FOULING OF FINE PORE DIFFUSED AERATORS: AN INTERPLANT COMPARISON

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/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

There has been increasing interest in fine pore aeration systems, along with concern about diffuser fouling and the subsequent loss of aeration efficiency. The objective of this study was to assess the relative fouling tendency of fine bubble diffusers at nine activated sludge treatment plants. A secondary objective was to relate fouling to mixed liquor and process parameters. A standardized diffuser test header containing four removable diffusers was installed at each of the participating plants. Diffusers were periodically removed and tested for oxygen transfer efficiency (OTE), bubble release vacuum (BRV), dynamic wet pressure (DWP), foulant accumulation, and increase in OTE after acid cleaning.

The results of this study showed that an increase in BRV was generally accompanied by a decrease in oxygen transfer efficiency, an accumulation of foulant, and an increase in DWP loss through the diffuser. The plants were classified according to their degree of fouling (as measured by BRV). The classifications were: heavily fouling, moderately fouling, fouling, and lightly fouling. The secondary objective was to relate fouling tendency to process parameters. Observations at individual plants suggested that high organic loads enhanced fouling, although interplant comparison suggested a weak association between fouling and organic load.

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

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ACKNOWLEDGMENTS

Significant effort on the part of the professional staff at the various wastewater treatment plants examined in this study was required to coordinate the field studies and to supply operating data. Contributions of the following individuals are gratefully acknowledged: Lee Hauswirth at the Portage Lake plant, Michael Pierner, David Schauer, and Jack Boex at the Green Bay plant, Paul Nehm at the Madison plant, Read Warriner at the Milwaukee Jones Island and South Shore Plants, Jerry Ellifson at the Monroe Plant, Dan Geyer at the Frankenmuth Plant, Mike Stenstrum at the Whittier Narrows Plant, and Ed Barnhart at the North Texas Plant.

This study utilized diffuser cleaning data collected by other investigators working on the EPA - ASCE Fine Bubble Diffused Aeration Design Manual Project. Such data and information contributed by David Redmon and Lloyd Ewing of Ewing Engineering and William Boyle of the University of Wisconsin are gratefully acknowledged.

This work could not have been completed without the efforts of several students at Michigan Tech. The contributions of Janette Lutz and Ronald Mauno are especially acknowledged.

SECTION 1

INTRODUCTION

The activated sludge process is the most widely used method for secondary wastewater treatment in the United States, and its popularity is increasing. Provision of oxygen to the active organisms through aeration is the most energy intensive aspect of activated sludge process operation and consumes 60% to 80% of the total energy requirements in wastewater treatment. Moreover, the performance of the biological treatment system is intimately linked to the proper functioning of the aeration system.

Contemporary interest in effective and economical wastewater treatment systems has resulted in an emphasis on more cost-effective aeration systems. Fine pore aeration systems, while not a new technology, have the potential to achieve energy savings in wastewater treatment. One perceived problem with these systems is the uncertainty involved in estimating their maintenance costs. In operation, the fine pore aeration devices can become fouled or covered by a biophysical foulant or slime, and this condition has been associated with severely reduced aeration efficiency (Boyle and Redmon, 1983). (U.S. Environmental Protection Agency, 1985). To effectively exploit the advantages of fine pore diffused aeration equipment, design and operating engineers need information not only on clean and process water performance, but also on fouling tendency and cleaning costs.

In recognition of this need, the American Society of Civil Engineers (ASCE) and the U.S. Environmental Protection Agency (EPA) entered into a cooperative agreement to develop design information on fine pore diffused aeration. This effort included a significant emphasis on plant-scale field studies conducted to fill gaps in knowledge relative to fouling and cleaning of fine pore air diffusers. One aspect of this effort, and the subject of this report, was focused on comparing the relative fouling tendencies observed at the various wastewater treatment plants participating in the ASCE-EPA project. The objective of this study, therefore, was to assess the relative fouling tendency of fine bubble diffusers at the participating activated sludge plants. This information was useful in interpreting the results of other related studies being conducted at these plants. A secondary objective was to relate fouling to mixed liquor and process parameters.

SECTION 2

METHODS AND APPROACH

PLAN OF STUDY

The general approach relied upon installation of a standardized diffuser test header in each of the nine participating activated sludge plants. Properties of the diffusers and accumulated foulant were monitored over a period of approximately 16 months. At the same time, information on wastewater and process operating conditions was collected. Comparisons between the plants were then made to indicate the relative fouling tendencies. In addition, the data were examined for possible association of fouling tendency with wastewater characteristics and process loading parameters. Additional studies related to the significance of biofilms in the diffuser fouling phenomenon were conducted on the diffuser test header stones removed at the 12 to 16 month interval. The results of these studies are presented elsewhere (Costerton, 1988).

DIFFUSER TEST HEADER

A standardized, instrumented and removable test header containing four Sanitaire 0.22 m. (9 in.) disk diffusers was installed in each of the nine participating activated sludge plants. The test header was attached to a removable downcomer, and instrumented so that air flow could be measured and controlled. Figure 1 shows the test header and its accessories. The section of the header feeding Diffuser 1 was separated from the section of the header feeding Diffusers 2, 3, and 4. This was because the stone in Diffuser 1 was replaced at four month intervals and was expected to have less resistance to air flow than the older stones in the other diffusers. Consequently, to maintain a constant air rate to each diffuser, the air flow to Diffuser 1 was independent of the common header feeding Diffusers 2, 3 and 4.

Figure 2 is a schematic of the pressure monitoring box and and associated tubing connected to a single diffuser. Quick disconnect fittings and valves were employed so that selected color coded tubes could be connected to the pressure monitoring box. Pressure taps into the header and diffuser plenums allowed measurement of the pressure differential across the orifice. Air flow was determined from a calibration curve developed for this orifice. For example, a pressure differential of 10 cm. (4.0 in.) across the orifice indicated an air flow of 1.7 m^3/hr (1.0 cfm) to the diffuser. The air bubble pipe terminated at the level of the diffuser so that pressure drop across the diffuser was equal to the differential pressure between the plenum and the bubble pipe. This is known as the dynamic wet pressure (DWP).

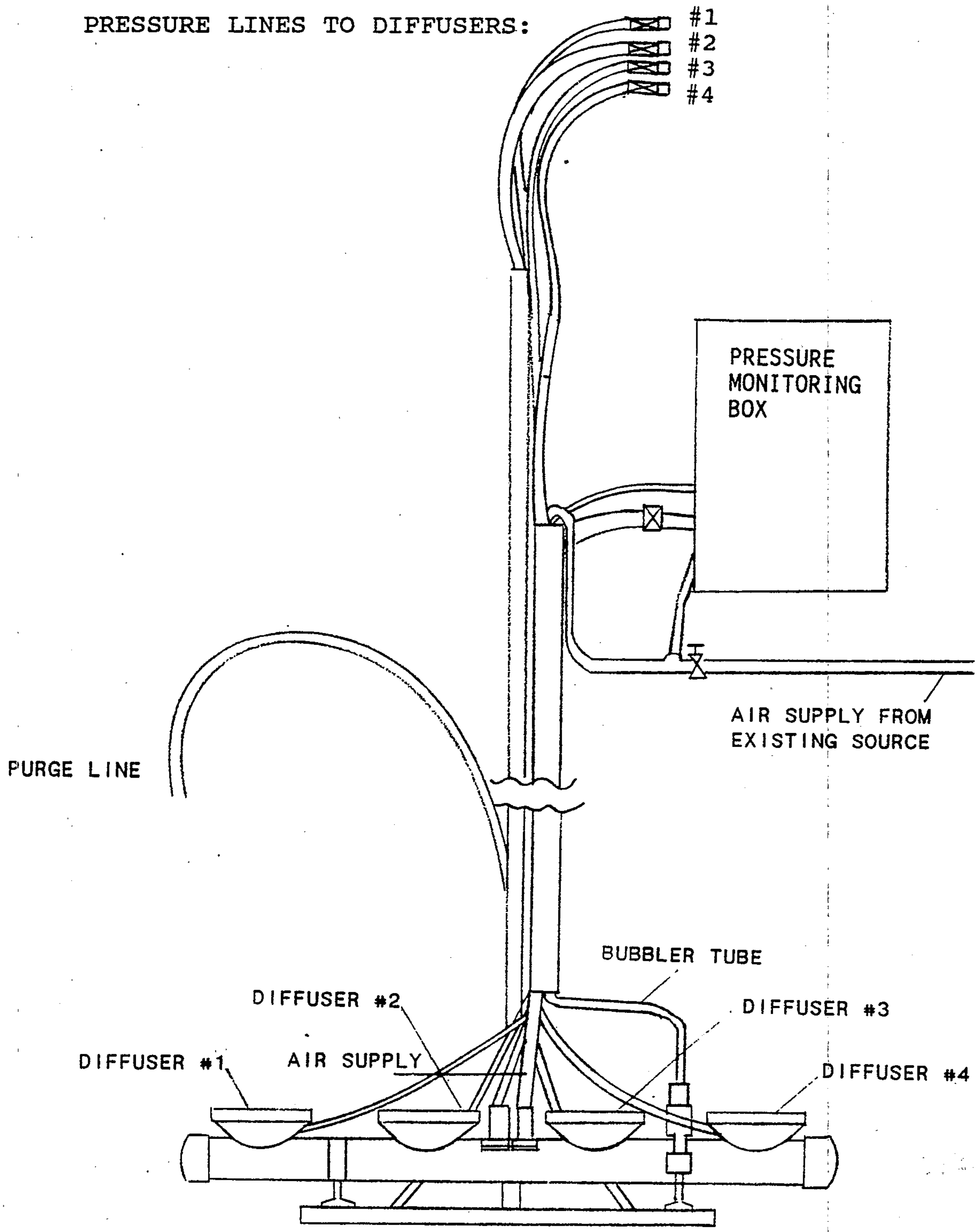

Figure 1. Sketch of test header and accessories.

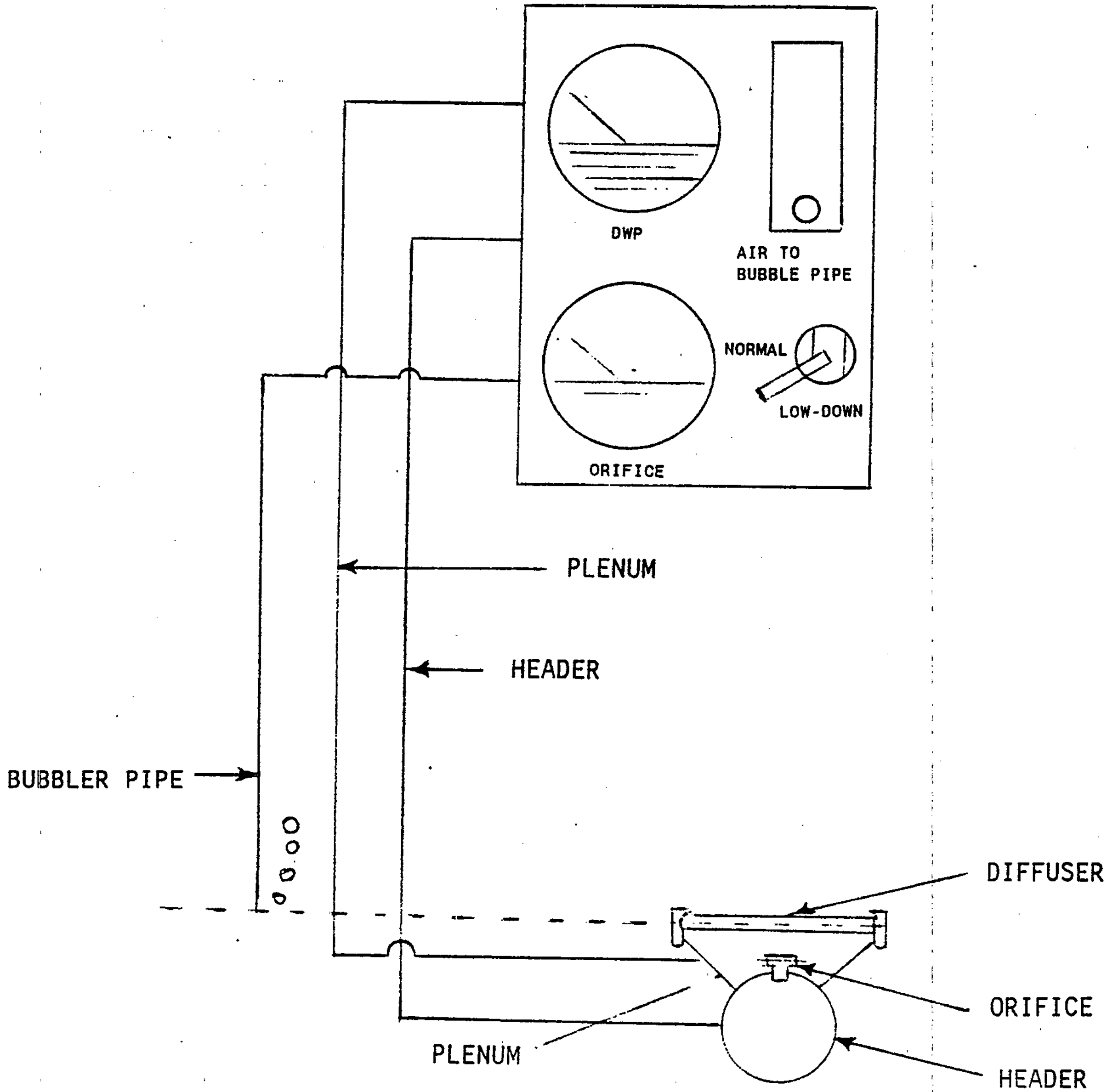

Figure 2. Sketch of test header and pressure monitoring box.

The test headers were installed so that the diffusers were at a depth of approximately 1.5 m. (5.0 ft.) and at a position in the tank which was meaningful for the assessment of fouling. The prescribed position was at the end of the first grid (in a tapered system), or at the quarter point of a plug flow tank, or anywhere in a completely mixed tank. When plant conditions made it impractical to install the pilot header at the prescribed position, the header was installed closer to the feed point.

MEASUREMENTS

The diffuser study at each plant was conducted over a period of roughly 16 months starting from the date of the test header installation. The study period was divided into phases, with each phase approximately four months long. Because of scheduling problems, the length of study at each plant was not always 16 months and the phases were not always four months in length.

Air Rates and Pressure Drops

Air rates were controlled at approximately 1.0 scfm per diffuser. This was accomplished by measuring and adjusting the flow rate at weekly intervals. At the same time, the dynamic wet pressure was recorded. The procedure was straight-forward and consisted of connecting the appropriate color-coded tubes to the pressure monitoring box, reading the desired pressure differential, and, if necessary, adjusting the air flow rate to the diffuser.

At the conclusion of each 4 month phase, dynamic wet pressures were measured at air rates of 1.0, 2.0 and 2.5 scfm, and the test header was lifted from the tank for removal and characterization of stones.

Diffuser Characterization Schedule

The diffuser removal and characterization schedule was designed so that the stones removed reflected both the incremental and cumulative effects of fouling. Thus, at the conclusion of each phase except the first, two stones were removed, one which had operated only the previous four months, and one which had operated since the beginning of the study. Normally, a routine characterization was performed on each stone removed. A special cleaning characterization was performed on stones removed at the 12 to 16 month intervals. This was accomplished by the schedule described below.

At the conclusion of the fourth month, the diffuser stone in Position 1 was removed and replaced by a new stone. The removed stone was subjected to a routine laboratory characterization for dynamic wet pressure (DWP), bubble release vacuum (BRV), foulant analysis, and flow profile. At the eighth month, the stone in Position 1 was again removed and replaced, and the stone in Position 2 was removed. The Position 2 air outlet was plugged. A routine characterization was performed on both stones. At the twelfth month, the diffuser in Position 1 was again removed and replaced, and the stone in position 3 was removed and the outlet was plugged. A routine characterization was normally performed on both removed stones. Finally, at the sixteenth month, the stones in Positions 1 and 4 were removed. A special cleaning characterization was performed on these stones. This consisted of a routine characterization for DWP, BRV, flow profile, and foulant analysis plus measurement of oxygen transfer efficiency before and after acid cleaning the stone. Certain stones removed at the 12 to 16 month periods were also studied to explore the influence of biofilm formation on fouling (Costerton, 1988)

Routine Diffuser Characterization

A routine diffuser characterization included the following:

Foulant Analysis: This consisted of scraping the foulant off the surface and analyzing for the weight of dry solids per unit area, volatile and non-volatile content, and acid solubility.

Bubble Release Vacuum: This was measured by applying a vacuum to a point on the working surface of a thoroughly wetted diffuser stone and measuring the vacuum required to withdraw bubbles at the specified flux rate from the point in question. A large number of points were sampled to obtain a distribution of BRV values and these were averaged to obtain the BRV values reported in this study. The BRV parameter is sensitive to the the effective pore diameter at any point on the surface of the stone.

Dynamic Wet Pressure: The dynamic wet pressure (DWP) test measured the pressure differential across the diffusers while operating in a submerged condition. The DWP was measured in situ during operation of the test header as well as in the laboratory during characterization. Normally, the DWP was reported at air rates of 1 and 2 SCFM. However, some of the DWP tests were reported at other air rates, and this required interpolation to obtain the DWP corresponding to the 1 and 2 SCFM.

Gas Flow Profile: The gas flow profile test measured the rate of air captured in three concentric circular areas centered over the diffuser stone. This was used to quantitate the uniformity of air release across the surface of the stone.

Details of the routine diffuser characterization procedure are given in Appendix C. Normally, this characterization was performed under the general supervision of William C. Boyle at the University of Wisconsin.

Special Cleaning Characterization.

Diffusers from the fourth phase of the study were subjected to a special cleaning characterization. This consisted of a routine characterization plus laboratory OTE measurement in clean water before and after cleaning. Cleaning was accomplished by hosing, acid application, and hosing (Milwaukee Method). In addition, the foulant ash was analyzed for elemental composition by energy dispersive spectroscopy. Details of this characterization are described in Appendix C. Normally, this characterization was performed under the supervision of David Redmon at the Ewing Engineering Laboratory in Milwaukee.

Plant Operating Data.

Throughout the study, operating data were collected by personnel at each participating plant. This information included influent and primary effluent wastewater characteristics, final effluent characteristics, and process information such as food/microorganism ratio, and sludge age.

COORDINATION

The diffuser test header was installed at the participating plants as part of other studies supported by the ASCE-EPA Fine Bubble Diffused Aeration Design Project. The investigators responsible for the various studies were responsible for collection of the test header operating data and for removal and shipment of the stones for characterization. C. Robert Baillod of Michigan Technological University was responsible for coordinating the diffuser test header studies and compiling and analyzing the data obtained from the various plants.

SECTION 3

PLANT DESCRIPTIONS

Nine municipal activated sludge plants participated in the interplant fouling comparison. Table I lists the plants along with the wastewater characteristics and typical operating conditions. The data from certain plants, such as Green Bay, and Madison were more complete than the data from other plants such as Whittier Narrows and North Texas. Appendix B summarizes the wastewater characteristics and operating conditions experienced at each plant during the fouling study.

TABLE 1. CHARACTERISTICS OF PARTICIPATING PLANTS

Plant	Average Annual		SRT (d)	Process Configuration	Industrial Contribution	
	Flow * (MGD)	BOD_5 * (mg/L)			% Flow	% BOD_5
Frankenmuth	1.47	652	15.9	CS	45	71
Green Bay	40.0	375	2.5	CS	30	50
Jones Island	58.9	278	4.0	C	11	38
Madison	13.2	87	11.0	C	6	38
Monroe	2.2	418	8.0	SF	17	50
North Texas	14.0	100	10.0	SF	NA	NA
Portage Lake	2.3	150	10.0	CS	< 5	< 5
South Shore	98.0	100	7.9	SF	6	18
Whittier Narrows	12.5	96	2.3	C	NA	NA

* Flow and BOD_5 values are for primary effluent except for Jones Island, which used fine screening and Portage Lake, which used only course screening.
CS = Contact Stabilization   C = Conventional   SF = Step Feed
** 1 MGD = 3785 m^3/d

FRANKENMUTH, MICHIGAN

This 5,560 m^3/d (1.47 MGD) contact stabilization plant includes four aeration tanks, or cells. The plant receives a substantial industrial load consisting primarily of brewery waste. The plant recycles effluent from an anaerobic digestor and filtrate from vacuum filters into the primary sedimentation tanks. Table 2 summarizes the wastewater characteristics, and Figure 3 shows a plan view of the aeration tanks.

TABLE 2. FRANKENMUTH PLANT PROCESS SUMMARY

Location: Frankenmuth, Michigan
Average Primary Effluent Characteristics:
- Daily Flow: 5,560 m^3/d (1.47 MGD)
- BOD_5: 652 mg/L
- TSS: 310 mg/L
- NH_3: 10.9 mg/l   pH: 7.0
- Temperature: 20 °C

Major Industrial Contributors: brewery and restaurants
- Fraction of Flow: 0.45
- Fraction of BOD_5: 0.71

Primary Treatment: sedimentation
Typical SRT: 15 days
Tank Dimensions (each cell, L x W x D): 13.4 m (94 ft) x 6.7 m (22 ft) x 5.01 m (16.4 ft)

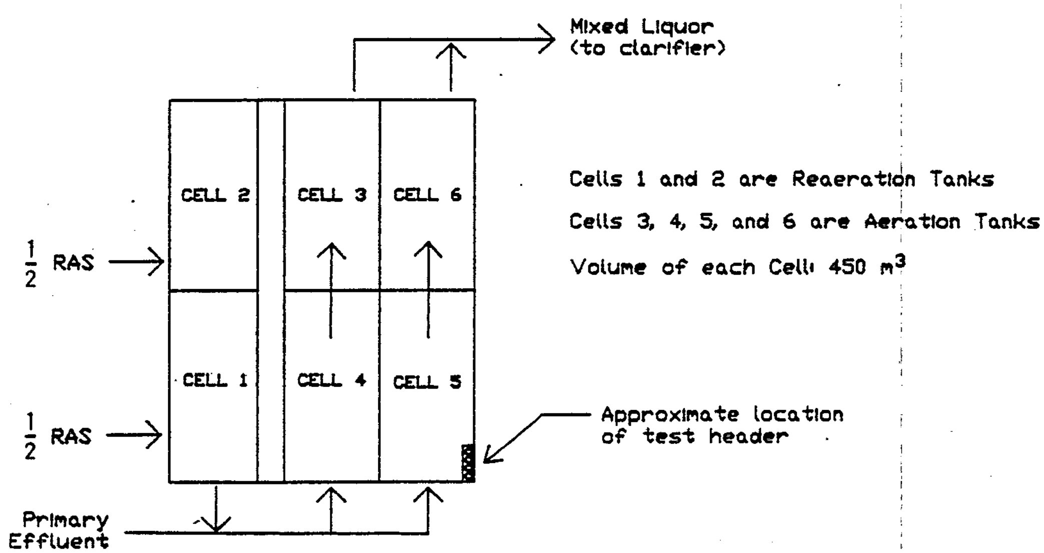

Figure 3. Frankenmuth plan sketch of Cells 1-6.

GREEN BAY, WISCONSIN

This plant consists of 4 parallel contact stabilization processes, each of which includes an aeration and reaeration tank. The plant has a thermal sludge conditioning system and recycles the thermal sludge conditioning liquor to the activated sludge process. Filtrate from the sludge filters is also recycled to the activated sludge process. Typical wastewater and process characteristics are given in Table 3. Figure 4 is a plan view of the contact and reaeration tanks of quadrant 4 showing the location of the diffuser test header.

TABLE 3. GREEN BAY PLANT PROCESS SUMMARY

Location: Green Bay, Wisconsin
Average Combined Influent Characteristics *:
- Daily Flow: 151,000 m^3/d (40 MGD)
- BOD_5: 375 mg/L
- TSS: 224 mg/L
- NH_3: 26 mg/L
- pH: 7.0
- Temperature: 25 °C

Thermal Sludge Conditioning Liquor and Sludge Filtrate:
- Average Daily Flow: 1,890 m^3/d (0.5 MGD)
- Average BOD_5: 7000 mg/L
- Average TSS: 3400 mg/L

Major Industrial Contributors: paper mills
- Fraction of Flow: 0.30
- Fraction of BOD_5: 0.50

Primary Treatment: sedimentation
Typical SRT: 2.5 days
Tank Dimensions (L x W x D): 74 m (245 ft) x 22 m (74 ft) x 6.4 m (21 ft)

* Primary effluent and mill waste.

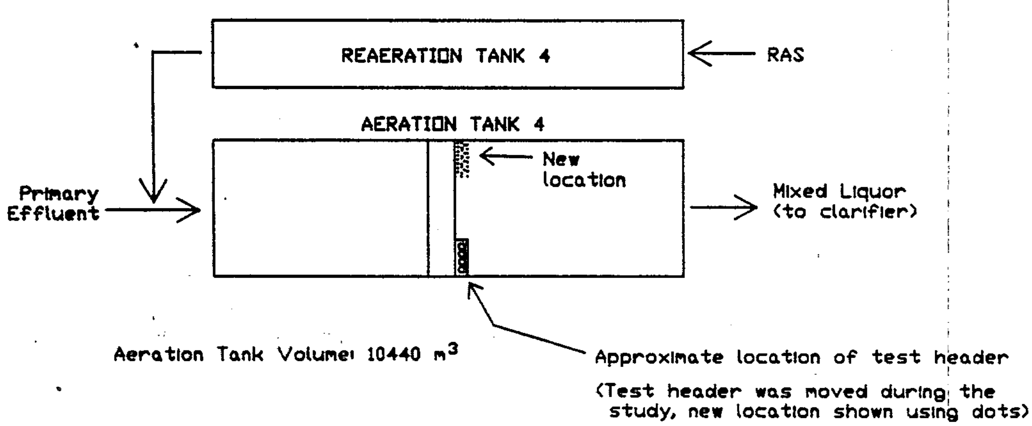

Figure 4. Green Bay Plant plan sketch of Tank 4.

JONES ISLAND WEST PLANT, MILWAUKEE, WISCONSIN

The Jones Island West Plant includes 2 batteries of 12 aeration tanks each located north and south of the secondary clarifiers. Each tank consists of two passes. The test header was installed in the first pass of Tank 6. Screened sewage is combined with recycled sludge before it flows into the aeration tanks. The plant recycles vacuum filter filtrate and scrubber water from dryers back into the activated sludge process. Characteristics of the combined recycle flows and plant influent are listed in Table 4. Figure 5 shows a plan view of Tank 6.

TABLE 4. JONES ISLAND WEST PLANT PROCESS SUMMARY

Location:	Milwaukee, Wisconsin
Average Screened Influent Characteristics *:	
Daily Flow:	222,940 m^3/d (58.9 MGD)
BOD_5:	278 mg/L
TSS:	232 mg/L
TKN:	32 mg/L
pH:	7.3
Temperature:	18 °C
Major Industrial Contributors:	breweries, food processors, tanneries
Fraction of Flow:	0.11
Fraction of BOD_5:	0.38
Primary Treatment:	fine screening
Typical SRT:	4 days
Tank Dimensions (each pass, L x W x D):	67.7 m (222 ft) x 6.7 m (22 ft) x 4.6 m (15 ft)

* Includes recycle flows

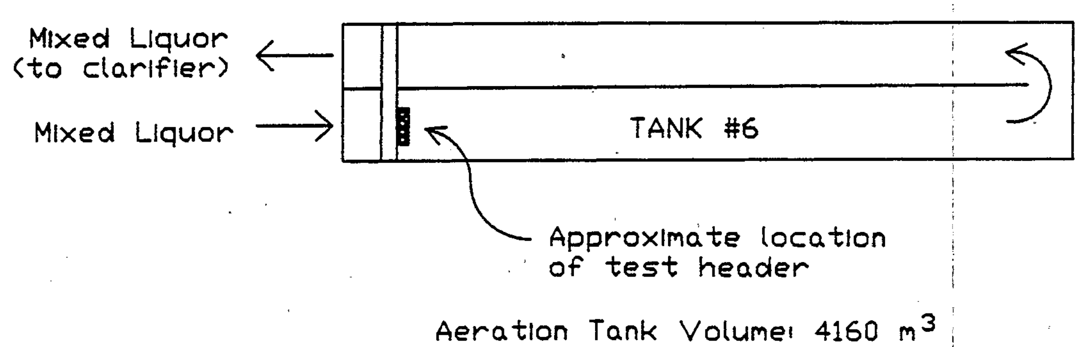

Figure 5. Jones Island West Plant plan sketch of Tank 6.

MADISON, WISCONSIN

This 151,000 m^3/d (40 MGD) activated sludge plant is divided into two sub-plants, East and West. The West Plant, in turn, is divided into Units 3 and 4. Each unit includes 1 three-pass aeration tank, and the test header was placed in the first pass (labeled Tank 24) of Unit 3. The plant normally runs at a relatively high SRT and produces a nitrified effluent. Table 4 lists some of the plants influent and process characteristics prior to the test header installation, and Figure 5 is a plan view of the Unit 3.

TABLE 5. MADISON PLANT PROCESS SUMMARY

Location:	Madison, Wisconsin
Average Primary Effluent Characteristics:	
Daily Flow (West Plant):	50,000 m^3/d (13.2 MGD)
BOD_5:	87 mg/L
TSS:	67 mg/L
NH_3:	15 mg/L
pH:	7.8
Temperature:	16 °C
Major Industrial Contributors:	meat and cheese processors
Fraction of Flow:	0.06
Fraction of BOD_5:	0.15
Primary Treatment:	sedimentation
Typical SRT:	11 days
Tank Dimensions (each pass, L x W x D):	80.8 m (265 ft) x 9.2 m (30 ft) x 5.1 m (16.7 ft)

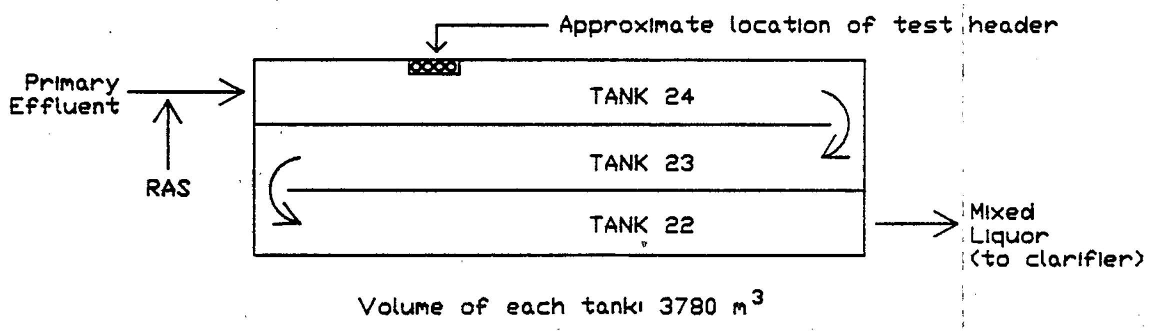

Figure 6. Madison Plant plan sketch of Unit 3 (Tanks 22, 23 and 24).

MONROE, WISCONSIN

This is an 8,330 m^3/d (2.2 MGD) plant that includes an aerated in-line equalization basin between the primary clarifiers and the aeration tanks. The equalization basin was in operation during most of the study. There are 3 two-pass aeration tanks, and the test header was installed at the end of the first pass in Tank 2. Influent is fed step-wise along the first pass. The plant receives a significant industrial load consisting primarily of soluble cheese processing and brewing wastes. Characteristics of total waste load is given in Table 6 and a plan view of the aeration basin which contained the test header is given in Figure 7.

TABLE 6. MONROE PLANT PROCESS SUMMARY

Location: Monroe, Wisconsin
Average Raw Influent Characteristics:
- Daily Flow: 8,330 m^3/d (2.2 MGD)
- BOD_5: 418 mg/L
- TSS: 212 mg/L
- TKN or NH_3: NA
- pH : NA
- Temperature: NA

Major Industrial Contributors: breweries and dairy and food processors
- Fraction of Flow: 0.17
- Fraction of BOD_5: 0.50

Primary Treatment: sedimentation plus aerated, in-line flow equalization
Typical SRT: 8 days
Tank Dimensions (each pass, L x W x D): 31.1 m (102 ft) x 7.6 m (25 ft) x 3.9 m (12.8 ft)

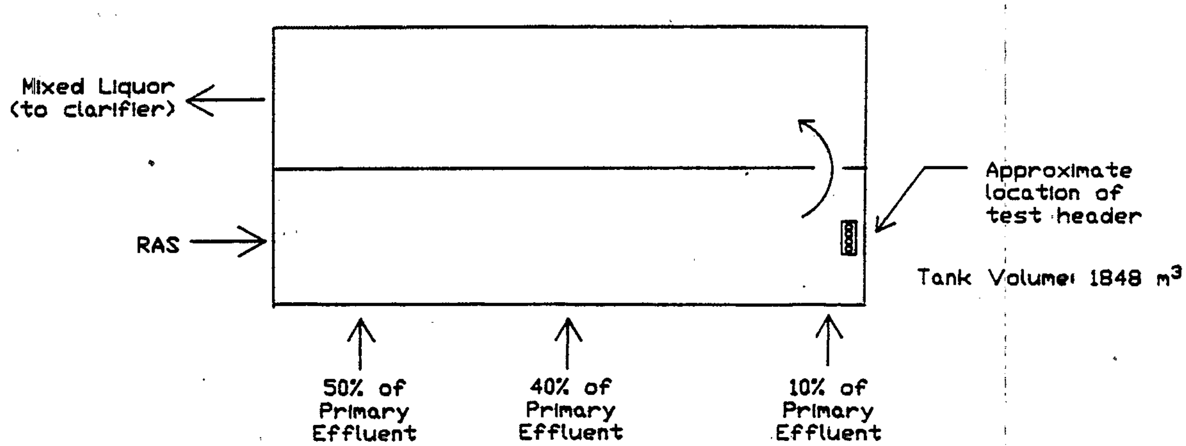

Figure 7. Monroe Plant plan sketch of Tank 2.

NORTH TEXAS PLANT, PLANO, TEXAS

This 53,000 m^3/d (14 MGD) treatment plant is located near Plano, Texas and is a combined trickling filter and activated sludge plant. Lack of information on the division of flow between the trickling filter and activated sludge portions of the plant hampered interpretation of the plant operating data. Figure 7 shows a plan view of the tank containing the test header.

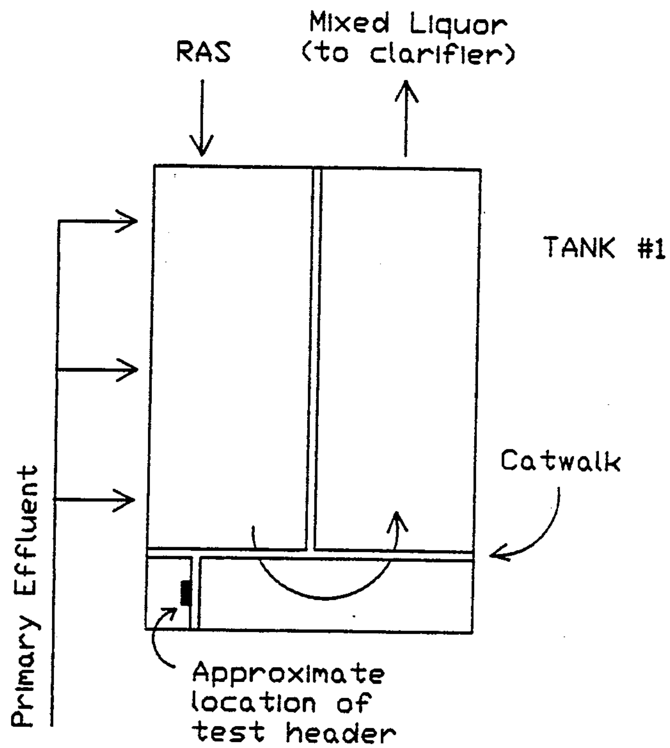

Figure 8. North Texas Plant plan sketch of Tank One.

PORTAGE LAKE PLANT, HANCOCK, MICHIGAN

This contact stabilization plant consists of two separate circular modular units, each of which includes a contact tank, reaeration tank, clarifier, and aerobic sludge digestor. Both units were in operation during the study. This plant receives a relatively low strength and low temperature influent, with almost no industrial contribution to the waste load. Table 7 summarizes typical influent and process conditions for the plant, and Figure 9 is a plan view of Unit 2, which contained the test header.

TABLE 7. PORTAGE LAKE PLANT PROCESS SUMMARY

Location: Hancock, Michigan
Average Raw Influent Characteristics:
- Daily Flow: 8,700 m^3/d (2.3 MGD)
- BOD_5: 150 mg/L
- TSS: 110 mg/l
- NH_3 or TKN: NA
- pH: 7.4
- Temperature: 16 °C

Major Industrial Contributors: none
Primary Treatment: coarse screening and preaeration
Fraction of Flow Treated by Aeration Basin Studied: 0.50
Typical SRT: 10 days
Tank Dimensions: Diameter of Clarifier: 11.9 m (39 ft)
Diameter each unit: 30 m (98.4 ft)
Depth: 4.6 m (15 ft)

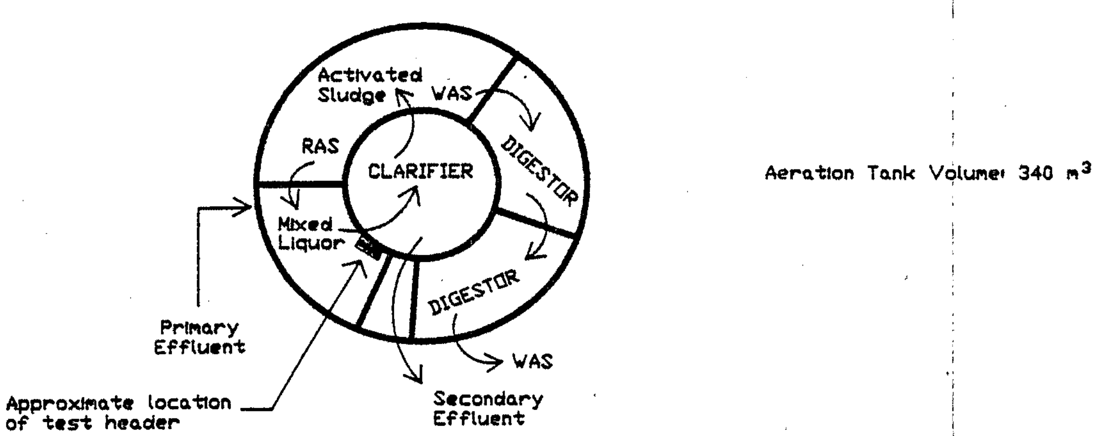

Figure 9. Portage Lake Plant plan sketch of Unit 2.

SOUTH SHORE PLANT, MILWAUKEE, WISCONSIN

This plant has 28 single-pass aeration tanks. Primary effluent is fed at the head and step-wise along both sides of each tank. The test header was located in Tank 9, approximately 27 m. (90 ft.) from the head of the tank. Typical primary effluent and process characteristics are given in Table 8, and Figure 10 shows a plan view of Tank 9.

TABLE 8. SOUTH SHORE PLANT PROCESS SUMMARY

Location: Milwaukee, Wisconsin
Average Primary Effluent Characteristics:
Daily Flow: 371,000 m^3/d (98 MGD)
BOD_5: 100 mg/L
TSS: 72 mg/L
TKN: 29 mg-N/L
pH: 7.7
Temperature: 15 °C
Major Industrial Contributors: glue processors, food processors, and machine industries
Fraction of Flow: 0.06
Fraction of BOD_5: 0.18
Primary Treatment: sedimentation
Typical SRT: 7.9 days
Tank Dimensions (each pass, L x W x D): 113 m (370 ft) x 9.1 m (30 ft) 4.6 m (15 ft)

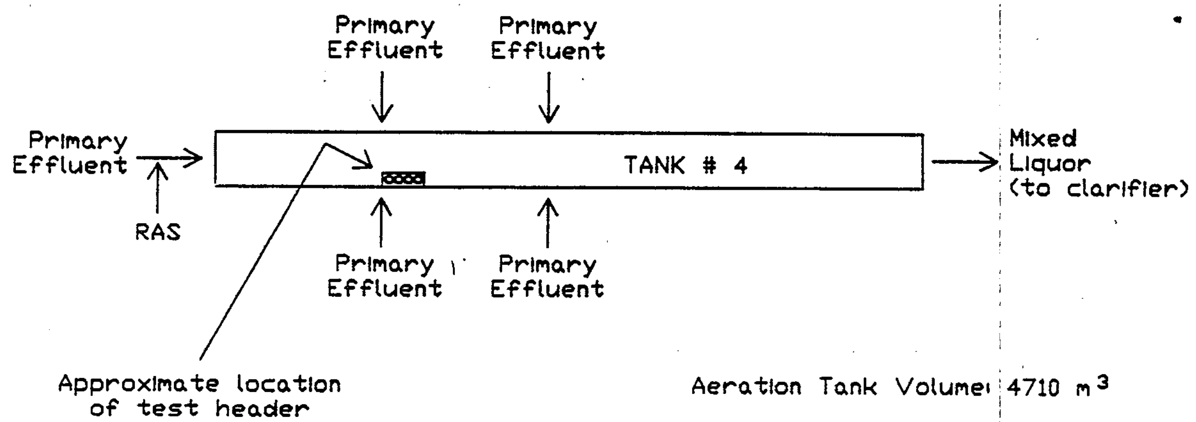

Figure 10. South Shore Plant plan sketch of Tank 9.

WHITTIER NARROWS PLANT, LOS ANGELES, CALIFORNIA

A notable feature of this plant, located in Los Angeles, is its capability to control its influent flow rate. This is possible because the plant withdraws wastewater from an interceptor sewer, and need only treat a portion of the flow. The portion not treated proceeds to another treatment facility. Because of this capability, the plant treats a relatively constant flow. Table 9 summarizes the wastewater and process characteristics, and Figure 11 shows a plan view of the aeration tanks.

TABLE 9. WHITTIER NARROWS PLANT PROCESS SUMMARY

Location: Los Angeles, California
Average Primary Effluent Characteristics:
- Daily Flow: 47,300 m^3/d (12.5 MGD)
- BOD_5: 96 mg/L
- TSS: 95 mg/l
- NH_3 or TKN: NA
- pH: NA
- Temperature: 25 °C

Major Industrial Contributors: NA
Primary Treatment: sedimentation
Typical SRT: 2.5 days

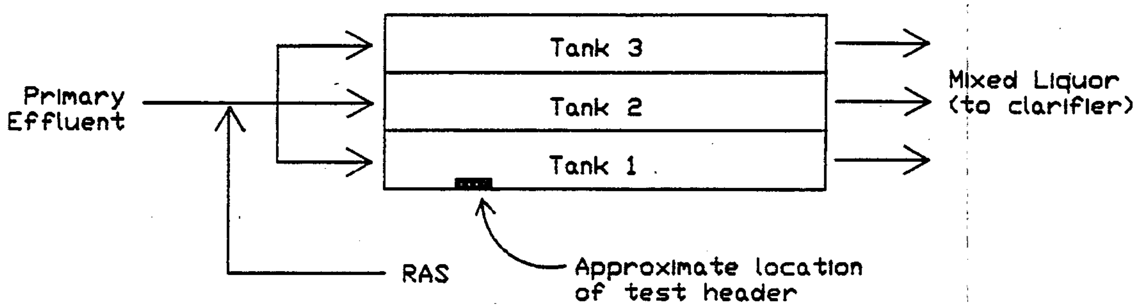

Figure 11. Whittier Narrows Plant plan sketch.

SECTION 4

RESULTS

DATA DIRECTORY

The reduced data are presented in three tables for each participating plant. These tables are titled:

(Plant Name) Summary of Diffuser Fouling

These tables list the date, elapsed time (time the characterized stone resided in the tank), field and laboratory DWP, laboratory BRV, flow profile (fraction of air flow collected in outer annular area), and fouling factor (SOTE of a fouled stone divided by the SOTE of a new stone). Table 10 is a summary of diffuser fouling for the Portage Lake Plant and is given here for illustration. Corresponding tables for the other participating plants are given in Appendix A (Tables A1, A3, A5, A7, A9, A11, and A13).

(Plant Name) Foulant Characteristics

These tables list the date, elapsed time (time the characterized stone resided in the tank), dry foulant accumulation expressed as mg/sq.cm, percent ash in the dry foulant, percent of the ash which was solubilized by hydrochloric acid, and percentages of silicon, calcium, and iron measured in the ash during a cleaning characterization. Table 11 shows the foulant characteristics for the Portage Lake Plant and is given here for illustration. Corresponding tables for the other participating plants are given in Appendix A (Tables A2, A4, A6, A8, A10, A12, and A14).

(Plant Name) Influent and Process Characteristics During the Study

These tables begin with the date and elapsed time followed by influent and process characteristics. Table 12 shows the influent and process characteristics for the Portage Lake Plant. In these tables, the elapsed time refers to the incremental time prior to the listed date. In Table 12, for example, the date 1/14/87 appears with elapsed times of 4.0 and 8.4 months. The influent and process data listed for the 4.0 month elapsed time pertain to the incremental 4.0 month period preceding 1/14/87. Likewise, the data listed for the 8.4 month elapsed time pertain to the cumulative 8.4 month period preceding 1/14/87. The cumulative period spans the time between the beginning of the study and the listed date. Corresponding tables for the other participating plants are given in Appendix B (Tables B1, B2, B3, B4, B5, B6, and B7).

TABLE 10. PORTAGE LAKE PLANT SUMMARY OF DIFFUSER FOULING

DATE	ELAPSED TIME MONTHS	FLD DWP in @ 1 SCFM	LAB DWP, in @ 1 SCFM	LAB DWP, in @ 2 SCFM	BRV in	FLOW PROFILE OUT/TOT	FOULING FACTOR
NEW DIFFUSER	0.0	5.0	5.0	5.6	5.3	0.80	NA
9/10/86	4.4	5.5	8.9	10.5	14.8	0.50	NA
1/14/87	4.0	6.0	6.5	9.0	13.5	0.70	NA
1/14/87	8.4	7.6	7.5	9.5	18.3	0.80	NA
5/21/87	4.2	9.0	6.4	9.4	13.0	0.70	NA
5/21/87	12.7	12.0	7.5	9.6	19.9	0.90	0.833
8/3/87	15.2	8.0	NA	NA	18.1	NA	NA

TEST HEADER INSTALLED: APRIL 29, 1986

TABLE 11. PORTAGE LAKE PLANT FOULANT CHARACTERISTICS

DATE	ELAPSED TIME MONTHS	MG/SQ.CM	% ASH	% Ac SOL ASH	%Si ASH	%Ca ASH	%Fe ASH
NEW DIFFUSER	0.0	0	NA	NA	NA	NA	NA
9/10/86	4.4	22	85	NA	NA	NA	NA
1/14/87	4.0	NIL	NA	NA	NA	NA	NA
1/14/87	8.4	4	78	9.7	NA	NA	NA
5/21/87	4.2	3	88	15.0	NA	NA	NA
5/21/87	12.7	2	65	13.8	16.4	3.5	13.4
8/3/87	15.2	NA	NA	NA	NA	NA	NA

TABLE 12. PORTAGE LAKE INFLUENT AND PROCESS CHARACTERISTICS DURING THE STUDY

DATE	ELAPSED TIME (mo)	RAW INFLUENT FLOW (MGD)	BOD$_5$ (mg/L)	TSS (mg/L)	BOD Loading (lb/1000 ft^3-d)	TSS Loading (lb/1000 ft^3-d)	pH	PROCESS CONDITIONS MLVSS (mg/L)	SRT (d)	F/M (1/d)	DO (mg/L)	TEMP (C)
9/10/86	4.4	0.89	122	107	75.5	66.2	7.4	1028	7.7	0.23	3.5	17
1/14/87	4.0	1.20	155	109	129.2	91.1	7.4	1463	9.4	0.28	3.0	16
1/14/87	8.4	1.05	139	108	101.1	78.7	7.4	1246	8.5	0.25	3.2	16
5/21/87	4.2	1.16	166	120	133.6	96.8	7.6	1964	8.7	0.22	** 3.0	12
5/21/87	12.7	1.08	148	112	111.1	84.3	7.4	1485	8.6	0.24	** 3.2	15
8/3/87	15.2	1.08	144	112	108.0	84.3	7.4	1514	8.5	0.24	** 2.9	15

TEST HEADER INSTALLED ON APRIL 29,1986
* Unit 2 only
** DO measurements were not taken from April 9 - June 14, 1987.
*** 1 MGD = 3785 m^3/d

DIFFUSER TEST HEADER BEHAVIOR DURING STUDY

Bubble Release Vacuum Trends

BRV data for the participating plants are plotted versus time in Figure 12. A general upward trend is evident for the more heavily fouling plants such as Jones Island and Frankenmuth, whereas a relatively constant pattern is shown for the more lightly fouling plants such as Madison and Monroe. The data suggest that the plants can be grouped as follows:

Heavily Fouling Plants: Jones Island and Frankenmuth.
BRV values increased rapidly to more than 100 cm (40 in) of water by the 12th month. These plants also tended to show high foulant accumulation with Jones Island accumulating over 150 mg/cm^2 in 13.6 months and Frankenmuth accumulating 95 mg/cm^2 in 5.3 months.

Moderately Fouling Plants: Green Bay, North Texas, and Whittier Narrows.
BRV values increased gradually but perceptibly to more than 50 cm (20 in) of water by the 12th month.

Fouling Plants: South Shore and Portage Lake.
BRV values increased somewhat but to less than 50 cm (20 in) of water by the 12th month. Foulant accumulations were less than 25 mg/cm^2 over 12 months

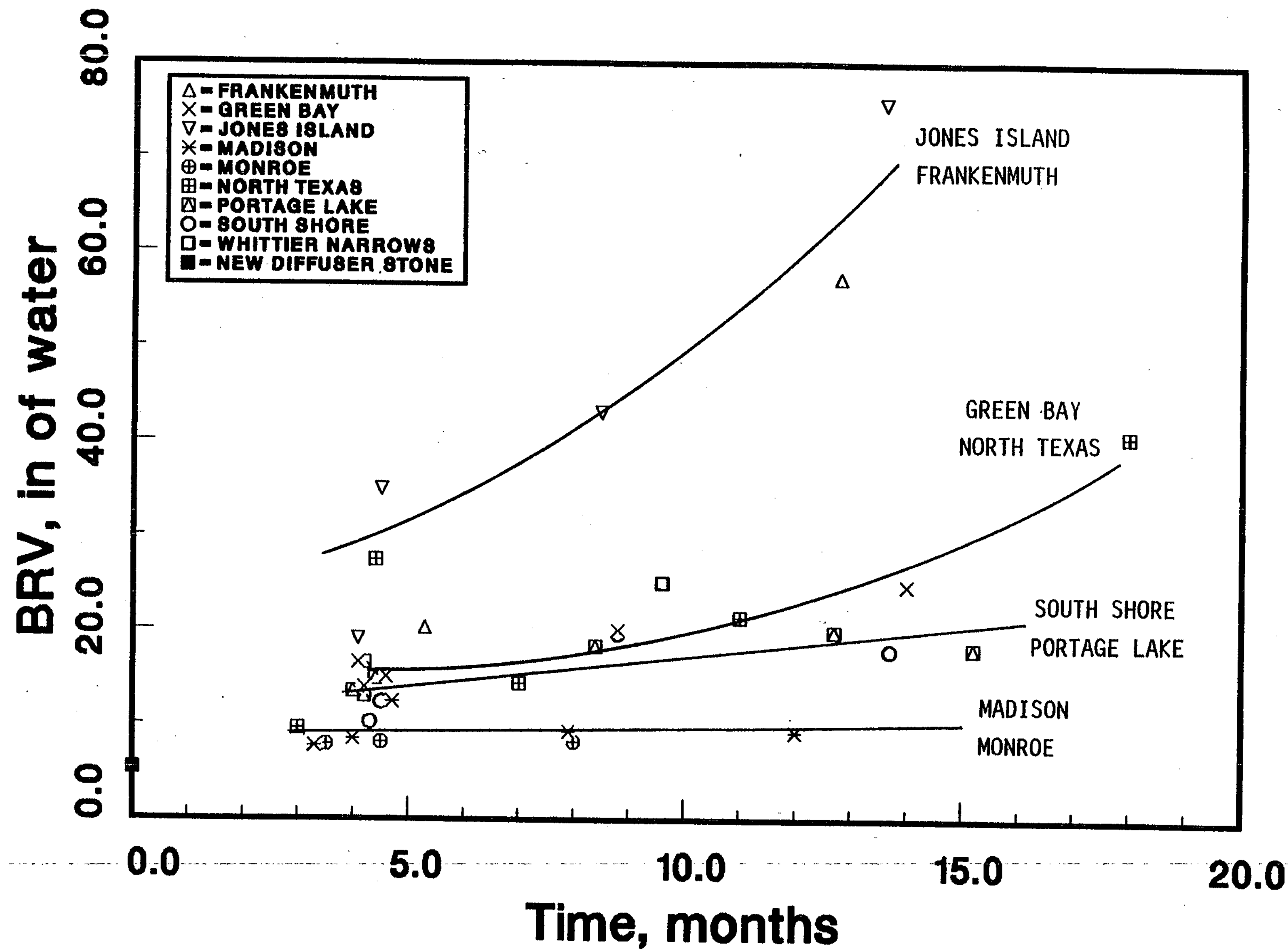

Figure 12. Trends in bubble release vacuum:

Lightly Fouling Plants: Madison and Monroe.
BRV values increased to about 25 cm (10 in) of water and then remained relatively constant. Foulant accumulations were variable but generally less than 10 mg/cm² over 12 months.

Dynamic Wet Pressure Trends

Dynamic wet pressure (DWP) data are plotted in Figure 13. A general upward trend is suggested with the plants judged to be more susceptible to fouling generally showing higher values for DWP. The exception to this observation is the Jones Island plant which exhibited an average DWP even though it was shown to be an extremely fouling plant by BRV and foulant accumulation.

Cumulative Versus Incremental Fouling

The schedule of diffuser removal and characterization was planned so that incremental fouling over four month periods might be distinguished from cumulative fouling over the entire study period. Consequently, many data points are shown at the four month time period in Figures 12 and 13. These represent the various stones removed from Position 1 on the test header at four month intervals. Based on these limited data, no consistent seasonal or incremental trend is evident. Hence, more attention was focused on the stones in the fouled condition after a cumulative period of 12 to 16 months.

COMPARATIVE ANALYSIS OF FOULING AFTER 12 TO 16 MONTHS

Table 13 is derived from the Tables in Appendices A and B and compares the characteristics of the fouled diffusers after an elapsed time of approximately 12 to 16 months along with selected plant operating parameters during the elapsed time period. Since this was a relatively uncontrolled study, care must be used in inferring cause and effect relationships from these data. Nevertheless, it is useful to examine these data for reasonable associations.

Relationship between Fouling Factor and BRV

Figure 14 shows the relationship between BRV and fouling factor, computed from SOTE measurements made on clean and fouled stones. Several SOTE measurements were also made on stones after acid cleaning and, in nearly all cases, the stones were restored to within 5% of the SOTE for a new stone.

Figure 14 shows that the fouling factor is reasonably well correlated with BRV (correlation coefficient = - 0.88). This is understandable as it was shown earlier that the plants which accumulated the most foulant had the highest BRV values. The heavily fouling and moderately fouling plants showed fouling factors ranging from about 0.55 to 0.74 whereas the fouling and lightly fouling plants showed fouling factors ranging from 0.83 to 0.99. Based upon these data and reasoning, BRV can be accepted as a measure of fouling.

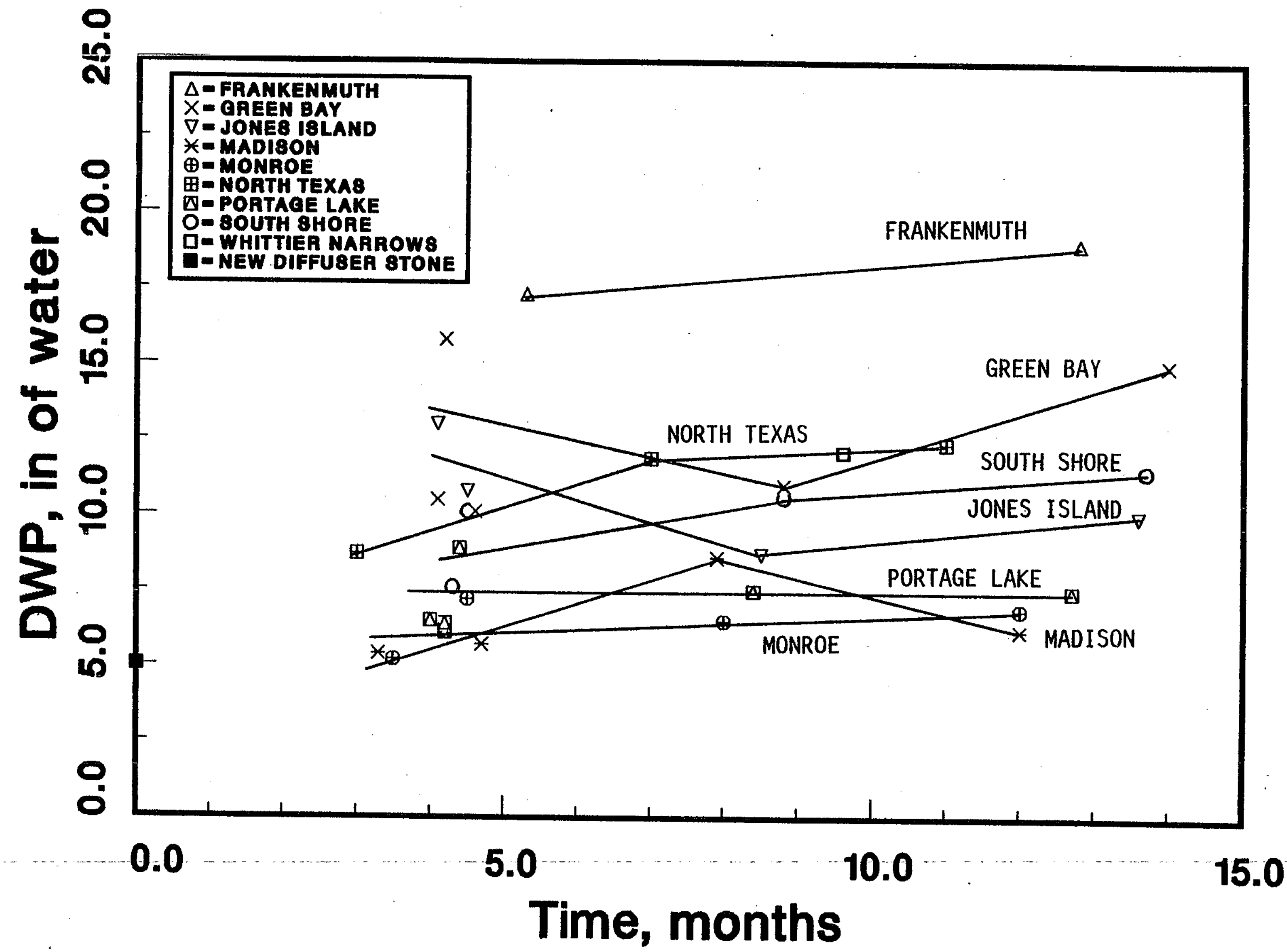

Figure 13. Trends in dynamic wet pressure..

TABLE 13. COMPARISON OF DIFFUSER CHARACTERISTICS AND PLANT OPERATING DATA

PLANT	ELAPSED TIME (mo)	FOULING FACTOR	FOULANT (g/cm^2)	FOULANT (%Volatile)	BRV (in)	DWP @1 SCFM (in)	DWP/BRV	F/M (1/d)	SRT (d)	BOD Loading ($lb/10^3 ft^3$-d)	TSS Loading ($lb/10^3 ft^3$-d)
Frankenmuth	12.8	0.737	0.096	11	57.3	19.0	0.33	0.14	14.4	95.5	46.2
Green Bay	14.0	0.714	0.030	8	24.8	15.0	0.60	0.48	3.1	146.1	78.0
Jones Island	13.6	0.555	0.152	14	75.7	10.0	0.13	0.53	3.6	53.7	NA
Madison	12.0	0.989	0.007	52	9.3	6.2	0.67	0.12	17.6	21.2	15.6
Monroe	12.0	0.976	0.003	55	9.3	6.9	0.74	0.32	7.4	77.4	NA
North Texas	11.0	NA	0.029	4	21.4	12.4	0.58	NA	10.0	NA	NA
Portage Lake	12.7	0.833	0.002	35	19.9	7.5	0.38	0.24	8.6	111.1	84.3
South Shore	13.7	0.994	0.023	24	18.0	11.5	0.64	0.36	5.8	25.0	NA
Whitter Narrows	9.6	0.896	NA	NA	25.0	12.1	0.48	0.67	2.2	28.7	28.1

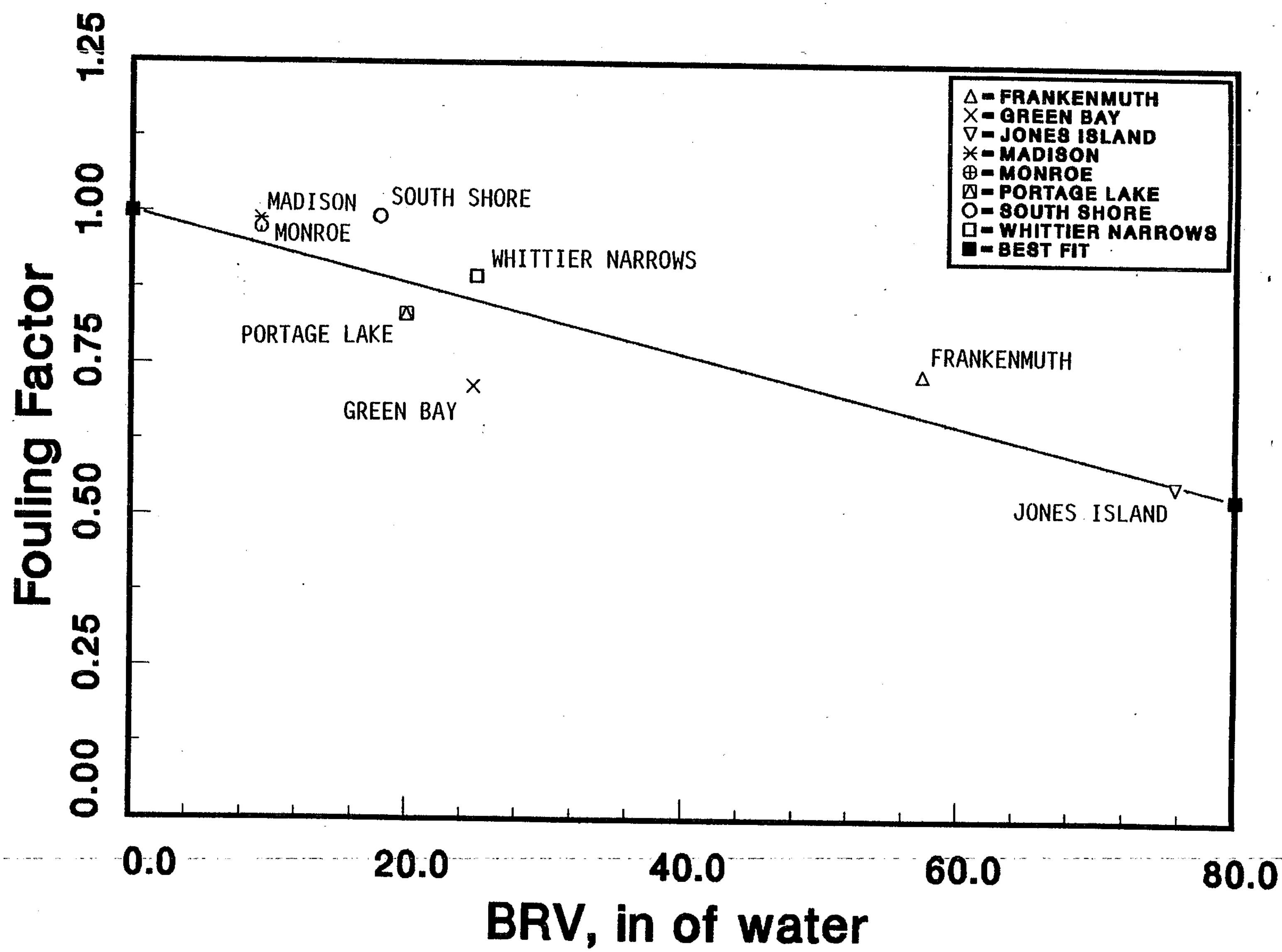

Figure 14. Relationship between BRV and fouling factor.

Relationship between BRV and Loading Parameters

It is interesting to explore the association between fouling, as measured by BRV, and activated sludge loading, as measured by the Food/Micro-organism ratio (F/M) or solids retention time (SRT). Here, F/M is expressed as mass of 5 day BOD fed/day per unit mass of mixed liquor volatile suspended solids (MLVSS), and SRT is determined as the mass of MLVSS in inventory divided by the mass of MLVSS wasted per day. Figure 15 shows the relationship between BRV and SRT, and Figure 16 shows the corresponding relationship between BRV and F/M. In each case, an understandable association is weakly suggested by the lines of best fit. However, the correlation coefficients are low (-0.52 for BRV vs. SRT, and 0.24 for BRV vs. F/M). In both associations, the Jones Island and Frankenmuth plants appear to behave differently than the other plants. The DWP/BRV ratio given in Table 13 also indicates different diffuser behavior at the Jones Island and Frankenmuth plants. Both the DWP and BRV tests measure bubble release pressure, and for a new stone the average DWP/BRV ratio will be close to 1.0. As the stone becomes fouled, this ratio will be less than 1.0. The DWP/BRV ratio for the Jones Island and Frankenmuth plants at 12 months are 0.13 and 0.33, respectfully. These are the lowest ratios among the nine plants studied, thus supporting the conclusion that these are the heavily fouling plants.

Relationship between BRV and Percent Volatiles in Foulant

Figure 17 explores the relationship between BRV and percent volatile solids (100% - ash%) in the foulant. Based on these data, it appears that foulant high in inorganic ash and low in organics is conducive to deleterious fouling. It appears that a foulant low in organics is a necessary, but not sufficient condition for deleterious fouling.

DISCUSSION

The reasons for the robust fouling observed at the Jones Island and Frankenmuth plants are not entirely clear. A possible contributing factor is that Jones Island was receiving an undetermined amount of additional waste activated sludge by tank truck from the South Shore plant. This could have provided inorganic particulates to the foulant matrix. The Frankenmuth waste contained the highest BOD_5 concentration (652 mg/l, much of which is soluble) and industrial contribution (71% of BOD_5) of the participating plants, and this appears to have stimulated fouling. Another possible contributing factor was the location of the test headers at the head of the tanks. Both Jones Island and Frankenmuth had their test headers placed within a few meters of the inlet. The combination of the each plant's waste characteristics and locating the headers at the tank inlets may have contributed to the heavy diffuser fouling.

Previous studies (EPA, 1985)(Reith, 1985) have observed severe fouling problems at the Madison and Monroe plants. Yet, in this interplant comparison, both plants showed only light fouling tendencies. Likely contributing factors to the lessened fouling tendency at Monroe are the incorporation of aerated in-line equalization and the addition of ammonia to

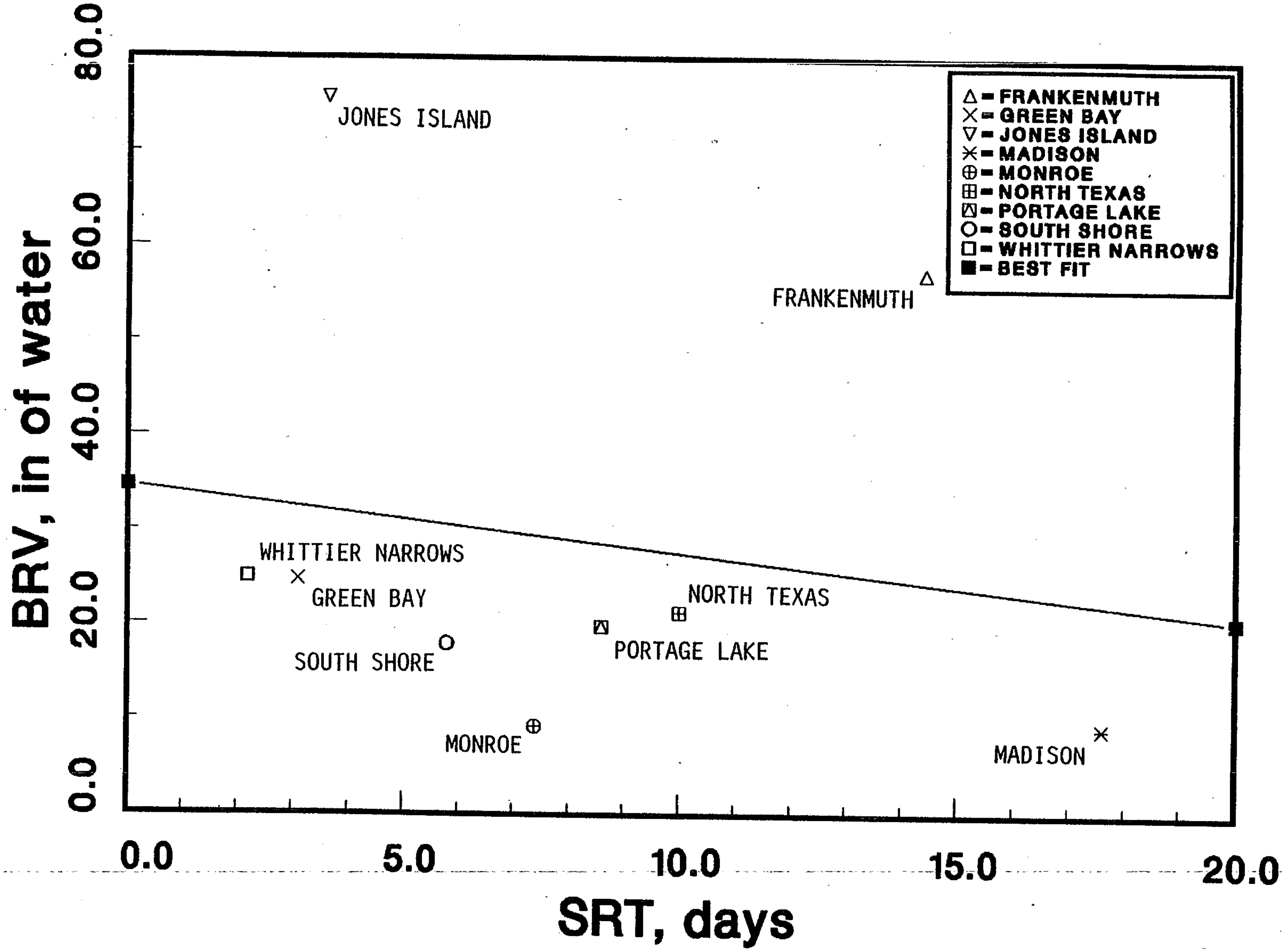

Figure 15. Relationship between BRV and SRT.

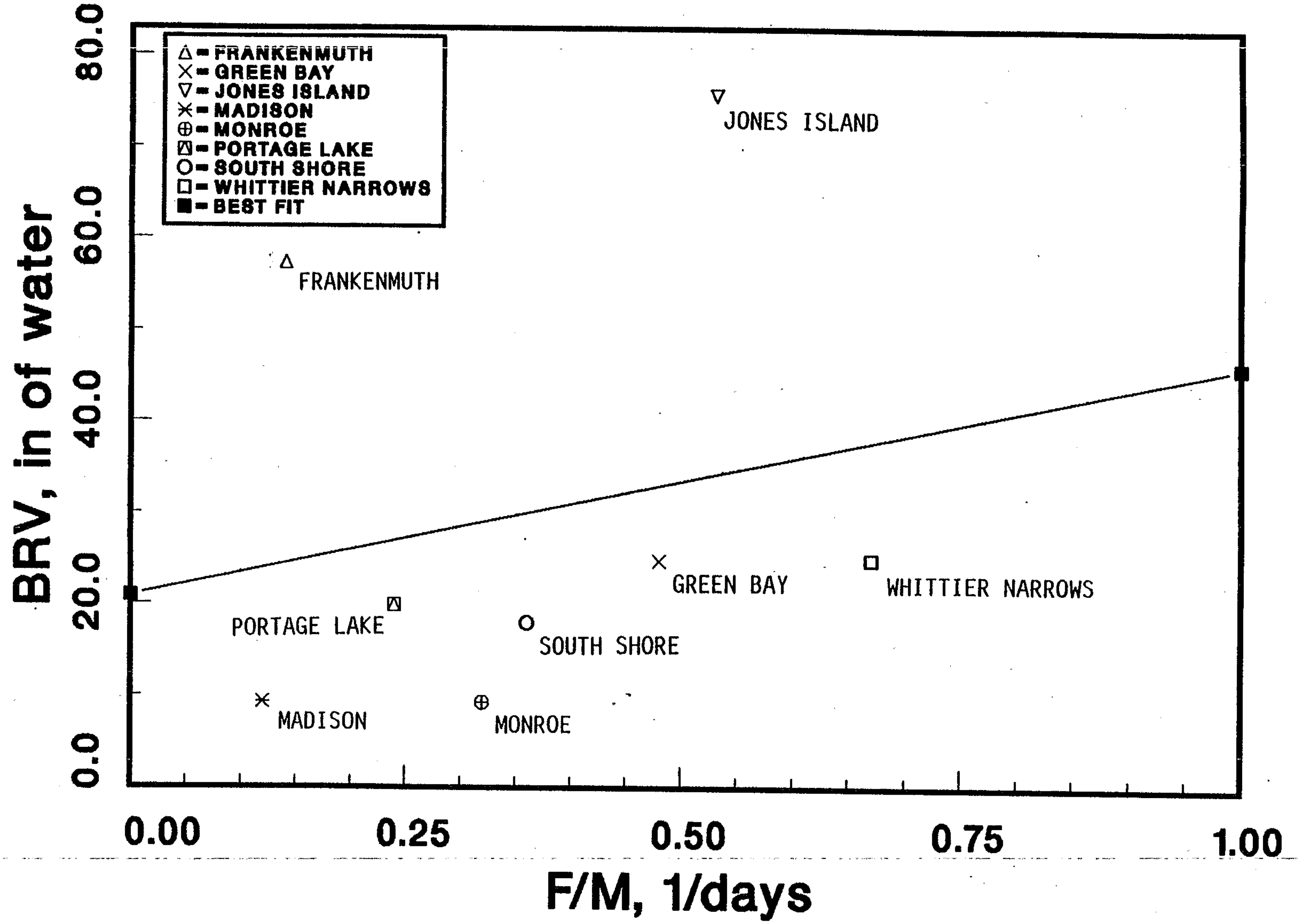

Figure 16. Relationship between BRV and F/M.

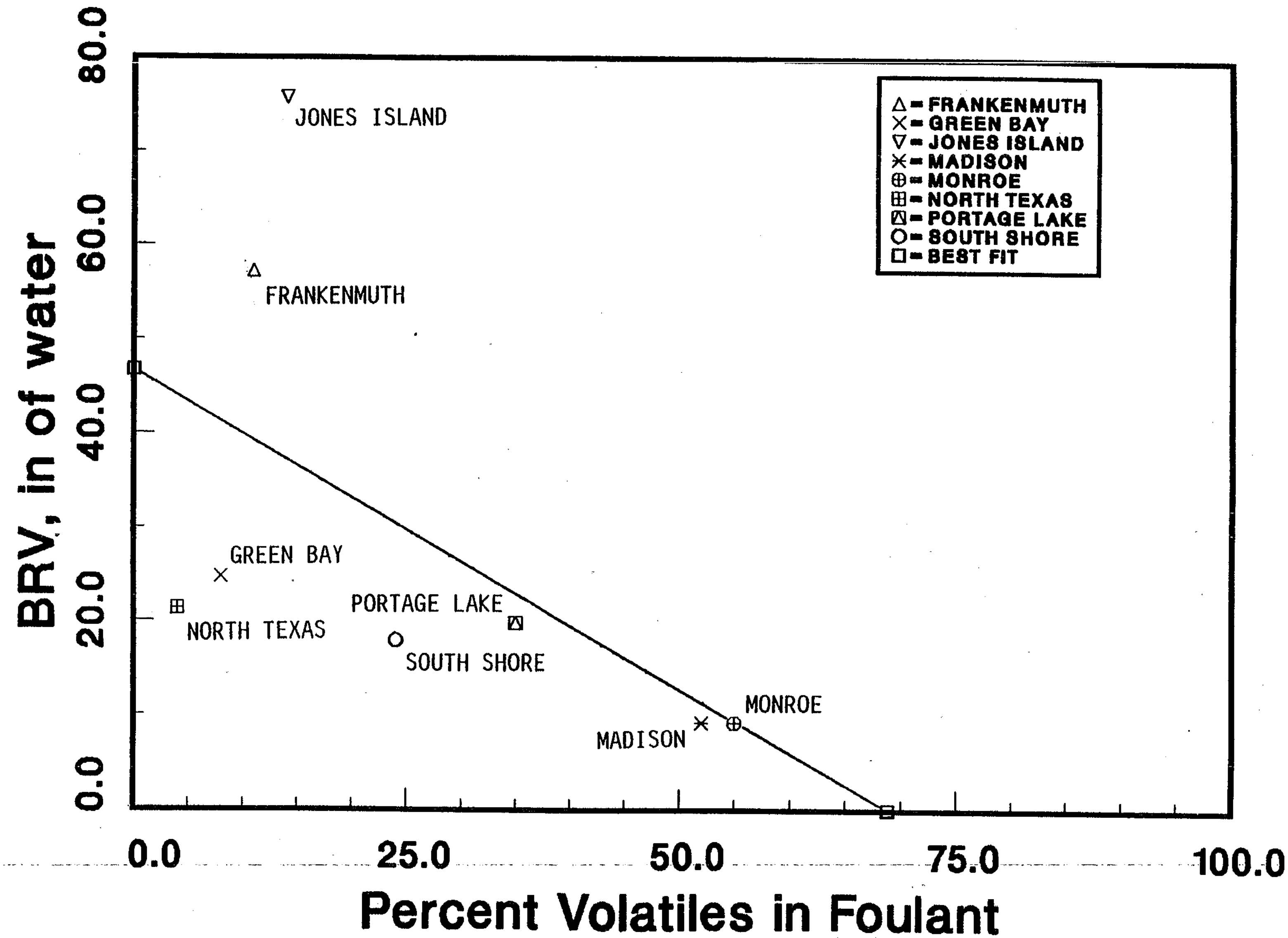

Figure 17. Relationship between BRV and percent volatiles in foulant.

improve the nutrient balance. The aerated equalization basin following primary treatment greatly reduced the soluble BOD_5 load on the activated sludge process (Baillod, 1988). Earlier fouling at the Madison plant appears to have been associated with heavy loadings of dairy waste.

SECTION 5

CONCLUSIONS

The objective of this study was to assess the relative fouling tendency of fine bubble diffusers at nine municipal activated sludge plants participating in comprehensive studies related to fouling and cleaning of fine bubble diffusers. The results showed that an increase in average bubble release vacuum (BRV) was generally accompanied by a decrease in oxygen transfer efficiency, an accumulation of foulant, and an increase in the dynamic wet pressure (DWP) loss through the diffuser. Based on these results, the participating plants were classified as:

Heavily Fouling : Jones Island West and Frankenmuth, characterized by BRV values increasing to more than 100 cm (40 in) of water and foulant accumulation greater than 100 mg/cm² over period of one year.

Moderately Fouling: Green Bay, North Texas, and Whittier Narrows, characterized by BRV values increasing to more than 50 cm (20 in) of water over one year.

Fouling: South Shore and Portage Lake, characterized by BRV values increasing to less than 50 cm (20 in) of water and foulant accumulations less than 25 mg/cm² over one year.

Lightly Fouling: Madison and Monroe, characterized by BRV values increasing to about 25 cm (10 in) of water and remaining relatively constant along with foulant accumulations generally less than 10 mg/cm² over one year.

A secondary objective was to relate fouling tendency to process parameters. Observations at individual plants suggested that high organic loads enhance fouling. However, interplant comparisons suggested a weak association between fouling and organic load. Thus, it appears that other plant and waste specific factors in addition to organic load also influence fouling.

REFERENCES

Boyle, W.C. and D.T. Redmon, "Biological Fouling of Fine Bubble Diffusers: State-of-Art", Jour. Env. Engr. Div. ASCE, 109(5):991-1005, 1983.

U.S. Environmental Protection Agency, "Summary Report: Fine Pore (Fine Bubble) Aeration Systems", EPA/625/8-85/010, 1985.

Costerton, J.W., "Investigations into Biofouling Phenomena in Fine Pore Aeration Devices", Draft Report Submitted to ASCE/EPA Fine Pore Aeration Project Committee, Cooperative Agreement No. 812167, March, 1988.

Danly, W.B., "Biological Fouling of Fine Bubble Diffusers - Phase I", M.S. Independent Study Report, Civil and Environmental Engineering Department, University of Wisconsin, Madison, 1984.

Reith, M.G., "Effects of Biological Fouling on the Oxygen Transfer Efficiency of Fine Bubble Diffusers", M.S. Thesis, University of Wisconsin-Madison, 1985.

Baillod, C.R., "Oxygen Utilization in Activated Sludge Plants: Simulation and Model Calibration", Final Report, U.S. Environmental Protection Agency, Water Engineering Research Laboratory, Cooperative Agreement CR813162-01-2, 1988.

APPENDIX A

DIFFUSER FOULANT CHARACTERISTICS

TABLE A1. FRANKENMUTH PLANT SUMMARY OF DIFFUSER FOULING

DATE	ELAPSED TIME MONTHS	FLD DWP in @ 1 SCFM	LAB DWP, in @ 1 SCFM	LAB DWP, in @ 2 SCFM	BRV in	FLOW PROFILE OUT/TOT	FOULING FACTOR
10/7/87	5.3	NA	17.3	27.1	20.2	0.50	NA
5/20/88	12.8	NA	19.0	42.0	57.3	NA	0.737

TEST HEADER INSTALLED: APRIL 28, 1987

TABLE A2. FRANKENMUTH PLANT FOULANT CHARACTERISTICS

DATE	ELAPSED TIME MONTHS	MG/SQ.CM	% ASH	% Ac SOL ASH	%Si ASH	%Ca ASH	%Fe ASH
10/7/87	5.3	95	95	32.0	21.0	4.8	8.6
5/20/88	12.8	96	89	NA	NA	NA	NA

TABLE A3. GREEN BAY PLANT SUMMARY OF DIFFUSER FOULING

DATE	ELAPSED TIME MONTHS	FLD DWP in @ 1 SCFM	LAB DWP, in @ 1 SCFM	LAB DWP, in @ 2 SCFM	BRV in	FLOW PROFILE OUT/TOT	FOULING FACTOR
10/18/86	4.6	NA	10.1	14.0	15.0	0.53	NA
2/24/87	4.1	5.5	10.5	13.3	16.5	0.48	NA
2/24/87	8.8	11.5	11.0	17.7	20.0	0.54	NA
6/19/87	3.9	12.5	NA	NA	NA	NA	NA
6/19/87	12.6	25.0	NA	NA	NA	NA	NA
8/3/87	14.0	14.5	15.0	34.0	24.8	NA	0.714
10/27/87	4.2	9.0	15.8	22.7	13.9	0.64	NA
10/27/87	2.8	5.5	NA	NA	NA	NA	NA

TEST HEADER INSTALLED JUNE 1, 1986

TABLE A4. GREEN BAY PLANT FOULANT CHARACTERISTICS

DATE	ELAPSED TIME MONTHS	MG/SQ.CM	% ASH	% Ac SOL ASH	%Si ASH	%Ca ASH	%Fe ASH
10/18/86	4.6	13	90	14.0	11.6	17.8	6.7
2/24/87	4.1	10	88	49.0	8.7	17.9	6.7
2/24/87	8.8	63	88	51.0	4.9	16.4	6.2
6/19/87	3.9	NA	NA	NA	NA	NA	NA
6/19/87	12.6	NA	NA	NA	NA	NA	NA
8/3/87	14.0	30	92	37.6	NA	NA	NA
10/27/87	4.2	33	94	29.0	13.1	12.6	8.4

TABLE A5. JONES ISLAND WEST PLANT SUMMARY OF DIFFUSER FOULING

DATE	ELAPSED TIME MONTHS	FLD DWP in @ 1 SCFM	LAB DWP, in @ 1 SCFM	LAB DWP, in @ 2 SCFM	BRV in	FLOW PROFILE OUT/TOT	FOULING FACTOR
10/20/86	4.1	14.1	13.0	26.9	19.0	0.78	NA
3/6/87	4.5	24.0	10.8	20.3	34.9	0.65	NA
3/6/87	8.5	23.4	8.7	16.9	43.0	0.79	NA
8/5/87	13.6	NA	10.0	19.8	75.7	NA	0.555

TEST HEADER INSTALLED: JUNE 18, 1986

TABLE A6. JONES ISLAND WEST PLANT FOULANT CHARACTERISTICS

DATE	ELAPSED TIME MONTHS	MG/SQ.CM	% ASH	% Ac SOL ASH	%Si ASH	%Ca ASH	%Fe ASH
10/20/86	4.1	100	90	4.0	14.9	10.1	7.3
3/6/87	4.5	26	86	33.1	18.0	11.9	6.6
3/6/87	8.5	107	87	21.6	11.7	7.8	9.3
8/5/87	13.6	152	86	NA	9.3	8.1	14.2

TABLE A7. MADISON PLANT SUMMARY OF DIFFUSER FOULING

DATE	ELAPSED TIME MONTHS	FLD DWP in @ 1 SCFM	LAB DWP, in @ 1 SCFM	LAB DWP, in @ 2 SCFM	BRV in	FLOW PROFILE OUT/TOT	FOULING FACTOR
1/14/87	4.7	3.2	5.7	6.7	12.4	0.50	NA
4/23/87	3.3	5.2	5.4	6.1	7.7	0.55	NA
4/23/87	7.9	9.8	8.6	11.3	9.3	0.53	NA
8/6/87	4.0	NA	NA	NA	8.4	NA	NA
8/6/87	12.0	NA	6.2	8.0	9.3	NA	0.989

TEST HEADER INSTALLED: AUGUST 25, 1986

TABLE A8. MADISON PLANT FOULANT CHARACTERISTICS

DATE	ELAPSED TIME MONTHS	MG/SQ.CM	% ASH	% Ac SOL ASH	%Si ASH	%Ca ASH	%Fe ASH
1/14/87	4.7	7	50	41.5	10.3	16.3	4.2
4/23/87	3.3	5	58	39.4	5.3	11.9	2.7
4/23/87	7.9	8	56	41.7	11.1	9.6	2.6
8/6/87	4.0	NA	NA	NA	NA	NA	NA
8/6/87	12.0	7	48	NA	NA	NA	NA

TABLE A9. MONROE PLANT SUMMARY OF DIFFUSER FOULING

DATE	ELAPSED TIME MONTHS	FLD DWP in @ 1 SCFM	LAB DWP, in @ 1 SCFM	LAB DWP, in @ 2 SCFM	BRV in	FLOW PROFILE OUT/TOT	FOULING FACTOR
12/4/86	4.5	NA	7.2	8.2	8.1	NA	NA
3/9/87	3.5	NA	5.2	6.6	7.8	NA	NA
3/9/87	8.0	NA	6.5	8.8	8.2	NA	NA
7/10/87	12.0	NA	6.9	8.1	9.3	NA	0.976

TEST HEADER INSTALLED: JULY 9, 1986

TABLE A10. MONROE PLANT FOULANT CHARACTERISTICS

DATE	ELAPSED TIME MONTHS	MG/SQ.CM	% ASH	% Ac SOL ASH	%Si ASH	%Ca ASH	%Fe ASH
12/4/86	4.5	50	75	NA	NA	NA	NA
3/9/87	3.5	13	45	NA	NA	NA	NA
3/9/87	8.0	81	73	NA	NA	NA	NA
7/10/87	12.0	2.6	45	NA	NA	NA	NA

TABLE A11. NORTH TEXAS PLANT SUMMARY OF DIFFUSER FOULING

DATE	ELAPSED TIME MONTHS	FLD DWP in @ 1 SCFM	LAB DWP, in @ 1 SCFM	LAB DWP, in @ 2 SCFM	BRV in	FLOW PROFILE OUT/TOT	FOULING FACTOR
5/12/86	4.4	NA	11.0	14.0	27.4	0.7	NA
7/86	7	NA	11.9	13.7	14.3	0.6	NA
11/86	11	NA	12.4	15.8	21.4	0.6	NA
7/87	3	NA	8.7	9.1	9.5	0.6	NA
7/87	18	NA	37.0	40.5	40.7	0.5	NA

TEST HEADER INSTALLED: DECEMBER 30, 1985

TABLE A12. NORTH TEXAS PLANT FOULANT CHARACTERISTICS

DATE	ELAPSED TIME MONTHS	MG/SQ.CM	% ASH	% Ac SOL ASH	%Si ASH	%Ca ASH	%Fe ASH
5/12/86	4.4	42	95	NA	NA	NA	NA
7/86	7	8	94	20.0	20.4	19.2	3.3
11/86	11	29	96	9.5	20.7	16.8	3.5
7/87	3	0.2	77	NA	11.7	8.3	2.1
7/87	18	18	88	40.3	22.8	0.5	2.3

TABLE A13. SOUTH SHORE PLANT SUMMARY OF DIFFUSER FOULING

DATE	ELAPSED TIME MONTHS	FLD DWP in @ 1 SCFM	LAB DWP, in @ 1 SCFM	LAB DWP, in @ 2 SCFM	BRV in	FLOW PROFILE OUT/TOT	FOULING FACTOR
10/21/86	4.3	7.6	7.6	9.0	10.2	0.21	NA
3/6/87	4.5	9.8	10.1	12.5	12.3	0.65	NA
3/6/87	8.8	11.9	10.6	14.1	19.6	0.63	NA
8/5/87	13.7	NA	11.5	16.0	18.0	NA	0.994

TEST HEADER INSTALLED: JUNE 13, 1986

TABLE A14. SOUTH SHORE PLANT FOULANT CHARACTERISTICS

DATE	ELAPSED TIME MONTHS	MG/SQ.CM	% ASH	% Ac SOL ASH	%Si ASH	%Ca ASH	%Fe ASH
10/21/86	4.3	6	87	NA	10.9	10.0	10.2
3/6/87	4.5	5	86	50.0	10.6	11.8	9.9
3/6/87	8.8	7	67	44.0	7.8	8.3	8.1
8/5/87	13.7	23	76	NA	4.7	10.2	1.3

TABLE A15. WHITTIER NARROWS PLANT SUMMARY OF DIFFUSER FOULING

DATE	ELAPSED TIME MONTHS	FLD DWP in @ 1 SCFM	LAB DWP, in @ 1 SCFM	LAB DWP, in @ 2 SCFM	BRV in	FLOW PROFILE OUT/TOT	FOULING FACTOR
6/28/88	* 9.6	NA	12.1	21.9	25.0	NA	0.896

TEST HEADER INSTALLED: AUGUST 22, 1986
* Data is for a diffuser stone installed on 9/9/87

TABLE A16. WHITTIER NARROWS PLANT FOULANT CHARACTERISTICS

DATE	ELAPSED TIME MONTHS	MG/SQ.CM	% ASH	% Ac SOL ASH	%Si ASH	%Ca ASH	%Fe ASH
6/28/87	9.6	NA	NA	NA	NA	NA	NA

APPENDIX B

INFLUENT AND PLANT PROCESS CONDITIONS DURING STUDY

TABLE B1. FRANKENMUTH INFLUENT AND PROCESS CHARACTERISTICS DURING THE STUDY

		PRIMARY EFFLUENT						PROCESS CONDITIONS				
DATE	ELAPSED TIME (mo)	FLOW (MGD)	BOD_5 (mg/L)	TSS (mg/L)	BOD Loading (lb/1000 ft^3-d)	TSS Loading (lb/1000 ft^3-d)	pH	MLVSS (mg/L)	SRT (d)	F/M (1/d)	DO (mg/L)	TEMP (C)
10/7/87	5.0	1.36	653	322	116.7	57.4	6.4	4877	23.6	0.29	0.97	26.8
*5/20/88	12.8	1.38	526	253	95.5	46.2	6.9	4720	21.8	0.24	1.03	22.0

TEST HEADER INSTALLED ON APRIL 28, 1987
*Estimated

TABLE B2. JONES ISLAND INFLUENT AND PROCESS CHARACTERISTICS DURING THE STUDY

		PRIMARY EFFLUENT						PROCESS CONDITIONS				
DATE	ELAPSED TIME (mo)	FLOW (MGD)	BOD_5 (mg/L)	TSS (mg/L)	BOD Loading (lb/1000 ft^3-d)	TSS Loading (lb/1000 ft^3-d)	pH	MLVSS (mg/L)	SRT (d)	F/M (1/d)	DO (mg/L)	TEMP (C)
10/20/86	4.1	4.65	220	NA	58.1	NA	7.7-6.9	1470	3.4	0.64	0.6	19.8
3/6/87	4.5	4.60	208	NA	54.3	NA	7.7-6.8	1443	3.4	0.61	1.6	14.2
3/6/87	8.5	3.83	245	NA	53.5	NA	9.4-6.8	1653	3.7	0.52	1.2	16.7
8/5/87	*13.6	3.74	253	NA	53.8	NA	9.4-6.8	1636	3.6	0.53	0.9	17.0

TEST HEADER INSTALLED ON JUNE 18, 1986

TABLE B3. GREEN BAY INFLUENT AND PROCESS CHARACTERISTICS DURING THE STUDY

DATE	ELAPSED TIME (mo)	FLOW (MGD)	BOD_5 (mg/L)	TSS (mg/L)	BOD Loading (lb/1000 ft^3-d)	TSS Loading (lb/1000 ft^3-d)	pH	MLVSS (mg/L)	SRT (d)	F/M (1/d)	DO (mg/L)	TEMP (C)
		COMBINED MILL WASTE AND PRIMARY EFFLUENT						PROCESS CONDITIONS				
10/18/86	4.6	18.8	396	220	168.6	93.6	7.1	1881	2.7	0.53	1.6	28
2/24/87	4.1	14.3	467	242	151.1	78.6	7.2	2320	3.1	0.47	2.2	20
2/24/87	8.8	16.4	433	228	160.4	84.9	7.2	2174	2.9	0.51	1.9	24
6/19/87	3.9	14.2	402	224	129.2	71.8	NA	1890	3.1	0.46	2.2	23
6/19/87	12.6	15.7	424	227	150.4	80.5	7.2	2060	3.0	0.49	2.0	24
8/3/87	14.0	15.5	417	223	146.1	78.0	7.2	2003	3.1	0.48	2.0	24
10/27/87	4.2	13.5	371	167	113.6	51.2	6.9	1513	3.8	0.38	2.0	28

TEST HEADER INSTALLED ON JUNE 1, 1986

* pH data was not available for June and July of 1986 and March, May, June and October of 1987.

** MLVSS was only measured one day out of each month during the study (1 to 3 samples per sample day). Data was not available for June, July and August of 1986.

TABLE B4. MADISON INFLUENT AND PROCESS CHARACTERISTICS DURING THE STUDY

DATE	ELAPSED TIME (mo)	FLOW (MGD)	BOD_5 (mg/L)	TSS (mg/L)	BOD Loading (lb/1000 ft^3-d)	TSS Loading (lb/1000 ft^3-d)	pH	MLVSS (mg/L)	SRT (d)	F/M (1/d)	DO (mg/L)	TEMP (C)
		PRIMARY EFFLUENT						PROCESS CONDITIONS				
1/14/87	4.7	11.6	83	67	20.0	16.2	*	1851	18.5	0.11	**	18
4/23/87	3.3	10.7	83	67	18.7	15.0	*	1944	18.5	0.11	**	14
4/23/87	7.9	11.3	90	67	21.2	15.6	*	1895	18.5	0.11	**	16
8/6/87	3.0	10.8	99	68	22.5	15.6	*	1641	15.8	0.14	**	20
8/6/87	11.0	11.2	92	67	21.2	15.6	*	1826	17.7	0.12	**	17

TEST HEADER INSTALLED ON AUGUST 25, 1986

* Average pH during the study was 7.6 (range: 7.4-7.7)

** Average DO during the study was 2.0 mg/L (range: 0.7-4.9 mg/L)

TABLE B5. MONROE INFLUENT AND PROCESS CHARACTERISTICS DURING THE STUDY

		EQUILIZATION BASIN EFFLUENT						PROCESS CONDITIONS				
DATE	ELAPSED TIME (mo)	FLOW (MGD)	BOD_5 (mg/L)	TSS (mg/L)	BOD Loading (lb/1000 ft^3-d)	TSS Loading (lb/1000 ft^3-d)	pH	MLVSS (mg/L)	SRT (d)	F/M (1/d)	DO (mg/L)	TEMP (C)
12/4/86	4.5	2.30	**290	104	85.5	30.6	8.9-6.9	1230	6.3	0.38	2.8	19/23
3/9/87	3.5	2.35	**285	103	85.5	30.9	8.8-7.0	1150	5.8	0.42	2.7	18/22
3/9/87	8.0	2.17	**283	120	78.6	33.3	8.9-7.2	1281	7.5	0.35	*3.4	*15/19
7/10/87	12.0	2.17	273	140	75.5	38.9	9.0-7.2	1361	7.4	0.32	*3.7	*16/20

TEST HEADER INSTALLED ON JULY 9, 1986
* DO and temperature data was not available for February, March, and April of 1987.
** Primary effluent
SRT's were estimated.

TABLE B6. SOUTH SHORE INFLUENT AND PROCESS CHARACTERISTICS DURING THE STUDY

		PRIMARY EFFLUENT						PROCESS CONDITIONS				
DATE	ELAPSED TIME (mo)	FLOW (MGD)	BOD_5 (mg/L)	TSS (mg/L)	BOD Loading (lb/1000 ft^3-d)	TSS Loading (lb/1000 ft^3-d)	pH	MLVSS (mg/L)	SRT (d)	F/M (1/d)	DO (mg/L)	TEMP (C)
10/21/86	4.3	6.00	74	NA	22.5	NA	7.9-7.6	1164	6.1	0.31	1.3	18.4
3/6/87	4.5	6.20	77	NA	23.7	NA	7.9-7.6	1165	6.0	0.33	0.9	13.4
3/6/87	8.8	5.51	90	NA	25.0	NA	8.1-7.4	1207	6.1	0.33	1.1	15.9
8/5/87	*13.7	5.69	90	NA	25.8	NA	8.1-6.8	1140	5.8	0.36	1.1	15.9

TEST HEADER INSTALLED ON JUNE 13, 1986

TABLE B7. WHITTIER NARROWS INFLUENT AND PROCESS CHARACTERISTICS DURING THE STUDY

		PRIMARY EFFLUENT						PROCESS CONDITIONS				
DATE	ELAPSED TIME (mo)	FLOW (m^3/d)	BOD_5 (mg/L)	TSS (mg/L)	BOD Loading (lb/1000 ft^3-d)	TSS Loading (lb/1000 ft^3-d)	pH	MLVSS (mg/L)	SRT (d)	F/M (1/d)	DO (mg/L)	TEMP (C)
1/1/87	9.6	4.54	97	95	28.7	28.1	NA	682	2.2	0.67	2.0	24.4

TEST HEADER INSTALLED ON AUGUST 22, 1987

APPENDIX C

DESCRIPTION OF METHODS

FOULANT ANALYSIS

An important aspect of the characterization of the fouled diffusers was the analysis of the nature of the foulant on the diffuser. The procedure for foulant analysis is given below:

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

BUBBLE RELEASE VACUUM

The bubble release vacuum, as indicated by the name, is a measure of the vacuum in inches of water gauge, required to emit bubbles from a localized point on the surface of a thoroughly wetted porous diffuser element. The test provides a means of determining the effective pore diameter at any point on the surface of a ceramic diffuser, and is an important measure of the relative fouling among plants. The test apparatus consists of a probe, manometer, vacuum source, and rotameter as shown in Figure C.1.

A brief description of the BRV testing procedure is listed below. Danly (1984) more thoroughly describes the test procedure.

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

2. Set BRV flow rate.

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

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

5. At equilibrium, read and record the manometer reading and the height of water in the probe. BRV equals the manometer reading less the height of water in the probe.

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

DYNAMIC WET PRESSURE

The dynamic wet pressure, DWP, is the pressure differential across the diffusion element when operating in a submerged condition, and is expressed in inches of water gauge. In the dynamic wet pressure test, most of the pressure differential is due to the force or pressure required to form bubbles against the force of surface tension and only a small fraction of the total pressure gradient is required to overcome frictional resistance.

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

Laboratory DWP was measured each time a stone was removed from the test header. The equipment required for measuring DWP in the lab includes an air source, rotameter, in-line mercury manometer, thermometer, diffuser plenum with standard orifice, water-filled manometer and aquarium. The test set-up looks very much like Figure C.2 without manometer A and the bubbler. The water-filled manometer (manometer B in Figure C.2) is tapped into the plenum at one end and open to atmosphere at the other end. The water in the aquarium is high enough so the diffuser was covered with water.

The following is a brief description of the DWP test. Consult Danly (1984) for more information on the test.

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

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

3. Place diffuser securely in plenum.

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

5. Place plenum in aquarium. Adjust air flow to minimum suggested rate of 0.85 m^3/hr/dome (0.5 scfm/dome). Visually inspect the flow profile. If the diffuser is not mounted correctly, coarse bubbling will be evident. If this is the case, take plenum out of the aquarium and reseat the diffuser.

6. Adjust air flow to maximum allowable rate for the test being time for excess water to be driven out of stone. When testing fouled diffusers, do not exceed the operating air flow rate.

7. Perform a DWP profile. This is done by checking DWP at three or more air flows. Typical air flows are 36.6, 73.2, 109.7, 146.3 m^3/hr/m^2 (2, 4, 6, and 8 scfm/ft^2). A bucket catch may be performed to check air flow rate. In line pressure and temperature readings are taken so air flow rates can be translated to standard conditions.

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

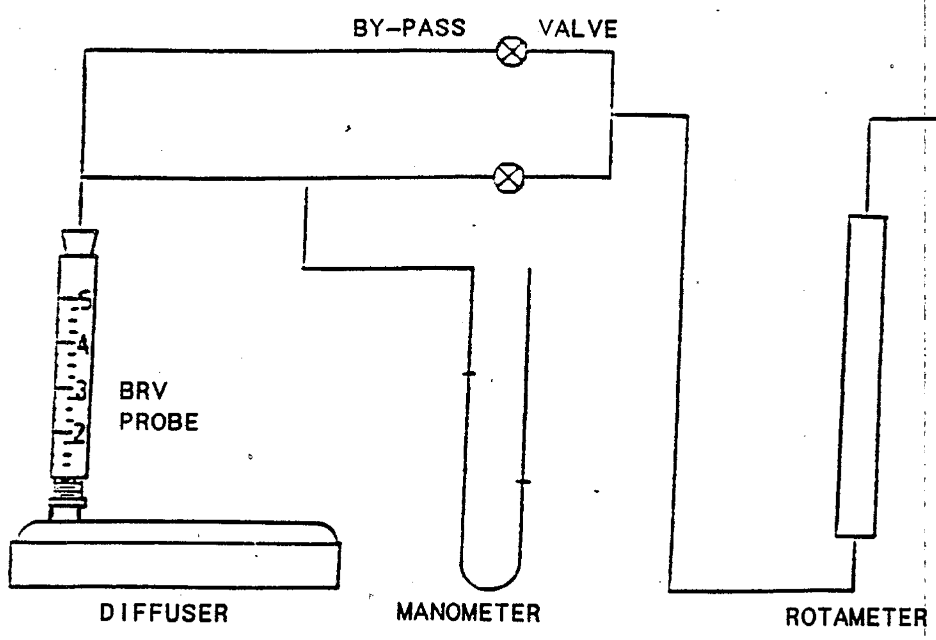

Figure C.1. BRV test apparatus.

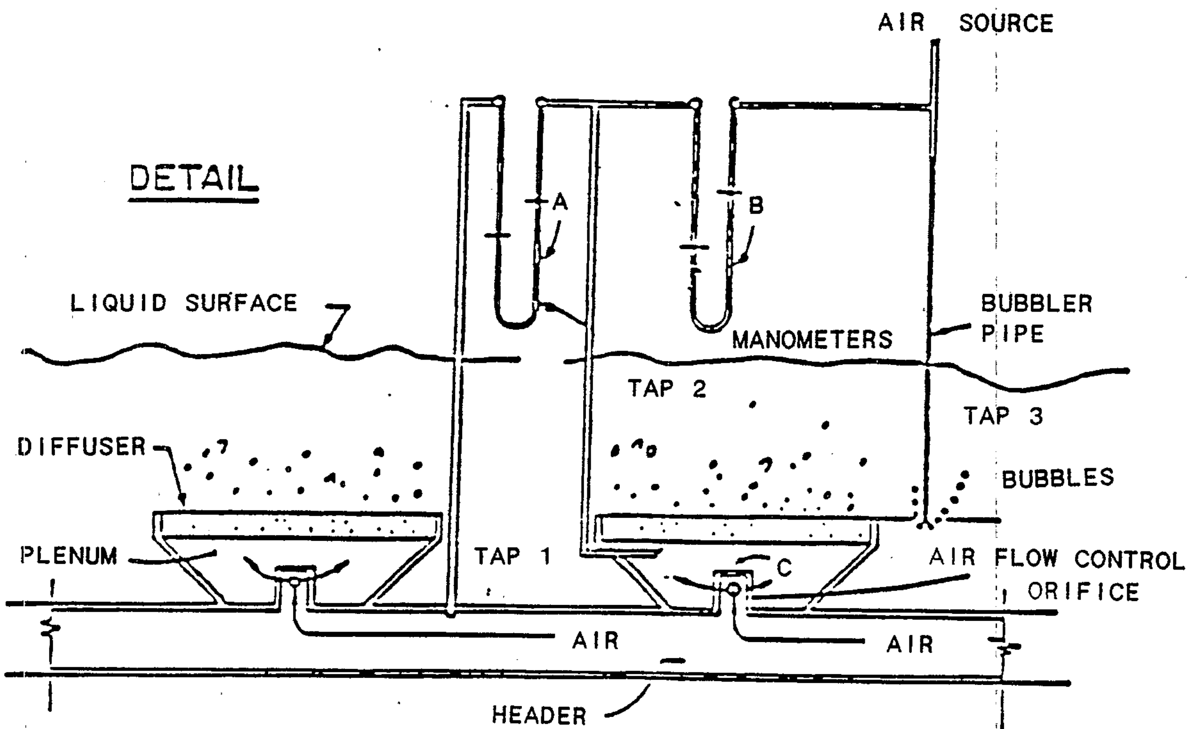

Figure C.2. Laboratory DWP test apparatus.

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

GAS FLOW PROFILE TEST

The gas flow profile test uses quantitative techniques to evaluate the uniformity of air release across the surface of ceramic diffusers, while operating, rather than appraising uniformity by visual means. This is accomplished by testing the element at an air rate which is approximately equal to 36.6 $m^3/hr/m^2$ (2.0 $scfm/ft^2$), or at the recommended design rate, with anywhere from 5.1 - 20.3 cm. (2 - 8 in.) of water over it.

The rate of air release from selected areas is measured by displacing water from an inverted container and recording the rate of displacement of water with a stopwatch. By combining the container area and the rate of air discharge, a flux rate, expressed as $m^3/hr/m^2$, or other convenient units, can be calculated. By comparing the flux rate of the selected area readings with one another, a quantitative measure or graphical representation of the profile can be generated.

Flux rate is determined by measuring the displacement of water by the rising gas stream from a vessel inverted over the diffuser. The vessel must first be filled with water, covered and deftly inverted so that the mouth of the vessel is just submerged. Captured gas volume is measured over a time of a few seconds taking care so that the captured volume is recorded at atmospheric pressure, i.e. equal water surface levels inside and outside of the inverted vessel. The flow rate is determined by dividing the captured volume by the time interval. The flux rate is defined as flow rate divided by the area of the capture vessel. A flow profile for a typical diffuser requires flow measurements on each of three concentric circles as shown in Figure C.3. Flow rates for the annular areas are determined by difference.

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

HOSE-ACID-HOSE CLEANING (MILWAUKEE METHOD)

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

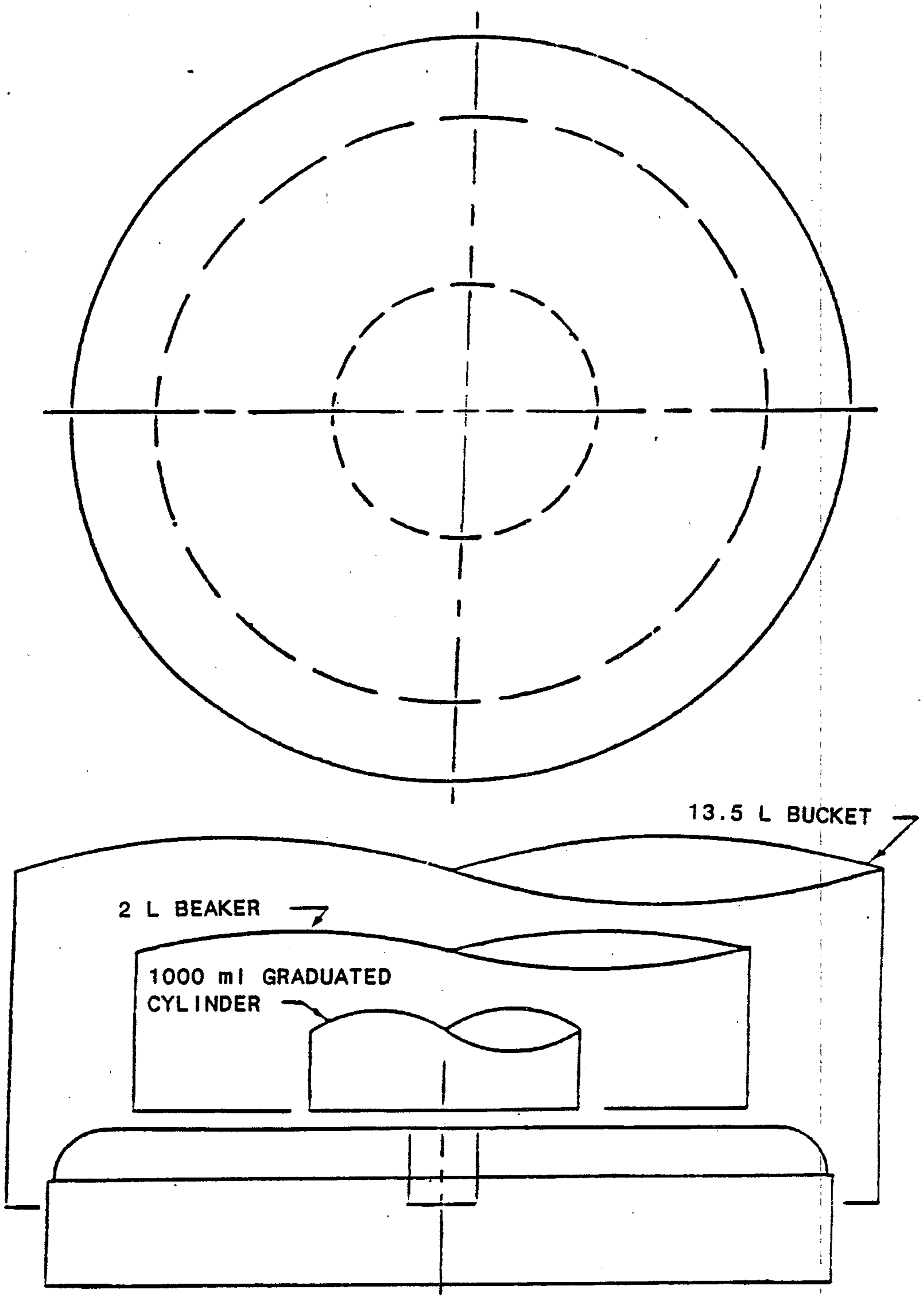

Figure C.3. Diffuser air flow profile.

Baume inhibited muriatic acid. This is equivalent to a 14% HCl solution. The procedure is given below:

1. Clean diffuser by high pressure or low pressure hosing with the air on at approximately 1.7 m^3/hr (1 cfm) per diffuser.

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

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

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