9 **MGD**	**BOD** 1655 **mg/1**
Machinery (including plating)	**Flow** 2.8 **MGD**	**BOD** 42 **mg/1**
Food	**Flow** 2.9 **MGD**	**BOD** 880 **mg/1**
Tanning	**Flow** 2.0 **MGD**	**BOD** 750 **mg/1**
Paper (recycled)	**Flow** .4 **MGD**	**BOD** 1860 **mg/1**

RETURN FLOWS FROM SLUDGE PROCESSING– Averages None

Source	Flow MGD	BOD mg/1	TSS mg/1	TKN mg/1	pH	...
....	....	....	....	....	.....	.....
....	....	....	....	....	.....	.....
....	....	....	....	....	.....	.....
....	....	....	....	....	.....	.....

Notes:

SCREENED SEWAGE
~~PRIMARY EFFLUENT~~ CHARACTERISTICS– AVERAGE INCLUDING RETURN FLOWS

Flow...82.....MGD BOD...277.....mg/1 TSS...224.....mg/1 TKN...30......mg/1

TDS...--....mg/1 Oil and Grease....--.....mg/1

PROCESS PARAMETERS– Based on Average Conditions

		+/- percent variability max. month to min. month	
		Min.	Max.
Primary Overflow Rate, gpd/sf	--	--	--
Aeration Detention Time, V/Q	6.0	4.7	9.3
MLSS Concentration mg/1	2400	1900	3300
Ratio, MLVSS/MLSS	70.6	66.4	77.2
MLSS Inventory lb*			
Solids Wasting Rate, lb MLSS/day			
Sludge Volume Index	103	64	192
Recycle Ratio, R/Q	.34	.25	.51

Sludge Age, Days*....3.3........................ 2.3 to 5.3.

F/M Ratio, per day*...0.65........................ 0.32 to 0.37
(based on MLVSS)

*estimated clarifier holdup included in solids inventory yes

AIR DIFFUSION SYSTEM: For Each Tank Studied. Tank Designation No. 6 (North or South)

Diffusers, Type and Number..1450 - square ceramic plates: 12 x 12 x 1.0 inch thick.

Recommended Air Rates for this Diffuser, SCFM Min..0.7...... Max..2.5.......

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

	at Min Rate	at Max Rate
Orifice Resistance, inches water	orifice is 1.0 inch diameter I.D.	
Clean Diffuser, inches water	As low as 6 inches at 1.0 scfm.	
Dirty Diffuser, inches water (if available)	As high as 25 inches........	

Year Installed 1983... Submergence, ft. 14....... Water Depth, ft. 14...

Cleaning Practice and History:..Hosing (100 psi) with or without acid cleaning (the Milwaukee Method)....Please see the Jones Island Wastewater Treatment Plant History Reports by Larry Ernest..................................

Sketch of Diffuser Arrangement in Tank. Give Essential Dimensions for Diffuser Spacing and Air Distribution Piping. Indicate Tapering. Begin with Downcomer.

Please see the Jones Island Wastewater Treatment Plant History Reports by Larry Ernest.

BLOWERS AND AIR SUPPLY PIPING

Blower Number	Type, Brand, Model Four stage axial vane	Year	HP	RPM	SCFM	Op. Time Hr/Year
1	Allis-Chalmers , VA904	1972	5500	4,882	110,000	46
2	Allis-Chalmers, VA904	1972	5500	4,882	110,000	5126
3	Allis-Chalmers, VA904	1972	5500	4,882	110,000	2682.25
4	Allis-Chalmers, VA904	1972	5500	4,882	110,000	939.25
5						
6						

Total Installed Blower HP 22,000 SCFM

Include the Rating Curve for Each Blower if Available

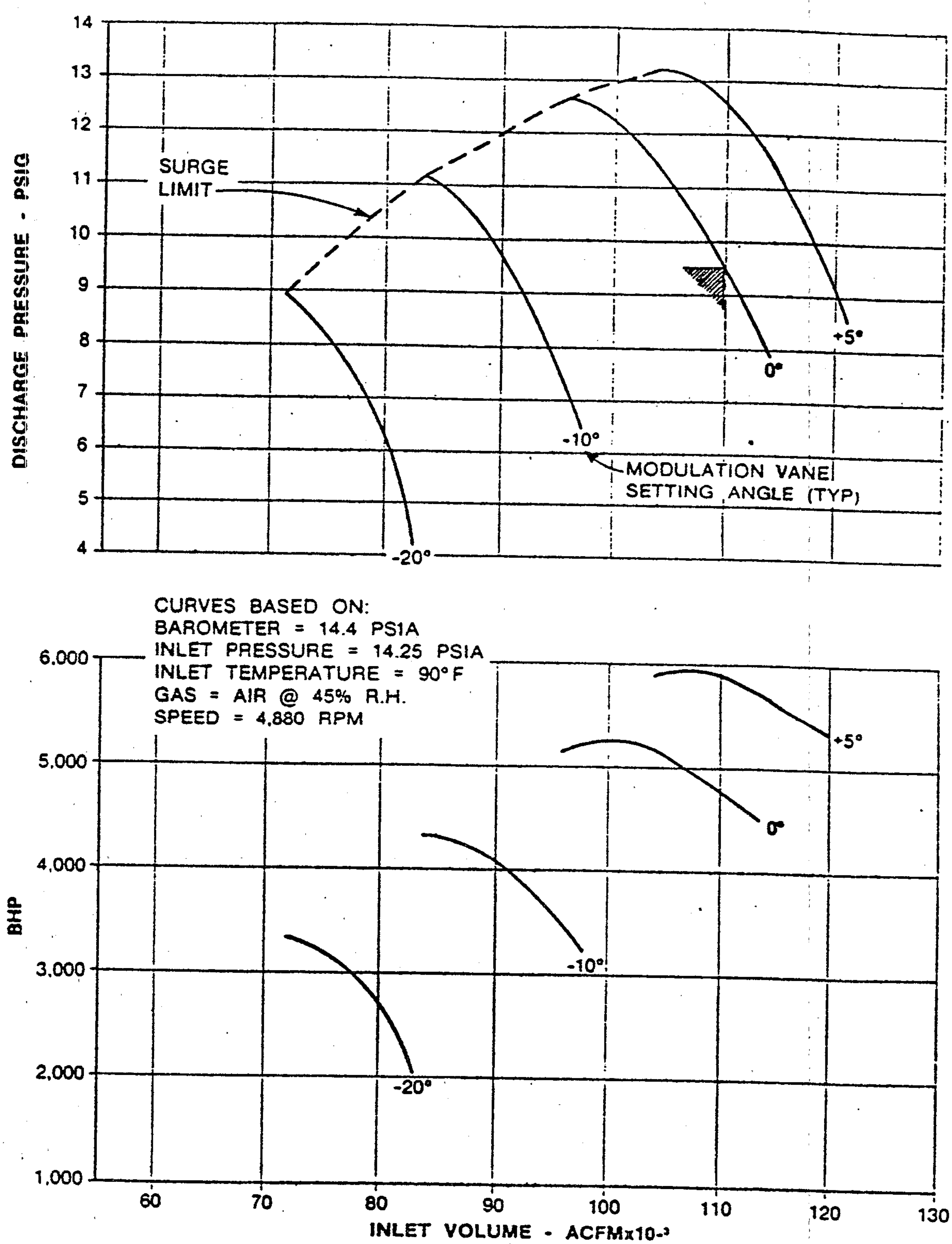
SEE ATTACHED

Describe the Air Filtration System:

Air flow first goes through a media type roll filter then goes through a agglomerator followed by a bag and cartridge system before reaching compressor inlet.

Supplemental Information on Blower Drives

Drive Number	Drive Type, Brand, Model Synchronous Motor	Year	Design RPM	HP at Design RPM
1	Allis-Chalmers	1972	1,200	5500
2	Allis-Chalmers	1972	1,200	5500
3	Allis-Chalmers	1972	1,200	5500
4	Allis-Chalmers	1972	1,200	5500
5				
6				



Note: Curves based on shop test data.

FIGURE 1
ALLIS-CHALMERS PAC CURVES

Typical Blowers Used at Average Operating Conditions:

Blower Numbers......1......Total Horsepower......4244......

Measured Pressure at Blower Discharge, psi......7.4......

Measured Dynamic Wet Pressure at Diffuser, psi............

Nominal SCFM per Diffuser..................

Typical Blowers Used at Maximum Operating Conditions:

Blower Numbers......1...... Total Horsepower......5180......

Measured Pressure at Blower Discharge, psi......8.2......

Nominal SCFM per Diffuser..................

Describe Blower Turndown Capability..................

......66520 scfm minimum output per blower......

....

....

Describe Strategy Used to Manage Blowers..................

....

....

Provide a Sketch Showing the Arrangement of Blowers and Transmission Piping. If possible, Show Sufficient Detail so that Friction Loss Calculations Could be Made. Show Pipe Sizes, Lengths, Control Valves and Number of Bends from the Blowers to the Aeration Tanks.

SEE ATTACHED

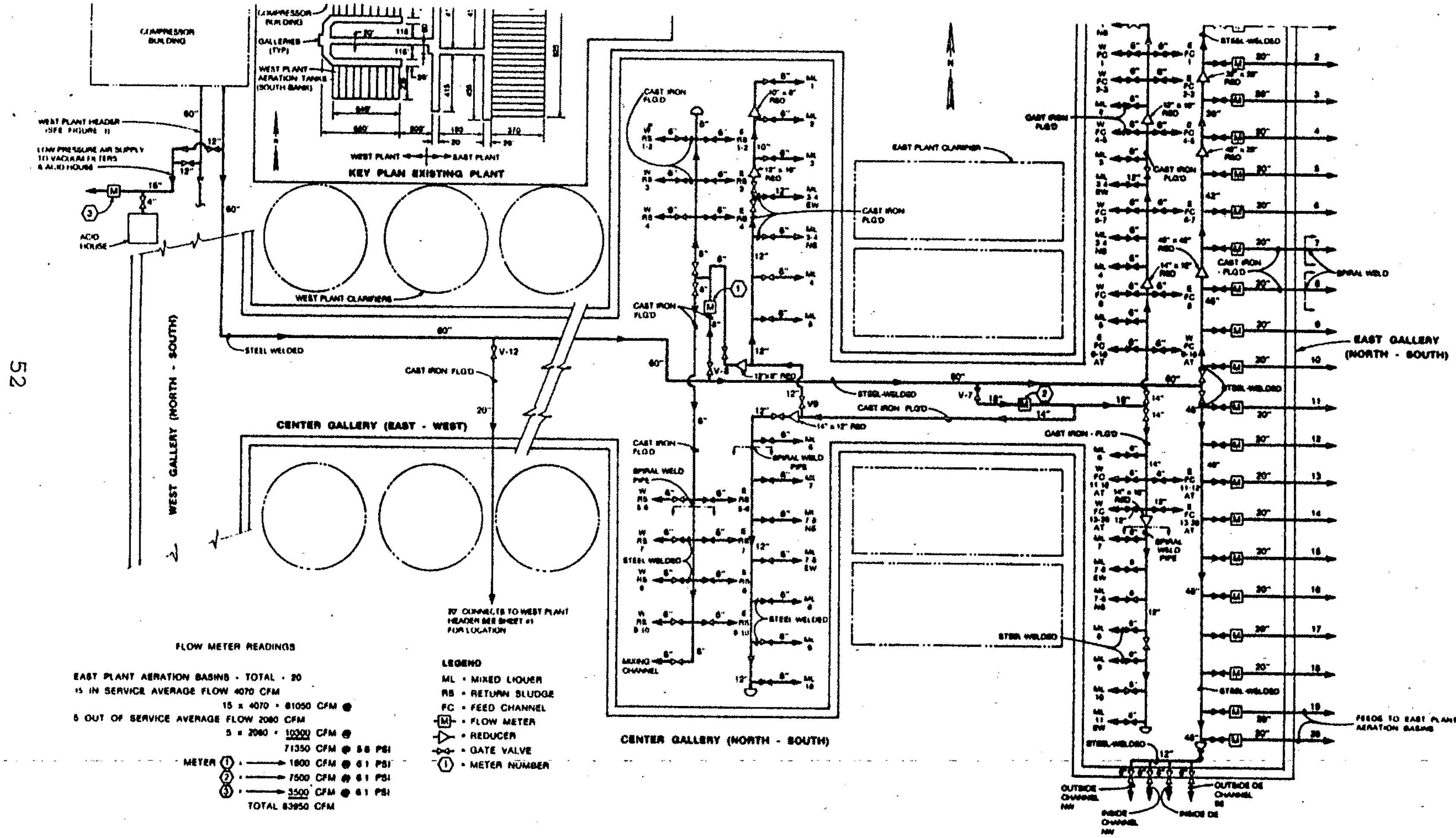


FIGURE 2
EAST PLANT PROCESS AIR DISTRIBUTION SYSTEM

APPENDIX C

JONES ISLAND SCREENED SEWAGE

MONTHLY DATA

DATE	FLOW (MGD)		5-DAY BOD (mg/1)		pH RANGE	ALK. (mg/1)	HARDNESS AS $CaCO_3$ (mg/1)	TKN (mg/1)	NH_3 (mg/1)
	MIXED LIQUOR	SCREEN SEWAGE	Tot	Sol					
June 1986	6.5	4.4	265	--	7.7-6.9	--	245	29	--
July 1986	6.1	4.2	207	113	7.5-7.0	225	--	23	--
August 1986	6.5	4.7	227	112	7.3-7.0	250	--	24	--
September 1986	7.2	5.3	181	--	7.5-7.1	--	--	21	--
October 1986	6.0	4.4	160	--	7.5-6.8	--	--	21	--
November 1986	3.0*	2.1*	213	--	8.2-6.8	--	--	28	--
December 1986	3.2*	2.0*	278	--	9.4-8.0	--	--	32	--
January 1987	5.2	3.5	330	--	8.8-7.6	--	--	46	--
February 1987	6.2	3.9	342	--	8.3-7.3	--	--	41	--
March 1987	6.7	4.3	270	--	8.4-7.5	--	--	36	--
April 1987	6.0	4.2	280	--	9.1-7.6	--	--	31	--
May 1987	4.7	3.0	280	--	--	--	--	38	--
June 1987	4.3	2.8	270	--	--	--	--	32	--
July 1987	4.7	3.5	236	109	--	243	--	28	--
August 1987	4.6	3.2	205	--	--	--	--	26	--
September 1987									

APPENDIX C

JONES ISLAND ACTIVATED SLUDGE

MONTHLY DATA FOR WEST PLANT BASIN 6

DATE	RETURN SLUDGE FLOW (MGD)	MLSS (mg/l)	RSSS (mg/l)	% VSS IN RSSS	MIXED LIQUOR pH	OVERALL (EAST & WEST) SLUDGE AGE	F/M
June 1986	2.1	2400	6200	68.6	--	3.5	.66
July 1986	1.9	2300	7000	65.8	--	3.5	.53
August 1986	1.8	2200	7600	66.4	7.3	3.4	.68
September 1986	1.9	1900	6400	66.4	7.2	3.1	.70
October 1986	1.6	1900	6500	70.2	7.5	3.3	.49
November 1986	0.9*	2500	7400	72.0	--	4.4	.23
December 1986	1.2*	2300	5700	72.6	--	3.7	.31
January 1987	1.7	2600	7500	73.6	--	4.0	.56
February 1987	2.3	3000	7800	76.1	7.4	4.6	.54
March 1987	2.4	2600	7800	74.1	7.6	3.4	.56
April 1987	1.8	2400	7500	71.3	7.6	3.0	.64
May 1987	1.7	2400	6300	69.0	7.4	3.6	.47
June 1987	1.5	2000	5600	69.9	7.3	3.5	.50
July 1987	1.2	1900	6500	70.2	7.4	2.9	.57
August 1987	1.4	1800	5400	70.0	--	2.7	.48