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Survey and Evaluation of Fine Bubble Dome Diffuser Aeration Equipment

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SURVEY AND EVALUATION OF FINE BUBBLE DOME DIFFUSER AERATION EQUIPMENT

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

As part of these activities, a survey project was undertaken in August 1979 to review, document, and evaluate power requirements, design practices, and operating and maintenance characteristics for 19 fine bubble dome diffuser aeration systems. Thirteen of these systems are located in the United Kingdom, two in The Netherlands, and four in the United States. The information documented in this report should be of particular interest to design engineers and municipal officials who are considering utilizing fine bubble air aeration equipment in new activated sludge treatment plants or switching to such equipment in existing plants.

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ABSTRACT

This research project was initiated with the overall objective of better defining the oxygen transfer performance, operation and maintenance requirements, and proper design approaches for fine bubble dome diffuser aeration systems used in activated sludge wastewater treatment.

Working in conjunction with the British Water Research Centre of Stevenage, England, a survey of 19 wastewater treatment plants with dome diffuser aeration equipment was carried out along with a review of the related literature. Thirteen of the plants were located in the United Kingdom (U.K.), two in The Netherlands, and four in the United States (U.S.). The U.K. plants were selected primarily on the basis of long-term experience (5 yr or longer) and were all municipal wastewater treatment plants with varying industrial flows. The Netherlands and U.S. plants were chosen on the basis of availability rather than longevity.

As nearly as possible, data on influent and effluent wastewater characteristics, power demand, air supply, and process parameters were compiled for a 5 yr period. Maintenance personnel were interviewed to develop a summary of long-term operation and maintenance experience. Specific designs and plant equipment for aeration, air cleaning, and diffuser maintenance were studied. Discussions were held with designers, equipment manufacturers, and research scientists to develop a better understanding of design and performance.

Results of this work indicate that, relative to other devices, fine bubble dome diffuser aeration systems can perform at high efficiency when proper design, operation, and maintenance practices are followed and when strong performance-depressing industrial wastes are absent. Operation and maintenance experience with this equipment has generally been very good, with 6-10 yr, and sometimes longer, between cleanings. Operation and maintenance performance was found to be closely related to conscientious adherence by plant operators to simple but necessary operating guidelines for this equipment. Oxygen transfer performance was found to be highly variable between the plants. The oxygen transfer rates of at least two of the aeration systems in the United Kingdom were apparently quite adversely affected by industrial wastes. Many plants carried excessive mixed liquor dissolved oxygen levels in the aeration basins. Plants with multiple-channel plug flow tanks generally performed less efficiently, from an energy standpoint, than those with single-pass systems.

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Agency. This report covers the period August 1, 1979, to February 1, 1980, and work was completed as of September 15, 1980.

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FIGURES

FIGURES (continued)

TABLES

TABLES (continued)

ABBREVIATIONS

BOD_5	--	5-day biochemical oxygen demand
BHP	--	brake horsepower
COD	--	chemical oxygen demand
D.O.	--	dissolved oxygen
DWF	--	dry weather flow
EPA	--	U.S. Environmental Protection Agency
F/M	--	food-to-microorganism ratio
kn	--	kilonewton
kWh	--	kilowatt hour
LACSD	--	Los Angeles County Sanitation Districts
L/W	--	length-to-width ratio
mgd	--	million gallons per day (U.S. gallons)
MLSS	--	mixed liquor suspended solids
MLVSS	--	mixed liquor volatile suspended solids
N/HS	--	Norton/Hawker-Siddeley
NH_3-N	--	ammonia nitrogen
NO_3-N	--	nitrate nitrogen
O&M	--	operation and maintenance
PI	--	principal investigator
SWD	--	side water depth
TSS	--	total suspended solids
U.K.	--	United Kingdom

ABBREVIATIONS (continued)

uPVC -- unplasticized polyvinyl chloride

U.S. -- United States

W/m^3 -- watts per cubic meter

WRC -- British Water Research Centre

ACKNOWLEDGEMENTS

The cooperation of the Thames Water Authority and the Severn Trent Water Authority in the United Kingdom, and the Zuiveringschap - West Overijssel Authority in The Netherlands is gratefully acknowledged. The generous assistance given to the principal investigator by the equipment manufacturers whose equipment is discussed herein is also greatly appreciated. Special thanks go to Alistair Stratton, Eric Branton and Ray Hull of Hawker-Siddeley Water Engineering Ltd. in the United Kingdom, and Paul Cummings of the Norton Company, Worcester, Massachusetts, for their fine efforts in support of this work. The considerable contributions of Lloyd Ewing, and Dave Redmon, Ewing Engineering Co., and Jerome Wren of the Sanitaire Corp., both of Milwaukee, Wisconsin, are also gratefully acknowledged.

SECTION I

INTRODUCTION

As with other energy-intensive industries, energy-conserving design and operation is receiving increased emphasis in the wastewater treatment field. Aeration equipment employed in activated sludge service is usually the single largest energy consumer in a wastewater treatment plant, normally accounting for 60-80 percent of total power demand. Because fine bubble aeration equipment has the potential for markedly higher oxygen transfer efficiencies than the more traditional coarse bubble spiral roll design, its use is rapidly expanding in new or retrofitted treatment plants.

Historically, fine bubble aeration equipment was widely used in the United States (U.S.) before 1950. It gradually fell into disfavor because of its fairly intensive maintenance requirements, being replaced by the very low maintenance coarse bubble equipment during the period of relatively cheap power prior to 1972. Rapid escalation in U.S. power costs since the 1974 Arab oil embargo has resulted in renewed interest in fine bubble aeration.

Because power costs have traditionally been much higher in the United Kingdom (U.K.) and Western Europe than in the United States, fine bubble aeration equipment, along with mechanical surface aerators, continued to be widely used and improved there. The ceramic dome diffuser, which is the main subject of this study, was first developed in 1954 and refined into its present form by 1961. In 1972, it became available in the United States under a licensing agreement. Although there are presently only a handful of U.S. installations, the dome diffuser is in use in several hundred treatment plants around the world and the last few years have seen the evolution of competing devices in either dome or disc form.

The purpose of this study was to assess the long-term oxygen transfer performance and operation and maintenance (O&M) history of dome diffuser aerators. A total of 19 treatment plants were studied, 13 in the United Kingdom because of the large number of major municipal treatment works with 5 yr or greater operating experience in that country. The British Water Research Centre (WRC) cooperated in the U.K. study and was able to add substantially to the data base. Two plants in The Netherlands were studied, and the considerable Dutch research effort on the various types of dome/disc diffuser aerators was reviewed. Four plants were visited in the United States, three of which were running side-by-side comparisons with other types of aeration equipment. A literature review was carried out in conjunction with the WRC and the U.S. Environmental Protection Agency (EPA).

A corollary activity in this project was a review of the process design of dome diffuser aerators and the formulation of design recommendations. The principal conclusions of this work are given in Section 2. Recommendations including areas of further study are summarized in Section 3. The study approach and the method of oxygen transfer performance estimation are described in Sections 4 and 5, respectively. The results of this investigation are evaluated in Section 6, currently available dome and disc fine bubble aerators are described in Section 7, and a discussion of approaches to dome diffuser aeration system design is presented in Section 8. A sample U.K. plant survey form and the detailed plant survey data are provided in Appendices A and B, respectively.

SECTION 2

CONCLUSIONS

In general, dome diffuser fine bubble aeration systems were providing relatively efficient, low maintenance service in the surveyed plants. However, the plant visits and related study clearly indicated a need for optimized design and operating control strategies if the full energy saving potential of the equipment is to be realized. Listed below are the principal conclusions resulting from this study:

1. Assessment of data from the surveyed plants resulted in widely varying estimates of field oxygen transfer performance for the dome diffuser. Generally, field performance was lower than might be expected from clean water oxygen transfer data. Using the mass balance technique described in Section 5, based on empirically derived oxygen consumption values for BOD_5 removed and ammonia nitrogen oxidized and a similarly derived oxygen credit for nitrate nitrogen denitrified, the process (i.e., dirty water or mixed liquor) aeration efficiency for the 16 of 19 plants with adequate data to make predictive estimates averaged 1.48 kg O_2 transferred/kWh consumed (2.43 lb O_2/wire hp-hr). The highest and lowest aeration efficiencies observed were 2.13 kg O_2/kWh (3.50 lb O_2/wire hp-hr) and 0.78 kg O_2/kWh (1.28 lb O_2/wire hp-hr) at Oxford and Steenwijk, respectively. For the three plants (Finham, Madison, and Glendale) with a reasonably sufficient comparative data base, fine bubble dome diffuser process aeration efficiency was approximately 1.65 times higher than for side-by-side coarse bubble diffuser systems: 1.56 kg O_2/kWh (2.56 lb O_2/wire hp-hr) vs. 0.95 kg O_2/kWh (1.56 lb O_2/wire hp-hr).

2. Methods of plant operation were frequently found to be contributing to less-than-optimum oxygen transfer performance.

   - In the U.K. plants particularly, volumetric and F/M loading rates were often lower than required for nitrification and/or high levels of BOD removal. The least efficient plants with two exceptions were underloaded volumetrically.

   - A number of the plants were also overaerating the mixed liquor and had taken no steps to monitor dissolved oxygen (D.O.) concentrations and reduce air flows to more efficient operating levels. The two most efficient plants, Oxford and Beckton, closely monitored mixed liquor D.O. and adjusted air flows accordingly.

3. Lowered oxygen transfer efficiency could also be traced to design practices that make it very difficult for operators to run treatment plants effectively.

- The use of multiple-pass plug flow systems results in poor matching of air supply capability with oxygen demand, particularly in the second and subsequent aeration channels, leading to overaeration in the latter passes and localized organic overloading and diffuser sliming in the first pass. Step feeding only partially alleviated the overaeration problem. Tapering the aeration dome configuration was also of limited value in suppressing overaeration in the second and subsequent passes of multiple-pass systems. However, it was of significant value in suppressing diffuser sliming. Tapered aeration did not exhibit any apparent advantage in overall oxygen transfer performance over non-tapered systems in the plants surveyed.

- The full practical operating range attainable with the equipment, in terms of air flow per dome, is not properly utilized in the selection of diffuser density. Providing too many domes creates a situation where the minimum total aeration system air flow is controlled by the minimum allowable air flow rate per dome (0.014 m^3/min or 0.5 cfm, defined by control orifice headloss characteristics) for large portions of the day, producing extended periods of overaeration. The recommended maximum unit dome air flow rate of 0.057 m^3/min (2.0 cfm) is consequently rarely approached in operation.

- Many of the plants had shallow aeration tanks, 3.7 m (12 ft) or less, reducing attainable oxygen transfer efficiency.

- Most of the plants surveyed lacked air flow monitoring capability for individual aeration grids, and air control valves, where provided, were usually too coarse in their adjustability to be of use in controlling air flows. Plant operators were often prevented from correcting overaeration conditions because of equipment limitations.

4. Significant industrial waste fractions in municipal wastewater may substantially lower dome diffuser oxygenation efficiency via a reduction in the alpha factor. Alpha is especially affected in the first segment of long, plug flow aeration tanks (to values reportedly as low as 0.3-0.4) where detergents and other surfactants haven't had sufficient contact time to be biodegraded. As these surfactants are oxidized in passing through the aeration process, alpha increases to values of 0.8 or higher at the effluent end of the tank. Beddington and Hartshill are two examples of plants that are adversely affected by industrial waste discharges.

5. It is the opinion of the authors that with enhanced design and operating techniques, aeration efficiencies (by the method of Section

5) of dome diffuser plants with no unusual alpha depressing wastes present could be increased 25-75 percent over the average value of 1.48 kg O_2 transferred/kWh (2.43 lb O_2/wire hp-hr) estimated from the survey.

6. The limited data evaluated in this study indicate some parity of performance among the ceramic dome and disc diffusers presently being marketed in the United States. There appears to be a definite correlation between dome or disc diameter (of the horizontal surface) and specific oxygen transfer per diffuser. Data from clean water tests suggest that fewer of the larger diameter units may be required to transfer equivalent amounts of oxygen at the same oxygen transfer efficiency.

7. Generally, maintenance experience with dome diffusers ranged from good to excellent. Both of the plants reporting significant maintenance problems, Beddington and Basingstoke, had developed operating strategies which were effectively controlling the problems without excessive costs or downtime. It is concluded that the generally quite good maintenance experience is directly attributable to two principal factors:

   - Conscientious (though not labor intensive) attention to aeration system operation, particularly as related to air cleaning and repair of infrequent equipment failures.

   - Steady improvement and refinement of the dome diffuser equipment and its application over the course of its history, particularly in piping and air cleaning.

8. Diffuser sliming, causing external fouling, is apparently produced by conditions of high F/M loading and/or low dissolved oxygen, such as can occur as a result of the introduction of strong industrial wastes into a plant. Three plants, Beckton (temporary reduction of loading), Beddington (brushing), and Madison (steam cleaning) have developed somewhat effective responses to sliming.

9. In designing new plants, close attention should be given to required air flow at minimum loading. Use of a wider range of air flows in the design of dome diffuser systems, as now recommended by the manufacturer, will improve operational flexibility and thereby improve overall system efficiency. Aeration efficiency is only one parameter of diffuser performance; high reliability and flexibility of operation should also be considered in conjunction with operational and capital costs.

10. Careful attention should be given to air cleaning to avoid internal fouling of dome diffusers. Manufacturer's recommendations in this area should be followed carefully. When dome diffuser systems are retrofitted into existing plants, existing air piping should be carefully checked for rusting or scaling and cleaned or coated as needed to avoid particle shedding from its pipe walls into the air

stream where it can cause internal diffuser fouling.

SECTION 3

RECOMMENDATIONS

This study has identified a number of significant research needs that should be addressed as soon as practicable:

1. The question of alpha sensitivity as it relates to the relative performance under field operating conditions of dome/disc diffusers vs. other aeration devices should be a high priority research need.

2. The opportunity to develop useful side-by-side comparison data for dome diffusers, coarse bubble aerators, and fine bubble tube diffusers (in wide band spiral flow) exists at three U.S. treatment plants: Madison, Wisconsin; Tallman Island (New York City); and Fort Worth, Texas. In conjunction with pending process (dirty water) testing at the Los Angeles County Sanitation Districts, data should be developed from these plants.

3. Oxygenation performance studies of plants that have been modified to optimize application of dome or disc diffusers should be conducted as soon as possible. It is quite possible that such studies could be rapidly implemented in cooperation with the WRC. In addition, one or more major tests in U.S. plants, using the design concepts discussed in Section 8, should be initiated in the near future, possibly under EPA's Innovative Technology Program.

4. The Nokia and Degremont diffusers, which have experienced significant overseas application, are now being marketed in the United States. A follow-up effort to evaluate the O&M performance of this equipment is recommended. The Nokia dome, in particular, represents a radical departure from conventional ceramic dome technology, and should be of prime interest in further studies.

5. Data evaluated during this project appear to predict substantial performance equivalence between the Norton/Hawker-Siddely dome, the Sanitaire disc, the Degremont disc, and the Nokia disc. The larger diameter Sanitaire and Degremont units may transfer more oxygen per diffuser, allowing the use of fewer diffusers, when compared to the smaller Norton/Hawker-Siddely dome. However, available data are too limited for final judgment and further evaluation is strongly recommended.

6. Diffuser cleaning is a labor intensive and costly process that can usually be forestalled by careful O&M. However, provision for dif-

fuser cleaning was the usual practice in the United Kingdom and appears prudent in light of British experience. Alternatives to refiring, notably ultrasonic cleaning, need further development. Further study of ultrasonic cleaning might be carried out in cooperation with the Fort Worth, Texas plant to document labor requirements, cleaning effectiveness, and equipment reliability.

It is recognized that these recommendations have been stated in terms of urgency; however, in view of the increasing number of dome and disc diffuser systems being designed and bid in the United States, it is believed that expedited research is necessary to avoid repeating the deficiencies observed at the surveyed plants.

SECTION 4

STUDY APPROACH

This section discusses the approach used in carrying out the survey and evaluation of fine bubble aerated plants. The approach used in analyzing data to estimate oxygen transfer performance is detailed in Section 5.

SELECTION OF PLANTS FOR VISITATION

The principal criteria utilized in selecting the plants to be visited were as follows:

1. Size: Plants with average flows in excess of 18,925 m^3/day (5 mgd) were of prime interest. A range of plant sizes from very large down to this minimum flow rate could provide insight into system design, performance, and O&M as a function of size.

2. Age: A principal concern the study was to address was the long term O&M requirements and system reliability of fine bubble dome diffuser currently being marketed in the United States. Consequently, plants with 5 or more yr of operating experience were emphasized.

3. Process type: In selecting plants, a range of process types, ranging from low-to high-rate and including nitrification constituted another primary criterion.

4. Industrial wastes: The study was to be concerned mainly with typical municipal wastewaters. However, plants that were receiving varying amounts of wastes from industries were also investigated.

5. Water characteristics: The effect of hard and/or alkaline waters on system performance and O&M requirements represented another area of interest.

6. Geographic location: Plants were to represent, as much as possible, the different geographic conditions of the host country. Variation in design and O&M practices with geographic location could then be assessed.

7. Availability of data: Plants that had adequate records and scientific staff were favored, for obvious reasons.

Selection of plants for visitation in the United Kingdom was principally carried out by the WRC. U.S. plants were selected by the principal investigator (PI) after consultation with equipment vendors and others. Dutch plants were selected by the Zuiveringschap-West Overijssel Authority.

DEVELOPMENT OF SURVEY FORMS

The survey forms shown in Appendix A were developed first by the PI and the EPA project officer and later substantially modified by the WRC to reflect data availability at U.K. plants. The initial study plan called for completing the survey forms at the time of the site visits. However, the WRC was able to carry out this activity in advance, working with the Thames Water Authority and the Severn Trent Water Authority. This enabled a substantial increase in the number of plants that could be visited, from the originally planned seven up to 13. The PI refined and added to the data in the survey forms as needed during the site visits.

In developing the survey forms, the goal was to document an adequate data base over a period up to 5 yr. Emphasis was given to annual and monthly average data as opposed to daily or weekly analyses, as the purpose of the study was to define long-term average performance histories rather than short-term or seasonal perturbations. Provision was made in the survey forms and during site visits to identify non-typical conditions, such as unusual flows or loading variations. The survey forms also included fairly specific data for plant design, emphasizing the aeration system, air cleaning and blowers, and secondary clarifiers. Considerable additional design data were generated by the plant visits. In many cases, the PI was given as-built drawings of the aeration system, detailing air supply grid and D.O. control design.

Very little O&M data were requested in the survey forms; rather, the information was developed through direct interviews with plant personnel.

PLANT VISITS

A total of 19 plants were surveyed, as listed below.

<u>United Kingdom</u>

Thames Water Authority:

Beckton (London)

Mogden (London)

Beddington (London)

Ryemeads

Basingstoke

Oxford

Long Reach (London)

Severn Trent Water Authority:

Minworth (Birmingham)

Coleshill (Birmingham)

Coalport

Hartshill

Finham (Birmingham)

Strongford (Stoke on Trent)

The Netherlands

Zuiveringschap-West Overijssel Authority:

Holten-Markelo

Steenwijk

United States

Fort Worth, Texas

Glendale, California

Tallman Island (NYC), New York

Madison, Wisconsin

Generally, 1-2 days were spent at each plant plus travel time. Survey forms for the British plants were completed in advance by the scientific staffs of the U.K. water authorities. Data for the other plants visited were developed by the PI at the time of the site visit, with the exception of Madison, Wisconsin, where plant personnel completed the survey forms in advance and Steenwijk for which data were provided by the Zuiveringschap-West Overijssel Authority in lieu of a plant visit.

LITERATURE SURVEY

In support of the field studies, a limited literature survey was carried out. A References section is provided at the conclusion of the body of the report. This activity was substantially assisted by the WRC and the EPA project officer.

SECTION 5

METHODS OF ANALYSIS

The approach used in estimating mixing and oxygen transfer performance from the data collected in the plant surveys is presented in this section. A discussion of the individual plant surveys along with a description of each plant is provided in Appendix B and includes tabulation of all calculated oxygen transfer and mixing performance results. Section 6 summarizes and compares these results.

ANALYSIS OF MIXING DATA

Mixing data analysis is based on minimum air flow rates per diffuser, normally 0.011-0.014 m^3/min/unit (0.4-0.5 cfm/unit). Emphasis was placed on documenting minimum air flow rates per unit surface area and per unit volume of the aeration tank. When correlated with direct observation by plant personnel and others, this technique can help define the lower threshhold of mixing requirements for dome diffusers. In most cases, the surveyed plants operated at minimum air flow rates for substantial portions of the day, month, and year.

Power per unit volume estimates were developed from power and air rate data obtained at each individual plant. No attempt was made to factor out energy losses in the air distribution grid or account for varying blower efficiencies. Equal air flow to each dome was assumed as was generally the case in the visited plants. Where this was not true, the plants were not monitoring actual air flows rates to subsections of the aeration systems. Therefore,in these plants, a minimum air flow rate had to be assumed.

ANALYSIS OF OXYGEN TRANSFER EFFICIENCY

Currently, there are many methods for measuring oxygen transfer efficiency, including steady and non-steady state procedures. The reader is referred to Reference 1 for a detailed discussion of current EPA efforts to develop a unified oxygen transfer testing standard.

For purposes of this study, oxygen transfer efficiency was estimated using influent and effluent BOD_5, NH_3-N, and NO_3-N data. The method described below was developed by Boon and Hoyland of the WRC based on the work of Eckenfelder[2] and has an estimated ± 20 percent accuracy. Several of the plants and other researchers have measured performance using the non-steady state sulfite reaeration method. These results are discussed in Section 8.

Oxygen Required by Activated Sludge Process

The net rate, G_t, of oxygen consumption by the microorganisms in an aeration tank is given by:

G_t = rate of oxygen consumption by the heterotrophs (G_h)

+ rate of oxygen consumption by the nitrifiers (G_n)

- rate of oxygen production by denitrification (G_d) (1)

The heterotrophs consume oxygen when assimilating substrate for growth and when respiring endogeneously. The rate, G_h (kg/sec), of oxygen consumption may therefore be described by:

$$G_h = 10^{-3} \left[fa\ (B_s - B_e) + bp\ MLSS\ V\right] \qquad (2)$$

where: f = average wastewater flow rate, m^3/sec

a = constant, kg O_2/kg BOD_5 removed

b = constant defining the rate of endogeneous respiration, kg O_2/kg heterotrophs/sec

MLSS = concentration of suspended solids in the aeration tank, mg/l

p = proportion of active heterotrophs

V = aeration tank volume, m^3

B_s = primary effluent BOD_5, mg/l

B_e = final effluent BOD_5, mg/l.

Typical values of a and b are 0.75 and 0.7 x 10^{-6} sec^{-1}, respectively, and a value of 0.75 for p has been assumed for F/M loadings from about 0.1 to 1 kg BOD_5/day/kg MLSS. At loadings less than about 0.1 kg BOD_5/day/kg MLSS, the value of p decreases, approaching a hypothetical value of zero in an aeration tank of infinite volume.

The rate of consumption of oxygen by the nitrifier microorganisms, G_n (kg/sec), may be approximated by:

$$G_n = 4.3 \times 10^{-3}\ f\ (N_s - N_e) \qquad (3)$$

where N_s and N_e are the concentrations (mg/l) of the ammoniacal nitrogen in the primary effluent and final effluent, respectively. The equation assumes that about 6 percent of the ammoniacal nitrogen is assimilated by the bacteria.

The rate, G_n (kg/sec), of conversion of nitrified nitrogen to gaseous nitrogen may be estimated from the following mass balance:

G_d = rate of conversion of ammoniacal nitrogen to nitrified nitrogen

- rate of loss of nitrified nitrogen in the final effluent

$$= 10^{-3} f [(N_s-N_e) (1-0.06)-N_e^*] \quad (4)$$

where N_e^* is the concentriation of nitrified nitrogen in the final effluent. Assuming 1 kg nitrified nitrogen provides 2.83 kg oxygen for biochemical oxidation, it follows from Equation 4 that:

$$G_d = 2.83\ 10^{-3} f[0.94 (N_s-N_e)-N_e^*] \quad (5)$$

From Equations 1, 2, 3, and 5 it may be deduced that:

$$G_t = 10^{-3} f[R(B_s-B_e) + 1.64 (N_s-N_e) + 2.83 N_e^*] \quad (6)$$

where R, kg O_2/kg BOD_5 removed, is given by:

$$R = a + bp \text{ MLSS } T/(B_s-B_e) \quad (7)$$

Substituting the typical values for a, b, and f in Equation 7 yields:

$$R = 0.75 + 2 \times 10^{-3} \times 24 \text{ MLSS } T/(B_s-B_e) \text{ (for } 0.1 \leq F/M \leq 0.5) \quad (8)$$

where T, days, is the aeration tank volume divided by the wastewater flow rate.

F/M, the food-to-microorganism ratio, can be defined as B_s-B_e/MLSS x T, on a total sludge mass basis (volatile + nonvolatile suspended solids). Substituting in Equation 8, the ratio, R, is expressed as follows:

$$R = 0.75 + 0.05/(F/M) \quad (9)$$

A plot of Equation 9 is presented in Figure 1 and was used to estimate R in making oxygen transfer efficiency computations in this report.

For purposes of computation, Equation 3 can be expressed in terms of mass flow in kg/day:

$$G_t = R (B_s-B_e) + 1.6 (N_s-N_e) + 2.83 (N_e^*) \quad (10)$$

where B_s-B_e, N_s-N_e, and N_e^* are expressed in kg/day. Equation 10 is used herein to compute total oxygen supplied on a daily basis by the aeration systems evaluated.

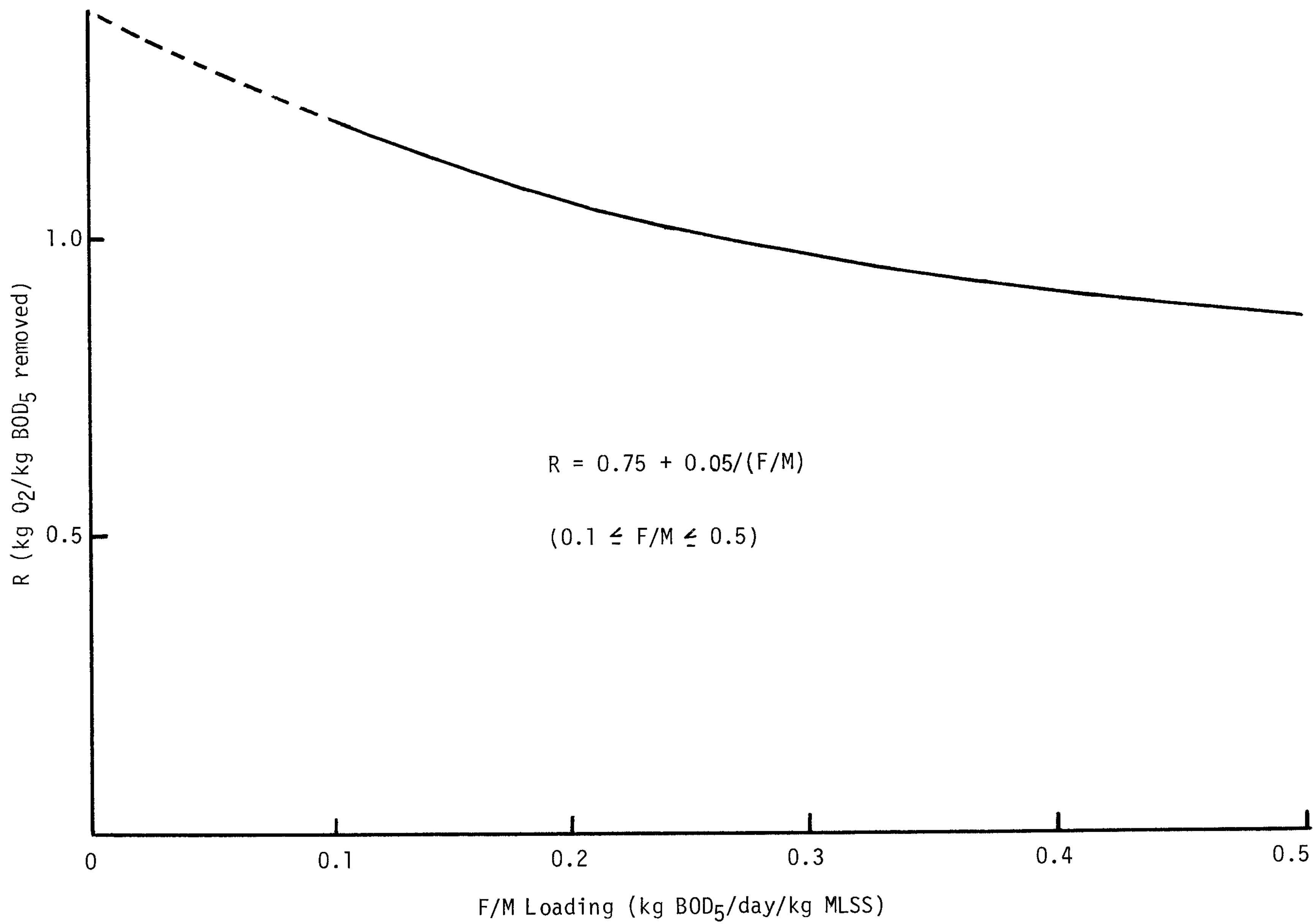

Figure 1. Relationship of oxygen demand to F/M loading.

SECTION 6

RESULTS

This section summarizes the results of the plant surveys and the findings of the supportive literature search with regard to general design characteristics, oxygen transfer performance, and O&M performance. Suggested revised design approaches based on direct observation, consultation with manufacturers and designers, and the literature review are presented in Section 8.

GENERAL DESIGN CHARACTERISTICS OF SURVEYED PLANTS

A total of 19 plants were surveyed during the study -- 13 in the United Kingdom, four in the United States, and two in The Netherlands. Because the emphasis of the study was on long-term performance and O&M data, all of the surveyed plants were equipped with dome diffusers manufactured by Norton/ Hawker-Siddeley. Other, similar equipment is now available and is discussed in Section 7.

Most of the visited plants had aeration systems of the plug flow configuration, using long, narrow channels with one or more passes. Several used step feeding for better load distribution. Most of the plants in the United Kingdom produced fully nitrified effluents of high quality; several practiced denitrification as well. A list of the surveyed plants and background data are provided in Table 1.

Clarification Systems

Although this project focused on aeration system performance, it was recognized early in the study that primary clarifier design and performance differed markedly between plants in the United States and United Kingdom. Table 2 summarizes clarifier loading parameters for the visited plants. With several exceptions, U.K. primary clarifiers are designed for hydraulic loadings that average 50-60 percent of those used in the United States and The Netherlands. Discussions with designers in the United Kingdom indicated that their prevailing philosophy is to maximize removal of BOD in a low energy process, primary settling, to save energy in the aeration systems. Also, most of the U.K. systems are designed to fully treat flows up to three times the average dry weather flow (DWF) and most had large stormwater holding/settling systems in addition to very conservative primary clarifiers.

Also of interest is the thickener style of design applied to most secondary clarifiers. Figure 2 depicts a typical secondary clarifier encountered at most of the plants visited in the United Kingdom. The steep floor slope, normally 30 degrees, greatly facilitates desludging, and the scraper mechanism

TABLE 1. SURVEYED PLANT CHARACTERISTICS

Plant Location/Name	Aeration System Description	1978/1979 Average Flow mgd	1978/1979 Average Flow m^3/sec	Average Performance $\%(BOD_5)_R$	Average Performance $\%TSS_R$	O & M Experience*
United Kingdom						
Basingstoke	Nitrifying, 1-pass plug flow, symmetrical aeration	4.9	0.22	97	97	A
Beckton (New Plant)	Nitrifying, 1-pass plug flow, tapered aeration	174	7.6	95	94	+
Beddington	Nitrifying, 2-pass plug flow, tapered aeration	25.5	1.12	96	97	-
Long Reach	Non-nitrifying, 4-pass plug flow, tapered aeration	52.8	2.31	94	91	+
Mogden (Battery B)	Nitrifying, 4-pass plug flow, some aeration taper	45.2	1.98	97	97	+
Oxford (1969 Plant)	Nitri/denit, 1-pass plug flow, tapered aeration	5.3	0.23	98	96	+
Ryemeads (Stage III)	Nitri/denit, 4-pass plug flow, tapered aeration	10.4	0.46	98	98	+
Coalport	Nitrifying, 2-pass step feed, symmetrical aeration	3.2	0.14	95	95	+
Coleshill (Stage III)	Nitri/denit, 1-pass plug flow, tapered aeration	13.5	0.59	96	96	+
Finham (South)	Non-nitrifying, 1-pass plug flow, symmetrical aeration	7.5	0.33	90	92	+
Hartshill	Non-nitrifying, 1-pass plug flow, tapered aeration	5.7	0.25	94	94	+
Minworth	Nitri/denit, 1-pass plug flow, tapered aeration	72.4	3.17	96	96	+
Strongford (New Plant)	Nitrifying, 1-pass plug flow, some aeration taper	10.6	0.46	95	--	+
The Netherlands						
Holten-Markelo	Nitri/denit, 2-pass plug flow, tapered aeration	4.7	0.21	93	92	+
Steenwijk	Nitrifying, 2-pass plug flow, tapered aeration	11.8	0.52	96	95	+
United States						
Glendale, Calif.	Non-nitrifying, 1-pass plug flow, tapered aeration	3.0**	0.13**	90	90	+
Madison, Wisc.	Non-nitrifying, 3-pass step feed, tapered aeration	14.5	0.64	88	92	+
Fort Worth, Tex.	Non-nitrifying, 1-pass plug flow, tapered aeration	99***	4.3***	--	--	-
Tallman Island, N.Y.	Non-nitrifying, 2 pass plug flow, step feed	68	2.98	86	--	+

*Key: A = average
+ = better than average
- = worse than average

**10 mo data.
*** 3 mo data.

TABLE 2. CLARIFIER DATA

Plant Location / Name	Primary System				Secondary System				Stormwater Retention
	Type	Surface Loading (gpd/ft^2)*	Detention Time (hr)	Average BOD_5 Removal	Type	Surface Loading (gpd/ft^2)*	Detention Time (hr)	Based On	
United Kingdom									
Basingstoke	Circ.	348	6.3	45	Circ.	410	5.0	DWF	Yes
Beckton (New Plant)	Rect.	490	4.1	55	Circ.	500	5.0	DWF	No
Beddington (New Tanks)	Circ.	306	6.2	52	Circ.	368	5.3	DWF	Yes
Long Reach	Rect.	670	3.0	46	Circ.	380-760$^+$	4.9-2.4	1979 Avg. Flow	No
Mogden (Battery B)	Circ./Rect.	1235/583**	1.8+3.7**	58	Circ.	619	4.1	DWF	Yes
Oxford (1969 Plant)	Circ./Rect.	141 overall	6.85/10.9^{++}	47	Circ.	260	8.65	DWF	Yes
Ryemeads (Stage III)	Rect.	300	6.0	54	Circ.	400	7.5	DWF	Yes
Coalport	Rect.	217	6.0	N.Av.	Circ.	414	6.0	DWF	Yes
Coleshill (Stage III)	Rect.	260	8.0	N.Av.	Circ.	325	6.0	DWF	Yes
Finham (South)	Circ.	--	--	50	Circ.	724	3.5	DWF	Yes
Hartshill	Circ.	346	6.3	N.Av.	Circ.	323	5.9	DWF	Yes
Minworth	Rect.	180	7.5	N.Av.	Circ.	271	6.0	DWF	Yes
Strongford (New Plant)	Circ.	327	8.0	N.Av.	Circ.	446	4.5	DWF	Yes
The Netherlands									
Holten-Markelo	Circ.	730	1.65	27	Circ.	300	5.0	Avg. Flow	No
Steenwijk	Circ.	700	2.0	31	Circ.	300 (est.)	5.0 (est.)	Avg. Flow	No
United States									
Glendale, Calif.**	Rect.	--	--	--	Rect.	442	6.5	Avg. Flow	No
Madison, Wisc.	Rect.	1000	1.4	25	Circ.	454	3.4	Avg. Design	No
Fort Worth, Tex.	Circ.	--	--	--	Circ.	--	--	Avg. Flow	No
Tallman Island, N.Y.	Rect.	--	--	30	Rect.	820	2.7	Avg. Flow	No

* 1 gpd/ft^2 = 0.041 m^3/day/m^2
\+ Unequally loaded.
** Two-stage primary tanks.
\+\+ Two types of primary tanks.

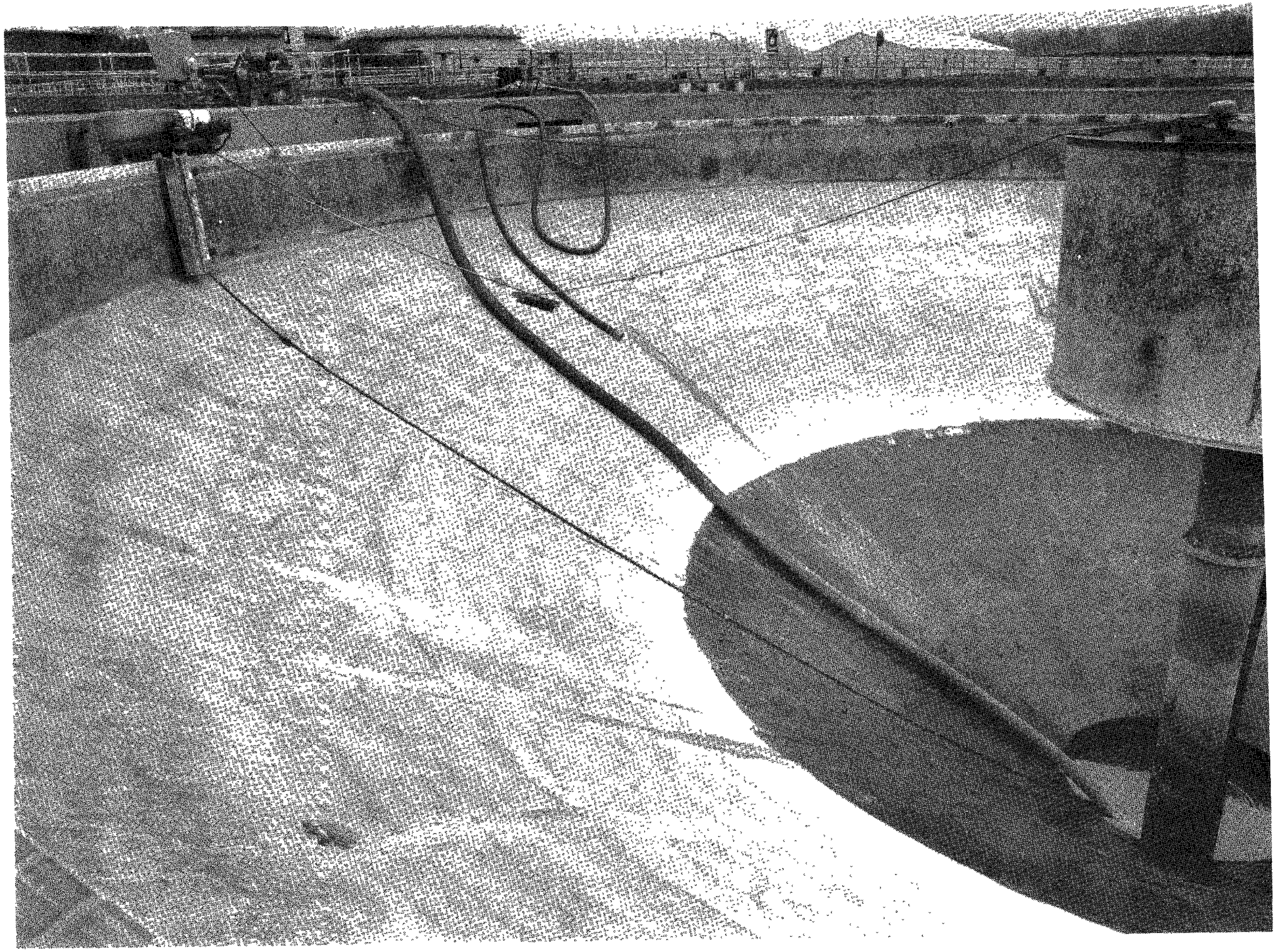

Figure 2. U.K. thickener-style secondary clarifier.

usually consists of a simple dragging chain mechanism. Several plants were equipped with this type of unit along with clarifiers using blade scraper mechanisms and relatively flat floors. Without exception, plant operators expressed a preference for the design shown in Figure 2. Typically, secondary clarifier diameter did not exceed 18-24 m (60-80 ft). U.K. designers indicated this was a common practice, even in the larger installations, for older plants. Newer secondary clarifiers in the United Kingdom generally have a floor slope of 7-10 degrees and have scrapers. Most of these newer clarifiers are 30 m (98 ft) in diameter.

The combination of highly nitrified effluents and long final clarifier detention time has often led to denitrification and associated flotation of clarifier sludge blankets in a number of U.K. plants. To alleviate this problem, four of the U.K. plants have created anoxic zones in the first section of the plug flow aeration channels, with variable results. Most of the plants reported improvement in settling but not to the point of fully solving the problem, partcularly during warm weather. Design of the anoxic zones is discussed later.

Aeration Systems

Aeration system design and process data for the surveyed plants are summarized in Tables 3 and 4, respectively, and discussed below.

Plug flow aeration systems were in use at all of the plants visited during this study. Approximately one-half of the plants had two or more passes per aeration tank. The majority of the plants were operated in the full plug flow mode with effective length-to-width ratios up to 106 when multiple passes were considered. The U.K. plants, again, exhibited very conservative design approaches, owing principally to very stringent discharge requirements. Only three plants were visited there that did not fully nitrify. Most achieved treatment levels exceeding 95 percent removal of BOD_5, suspended solids, and ammoniacal nitrogen. Food-to-microorganism (F/M) loadings in U.K. plants typically ranged from 0.1-0.2 kg BOD_5/day/kg MLSS, and volumetric loadings ranged from 0.16-0.40 kg $BOD_5/day/m^3$ (10-25 lb/day/1000 ft^3) except in the higher rate plants or those receiving strong industrial wastes. Similarly, the nitrifying U.K. plants consumed two to three times more air per unit of BOD_5 removed than did the conventional activated sludge, non nitrifying, U.S. plants. However, because volumetric loading rates were lower, air flow rates per unit volume of aeration tank were similar to those in U.S. plants. Diffuser density and air flow rates per diffuser were also quite similar, reflecting the commonality of dome diffuser aeration design in both countries.* Tapered aeration, full or partial, was used in all but four of the 19 plants surveyed.**

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* The dome diffuser was introduced in the United States under license by the U.K. manufacturer, Hawker-Siddeley, who provided most of the initial design expertise to the U.S. vendor, Norton Company.

** Discussed in Section 8.

TABLE 3. AERATION SYSTEM DESIGN DATA

Plant Location/Name	Aeration Basin Dimensions Lgth (m)*	Wdth (m)*	Dpth (m)*	L/W	Diffuser Density (domes/m^2)$^+$	Aeration Taper (%)	Minimum Mixing Power Level (W/m^3)**	Avg. Air Flow/ Min. Air Flow	Remarks
United Kingdom									
Basingstoke	79.2	6.7	2.5	12	3.9	none	20.8	1.5	Large basin. Small basin L/W = 24
Beckton (New Plant)	223	41.2	3.1	5.4	2.8-1.9	46/31/23	13.6-6.8	1.5	Basin No. 6. L/W = 98 (old plant)
Beddington (New Tanks)	67	7.3	2.4	18.4	2.7-1.1	34/28/23/15	16.1-6.4	1.8	New basin Nos. 1, 8, 9, and 16
Long Reach	80	6.0	3.8	53	7.8-3.5	35/27/23/15	58.7-25.7	2.0	Mixing power at operating air flow
Mogden (Battery B)	122	4.6	3.7	106	5.0-3.1	34/22/22/22	29-18.5	1.0	Mixing power at operating air flow
Oxford (1969 Plant)	37.8	6.9	2.4	5.5	3.8	43/28	18.8	1.5	1 basin tapered, 7 step feed
Ryemeads (Stage III)	70	4.3	3.0	65	4.6-2.3	21/33/28/18	29-13.8	2.4	First pass anoxic for first 29 m
Coalport	65	4.6	4.3	27.8	2.8	none	25-16.7	1.2	Air split 60/40 between passes
Coleshill (Stage III)	64	18.3	2.9	3.5	3.9-2.0	See Appendix B	36.9-16.7	2.0	5.7 W/m^3 in anxoic zone
Finham (South)	61	3.0	3.6	20.3	4.3	none	36.0	1.5	High rate plant
Hartshill	27.4	9.2	3.2	3.0	5.9-4.1	59/41	89.0-62.0	--	Mixing power at operating air flow
Minworth	178	18.3	3.0	9.7	0.4/1.9-0.9	See Appendix B	26.8-13.4	1.25	2.6 W/m^3 in anoxic zone
Strongford (New Plant)	108	9.3	3.0	46.4	2.3-1.9	See Appendix B	--	--	
The Netherlands									
Holten-Markelo	30	6.6	4.0	9.1	1.9-0.9	34/25/25/16	--	--	Air supplied by gas engines
Steenwijk	100	6.75	4.0	29.6	2.8-1.5	34/25/25/16	20-10	--	
United States									
Glendale, Calif.	73.2	9.75	4.9	7.5	3.0-0.9	57/43	24-7.5	1.4	1 tank test
Madison, Wisc.	41.2	9.1	4.7	13.6	9.1-3.6	48/29/23	33.7-13.4	1.5	Tank Nos. 1-6
Fort Worth, Tex.	83.8	36.6	4.3	23	5.4-3.0	34/27/21/18	--	1.4	Tank Nos. 1, 2, and 4
Tallman Island, N.Y.	110	28	4.9	7.9	1.3	none	--	1.2	Tank Nos. 1 and 2

* 1 m = 3.28 ft
\+ 1 dome/m^2 = 9.29 domes/100 ft^2
** 1 W/m^3 = 0.038 wire hp/1000 ft^3

TABLE 4. AERATION PROCESS PERFORMANCE DATA

Plant Name/Location	Average Flow & Data Year (m^3/sec)*	Design DWF (m^3/sec)*	BOD_5 (mg/l) Raw	BOD_5 (mg/l) Primary	BOD_5 (mg/l) Effluent	Volumetric Loading (lb BOD_5/day/1000 ft^3)**	F/M Loading (kg BOD_5/day/kg^2)	Average Air Flow ft^3/lb BOD_5+	Average Air Flow cfm/1000 ft^3++	Remarks
United Kingdom										
Basingstoke	0.22/78-79	0.26	281	157	4	22.4	0.08	1910	28.9	Large basin
Beckton (New Plant)	7.6/78-79	8.8	169	96	8	20.6	0.13	1110	16.8	Basin No. 6 Non-nitrifying
Beddington (New tanks)	1.12/78-79	0.96	320	149	12	11.7	0.20	1785	13.4	
Long Reach	2.31/78-79	1.97	334	180	20	44.0	0.30	612	16.6	Non-nitrifying
Mogden (Battery B)	1.98/78-79	1.53	238	99	8	9.8	0.18	1392	20.8	
Oxford (1969 Plant)	0.23/78-79	0.17	367	165	7	41.0	0.10	1046	26.2	Initial anoxic zone
Ryemeads (Stage III)	0.45/78-79	0.42	310	144	5	24.3	0.08	1416	23.0	Initial anoxic zone
Coalport	0.14/78-79	0.20	--	157	9	36.0	0.14	1402	11.0	
Coleshill (Stage III)	0.42/78-79	0.62	--	158	12	22.9	0.10	1000	15.8	Initial anoxic zone
Finham (South)	0.32/1979	0.26	321	162	32	70.0	0.45	693	34.4	High rate, non-nitrifying
Hartshill	0.25/1979	0.28	500-700	400-500	20-40	112	0.30	747	43.8	1 mo data
Minworth	3.17/1978	2.11	--	142	6	22.2	0.09	689	10.1	Initial anoxic zone
Strongford (New Plant)	0.47/1979	0.77	250	50-100	10	--	0.05	--	--	Figures approx.
The Netherlands										
Holten-Markelo	0.21/1978	0.15	400	182	21	30.4	0.18	--	--	Non-nitrifying
Steenwijk	0.52/1978	0.62	312	102	12	24.2	0.11	--	--	Partial nitrification
United States										
Glendale, Calif.	0.13/78-79	--	220	158	11	31.9	0.35	748	15.4	Non-nitrifying
Madison, Wisc.	0.63/1979	--	213	156	19	27.0	0.30	732	80.0	Non-nitrifying
Fort Worth, Tex.	4.3/pt. 1979	4.2	--	--	--	--	--	--	--	Non-nitrifying
Tallman Island, NY	3.0/78-79	3.5	91	64	13	29.6	0.24	--	--	Non-nitrifying

* 1 m^3/sec = 22.8 mgd

** 1 lb/day/1000 ft^3 = 0.016 $m^3/day/m^2$

\+ 1 ft^3/lb = 0.062 m^3/kg

\++ 1 cfm/1000 ft^3 = 0.017 l/m^3/sec

Mixing power levels at minimum air flow rates were relatively low in most of the plants. Only one plant, Minworth, reported any deposition of mixed liquor solids, that occuring in the lightly mixed anoxic zone. Significantly, all of the lightly mixed plants had very effective primary sedimentation. Mixed liquor suspended solids (MLSS) at all of the plants except Oxford were less than 3500 mg/l. Oxford compensates for higher-than-average volumetric loadings by carrying 4500-5000 mg/l MLSS, maintaining low F/M loadings to promote nitrification. The range of power levels given reflects the practice of tapered aeration, whereby air input (and hence power input) is front loaded in the plug flow plants. Often, mixing in the lightly aerated section of plug flow plants with tapered aeration was enhanced by central placement of the diffusers, along the tank length axis, carrying a double spiral mixing pattern (see Section 8).

Single-stage nitrification (BOD removal and nitrification in the same tank) was being achieved in most of the U.K. plants surveyed. To combat denitrification in the final clarifiers, four plants have been experimenting with partial denitrification using anoxic zones. Table 5 provides basic design parameters for these zones.

TABLE 5. ANOXIC ZONE DESIGN DATA

Plant	Description	Zone Volume (m^3)*	Detention Time (hr)	Mixing Power Level (W/m^3)+	Remarks
Oxford	Maintain low D.O. in first 25 percent of tank length, prior to introduction of first 50% of wastewater flow	160	2	--	Minimal effectiveness
Ryemeads	First 50 percent of first pass (four total passes) anoxic zone. Five mechanical stirrers, three of which are in operation	452	1.5	29	Removes 30-40 percent of oxidized nitrogen; mechanically mixed
Minworth	First 17 percent of single-pass tank has dome density reduced to 0.4 dome/m^2**	1629	2	2.9	Removes 10-20 percent of oxidized nitrogen
Coleshill	First 28 percent of single-pass tank has dome density reduced to 0.7 dome/m^2	950	1.5	5.7	Removes 40-50 percent of oxidized nitrogen

* 1 m^3 = 35.3 ft^3
\+ 1 W/m^3 = 0.038 wire hp/1000 ft^3
** 1 dome/m^2 = 9.29 domes/100 ft^2

Experimental denitrification studies have been conducted at Ryemeads by the WRC and the Thames Water Authority.[3] It was determined that 50 percent removal of nitrate nitrogen was the practical upper limit of the process as used at Ryemeads. Parallel laboratory studies suggested that the degree of denitrification might be increased by a further 10-20 percent by adding a second anoxic zone at the beginning of the third pass at Ryemeads. This has not been fully supported by the experimental results at Ryemeads.

Process modifications have been undertaken at Coleshill to optimize overall activated sludge performance and reduce settling problems in the final clarifiers caused by denitrification.[4] In the period June-December 1978, nitrate removal through the process (including that occurring in final clarifiers) ranged from 42-57 percent. Dramatic improvement in the problem of rising sludge in the clarifiers was reported. A change in the clarifier desludging schedule, decreasing detention time during low flow periods, also helped to alleviate the problem.

Blower/Air Cleaning Equipment

Out of 19 visited plants, ten had centrifugal-type blowers and nine had positive displacement types. There was no apparent preference for the selection of one type over the other and most were designed to operate in the range of 28-55 kN/m^2 (4-8 psi).

The three types of air cleaning equipment encountered included bag house collectors, electrostatic precipitators, and disposable cartridges. Of these, bag house collectors were most commonly used in the U.K. plants visited. The units are constructed as steel enclosures which house sets of cloth stocking tubes that are precoated with filter aid before being placed in service and after each cleaning. Historically, an asbestos-based precoat was used. However, because of health and safety considerations, it is rapidly being supplanted with a cellulose-based precoat. Figure 3 shows three of the large bag house air filters at Beddington. Currently, six units are in service continuously and another one is on standby.

The size, expense, and precoat requirements of bag filters have diminished their selection for newer plants. Rather, replaceable filters (Figure 4) or electrostatic precipitators (Figure 5) are increasingly the technologies of choice in the newer plants. The precipitators can be installed in a third to half the space required for bag houses and have relatively simple maintenance needs. Simplest of all are the replaceable cartridge filters. As discussed in Section 8, these units are relatively expensive to replace but take up minimal room and require very little maintenance.

Table 6 summarizes blower/air cleaner data for the surveyed plants. Air cleaning design and cost data are provided in Section 8 of this report.

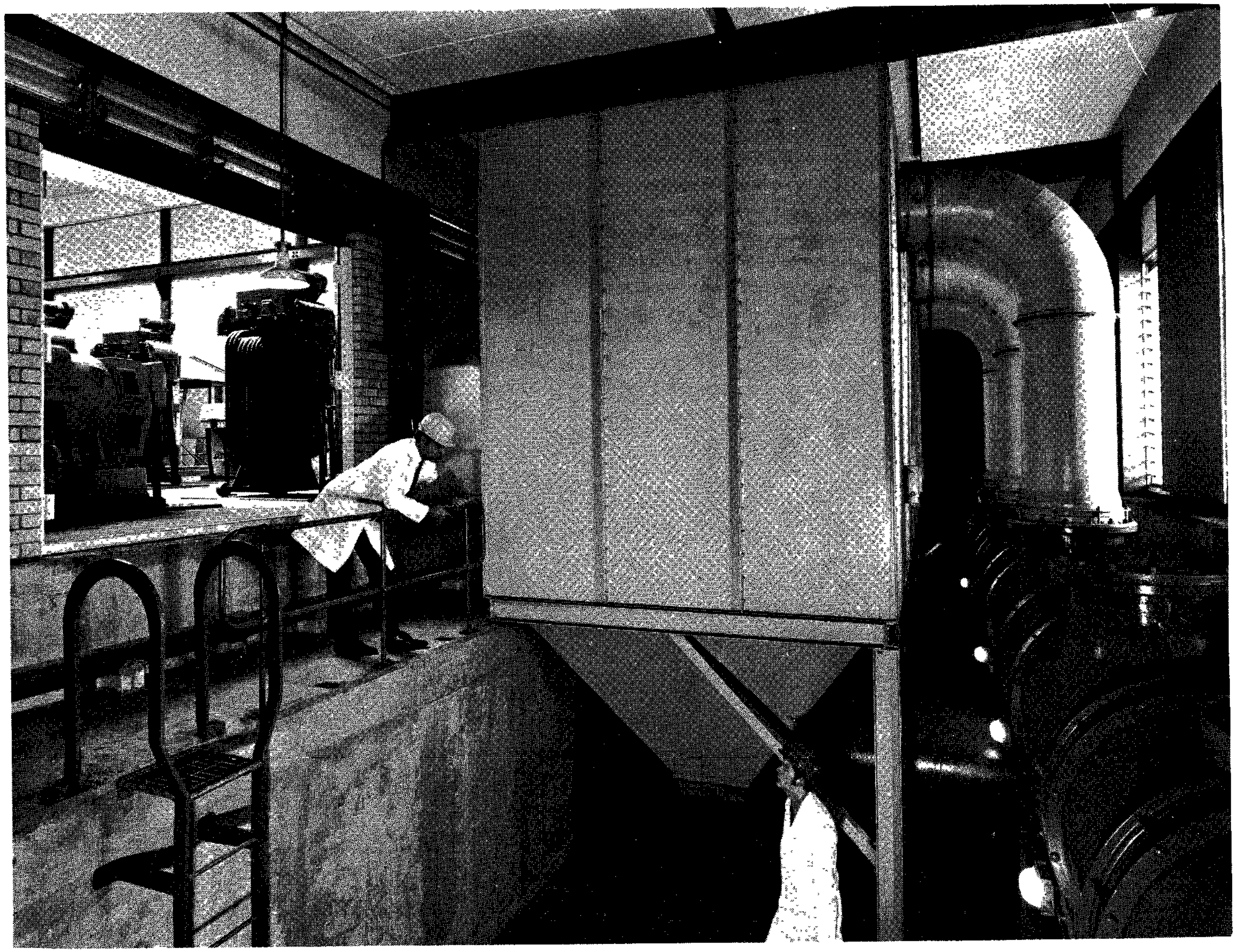
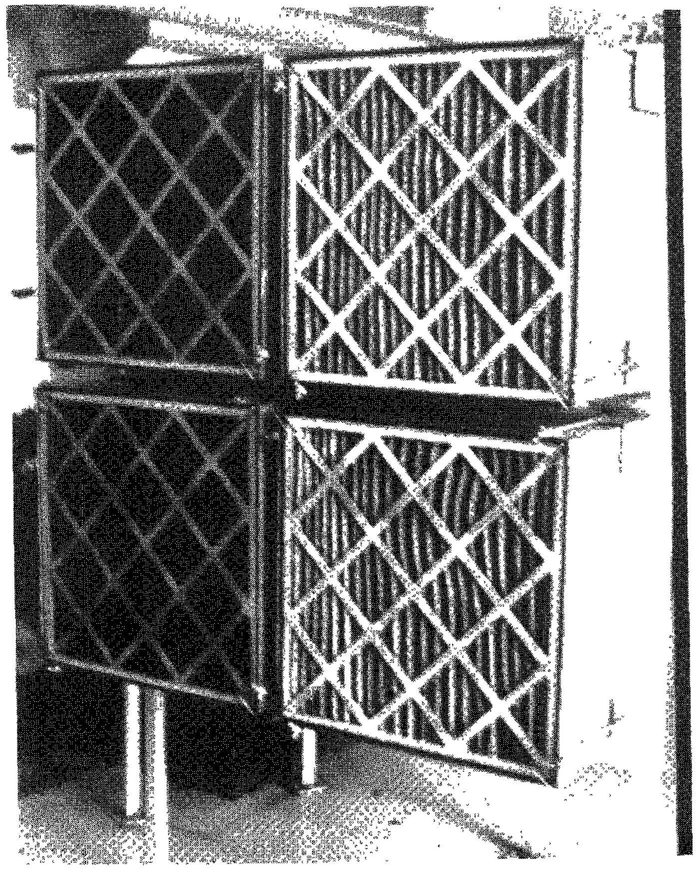


Photo courtesy of
Thames Water Authority

Figure 3. Bag house air filters at Beddington.



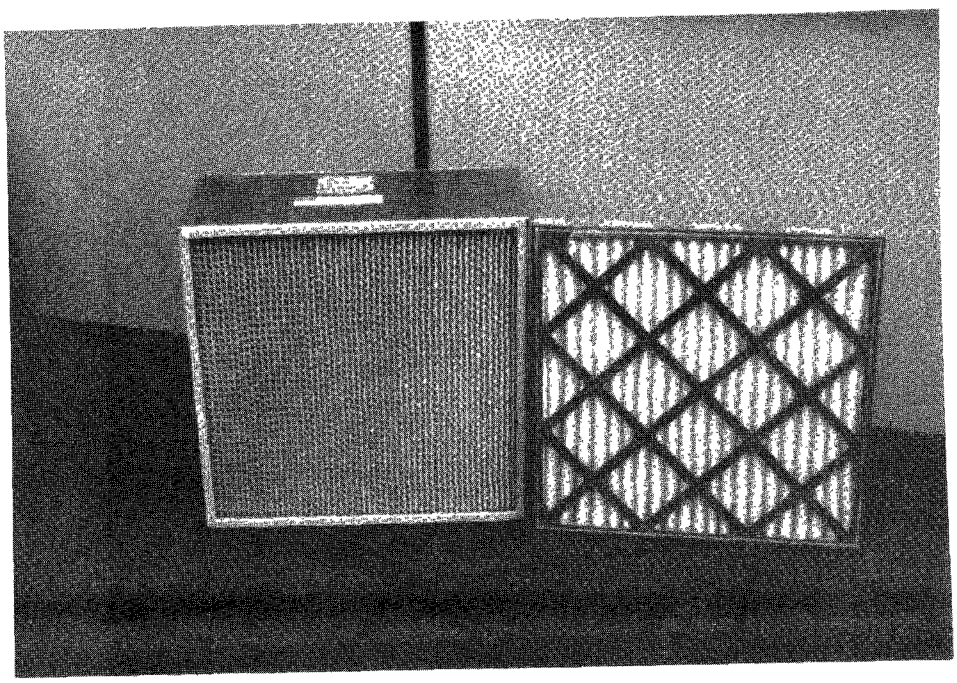


Figure 4. Disposable cartridge filters at Finham.

TABLE 6. BLOWER / AIR CLEANER DATA

	Blower Data				Air Cleaner Data		
Plant Location/Name	Type*	No.	Size Range (cfm)+	Design Pressure (psi)**	Type	No.	Rated Air Flow/Unit (cfm)
United Kingdom							
Basingstoke	PD	5	1362-3373	4.8	Bag	3	8200
Beckton							
Old Plant	C	5	--	--	Elect.	8	--
New Plant	C	16	21,000	6.0	Elect.	16	--
Beddington	C	6	6357-10,383	5.5	Bag	5	10,000
Long Reach	C	3	18,750	5.8	Bag	--	--
Mogden (Battery B)	C	10	18,000-27,000	6.2	Repl.	--	--
Oxford							
1969 Plant	PD	3	2000-3000	6.0	Bag	2	3000
Renov. Plant	PD	6	1400-2400	8.6	Elect.	3	5000
Ryemeads (Stage III)	C	3	7400	7.1	Elect.	5	5000
Coalport	C	4	2145	5.5-7.0	Bag	2	6300
Coleshill (Stage III)	PD	16	1600	6.0	Bag	2	12,800
Finham (South)	PD	4	1650	6.0	2 Stage Filter	4	1650
Hartshill	PD	3	3000-5000	--	Elect.	3	8200
Minworth	C	8	11,500-17,500	--	Bag	--	--
Strongford (New Plant)	C	4	11,400	--	Bag	4	12,000
The Netherlands							
Holten-Markelo	C	2	--	--	Elect.	1	--
Steenwijk	C	3	2500	60	Elect.	1	--
United States							
Glendale, Calif.	C	3	10,000-20,000	7.5	Repl.	2	24,000
Madison, Wisc.	PD	5	5,840-11,000	9.5	Repl.	5	12,500
Fort Worth, Tex.	C	5	--	--	Elect.	2	--
Tallman Island, N.Y.	PD	5	20,100	8.25	Elect.	1	25,000

* PD = positive displacement, C = centrifugal
\+ 1 cfm = 0.472 l/sec
** 1 psi = 6.90 kN/m^2

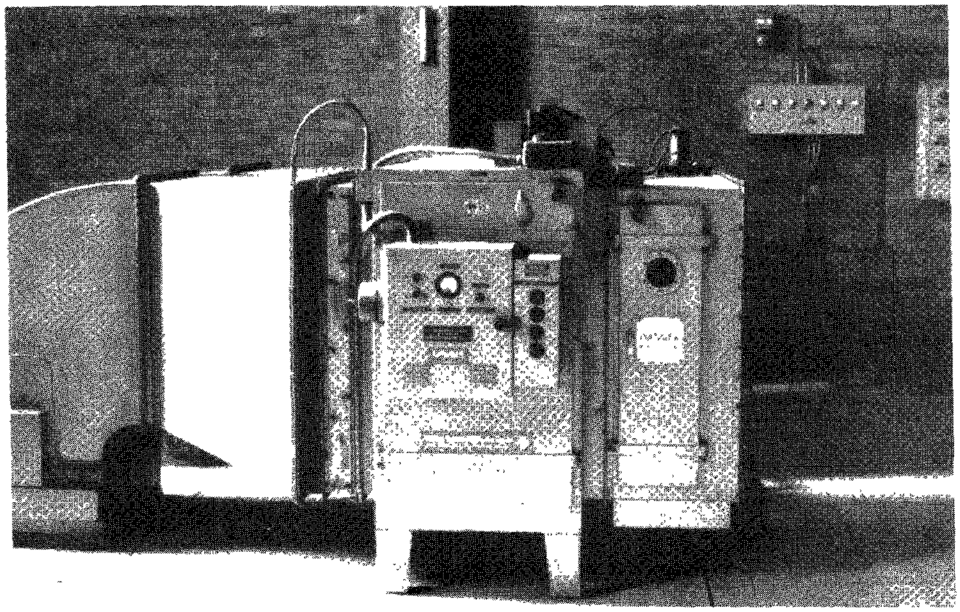


Figure 5. Electrostatic air filter at Basingstoke.

OXYGEN TRANSFER PERFORMANCE

The results of the plant surveys are discussed in this subsection along with factors that affect field (i.e., mixed liquor) oxygen transfer performance. A summary of oxygen transfer performance data from literature sources is also given.

Results of Plant Surveys

Table 7 summarizes the oxygen transfer performance developed as a result of the plant surveys. Oxygen transfer performance is typically expressed in terms of aeration efficiency, which is defined as the mass transfer of oxygen per unit of line, or wire, power input. The values of aeration efficiency shown in Table 7 for the various plants were estimated using the methodology presented in Section 5.

A wide range of performance levels are apparently occurring at the dome diffuser plants surveyed, even where process conditions are seemingly similar. Plants with long-term performance data, such as Beddington, exhibit fairly constant performance data over the period of record. The two U.S. plants for which performance could be estimated seem to be similar in both process design and performance. The Dutch plants are more closely related to U.S. plants in design; however, the estimated performance at Steenwijk is somewhat less for unknown reasons.

Coarse Bubble vs. Fine Bubble Comparison

Five plants had coarse bubble aeration tanks in parallel with dome diffuser equipped tanks:

- Finham, United Kingdom
- Madison, Wisconsin
- Glendale, California
- New York City, Tallman Island

TABLE 7. OXYGEN TRANSFER PERFORMANCE DATA SUMMARY

Plant	Aeration Tank L/W	MLSS (mg/l)	Percent Saturation of Mixed Liquor D.O.		Aeration Efficiency*				Years of Data
			Range	Average	High (kg/kWh)	Low (kg/kWh)	Average (kg/kWh)	Average (lb/hp-hr)	
Beckton	5.4	2900	10-80	40	1.95	1.54	1.75	2.88	3
Basingstoke	12	4900	10-60	30	1.20	1.08	1.16	1.91	5
Mogden	106	2300	10-100	50	1.62	1.12	1.37	2.25	5
Oxford	5.5	5500	10-40	20	2.34	1.93	2.13	3.50	5
Ryemeads	65	4700	20-100	60	1.14	1.04	1.09	1.79	3
Coalport	27.8	2500	--	--	--	--	1.08	1.78	1
Coleshill	3.5	3000	20-50	35	--	--	2.12	3.49	1
Minworth	9.7	3200	--	--	--	--	1.71	2.81	1
Strongford	46.4	5000	20-100	80	--	--	1.49	2.45	1 wk
Beddington	18.4	2300	--	15	1.25	1.05	1.11	1.83	10
Hartshill	3.0	3000	reported low	--	--	--	1.11	1.83	1 mo
Long Reach	53	1700	10-40	20	--	--	2.07	3.40	1
Finham	20.3	2000	--	--	--	--	1.76	2.89	1
Steenwijk	29.6	3300	--	--	--	--	0.78	1.28	1
Glendale	7.5	2000	10-30	20	--	--	1.14	1.87	10 mo
Madison	13.6	2000	10-30	20	1.99	1.56	1.77	2.91	2
						Average:	1.48	2.43	

* Defined as mass of O_2 transferred per unit of power input as measured by the line draw.

• Fort Worth, Texas.

Of these, four had comparative data of value. Operational problems at the Fort Worth plant prevent meaningful comparisons at this time. The New York City plant had data from a one-time test performed in 1978. Results from this plant and the other three comparisons are discussed below.

Finham --

Finham employs a trickling filter plant with activated sludge pretreatment. The North works has four 563-m^3 (19,880-ft^3) basins providing 1 hr detention time for a DWF of 54,550 m^3/day (14.4 mgd). The South works has six 656-m^3 (21,160-ft^3) basins providing 3.5 hr detention time for a DWF of 22,730 m^3/day (6.0 mgd). F/M loadings are 1.80 and 0.45 kg BOD_5/day/kg MLSS, respectively.

The North works has coarse bubble aerators of British design that provide essentially symmetrical tank floor coverage. The South works has dome diffusers symmetrically distributed on the basin floor at a density of 4.3 domes/m^2 (39.9 domes/100 ft^2).

Using the method of Section 5, aeration efficiency was estimated at 1.50 kg O_2/kWh (2.46 lb/wire hp-hr) for the North works and 1.76 kg O_2/kWh (2.89 lb/wire hp-hr) for the South works. This was the smallest difference noted in side-by-side coarse bubble and fine bubble system comparisons. Two factors may account for this:

1. The coarse bubble aeration system covered the tank floor, a configuration that is known to improve efficiency.[5]

2. Detergent concentrations at Finham were quite high, often exceeding 10 mg/l. Fine bubble diffusers may be more adversely affected by surfactants than coarse bubble diffusers.

It is believed that the comparisons from the other three plants, discussed below, are more representative of the typical performance difference between coarse and fine bubble aeration in municipal wastewater service.

Madison, Wisconsin --

In 1977, Madison retrofitted six of 16 activated sludge basins at its Nine Springs treatment plant with fine bubble dome diffusers. The purpose was twofold: to increase oxygenation capacity of the plant and to study the performance and O&M requirements of the equipment for possible later retrofit in the remaining aeration basins. Madison's coarse bubble system consists of wide band aerators placed along one side of the tanks. The fine bubble system is comprised of dome diffusers in a tapered configuration with full floor coverage (See Appendix B for description of facilities).

Three assessments of oxygen transfer performance have been carried out at Madison. Rollins and Kocurek, graduate students at the University of Wisconsin (Madison), used gas capture analysis in 1978 to estimate performance in

Tank No. 4 (fine bubble) vs. Tank No. 7 (coarse bubble) and found, with limited data, that the fine bubble system was approximately 2.8 times as efficient as the coarse bubble system.[6] Coarse bubble oxygen transfer efficiency averaged 5 percent vs. 14 percent for the fine bubble system. Both tanks were being used for sludge reaeration at the time, and loading rates were somewhat lower on the coarse bubble system.

Later in 1978, the staff of the Madison plant repeated the experiment when both sides of the plant were being operated in the contact stabilization mode, but using only the sludge reaeration tanks for the tests. Their studies indicated that the fine bubble aerators were approximately 3.3 times as efficient as the coarse bubble units. Oxygen transfer efficiency averaged 5.6 percent for the coarse bubble diffusers vs. 18.6 percent for the fine bubble diffusers.

Finally, as part of this study, performance for both systems, now being operated as step feed activated sludge units, was estimated by the method of Section 5. Coarse bubble aeration efficiency averaged 0.66 kg O_2/kWh (1.09 lb/wire hp-hr); fine bubble aeration efficiency averaged 1.77 kg O_2/kWh (2.91 lb/wire hp-hr), or apparently 2.7 times more efficient than the coarse bubble system.

The agreement between the different tests at Madison is excellent. The tests conducted by the plant staff show the widest performance gap, not unexpectedly since these tests were run when the tanks were reaerating return sludge and were not receiving influent wastewater. Under this condition, it can be expected that much of the influent detergent, which particularly affects fine bubble performance, had already been removed in the contact part of the process. The other two tests were performed with the systems operating in the step feed mode.

It should be noted, however, that operating conditions at Madison tend to make comparative analyses of the type discussed above somewhat difficult. Firstly, there is not complete system separation between coarse and fine bubble units. Mixed liquor is settled in a common secondary settling system, and return sludges are intermixed. Secondly, to provide the higher pressure required by the fine bubble system and to distribute air flow, the coarse bubble system is throttled, decreasing its efficiency. The quantitative effect of both factors could not be evaluated during this study.

Glendale, California --

One aeration tank at the Glendale plant was converted to fine bubble aeration and a 10-mo comparative study initiated in July 1978.[7] Using a steady state analytical approach, the fine bubble system was found to be approximately twice as efficient as the wide band coarse bubble system. Aeration efficiency was estimated at 1.14 kg O_2/kWh (1.87 lb/wire hp-hr) for the fine bubble system, using data from Reference 7, and 0.7 kg O_2/kWh (1.15 lb/wire hp-hr) for the coarse bubble system.

Based on these results, fine bubble retrofits were proposed for both the Glendale and Terminal Island plants in the Los Angeles City system. Table 8

TABLE 8. LOS ANGELES FINE BUBBLE RETROFIT ANALYSIS

Parameter	Glendale Treatment Plant	Terminal Island Treatment Plant
Air Flow, ft^3/gal wastewater flow*		
Coarse Bubble	1.9	5
Fine Bubble	1.0	2.6
Air Compressors		
Coarse Bubble (hp)**	960	3665
Fine Bubble (hp)**	510	1900
Power Saved (kWh/yr x 10^6)	2.94	11.53
Cost Savings ($/yr)+	97,000	415,000
Construction Costs		
Equipment++	$420,000	$450,000
Misc. (20%)	84,000	90,000
Contingencies (20%)	84,000	90,000
Profit (15%)	63,000	67,500
Subtotal	651,000	697,500
Inflation (20%)	130,200	139,500
TOTAL COST	$781,200	$837,000
Payback (yr)	8.07	2.02

* 1 ft^3/gal = 7.48 m^3/m^3

** Assumes an air compressor efficiency of 75 percent and a discharge pressure of 7 psi (48.3 kN/m^2); 1 hp = 0.746 kW.

\+ At $0.033/kWh for Glendale and $0.036/kWh for Terminal Island.

++ Includes diffusers, in-tank aeration piping, connection to existing piping, air filtration system, and appurtenant controls and meters.

summarizes the data and computations from these analyses. Los Angeles projects an 8-yr payback on a fine bubble retrofit at Glendale and a 2-yr payback at Terminal Island.

New York City (Tallman Island) --

The Tallman Island plant, located in the New York City Borough of Queens, has recently been upgraded, and a side-by-side test of fine bubble dome diffusers, wide-band coarse bubble diffusers, and wide-band fine bubble tubular diffusers will be conducted in the near future. Full-scale long term testing is awaiting the acceptance of air metering equipment. However, a limited field analysis of fine bubble vs. coarse bubble equipment was carried out in early 1979 by students of Manhattan College. That work indicated an oxygen transfer efficiency of about 6-8 percent for course bubble aeration and 18-20 percent for fine bubble aeration.[8] When correlated with blower requirements, the installed power for a fine bubble system was estimated at approximately one-half that for a coarse bubble system, based on the results of this single test.

Factors that Affected Oxygen Transfer Performance at the Surveyed Plants

The relationship between oxygen transfer rate as measured under field operating conditions vs. clean water conditions can be expressed as follows:

$$OTR = SOTR\ (\alpha)\ [\beta C_y^* - C)/C_y^*]\ \theta^{T-20} \qquad (11)$$

where: OTR = field oxygen transfer rate, kg/hr

SOTR = standardized oxygen transfer rate in clean water at stated conditions of temperature, D.O., mixing, geometry, etc., kg/hr

α = Alpha factor = ratio of K_La in wastewater application to K_La in clean water at equivalent conditions of temperature, geometry, mixing, etc.

β = Beta factor = ratio of D.O. saturation concentration in wastewater to D.O. saturation concentration in clean water at equivalent conditions of temerature and partial pressure

C_y^* = D.O. saturation concentration in clean water corresponding to a given partial pressure and temperature, mg/l

C = desired average mixed liquor D.O. concentration, mg/l

θ = temperature adjustment factor defined so that (K_La at temp. T_1) /(K_La at temp. T_2) = θ (T_1-T_2)

K_La = volumetric mass transfer coefficient, given conditions of geometry, mixing, temperature, etc., based on the liquid film, hr^{-1}.

This seemingly simple generalized relationship is subject to numerous modifiers and corrections, which will not be enumerated here. The reader is referred to Boyle et al.[1] for an extensive discussion of the art of oxygen transfer testing and analysis. However, the above equation can be used to illustrate the relationships between oxygen transfer rate and the principal factors that were observed to markedly affect plant performance at the visited plants. These are listed below in order of anticipated significance:

- Mixed liquor D.O. (C)
- Alpha factor (α)
- Aeration system geometry

  Tank depth

  Tand length-to-width ratio (degree of plug flow)

The relationship of these and other factors to plant design is discussed in Section 8 as well. There are other variables which can markedly affect oxygen transfer efficiency, including diffuser type and configuration and air flow rate. These variables were quite similar at the visited plants, and it is concluded that they did not significantly enter into the efficiency variations observed.

Mixed Liquor D.O. --

With the exception of the two plants that were receiving large industrial waste loads, Beddington and Hartshill, control of mixed liquor D.O., or lack of it, seemed to be the principal determinant of aeration efficiency. The inverse relationship between mixed liquor D.O. and aeration efficiency is evident in the data of Table 7 and the plotted band of Figure 6. Many of the less efficient plants had large portions of the total aeration volume in which D.O. approached saturation, particularly in the third and subsequent tanks of multi-channel plug flow plants.

Holding all other factors constant, Equation 11 can be expressed as a ratio for comparison of two cases of mixed liquor D.O.:

$$OTR_1/OTR_2 = (\beta C_y^* - C_1)/(\beta C_y^* - C_2) \quad (12)$$

where: C_1 = mixed liquor D.O. concentration in situation 1, mg/l

C_2 = mixed liquor D.O. concentration in situation 2, mg/l.

This can be further simplified by estimating C_1 and C_2 as follows:

$$C_1 = \%\ Sat_1\ (C_y^*/100) \quad (13)$$

$$C_2 = \%\ Sat_2\ (C_y^*/100) \quad (14)$$

Combining Equations 12, 13, and 14 yields:

$$OTR_1/OTR_2 = [\beta - (\%\ Sat_1/100)]/[\beta - (\%\ Sat_2/100)] \quad (15)$$

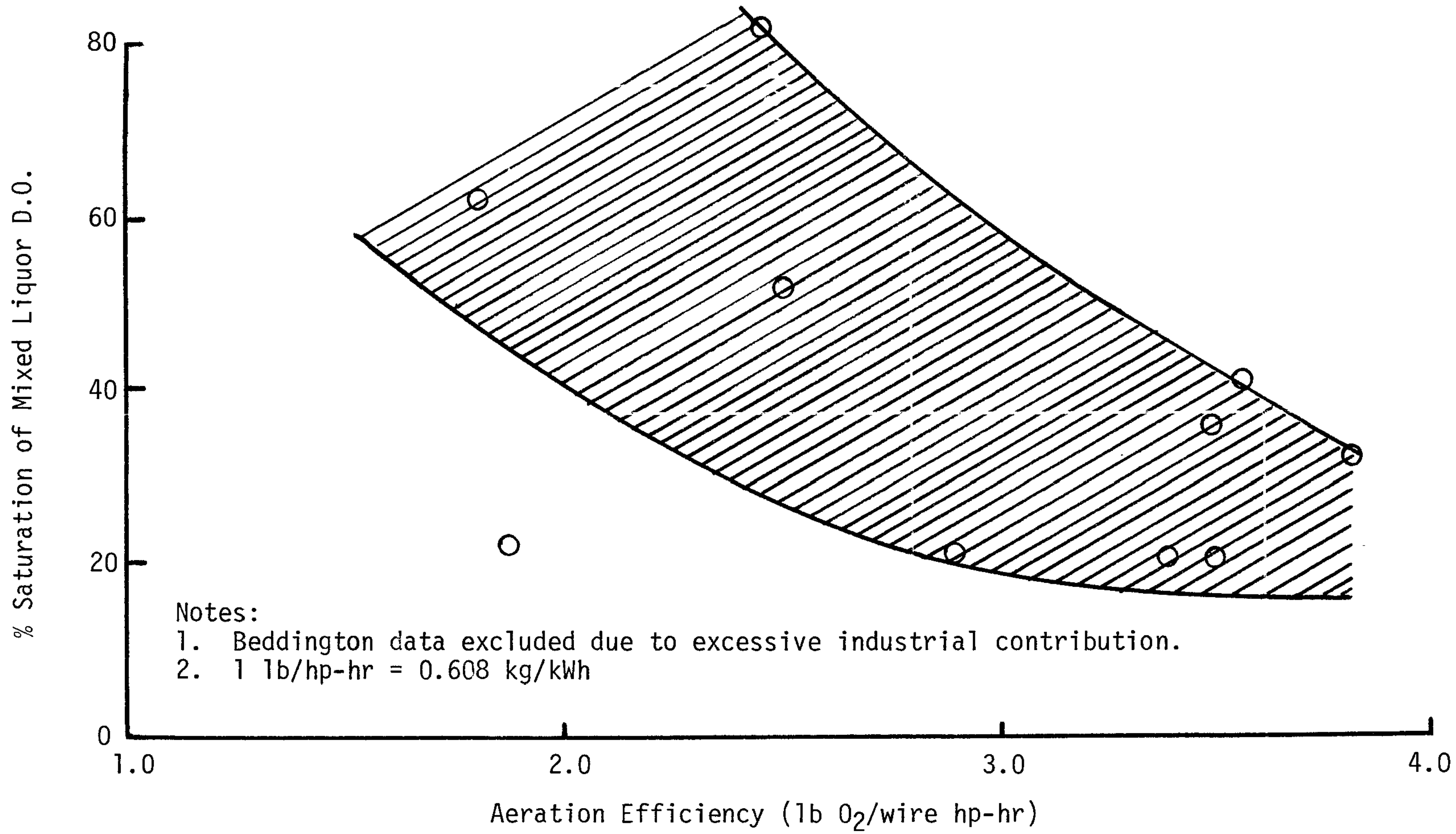


Figure 6. Impact of mixed liquor D.O. on aeration efficiency.

At 20°C (68°F) and assuming a typical β value for domestic wastewater of 0.95, it is seen that an aeration process operating at 20 percent of saturation has an oxygen transfer rate five times greater than one operating at 80 percent of saturation:

$$OTR_1/OTR_2 = [0.95 - (20/100)]/[0.95 - (80/100)] = 5 \qquad (16)$$

Comparing Oxford and Ryemeads, for example, averaging 60 and 20 percent of saturation, respectively, this simplified analysis would indicate that Oxford would have an oxygen transfer rate 2.1 times higher than Ryemeads. This agrees closely with the average aeration efficiency results shown in Table 7. Similarly, the ratio between Oxford and Mogden would be 1.67, again close to the average data summarized in Table 7. It is recognized that this highly simplified comparison is valid only where conditions of temperature, alpha, and D.O. saturation are similar. However, in the case of the plants compared above, this is a reasonable assumption. All of the plants in this comparison were quite similar with respect to these variables.

Overaeration seemed to be present in all of the U.K. plants to some degree, with the exception of Beddington and Hartshill. In most cases, plant personnel noted that they were constrained by minimum required air flow rates of 0.014 m^3/min/dome (0.5 cfm/dome) and relatively low volumetric loading rates, the latter needed in most cases to maintain appropriate sludge retention times for single-stage nitrification. (Design approaches to avoid this problem are discussed in Section 8). Most of the plants were not equipped with adequate D.O. and air flow monitoring equipment or valves to control air flow to tank sections and/or individual aeration channels. D.O. levels were highest in the latter half of the aeration process, particularly in those plants with multiple-pass plug flow configurations.

Alpha Factor Variation --

The alpha (α) factor is a dimensionless conversion factor that relates the oxygen mass transfer coefficient expected for a given aerator when operated in wastewater (i.e., respiring biomass) to that measured with the same aerator in clean water under similar conditions of temperature, geometry, mixing, etc. In effect, it is used to derate the clean water data to field conditions. Alpha is most affected by the presence of surfactants (surface active agents), which interfere with the transfer of oxygen across the film of liquid surrounding the bubbles. It has been known for some time that alpha varies with mixing power level, surfactant concentration, basin geometry, and aerator type.[9,10,11,12] The surfactant effect appears to be more pronounced with fine bubbles than coarse bubbles. Boon[11] reported on experiments with dome diffusers where alpha varied from 0.3-0.8 from the inlet to the outlet of a plug flow system treating domestic wastes and producing a highly nitrified effluent. For purposes of comparison, he states that a mechanical aeration system can have an alpha of 1.2 vs. 0.4 for fine bubble diffused air on the same wastewater.

Alpha variation provides a likely explanation for two apparent inconsistencies observed during the plant visits:

1. Air flow requirements in the plug flow systems seemed to decrease more rapidly along the length of the aeration channel than would be

expected from process oxygen demand gradients as the wastewater passed from inlet to exit.

2. Although clean water test comparisons between fine bubble dome diffusers and coarse bubble (single wide band) diffusers indicate that the fine bubble unit is 3-4 times more efficient,[13,14] data from side-by-side field comparisons indicate that fine bubble diffusers are only 1.5-2.5 times more efficient.

The first observation can be explained by the increase in alpha as the detergent initially present in the raw wastewater (5-10 mg/l) is removed in the plug flow aeration process. As alpha increases, oxygen transfer efficiency increases and substantially less air flow is required to meet the process oxygen demand.

Observation No. 2 seems to suggest that coarse bubble aerators are somewhat less "alpha sensitive" owing to larger bubbles and more turbulence resulting from greater air flow per unit volume of tank. At the visited plants, the fine bubble aerators still exhibited a substantial aeration efficiency edge over the coarse bubble units, but it was considerably less than clean water data would indicate. However, data from extensive side-by-side clean water testing, submitted by the Sanitaire Corporation, does not support this observation.[15] The Sanitaire data*, comparing the company's fine bubble disc aerator to a single wide band spiral flow coarse bubble diffuser suggest that alpha, with 5 mg/l of surfactant added, is the same for either system. In view of this apparent contradiction, the variation of alpha for different types of aerators merits further research.

The relatively poor oxygen transfer performance of the Beddington and Hartshill plants, even with reasonably low mixed liquor D.O., can probably be attributed to the presence of strong industrial wastes, which significantly depressed alpha and caused marked reduction in oxygen transfer efficiency. Beddington personnel reported that the date of the introduction of the wastewater flow from organic chemicals manufacture coincided with a severe loss in apparent oxygen transfer efficiency. Hartshill has always treated the rendering waste it receives and has adequate oxygenation capacity, but plant personnel were aware of the relatively low level of oxygen transfer efficiency being achieved by their dome diffuser aeration system.

Aeration System Geometry --

Aeration system geometry affects mixed liquor D.O. control, and the alpha factor, as discussed above. Systems that had the greatest D.O. control problems, as evidenced by overaeration and lower aeration efficiencies, were usually those with multiple-pass aeration basins. Conversely, with the exception of Long Reach and Basingstoke, plants with single pass plug flow systems tended to be more efficient. The three most efficient plants, Oxford, Beckton, and Coleshill, all had a length-to-width (L/W) ratio of less than 12.

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* Available on request from Sanitaire Corporation, Milwaukee, Wisconsin.

As shown in Figure 7, the data suggest a correlation between L/W and aeration efficiency. The only single-pass plug flow plant with relatively low aeration efficiency was Basingstoke, for reasons which are discussed in Appendix B. Long Reach, a four-pass plug flow plant, was more efficient than other multiple-pass plug flow systems due to stringent D.O. control by plant operators.

As discussed in Section 8, overall aeration efficiency should improve with increasing tank depth. However, the plant data showed no clear correlation between mixed liquor depth and oxygenation efficiency. It is likely that the impact of tank depth was overshadowed by other factors, notably mixed liquor D.O. and alpha, in the aeration systems of the surveyed plants.

OPERATION AND MAINTENANCE

With a few exceptions, the surveyed plants reported minimal problems with their dome diffuser aeration systems. This subsection summarizes the overall maintenance history encountered, including special maintenance problems encountered at some plants.

General Maintenance Experiences

Maintenance observations at the 19 survey plants are summarized in Table 9. Generally, the plants have had good, and often exceptional, reliability from dome diffuser equipment. After initial shakedown, the plastic pipe mounted systems have performed well. Earlier plants used dome diffusers mounted on a cast iron air distribution grid. Rusting of the interior surfaces of the air lines led to deposition of rusts and scale on the interiors of the domes, causing plugging after 5-6 yr. Most of the plants with iron pipe are retrofitting to plastic pipe with generally good results. Several of the retrofitted plants have experienced minor problems with pulling out of the anchors that hold the plastic pipe saddles to the tank floor (refer to Figure 8). The cause of this seems to be spalling of concrete around the mounting holes in the floors. This has not been reported as a problem in systems where tank concrete is new and apparently less vulnerable to spalling.

Several plants have also reported scattered failures of other plastic parts, notably the pipe coupling straps and orifice bolts. Beckton had major problems on startup with the coupling straps. Mogden has had considerable problems with failure of the orifice bolts, probably related to over tightening during installation. Most of the plants, however, reported few or no startup problems of this nature. Careful supervision of installation to avoid over tightening of plastic parts was cited as the key to trouble free startup by most of the plant personnel. It was also noted that the plastic parts were much less costly to replace than previously used brass bolts.

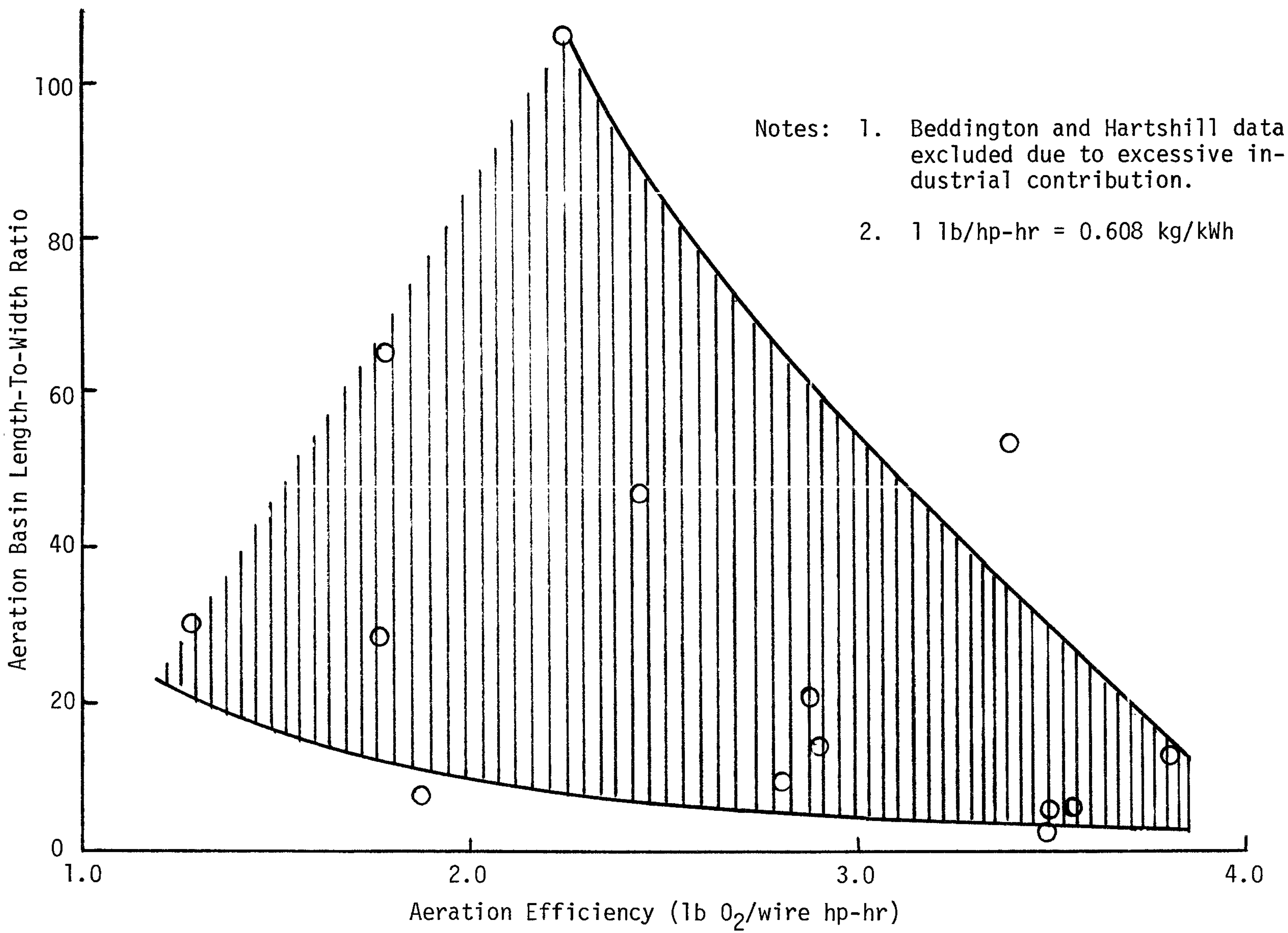
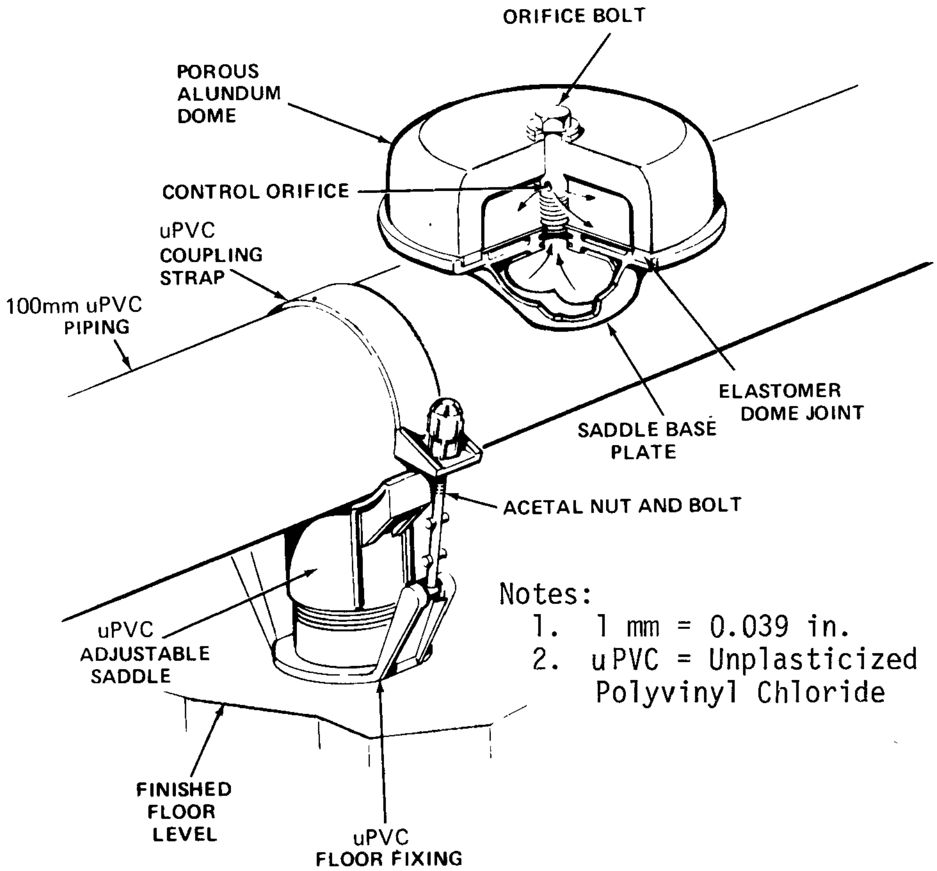


Figure 7. Impact of length-to-width ratio on aeration efficiency.

TABLE 9. MAINTENANCE DATA SUMMARY

Plant Name/Location	Started Up	Startup Experience	Cleaned	Operating Experience
United Kingdom				
Basingstoke	1964-71	Some problems with plastic tank bottom mounts	Every 5 yr	Fair, scale problems (see discussion)
Beckton				
New Plant	1970	Problems with plastic holddowns	Every 8 yr	Good after initial problems
Old Plant	1959	No significant problems	Twice in 15 yr	Gradual plugging due to rust in cast iron pipes
Beddington (New Tanks)	1969	No significant problems	Every 4 yr*	Poor but improving major slime problem
Long Reach	1978	No significant problems	Not yet	Good, new plant
Mogden (Battery B)	1961	No significant problems	Every 6 yr	Plastic retrofit in Battery B (1968) has not yet required cleaning
Oxford	1969	Some problems with plastic tank bottom mounts	Not yet	Good, no apparent loss of effluenty quality after 10 yr
Ryemeads	1956-70	Some problems with retrofitted plastic piping	Every 6 yr	Fair, plugging due to rust in older lines. Plastic system good
Coalport	1970	No significant problems	Not yet	Good
Coleshill (Stage III)	1968	No significant problems	Not yet	Good, tanks cleaned once/year and domes brushed
Finham (South)	1974	No significant problems	Not yet	Good, only have had to repair several small line leaks
Hartshill	1973	No significant problems	Not yet	Fair, some slime growth
Minworth	1971	No significant problems	Not yet	Good, tanks cleaned once/year and domes brushed
Strongford (New Plant)	1972	No significant problems	Not yet	Good
The Netherlands				
Holten-Markelo	1978	No significant problems	Not yet	Good
Steenwijk	1977	No significant problems	Not yet	Good
United States				
Glendale, Calif.	1978	Several blowoff lines failed	Not yet	Good, small evidence of slime
Madison, Wisc.	1977	No significant problems	Not yet	Substantial sliming problem in mid-1980 after 3 yr of operation
Fort Worth, Tex.	1978	Some problems with blowoffs	Not yet	Some line breaks and problems evident, but overall performance stable
Tallman Island, N.Y.	1979	No significant problems	Not yet	Good

*Initially. Cleaning has not been required for the last 6 yr.



Courtesy Hawker-Siddeley Ltd. and Norton Company

Figure 8. The Norton/Hawker-Siddeley dome diffuser.

Formation of Biological Slimes on Diffusers

The major operational problem associated with the dome diffusers was the formation of biological slimes on diffusers operating in zones of high volumetric loading and/or low D.O. Beddington continues to have major problems with slime formation, which manifests itself as coarse bubbling at the surface of the aeration tank. The slime growth, shown on Beddington domes in Figure 9, does not cause an increase in air pressure; rather, it induces an apparently wholly external surface fouling which causes the air bubbles to coalesce after exiting the surface of the diffuser domes. The resulting coarse bubbling lowers oxygen transfer efficiency, thereby lowering mixed liquor D.O. and further encouraging slime growth.

When first confronted with the problem, Beddington removed and refired their fouled domes. However, upon startup of a cleaned tank, the problem quickly recurred and it was soon obvious that other, less costly solutions were needed. In further tests, it was found that a vigorous brushing of the dome surface accompanied by high air flow rates would return the dome to nearly new performance levels. Periodic tank cleaning and dome brushing (depicted in Figure 10) have allowed Beddington to control (not eliminate) the problem at moderate cost.

While Beddington's sliming problem was intensified by the presence of strong industrial wastes, which depressed oxygen transfer efficiency causing low D.O. in the first passes of the multi-pass plug flow tanks, it was not the only plant that exhibited sliming. Indeed, every visited plant exhibited some signs of coarse bubbling, likely attributable to slime growth on domes. Without exception, the phenomenon occurred at the primary effluent feed points or at the transition from anoxic to aerobic treatment. It was particularly severe in the first 20-50 percent of the first pass of two-to four-pass plug flow systems. Tapering the aeration helped somewhat but did not fully cure the problem.

The WRC has conducted experiments to verify the causes of diffuser sliming. The photograph in Figure 11 was taken during one of those experiments and shows diffuser fouling as a result of very high loading rates. It was found that the diffusers could be returned to normal service by brushing the growths off while at the same time allowing air to flow through the units from the inside.

Several plants observed that mild slime growth could be reversed by greatly increasing air flow and reducing primary effluent flow for 24-48 hr. Degremont, a manufacturer of disc ceramic aerators (Section 7), recommends this procedure as a routine O&M activity.

Following the plant visit to Madison in early 1979, but prior to completion of the final report for this study, the Madison plant experienced a major episode of diffuser sliming in all three dome diffuser aerated tanks. Madison personnel reported that sliming was most pronounced in the first pass.

To summarize, slime growths appeared to occur in zones of heavy organic loading and/or low D.O. The occurrence of these growths was exacerbated by extreme plug flow aeration tank design and the presence of strong industrial wastes. Section 8 discusses design approaches that might ameliorate or eliminate the problem.

Scale Formation on Domes

One plant, Basingstoke, had substantial problems with formation of calcium carbonate scale on the exteriors of their domes (Figure 12). The scale is thickest toward the center of the domes, immediately around the dome hold-down bolts. Cleaning, required every 5 yr, consists of scrubbing, acid soak-

Figure 9. Slime growth on domes at Beddington.

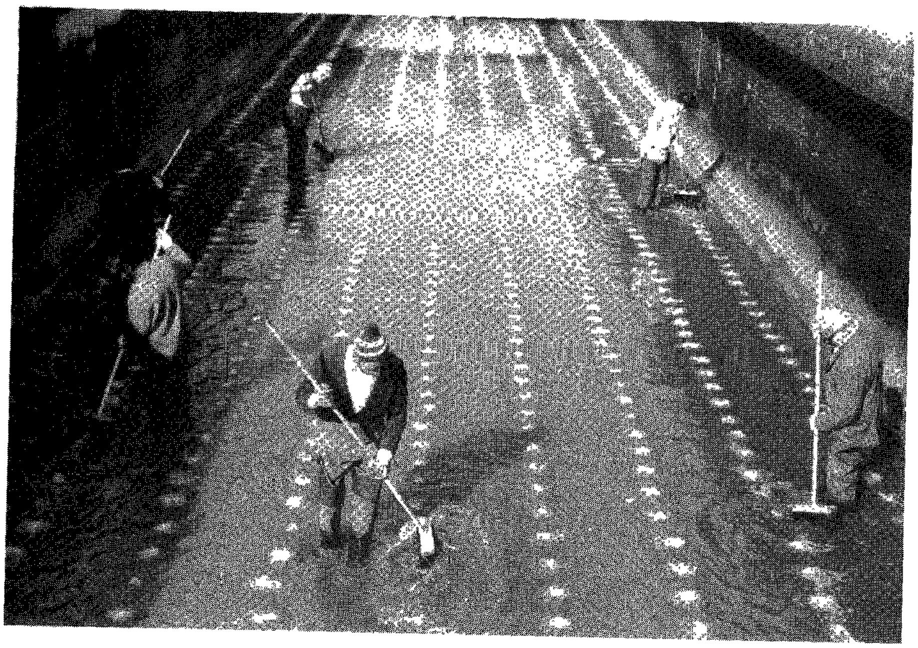


Figure 10. Brushing domes at Beddington.

Photos courtesy of Beddington works.

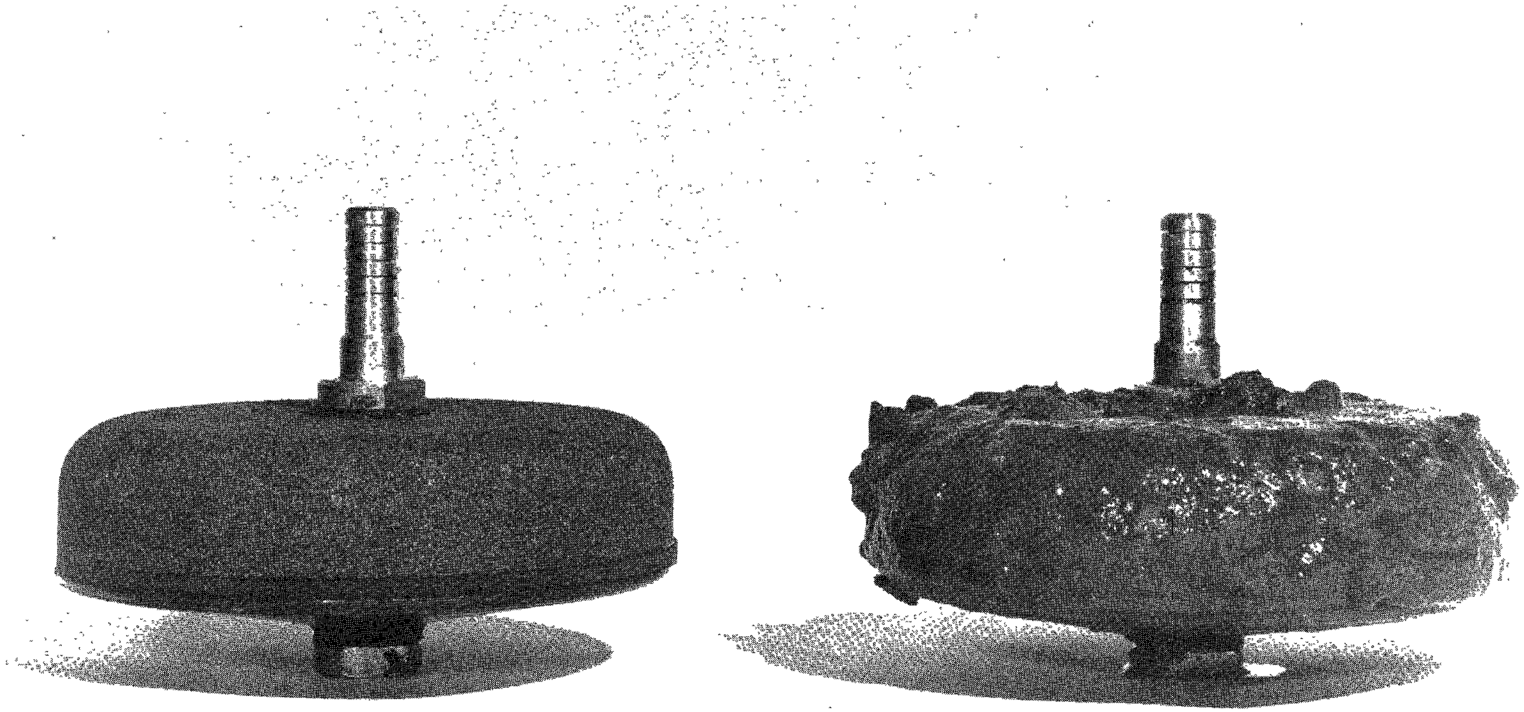


Photo courtesy of British Water Research Centre.

Figure 11. Clean and slimed domes from WRC tests.

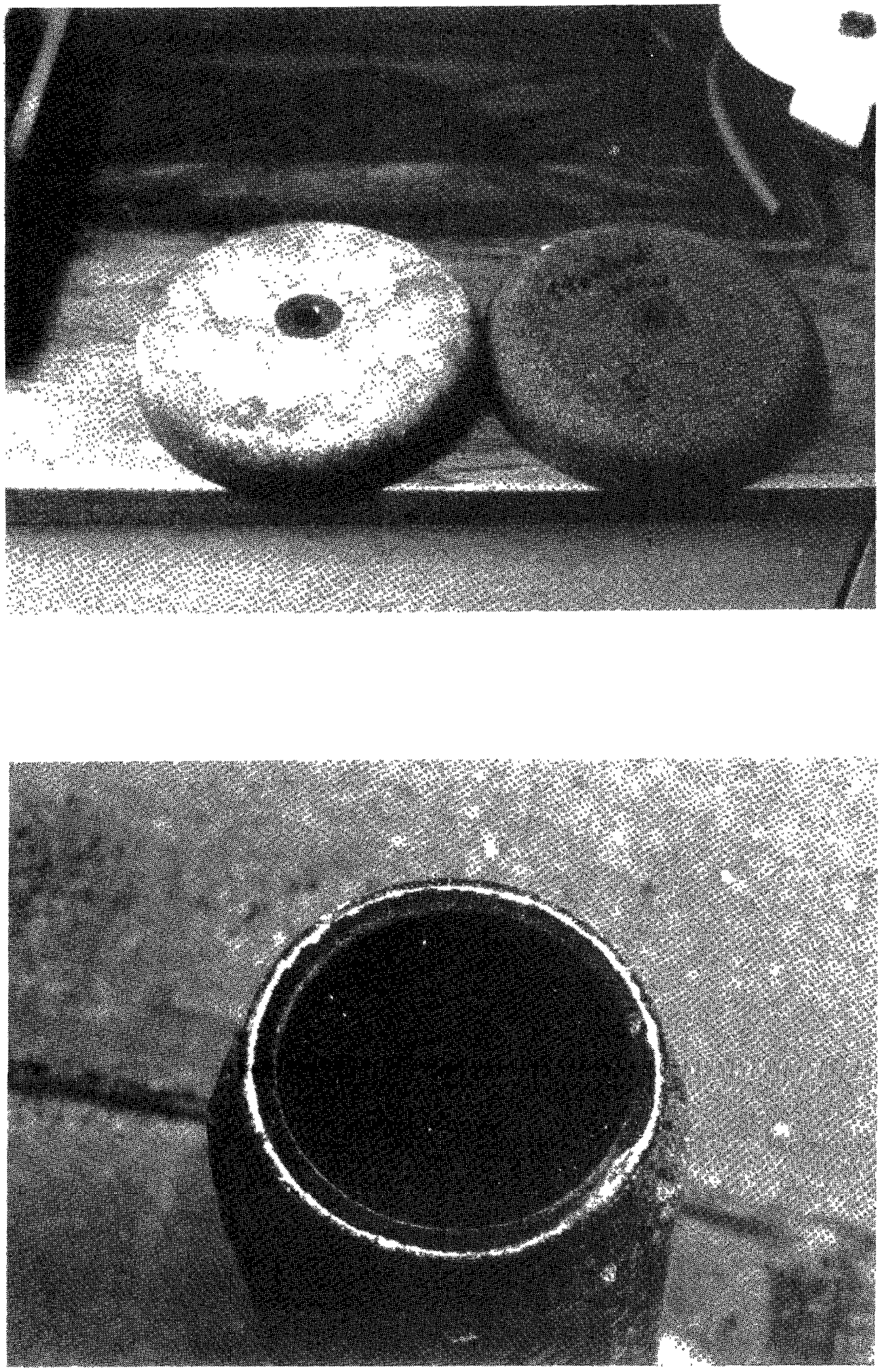


Figure 12. Formation of scale on Basingstoke dome.

ing in a 10 percent hydrochloric acid solution for 24 hr, and steam cleaning. The domes are not refired, although the manufacturer (Hawker-Siddeley) expressed a belief this should be done at least after every other cleaning.

Some evidence of light calcium carbonate scaling was also seen at Mogden and Beckton. It did not appear to affect oxygen transfer performance or increase O&M requirements at these plants. A review of the water quality data for the various plants in and around London indicates that all had hardness in the range 250-300 mg/l (as $CaCO_3$), but only Basingstoke had alkalinity in the same range. Basingstoke was receiving industrial effluents from light manufacturing as well.

Removal, Cleaning, and Replacement of Domes

Plants in the United Kingdom and The Netherlands virtually without exception scrupulously maintain their aeration equipment, minimizing interruption of air flow, and maintain a minimum air flow per dome of 0.014 m^3/min (0.5 cfm).

These practices undoubtedly have contributed substantially to the low incidence of maintenance-related problems encountered with domes in Europe. With several exceptions, most of the plants had never undertaken a major dome removal, cleaning, and replacement operation. Three plants, Beckton, Mogden, and Basingstoke, however, have accrued substantial experience with dome renewal. Beckton and Mogden have dome refiring furnaces. Data on the maintenance experiences of all three plants are summarized below.

Beckton Dome Cleaning Program --

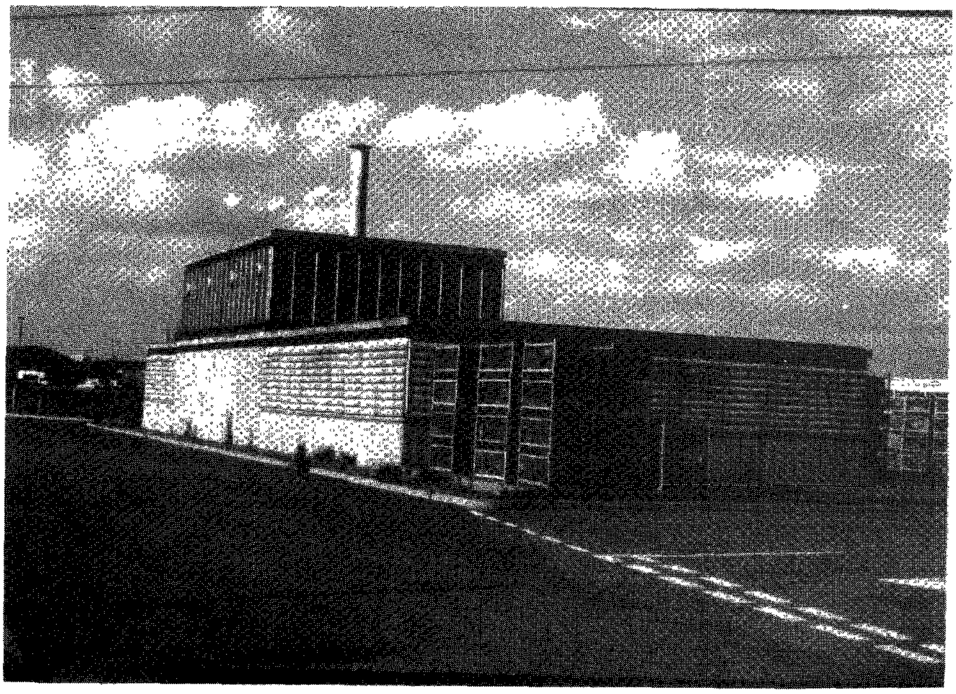
In 1971, a diffuser dome refiring furnace, shown in Figure 13, was constructed at Beckton. The facility has a capacity of 100,000 domes/yr and was designed to service domes from other Thames Water Authority plants as well as Beckton. It was constructed at a cost of £66,130 ($132,260 U.S.) in 1971, and its current estimated replacement cost is three-and-a-half times its initial cost.

The furnace is capable of firing 650 domes per cycle with a fuel oil consumption of 318 ℓ (84 gal). Each cycle lasts about 24 hr and is divided as follows:

- Heat up to 1000°C (1832°F) - 10 hr
- Hold at 1000°C (1832°F) - 4 hr
- Cool down to 200°C (366°F) - 10 hr.

The firing operation is the principal cleaning method used by Beckton personnel. It is augmented by acid washing of the domes after firing, using hydrochloric acid (HCl) to remove light carbonate deposits.

Significant labor is involved in loading and unloading the domes, maintaining the furnace, and carrying out the complete dome cleaning cycle.



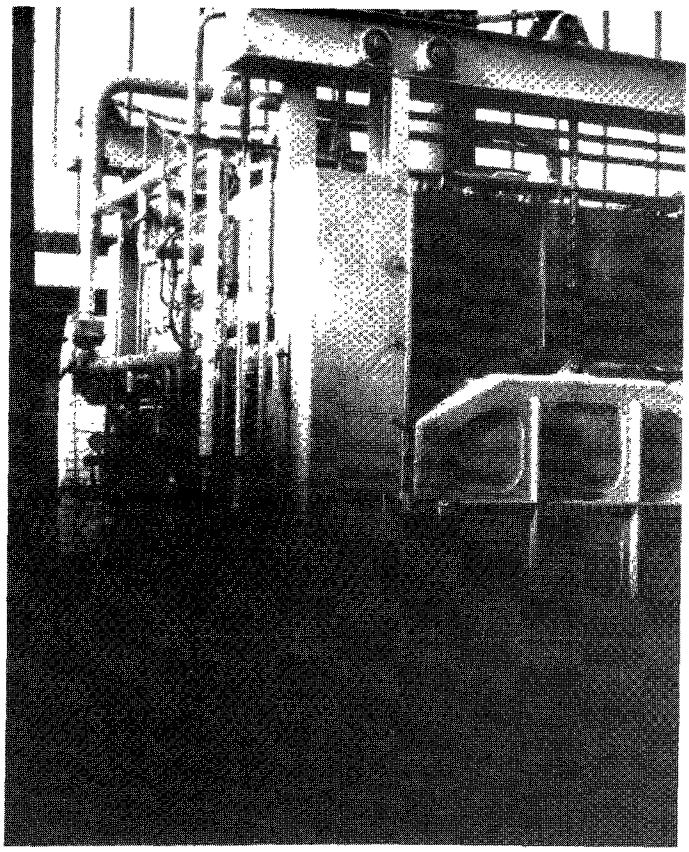


Figure 13. Beckton dome firing facility.

Beckton reported the following labor data:

1. Unload 650 domes from transport pallet, stack in furnace, and start furnace - 2 man-hr (unskilled).

2. Remove 650 domes from furnace and place in storage - 1.5 man-hr (unskilled).

3. Load 650 domes into acid cleaning bath, remove, and place in storage- 8 man-hr (unskilled).

4. Furnace maintenance (skilled).

   a. Every 3 wk - 2.5 hr

   b. Every 3 mo - 7.5 hr

   c. Every 6 mo - 7.5 hr.

The Beckton furnace is currently processing about 40,000 domes/yr, or 40 percent of maximum capacity.

Mogden Dome Firing Facility --

Mogden has a much older dome firing plant used for cleaning domes at Mogden only. It is fueled by natural gas and consumes 340 m^3 (12,000 ft^3) per 900 domes cleaned. Mogden estimated a cost of approximately 20 pence (40¢) per dome cleaned, 17 pence (35¢) for labor, and 3 pence (6¢) for gas, exclusive of the cost of removing and replacing the domes in the aeration basin.

The Mogden dome kiln is 20 yr old and not representative of current technology. The cost of operation could be expected to be much higher in a newer kiln if capital cost amortization and depreciation are added in.

Removing and Replacing Domes --

Substantial labor cost is associated with removing and replacing the domes in the aeration basins of large activated sludge plants such as were visited during this study. The most extreme example is Beckton with 30,000 domes per basin. In excess of 1000 man-hr are required to remove and replace domes in one of the large Beckton basins. Hundreds of man-hr are required for basin cleaning as well. Check out and minor repairs when the aeration basin is refilled require another 200 man-hr. Lifting baskets of domes out of the basin and stacking for transportation to the dome kiln requires 3-4 man-days at Beckton and entails hard manual labor.

Beckton, Mogden, and Basingstoke all reported that 5-10 percent of the domes, valued at £2.5-3.5 ($5-7) each, were lost due to breakage during handling and firing. In addition, the large rubber gaskets on which the domes are seated and the small rubber gaskets around the orifice bolts are normally replaced when the domes are cleaned.

Routine Dome System Maintenance --

The plant operators reported a variety of approaches, but all could be summarized thusly:

1. Careful attention to avoiding loss of air flow and maintaining minimum air flow rates per dome.

2. Periodic, usually weekly, operation of the air vents to vent off any trapped moisture.

3. Prompt repair of air leaks and daily surveillance of aeration patterns to detect abnormalities.

All plant operators stressed that good preventive maintenance and careful attention to air flow rates were much less costly in the long run than the more frequent full-maintenance cycles (removal, cleaning, replacement) that would result without such precautions.

Maintenance of Air Cleaning Equipment

All of the plants reported very low maintenance requirements for their air cleaing equipment, no matter which type was used. Bag filters seemed to require the least attention, with cleaning cycles of 1-2 yr. Electrostatic units required three to four cleanings/yr, but each cleaning operation is simple and takes less than half a man-hr. Every 2 yr, the electrostatic units require a more thorough workdown, consuming half a man-day. Disposable filters were the simplest of all, maintenance wise, but replacement filters are costly (see Section 8) and care must be taken when locating air intakes to avoid premature fouling from heavily contaminated air.

SECTION 7

DOME AND DISC FINE BUBBLE AERATORS

A brief description of dome and disc fine bubble aerators currently available from U.S. sources at the time that this report was prepared is given in this section. Clean water oxygen transfer data for some of the equipment is also discussed here.

THE NORTON/HAWKER-SIDDELEY DOME DIFFUSER

The Norton/Hawker-Siddeley (N/HS) dome diffuser, shown previously in Figure 8, was in use in all of the plants surveyed in this study. This device, developed in 1954, has been installed in activated sludge plants world wide. It is available in the United States from the licensee, Norton Company of Worcester, Mass. It is 17.8 cm (7 in.) in diameter and constructed of aluminum oxide (alundum), which is fused at high temperature into a rigid, dome shape. The manufacturer specifies an average pore diameter of 150 microns. It is normally installed in a grid configuration covering the entire aeration tank floor with unplasticized polyvinyl chloride (uPVC) air supply piping and appurtenant hardware.

OTHER FINE BUBBLE DIFFUSION EQUIPMENT

Because this study focused on long-term O&M and oxygen transfer performance data, N/HS dome diffusers were emphasized. However, during the course of the work, the number of similar competing dome or disc aerators available in the United States expanded rapidly. As of June 1980, five U.S. vendors of this equipment were identified:

• Ajax International Corporated	San Diego, California	Disc diffuser
• Envirex, Incorporated	Milwaukee, Wisconsin	Disc diffuser
• EPI Corporation	Richmond, Virginia	Disc diffuser
• Infilco/Degremont	Richmond, Virginia	Disc diffuser
• Sanitaire, Incorporated	Milwaukee, Wisconsin	Disc diffuser
• W.E. Farrer, Limited	Birmingham, England*	Dome diffuser

* Presently not sold in the United States.

This equipment is discussed in turn below.

Ajax International Corporation

Ajax is the U.S. vendor for the ceramic disc diffuser system manufactured by Ames Crosta Babcock, Ltd., of the United Kingdom. The discs are 18.5 cm (7.3 in.) in diameter and are secured in a uPVC holder with a threaded collar (Figure 14). Air is metered to each disc through a control orifice similar to the N/HS diffuser. A grid diffuser configuration is employed.

Envirex, Incorporated

Envirex markets a ceramic disc, 23 cm (9 in.) in diameter, which are mounted on uPVC pipe in a grid arrangement. The diffuser housing snaps onto the pipe grid using a snap-on attachment developed by Envirex for thin wall pipe (Figure 15). The discs are flat and are molded of fused aluminum oxide.

EPI Corporation

EPI has recently been licensed to market the Nokia diffuser line in the United States. Nokia, a Finnish manufacturer, supplies the Nokia disc in either ceramic or porous polyethylene plastic (Figure 16). The latter is provided in either a medium bubble or fine bubble configuration. The geometry of the device is similar to that of the N/HS dome aerators in that a control orifice is used to meter the air into a conical housing, which is supplied mounted on a uPVC grid.

The polyethylene plastic diffuser element differs markedly from the ceramic units provided by other U.S. sources. EPI reports that it is cleanable in soap and water and that there are approximately 30 installations worldwide, mostly in Western Europe.

Infilco/Degremont

Infilco/Degremont is the U.S. subsidiary of the French firm, Degremont, a major European manufacturer of water and wastewater equipment. Degremont has marketed an alumina disc diffuser (Figure 17) on the continent for some time. As discussed later, the device has been tested by Dutch investigators and found to be similar in performance to the N/HS domes. It is designed as a flat plate, 22.9 cm (9 in.) in diameter, 19 mm (3/4 in.) thick, and is supplied on a uPVC piping grid which uses some brass hardware.

Sanitaire, Incorporated

The Sanitaire disc diffuser, shown in Figure 18, measures 22 cm (8.7 in.) in diameter and is installed in a grid layout on uPVC piping. The diffuser disc is constructed of fused alumina and is retained on the conical housing by a threaded collar. Air is metered to each disc through a control orifice.

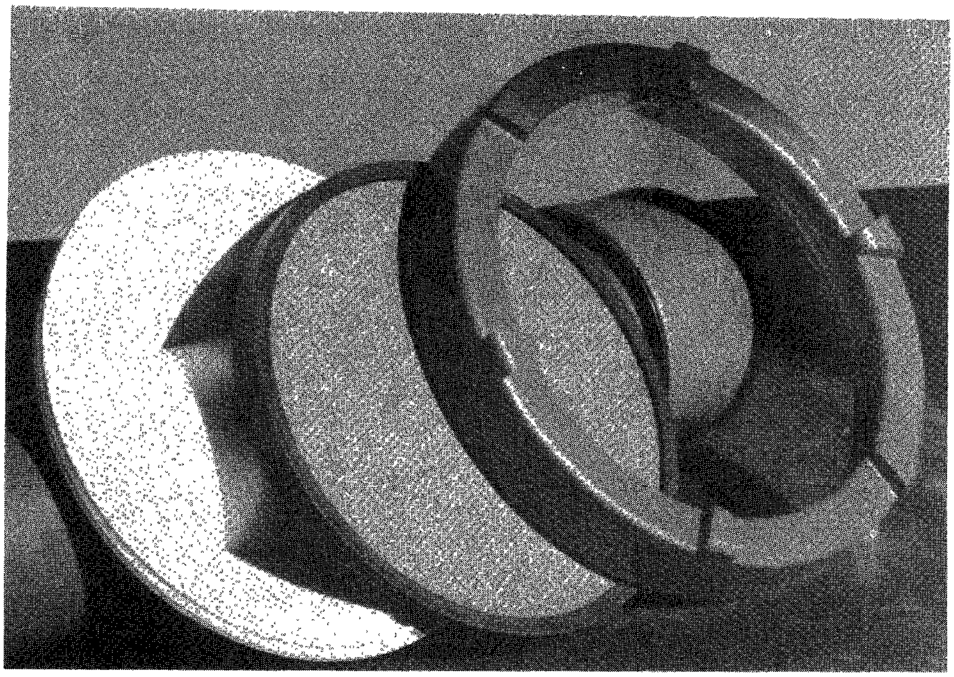


Figure 14. The Ames Crosta-Babcock diffuser.

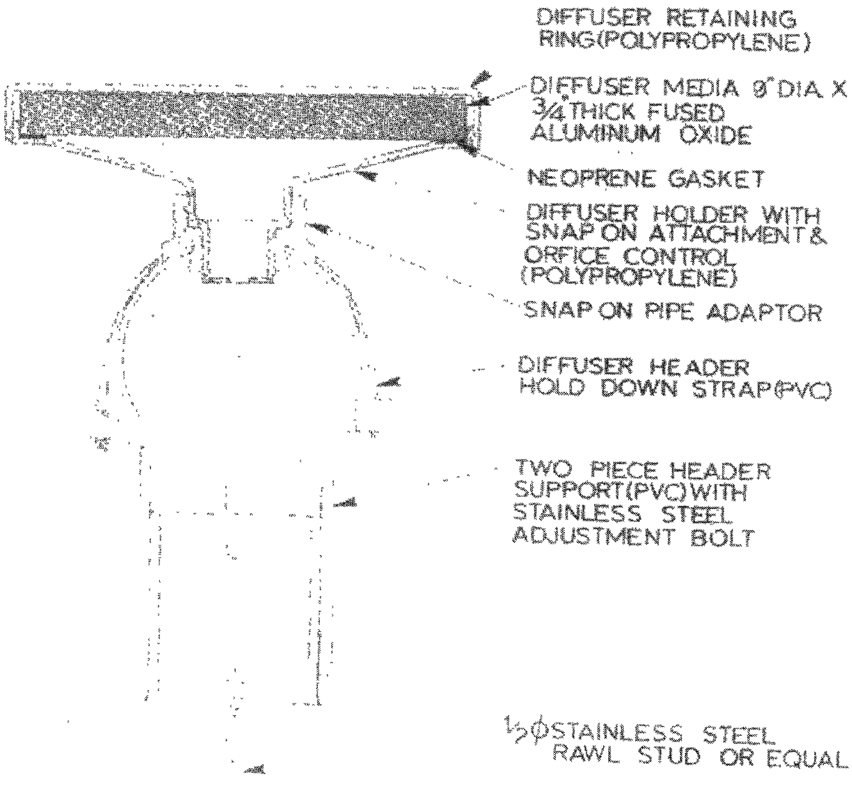
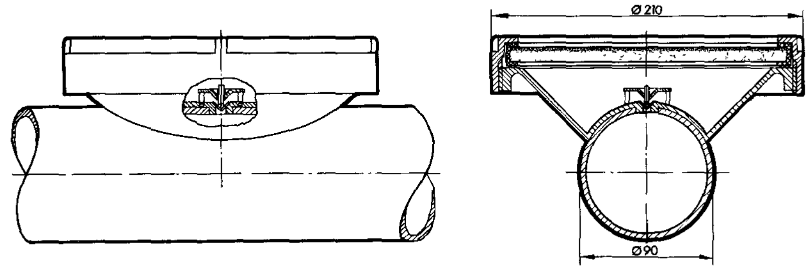


Figure 15. The Envirex disc diffuser.



HKL 210 or MKL 210 diffuser,
side and front

Figure 16. The EPI/Nokia disc diffuser.

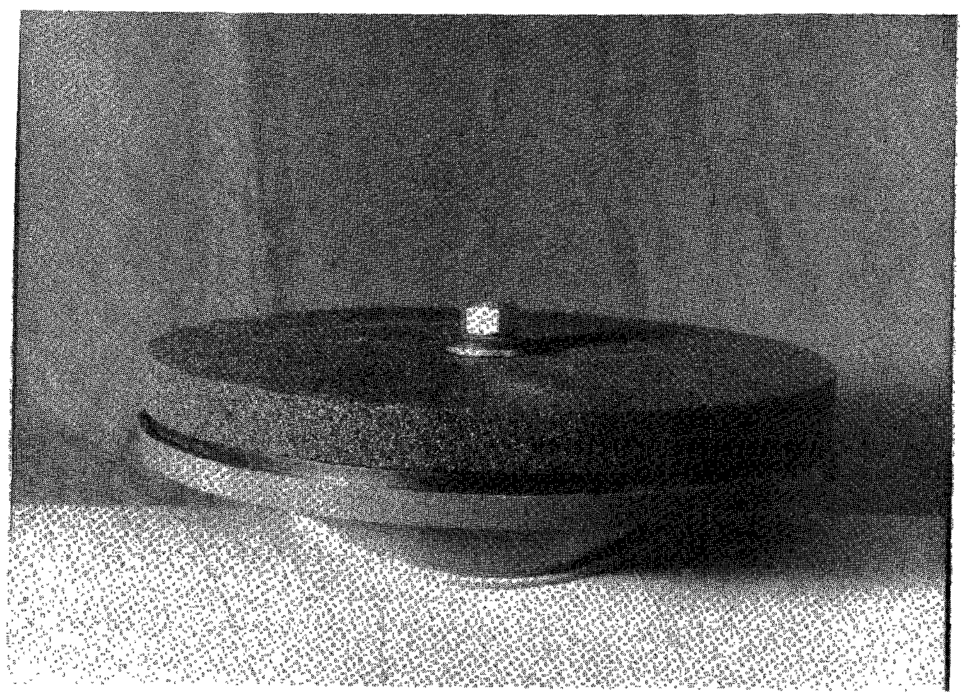


Figure 17. The Infilco/Degremont disc diffuser.

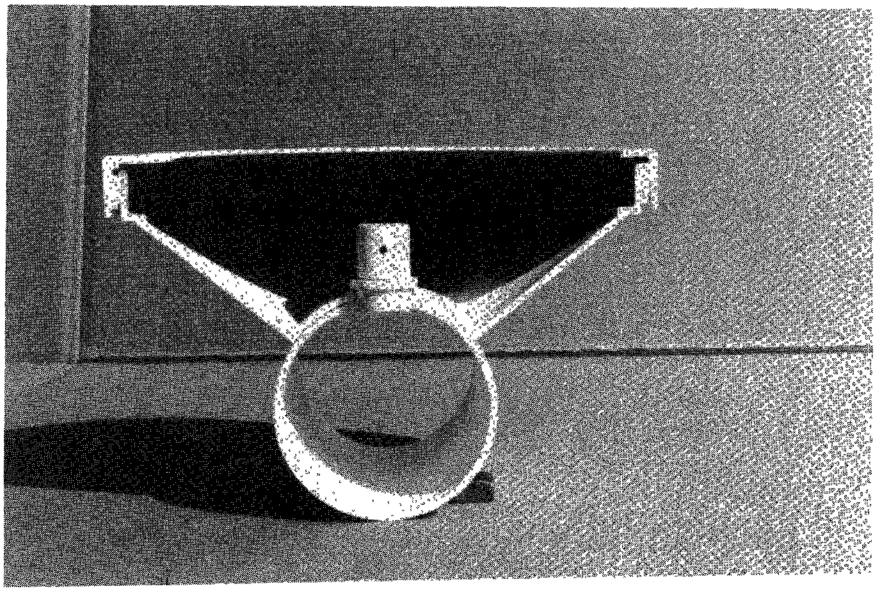


Figure 18. The Sanitaire disc diffuser.

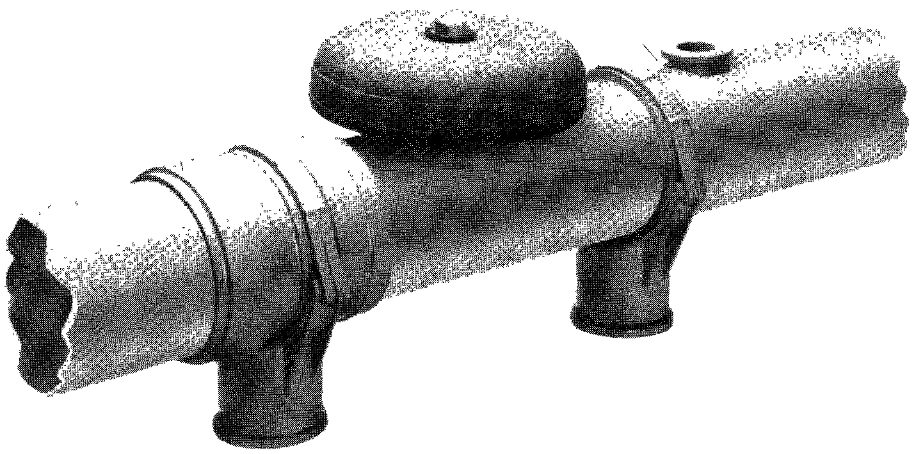


Figure 19. The W. E. Farrer dome diffuser.

W.E. Farrer, Limited

The W.E. Farrer diffuser is quite similar to the N/HS unit, using a 17.8-cm (7-in.) dome diffuser mounted on uPVC pipe, in a grid system. The device, shown in Figure 19, features a fully sealed dome unit which is affixed to the manifold directly, eliminating the conical dome plate used on the N/HS dome. The Farrer diffusers are currently not directly marketed in the United States; however, it is quite possible that they will be sold here in the future.

CLEAN WATER OXYGEN TRANFER PERFORMANCE DATA

Table 10 summarizes some recent water test data for the fine bubble aerators listed above. All tests were conducted using the non-steady state sulfite reaeration (cobalt catalyzed) test method. All of the tests were conducted within 5°C (9°F) of the standard 20°C (68°F) test temperature and were carried out by experienced investigators.

Recognizing the dangers inherent in comparing clean water test data from widely divergent sources, Table 10 nevertheless exhibits remarkable consistency relative to the different tests for the N/HS dome. Additional data not shown in this table parallel these results closely. It appears that clean water aeration efficiency for this device will fall in the range of 4.5-5.0 kg O_2/kWh (7.4-8.2 lb/wire hp-hr) for submergence depths of 4.0-4.5 m (13-15 ft).

The various dome or disc diffusers appear to perform similarly when tested under the same conditions. At Los Angeles County Sanitation Districts (LACSD), the N/HS and Sanitaire units tracked closely, even though there were fewer of the Sanitaire units (98 vs. 126) in the tank. At Holten-Markelo, the Nokia and N/HS tracked closely; the Degremont dome, at first glance, performed better. However, unlike the LACSD tests, the number of diffusers in the tank was not adjusted to reflect the larger (22.9 cm vs. 17.8 cm, 9 in. vs. 7 in.) diameter of the Degremont disc. The Dutch researchers who conducted these tests stated that they considered the performance of the three units nearly equivalent, with the ceramic units perhaps having a slight advantage over the Nokia units. The Nokia disc and the N/HS dome are the same diameter.

At the air flow rates that would be found in activated sludge systems, 0.014-0.042 m^3/min/diffuser (0.5-1.5 cfm/diffuser), the air will primarily exit the horizontal surfaces of either dome or disc diffusers. Thus, a diffuser with a larger surface area would have a higher transfer rate per dome and fewer diffusers would (theoretically) be needed to tranfer a given amount of oxygen. The N/HS vs. Sanitaire data from LACSD (17.8 cm vs. 22 cm or 7 in. vs. 8.7 in. diameter) and N/HS vs. Degremont data from Holten-Markelo (17.8 cm vs. 22.9 cm or 7 in. vs. 9 in. diameter) would seem to bear this out. The relationship between disc/dome area and oxygen transfer capability per dome should be studied further. A 20-25 percent differential in diffuser units required in a large activated sludge plant could be quite significant in terms of equipment costs.

TABLE 10. CLEAN WATER OXYGEN TRANSFER EFFICIENCY COMPARISON

Device	Data Source	Description	Submergence Depth (m)*	Diffuser Density (domes/m^2)**	Air Flow Dome (cfm)+	Oxygen Transfer Efficiency (%)	Remarks
N/HS Dome	Paulson, 16	37.8-m^3 (10,000-gal) treated river water supply from municipal system	4.4	4.8	1.0	31.5	Lab-scale tests
			2.8	2.6	1.0	19.4	
N/HS Dome	Paulson & McMullen, 17	250-m^3 (66,000-gal) treated lake water from municipal system	4.1	3.6	0.5	35.9	Equivalent to 4.9 kg O_2/kWh++
			3.5	3.6	0.5	25.1	
N/HS Dome	WRC #537R, 18	9.6-m^3 (2530-gal) lab-scale test tank at WRC	2.0	2.5	1.0	17.4	Second test with 6 mg/l of detergent
			2.8	2.5	1.0	10.0	
N/HS Dome	LASCD+++,14	170 m^3 (45,000 gal) municipal water	4.3	3.4	0.6	31.3	Equivalent to 4.92 kg O_2/kWh++
			4.3	3.4	1.0	29.7	Equivalent to 4.52 kg O_2/kWh++
Sanitaire Disc	LASCD+++, 14	6.1-m (20-ft) square tank	4.3	2.6	1.1	34.0	
N/HS Dome	Holten-Markelo, 19	Cylindrical 9.5-m (2500-gal) test tank at Holten-Markelo (Netherlands) wastewater treatment plant	3.8	2.8	0.6	36.2	
			3.8	2.8	1.2	33.7	
Nokia Disc	Ref. 19		3.8	2.8	0.6	33.8	
			3.8	2.8	1.2	32.0	
Degremont Disc	Ref. 19		3.8	2.8	0.6	49.7	
			3.8	2.8	1.2	40.1	

* 1 m = 3.28 ft

** 1 dome/m^2 = 9.29 domes/100 ft^2

\+ 1 cfm = 0.028 m^3/min

++ 1 kg/kWh = 1.64 lb/wire hp-hr

+++ LACSD - Los Angeles County Sanitation Districts

SECTION 8

DESIGN OF DOME DIFFUSER ACTIVATED SLUDGE SYSTEMS

In visiting and studying a large number of dome diffuser activated sludge plants, it was observed that O&M played a large part in oxygen transfer efficiency. However, it was also apparent that design was as much or more a factor in efficient use of electrical power. This section discusses the principal design factors that affect oxygen transfer performance and aeration efficiency and offers suggested approaches for more efficient design.

CHARACTERISTICS OF DOME DIFFUSERS THAT AFFECT DESIGN

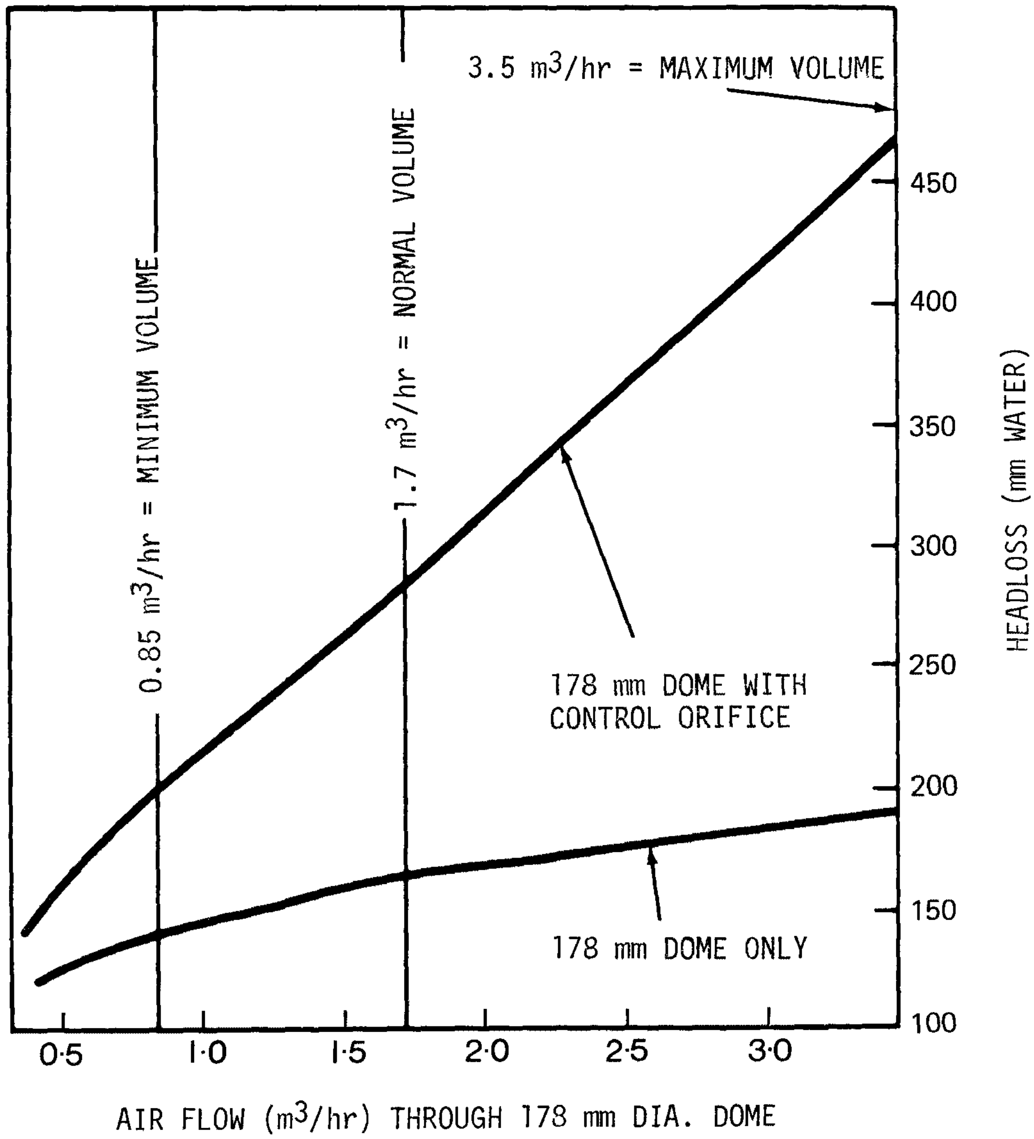
Like any process equipment, dome diffusers have performance characteristics that define design boundaries. These include the following:

- Range of air flow per diffuser
- Diffuser density
- Diffuser depth.

It was observed that dome diffusers have flexibility in design that has not been fully exploited by existing design practices, particularly as related to these three factors.

Air Flow Range

Any given dome diffuser will have a minimum air flow below which it should not be operated and a maximum air flow above which oxygen transfer efficiency decreases rapidly. The minimum air flow rate for the N/HS dome is defined by the headloss across the control orifice (see Figure 20). At an air flow rate of 0.014 m^3/min/dome (0.5 cfm/dome), the headloss across the control orifice is essentially zero and the headloss across the dome is about 12.7 cm (5 in.) of water, which is also equal to the distance from the invert of the air supply pipe to the inside surface of the dome (Figure 20). Thus, in operation, the air pressure in the pipe counterbalances the outside pressure, minimizing the infiltration of mixed liquor into the pipe. In addition, plant operators at Mogden reported that mixed liquor appeared to infiltrate through the lower part of the sides of the dome at lower air flow rates. Based on these and similar observations, it would appear that Norton/Hawker-Siddeley's suggested minimum air flow rate of 0.014 m^3/min/dome (0.5 cfm/dome) is not overly conservative and should be followed in design of N/HS dome aerated plants.



Notes:

1. 1 m^3/hr = 35.3 ft^3/hr
2. 1 mm = 0.039 in.

Courtesy of Hawker-Siddeley, Ltd.

Figure 20. Dome diffuser head loss vs. air flow rate.

Maximum air flow rates per dome are selected on the basis of their relationship with oxygen transfer efficiency, which decrease with increasing air flow. Clean water studies of the N/HS diffuser at LACSD[14] produced the results given in Figure 21. Wire-to-water efficiency at the 4.6-m (15-ft) water depth decreased by about 14 percent in the air flow range of 0.017-0.56 m^3/min/dome (0.6-2.0 cfm/dome). A similar study at Steenwijk (The Netherlands)[20] showed a 13 percent loss in oxygen transfer efficiency over the same air flow range. The Steenwijk study was performed as a full-scale test, using a portion of the plant's aeration tank which had been baffled off to produce a test area measuring 6.4 m x 6.8 m x 4 m deep (20.9 ft x 22.3 ft x 13.1 ft).

Most of the U.K. plants visited were designed using an air flow range of 0.014-0.028 m^3/min/diffuser (0.5-1.0 cfm/dome)*. Several U.K. designers expressed the belief that 0.021 m^3/min/dome (0.75 cfm/dome) was the optimum operating air flow rate. This rather narrow design air flow range is apparently justified in the United Kingdom by the above described decrease in clean water oxygen transfer efficiency exhibited by the N/HS diffuser with increasing air flow rate.

The plant survey identified a fairly consistent pattern of aeration system overdesign and lack of operational flexibility, at least partly attributable to the aforementioned use of narrow air flow ranges for dome systems. The number of domes required was based on very conservative loading considerations as well. In actual operation many of the plants found it necessary to operate at a minimum total plant air flow rate dictated by the number of installed domes x 0.014 m^3/min (0.5 cfm) during periods of reduced flow and load and low oxygen demand. The result was that the plants overaerated during much of the 24-hr diurnal cycle. Strongford operated at minimum allowable air flow for 18-20 hr/day. Mogden operated for at least 12-16 hr/day at minimum allowable air flow. At Beckton, an ongoing program of experimental dome removal is addressing the overaeration problem (see Appendix B).

Use of a wider air flow range, up to 0.057 m^3/min/dome (2.0 cfm/dome) during peak load periods, would allow the use of fewer domes, lowering the mandatory total plant minimum air flow rate. Rarely would the maximum oxygen demand be greater than three to four times the minimum demand in a municipal treatment plant. If the number of domes is derived equating the anticipated minimum oxygen demand during a typical day to the minimum recommended air flow rate of 0.014 m^3/min/dome (0.5 cfm/dome), the system should be more than capable of meeting maximum oxygen demand without causing overaeration during much of the daily treatment cycle. Hawker-Siddeley currently recommends that their diffusers be designed for a 5:1 maximum:minimum air flow ratio.

In advancing this argument, it is recognized that the diffusers would be operated at less than optimal efficiency during a portion of the daily treatment cycle. However, as discussed in Section 6 of this report, the alpha

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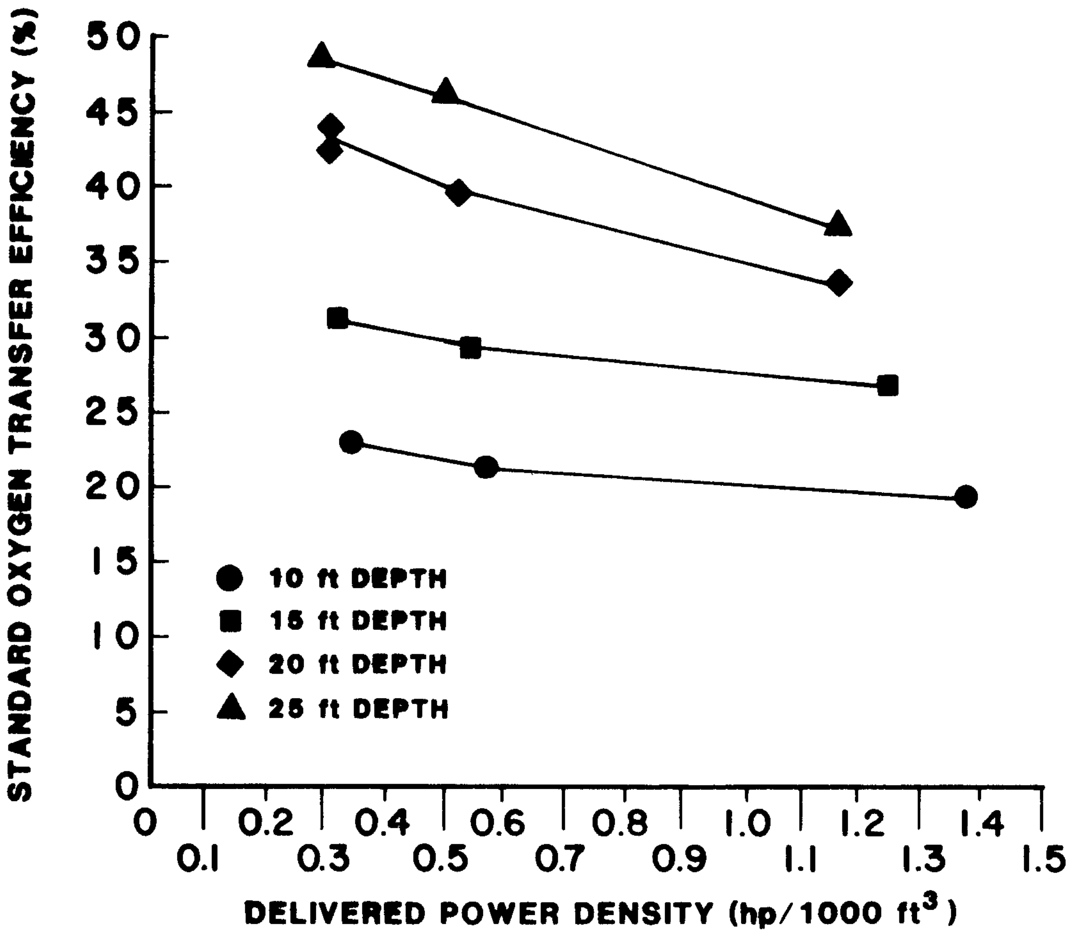
* The air flow rates cited above are directly applicable to the N/HS diffuser only. The larger Sanitaire and Degremont discs could be expected to have higher minimum and maximum air flow rates. However, if the number of diffusers is adjusted to reflect the larger surface area of these discs, the overall effect should be the same.



126 FINE BUBBLE CERAMIC DIFFUSERS APPLIED IN A TOTAL FLOOR COVERAGE CONFIGURATION

Notes:

1. 1 ft = 0.305 m

2. 1 hp/1000 ft^3 = 0.026 kW/m^3

Source: Reference 14

Figure 21. Relationship between specific oxygen transfer and air flow per dome.

factor is affected by mixing power level, tending to higher values as mixing intensity increases. It is possible in an operating activated sludge tank that a three-or four-fold increase in the mixing power level could increase alpha sufficiently to offset much of the oxygen transfer efficiency lost at higher air flow rates. Also, the net daily treatment efficiency, expressed as units of BOD_5 removed per kWh of power could well be improved significantly by reducing or eliminating the long periods of overaeration.

This question should be researched as part of an overall study to optimize the design of dome/disc systems. It is the authors' belief that design of dome diffuser systems should be predicated on a wider air flow range, possibly 0.014-0.056 m^3/min/diffuser (0.5-2.0 cfm/diffuser), and that this approach would considerably improve overall system efficiency.

Diffuser Density

Diffuser density is defined as the number of aerators per unit floor area. Theoretically, there would be no lower limit except as dictated by oxygen demand and mixing considerations and the upper limit would be reached when the tank floor was covered with diffusers, each touching the other at the perimeter. Practically speaking, some spacing between domes is needed to allow for cleaning and other maintenance. A spacing of 30 cm (1 ft) between dome centers is a practical minimum limit, corresponding to a diffuser density of 10.8 domes/m^2 (100.3 domes 100/ft^2).

Several researchers have noted the apparent increase in oxygen transfer efficiency with increasing diffuser density. Lister and Boon[21] conducted tests on N/HS domes in a bench-scale tank of 2.25-m^2 (24.2-ft^2) floor area over a range of depths. Figure 22(A) summarizes the results at one depth of those tests, run using the non-steady state reaeration procedure with 5 mg/l of detergent added. Oxygen transfer efficiency increased somewhat faster than would be predicted by the increase in total gas flow rate alone. Interestingly, these data tend to support the possibility of alpha enhancement with higher air flow (power level) as a possible offset to lower clean water efficiency per dome with increasing air flow.

Paulson[16] evaluated N/HS domes in clean water (no detergent added), also employing the non-steady state sulfite reaeration method. His results, shown in Figure 22(B), depict an almost linear rise in oxygen transfer efficiency with increasing diffuser density.

Therefore, when designing new systems, diffuser density should be maximized within the contraints of minimum allowable air flows (discussed above) and economic costs. It is expected, however, that the aeration efficiency improvement possible with optimized air flow ranges would be substantially higher than those which would accrue from increased diffuser density alone, other factors being equal. It is possible that allowable volumetric organic loadings of dome diffuser plants might be substantially increased, within constraints imposed by process requirement, by utilizing greater diffuser densities. A plant designed in this manner should realize the higher oxygen transfer efficiency associated with increased diffuser density and greater turbulence levels, while at the same time still alowing the use of an optimized air flow range. Higher volumetric loadings for dome (or disc) fine bubble diffuser systems should be studied to determine practicability and limits.

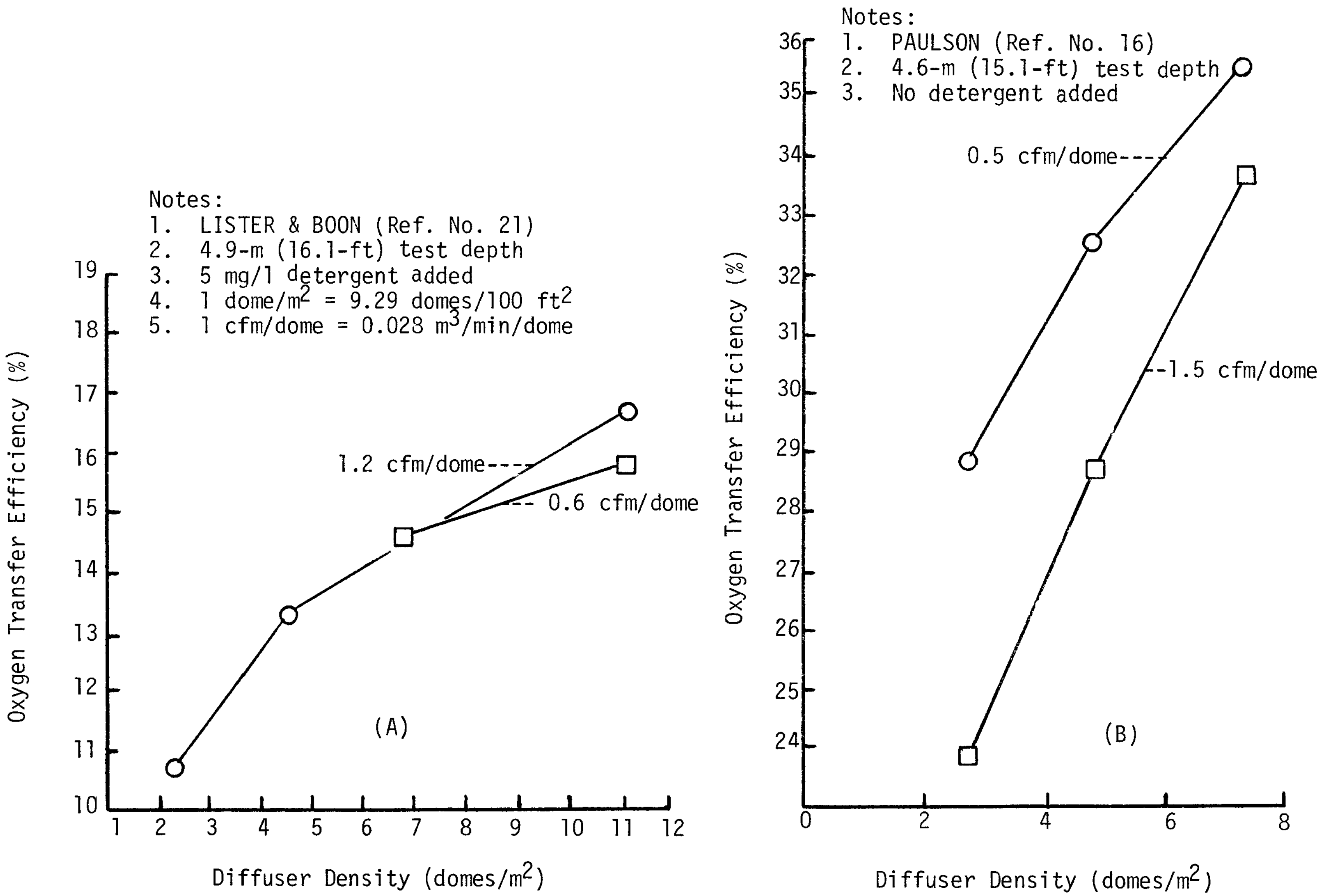


Figure 22. Effect of diffuser density on oxygen transfer efficiency.

Diffuser Depth

A review of the clean water research work cited earlier reveals that all of the studies noted a nearly linear correlation between oxygen transfer efficiency and depth, up to about 6.1 m (20 ft), with or without detergent addetion. The LACSD tests on the N/HS dome, plotted in Figure 23 (B), are typical of these results. The tapering off of oxygen transfer efficiency at greater depths is caused by oxygen depletion in the bubble, which places an overall limit on the efficiency/depth relationship. Paulson[16] found transfer efficiency to be essentially linear up to a test depth of 4.6 m (15 ft) if data scatter is taken into account. Figure 23 (A) summarizes several years of testing by Wheatland and Boon[22] at the WRC, who concluded that oxygenation capacity, with 5 mg/l detergent added, is essentially linear in the depth range of 1-8 m (3-26 ft). The oxygenation rate does not taper off at greater depths in their plot because bubble oxygen depletion occurs less rapidly due to the surfactant effect of the added detergent.

Assuming that oxygen transfer efficiency is linear up to 6.1 m depth (20 ft), a comparison of power required vs. depth to transfer an equivalent amount of oxygen can be developed, using the blower equation:

$$BHP_{adiabatic} = [WRT_1/(33{,}000\ nE)]\ [(P_2/P_1)^n - 1.0] \qquad (17)$$

where:

W = weight flow of air, lb/min

R = gas constant, 53.5

n = 0.283 for air

E = combined efficiency of blower, coupling, and motor

T_1 = inlet air temperature, degrees Rankine

P_1 = absolute inlet air pressure, psia

P_2 = absolute outlet air pressure, psia.

The weight of air flow, W, can be related to the inlet air flow, as follows:

$$W = ICFM \times Pair_{T°F} \qquad (18)$$

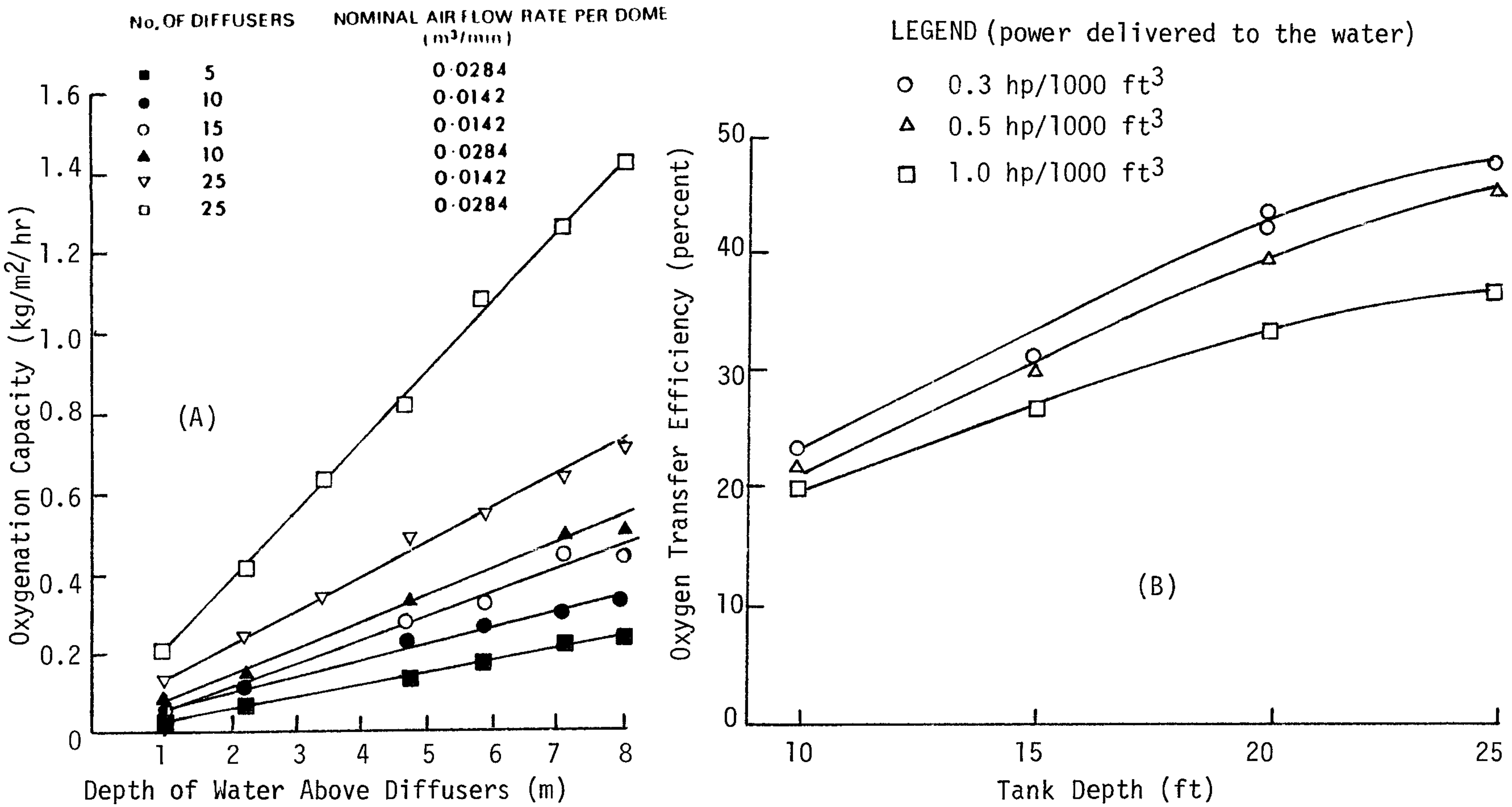
where:

ICFM = inlet air flow, actual cfm at inlet conditions P_1 and T_1

$Pair_{T°F}$ = density of air flow at inlet conditions, lb/ft^3.

The density of air is proportioned to temperature and pressure. Thus, air density at inlet conditions can be related to those at standard conditions as follows:

$$Pair_{STD}/Pair_{T°F} = (P_{STD}/T_{SD})/(P_1/T_1) \qquad (19)$$



Notes:
1. 1 m = 3.28 ft
2. 1 kg/m^2/hr = 0.205 lb/ft^2/hr
3. 1 m^3/min = 35.3 ft^3/min
4. Floor area = 2.25 m^2 (24.2 ft^2)
5. 5 mg/l detergent added.
6. Source: Reference 22

Notes:
1. 1 ft = 3.28 m
2. 1 hp/1000 ft^3 = 0.026 kW/m^3
3. Floor area = 36.5 m^2 (400 ft^2)
4. No detergent added.
5. Source: Reference 14

Figure 23. Variation of diffuser oxygenation efficiency with depth.

Substituting in Equation (17):

$$BHPadiabatic = (4.2965 \times 10^{-4}/e)(T_1)(SCFM)[(P_2/P_1)^{0.283} - 1.0] \quad (20)$$

This relationship is used to develop a comparison of blower efficiency with depth, based on the following assumptions:

e = combined efficiency of motor, coupling, and blower = 0.65

P_2 = hydrostatic pressure + 1 psia system headloss

P_1 = inlet pressure at standard temperature of 68°F (20°C) = 14.7 psia

The results, plotted in Figure 24, show a 15.4-percent reduction in blower power required as depth is increased from 2.4 to 4.6 m (8 to 15 ft). A further increase to a 9.1-m (30-ft) depth reduces the calculated power demand by an overall 28.7 percent. Of course, any power savings at increased depths may be offset by non-linearity of oxygen transfer at higher depths, and by deviations of actual blower systems from the idealized conditions of this analysis. Nevertheless, it is probably realistic to expect some efficiency gains with increasing depths, up to 9.1 m (30 ft). Further study in mixed liquor of the relationship of depth to oxygen transfer efficiency (OTE), and the relationship of blower power to depth (with linear OTE), is recommended.

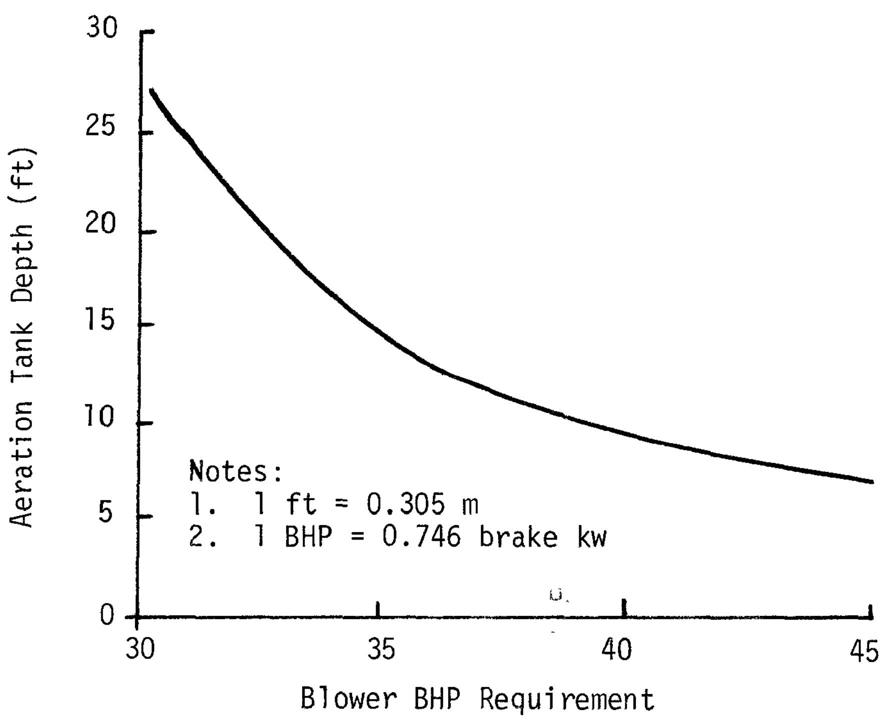


Figure 24. Blower brake horsepower requirement vs. aeration tank depth.

PRIMARY AND SECONDARY CLARIFIER DESIGN

As noted in Section 6, primary and secondary clarifier design was observed to be a significant factor in the impressive pollutant removal performance of the U.K. plants. Primary clarification consistently removed 45-55 percent of the influent BOD_5 and 55-70 percent of the influent suspended solids. Primary clarifier configuration was basically the same as that used in the United States. However, surface loading rates were substantially less. Several British design engineers noted that the philosophy in the United Kingdom is to remove as much of the influent suspended solids and BOD as practicable to minimize power requirements in the aeration process and maximize gas production in the anaerobic digesters.

The tradeoff between expenditure for larger primary tanks vs. aeration power is highly plant specific and will not be pursued further here. However, the British approach suggests that primary clarifier design should be given more careful consideration in future new plant design in the United States. Larger primary clarifiers that might remove 40-45 percent of the influent BOD_5 could be economically justifiable in light of sharply higher power costs.

Likewise, U.K. secondary clarifier designs were quite conservative and appeared to give plant operators more reserve capability in the event of process upsets and episodes of poor sludge settleability. However, the long detention times used could be a source of problems with sludge blanket denitrification as well, as noted in Section 6. The U.K. design configuration that utilizes steeply sloped floors (30^o slope) may merit further attention in the United States in view of the very good operating experience with this simple design (see Figure 2, Section 6).

TAPERED AERATION

The term "tapered aeration" is used to describe systems which have progressively fewer diffusers as the tank is traversed from the inlet to the outlet end. Figure 25 shows a schematic of a plug flow tank at Oxford with tapered aeration. The diffuser distribution shown in Figure 25 is quite typical for this design approach. The diffusers in the last quarter section are concentrated in the center of the tank, causing a double spiral roll mixing effect in this zone of the tank.

The basis for tapered aeration is derived from the two principal mechanisms that affect oxygen transfer in a plug flow tank:

- Rate of oxygen demand decreases with distance from the inlet end
- As surfactants (surface active agents) are oxidized in the process, alpha values increase; hence (all other factors unchanged) oxygen transfer efficiency increases along the tank length (Figure 26).

Seeking to create a relatively flat D.O. profile (with distance from the inlet end), tapered aeration was empirically developed by Hawker-Siddeley and first applied in the late 1960's. It has been used since that time, with variable success, on most of the plug flow systems equipped with Norton/Hawker-Siddeley dome diffusers. Most of the tapered aeration plants visited during the course of this study still exhibited rising mixed liquor D.O. as the flow passed from inlet to exit; however, the rise may have been more moderate than it would have been with a symmetrical diffuser configuration. Qualitatively, it appears that tapered aeration may be more effectively used in single-pass systems such as Oxford. Further study of this possibility is suggested.

AERATION BASIN GEOMETRY

Dome diffusers have several operating characteristics that are markedly affected by aeration basin geometry:

- Alpha sensitivity and variation
- Sliming tendency in zones of high localized loading and/or low D.O.
- Minimum allowable air flow requirements
- Depth vs. oxygen transfer efficiency (discussed above)
- Other factors.

As noted in Section 6, all of the surveyed plants had varying degrees of excess aeration in multi-pass systems and slime growth on domes in zones where primary effluent was introduced. These problems were largely caused by aeration basin geometry that is poorly suited to the optimum operating characteristics of dome diffusers. Discussed below is each major characteristic and how it is impacted by current basin design practices.

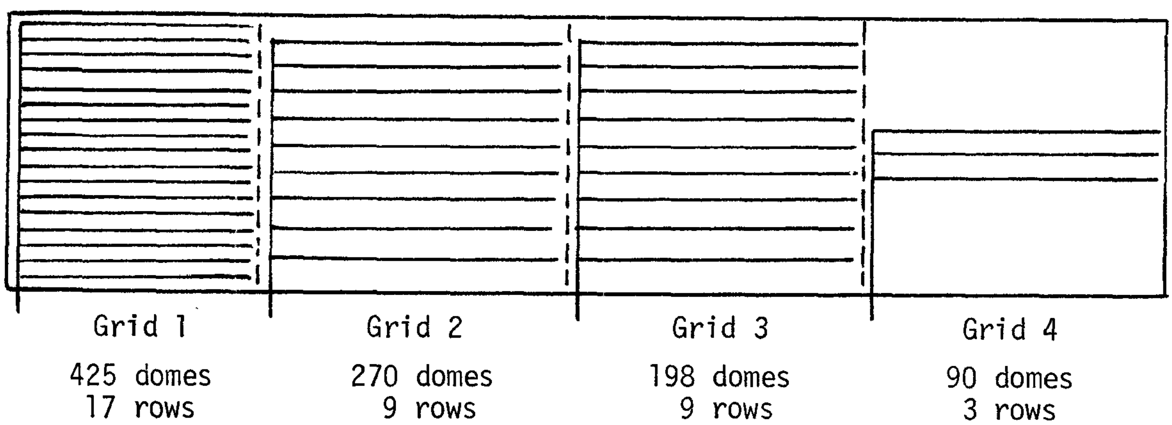


Figure 25. Tapered aeration at Oxford.

Alpha Sensitivity

As discussed in Section 6, fine bubble dome diffusers exhibit alpha sensitivity, i.e., they are greatly affected by the presence and concentration of surfactant contaminants in the wastewater. Wheatland and Boon[22] summarizing the investigations of the WRC over a period of years note that alpha in plug flow dome diffuser systems can double as wastewater is progressively oxidized in passing from the inlet to the outlet end (Figure 26). Thus, all other things being equal, a dome diffuser in the outlet section of a plug flow system will be about twice as efficient as one at the inlet. Tapering of the aeration system, used to deal with this inbalance (Figure 25), is only partly successful because of the high localized volumetric loading and sliming that occurs.

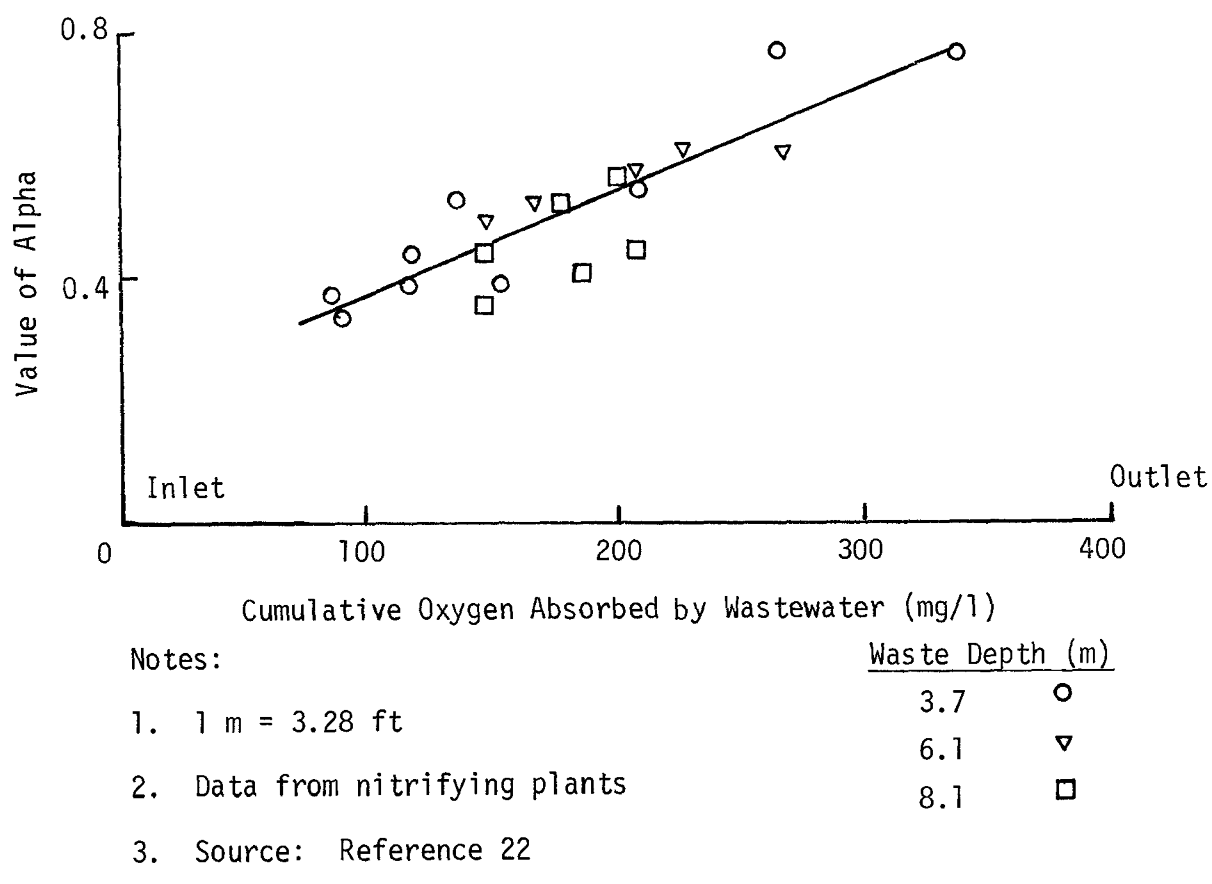


Figure 26. Variation of alpha with degree of treatment.

Sliming and Plug Flow

Boon and Burgess[23] reported on studies that indicated dome diffusers could effectively transfer oxygen into activated sludge systems that were experiencing high volumetric loading rates. However, a side effect of this condition was the heavy slime growth shown earlier in Figure 11. Periodic brushing maintained oxygen transfer efficiency in this test case. Otherwise, the slime growth caused the fine bubbles emerging from the diffuser stone to coalesce into medium and coarse bubbles, markedly reducing oxygen transfer efficiency. A similar phenomenon has occurred with regularity at Beddington (discussed in Section 6), apparently caused by the strong industrial wastes being treated there.

Recently, the Madison, Wisconsin plant also experienced extensive diffuser sliming related to increased loading on the dome diffuser tanks. A combination of a 40-percent increase in BOD_5 loading from a dairy waste and decreased air flow to the dome tanks caused rapid slime growth which began at the head of the two three-pass step feed tanks and progressed to the effluent end of the first pass over a period of 2 mo. Oxygen transfer efficiency measurements by plant personnel indicated that aeration efficiency decreased by nearly 50 percent as a result of the sliming. Draining the tanks and steam cleaning were used by Madison to restore aerator performance. The Madison experience, coming after 3 yr of stable performance with little apparent sliming, further strengthens the suspected relationship of dome sliming to zones of low D.O. and/or high volumetric loading.

As noted earlier, sliming was apparently occurring to some degree in most of the visited plants and was most noticeable in those plants with a high degree of plug flow. Plug flow exacerbates volumetric loading by effectively causing an initial zone in the inlet area of the aeration tank of relatively high F/M loading with associated high oxygen demand. At the same time, the alpha factor in this zone is likely to be low as a result of surfactants in the incoming raw wastewater. With increasing L/W, all of these effects become more pronounced, with a resulting increase in the number of diffusers affected by slime growth. Tapering the aeration is a partial solution, limited by the aeration/mixing requirements of the lightly loaded back end of the plug flow system. Step feeding helps distribute oxygen demand and alpha depression more equally; however, its use is limited in single-stage nitification systems. Hawker-Siddeley reports that some plants have had good experience with feeding raw wastewater downstream of the return sludge feed point, effectively creating a zone of sludge reaeration in the first section of the aeration tank.

Commensurate with the process advantages of plug flow, new dome (or disc) diffuser systems should be designed at the lowest practicable L/W. Tapered aeration and provision for step feeding at least to mid-length should be provided. D.O. monitoring and provision for independent air flow control should be provided for each aeration grid and/or pass (in multiple channel) systems. In designing plug flow systems, the oxygen demand for each distinct segment of the aeration process should be calculated and the aeration system should be sized taking into account the variation of alpha from inlet to outlet.

An optimal system configuration, providing the benefits of plug flow with more efficient utilization of dome (disc) diffusers, should be the subject of further study, preferably in a full-scale operating facility.

Air Flow Requirements

The rationale behind minimum allowable air flow was discussed above. It is believed that the lower limit is valid and should be observed in operation. Careful adherence to minimum allowable levels was the standing rule at virtually all of the U.K. plants, and it is believed that this practice played an important part in the excellent aeration system maintenance history at most of these plants.

However, the adherence to minimum air flow per diffuser was also apparently a main reason for the mediocre energy efficiency of many of the plants. Plant operators at most of the plants were aware of the connection between minimum air flows that greatly exceeded process air requirements much of the time and higher than necessary electrical costs. Better matching of process and aeration tank design to diffuser system design constraints will probably be the most effective solution to the problem of overaeration.

Other Factors

Depending on the age of the plant, some aeration basins were constructed with ridge and furrow floor designs. This configuration, shown in Figure 27, was originally developed as an aid in mixing and tank circulation. It has since been determined in the United Kingdom that it is costly to construct and adds little to performance; consequently, it was not seen in the newer plants included in the survey.

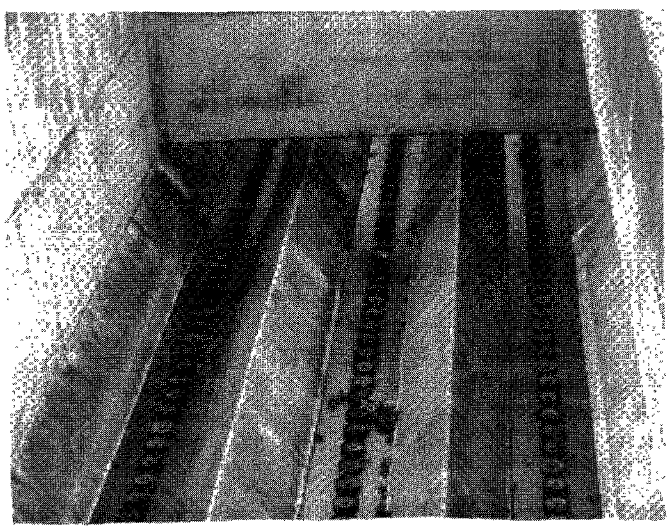


Figure 27. Ridge and Furrow tank at Ryemeads.

Filets along the bottom of the tank where the floor meets the wall were observed in about half of the plants. Where whole tank coverage of diffusers is used, it is believed that fillets are not totally necessary, though they probably prevent the deposition of small amounts of solids in the corners of the aeration basin.

EFFECT OF PROCESS DESIGN

It is believed by the authors that dome diffuser systems in complete mix basins might be operated at volumetric and F/M loadings in excess of those currently used. Except for lab-scale studies at the WRC, no real test of this belief has been made, either by the manufacturers of this equipment or in actual plant designs. The highest F/M loading rates observed were in the U.S. plants at Glendale (0.35 kg BOD_5/day/kg MLSS) and Madison (0.3 kg BOD_5/day/kg MLSS). F/M loadings up to 0.5-0.6 kg BOD_5/day/kg MLSS might be achievable with this equipment. If practicable, this would allow operation at loading rates approaching that of pure oxygen systems (0.6-0.8 kg BOD_5/day/kg MLVSS) and could significantly affect economic comparisons between the two alternatives. Recognizing that sludge settling characteristics and diffuser sliming may impose the ultimate limit on loading, research along these lines is strongly recommended.

Single-stage nitrification appears to be practical, and potentially efficient, based on the results from Oxford. The use of anoxic zones in the aeration tank, as typified by Ryemeads, has definite merit as an aid to clarifier performance but may pose problems for the downstream aerobic zones. The first aerobic zone following the anoxic zone always exhibited severe coarse bubbling, indicative of slime growth. A change in tank geometry, a higher concentration of diffusers, and/or higher air flow rates may be needed to alleviate this problem. Anoxic zones should be mechanically mixed. Full scale study of anoxic zone optimization is also suggested.

MIXING

Minimum and average mixing power levels in use at the surveyed plants often were quite low (refer to Table 3). Usually, the power imput required to satisfy oxygen demand exceeds that needed to prevent solids deposition, i.e., to sustain adequate mixing. The data in Table 3 indicate that power levels as low as 10 W/m^3 (0.38 wire hp/1000 ft^3) are satisfactory for suspension of biological solids. Concentrating the aerators along the center of the tank in tapered aeration systems, creating a spiral flow situation, enhances mixing at the expense of oxygen transfer and can be avoided by avoiding the long multi-pass plug flow designs that require excessive diffuser taper in back-end passes to prevent overaeration.

DESIGN OF AIR CLEANING SYSTEMS

Of the three types of air cleaning systems observed, the replaceable filters are the simplest to construct and operate. For example, a replaceable air filter assembly for an air flow of 283 m^3/min (10,000 cfm), adequate for a 75,700-m^3/day (20-mgd) municipal wastewater treatment plant, costs about \$1200 for the enclosure and \$1000 for the filter elements. Only one enclosure is required as system backup is provided by stocking a set of replacement air filters at a cost of \$1000 more. By comparison, an electrostatic air filter system for the same size plant would require two units, each sized for an air flow of about 198 m^3/min (7000 cfm), allowing for temporary operation on one unit when the other is shut down for maintenance. Equipment costs would be at least $25,000 for this approach.

Replaceable air filter systems are generally provided with a coarse fiberglass prefilter, followed by fine final filters. The prefilter normally consists of a roll of fiberglass cloth mounted on a frame across which it is automatically advanced by an opacity sensor. The final filters are housed in racks behind the prefilter (Figure 28). This system will remove 95 percent of the particles in excess of 0.3 microns and larger, the required standard for N/HS dome diffusers.

Bag house dust collectors are bulky and expensive, though apparently not maintenance intensive. None of the U.S. installations visited use bag house systems; rather, most prefer replaceable units. Four of the newer U.K. plants utilize bag houses, and the Dutch plants all employ electrostatic precipitators.

Replaceable air filters are the recommended approach except where poor air quality requires replacement of the fine filtration elements more frequently then once per year. In this case, electrostatic units may be cost effective and should be considered.

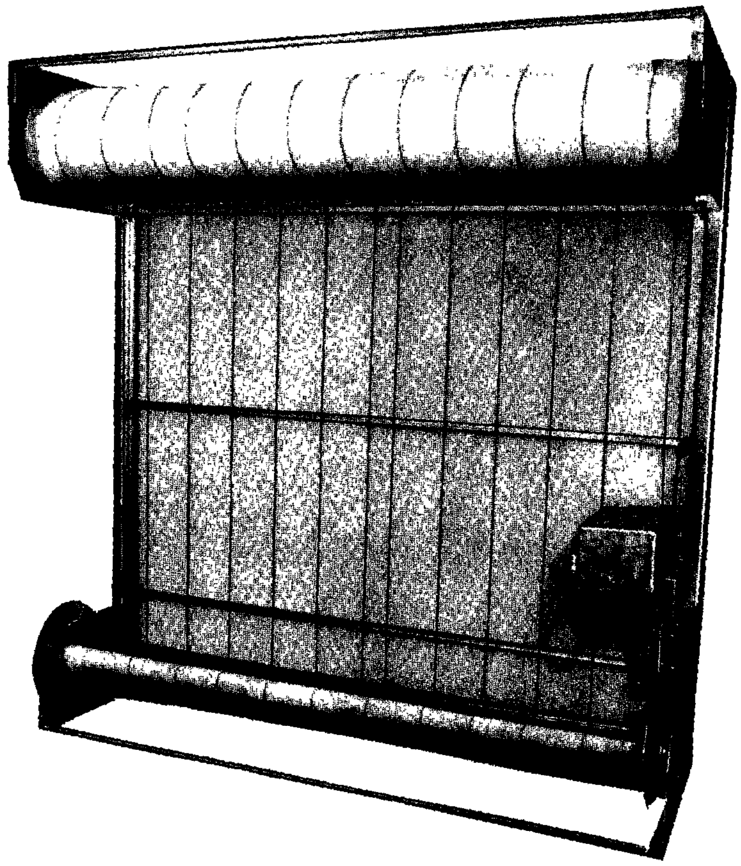
DIFFUSER CLEANING SYSTEMS

A variety of techniques and equipment for diffuser cleaning were evident during the plant surveys. Organic fouling was generally removed by dome refiring. Acid washing combined with clean water and steam cleaning was used to deal with the inorganic calcium carbonate fouling observed at Basingstoke and to a lesser degree at Beckton.

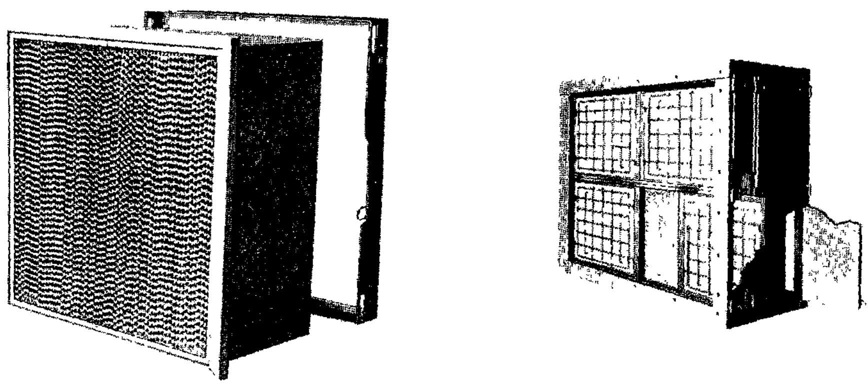
As detailed in Section 6, ceramic diffuser firing systems are costly to build and use and are probably not justified except for the very largest plants. Their advantage is the wide range of fouling problems that can be successfully remedied by this approach and the number of diffusers that can be cleaned at a time.

Ultrasonic cleaning has been experimented with in the United Kingdom and installed at Fort Worth, Texas, in the United States. The units at Fort Worth operate at 25 kilocycles/sec frequency and can clean six domes per 8-min cycle per unit. The diffusers are presoaked in a hot bath (40°C, 104°F) of clean water to which a wetting agent (e.g., detergent) has been added. An estimated 600 diffusers can be cleaned per operator work shift.

Currently, no U.S. or foreign plant has operated ultrasonic cleaners over a long enough period of time to establish their suitability for this application. In view of the high cost of the equipment, caution is suggested in relying on ultrasonic cleaning for diffuser cleaning. Firing and/or acid washing have been well established as effective techniques and should be used where possible.



(A) Coarse Filters



(B) Fine Filters

Courtesy:
American Air Filter Company

Figure 28. Replaceable air filter system.

DESIGN TO FACILITATE O&M

Plant designers can ease the operator's work by building in aids to facilitate dome diffuser system maintenance. The following items were observed to be needed and/or were mentioned most frequently by operators:

- Provision for rapid tank draining and cleaning. -- Tanks should be constructed with longitudinal drain channels feeding into a sump. Connection of the sump to plant drains/pumping is preferred; however, a convenient-to-use portable pump is satisfactory.

- A simple portable hoist for lifting baskets of domes out of the aeration basin, particularly where tanks are large (many domes) and/or very deep.

- A convenient clear water source, such as plant effluent, connected to the tank so that it can be readily added to the tank during startup after cleaning.

- Either provision of facilities for on-site dome cleaning or a determination that cleaning service can be obtained conveniently elsewhere. -- Providing a central facility for cleaning domes from several plants proved to be cost effective for the Thames Water Authority and should be considered where appropriate.

- Spare parts stocked at the plant. -- At minimum, enough domes to fully retrofit one aeration tank, along with gaskets, spare holddown bolts, and spare air supply piping should be provided.

- Provision of individual air valves for each grid of the aeration system. -- In many cases, plant operators were unable to correct overaeration problems due to the lack of air flow control to sections of the aeration tanks. Air valves should be provided for each grid and should be of a type that can be adjusted with some sensitivity and repeatability.

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APPENDIX A

SAMPLE U.K. PLANT SURVEY FORM

PLANT PERFORMANCE DATA FOR YEAR ..1975-1976....

Name of plant ..BASINGSTOKE SEWAGE TREATMENT WORKS.........................

1. RAW SEWAGE

Any significant industrial contribution ...No..........................

If yes, what type of industry ....

....

....

Average percentage industrial contribution:

by flow (%) ....4-6..

....

by BOD_5 mass loading (%) ....

Define any liquors recycled to head of works: Microstrainer waste: Surplus activated sludge: Supernatant from sludge treatment: Air flotation treatment waste.

	Annual average (mg/l)	Monthly average (mg/l)	
		Max *	Min *
BOD_5 total	328	381	296
BOD_5 soluble	Not assessed	Not assessed	Not assessed
COD total	700	817	651
Anionic surfactant as Manoxol OT (Detergent)	20.5	23.6	20.7
Total suspended solids (TSS)	378	403	392
Volatile suspended solids (VSS)	Not assessed	Not assessed	Not assessed
Total Kjeldahl nitrogen (TKN)	54.1	61.0	51.2
Ammoniacal nitrogen (NH_3-N)	36.9	41.6	36.8

* Max and Min denote months when the organic loading rates (kg BOD/day) are at the maximum and minimum respectively. Please define the months:

Max ...January........... Min ....August.............

PLANT PERFORMANCE DATA FOR YEAR ..1975-1976 (contd)

	Annual average (mg/l)	Monthly average (mg/l)	
		Max	Min
2. SETTLED SEWAGE			
BOD_5 total	174	216	132
BOD_5 soluble	Not assessed	Not assessed	Not assessed
COD total	366	434	314
Detergent	13.8	17.0	12.9
TSS	121	153	90.1
VSS	Not assessed	Not assessed	Not assessed
TKN	47.1	55.2	47.5
NH_3-N	36.1	41.0	34.4
Dissolved oxygen (DO)	Not assessed	Not assessed	Not assessed
pH	7.75	7.85	7.60
3. MIXED LIQUOR SS	3847	6197	4646
VSS	Not assessed	Not assessed	Not assessed
DO	"	"	"
pH	"	"	"
4. FINAL EFFLUENT			
BOD_5 total	3.46	5.78	1.31
BOD_5 soluble	Not assessed	Not assessed	Not assessed
COD total	30.3	36.5	21.5
Detergent	0.27	0.34	0.35
TSS	6.1	9.1	2.76

PLANT PERFORMANCE DATA FOR YEAR ..1975-1976...(Contd)

	Annual average (mg/l)	Monthly average (mg/l)	
		Max	Min
VSS	Not assessed	Not assessed	Not assessed
TKN	2.96	3.0	2.4
NH_3-N	0.97	0.95	0.04
Nitrate nitrogen (NO_3-N)	33.0	34.7	33.9
DO	Not assessed	Not assessed	Not assessed
5. UNDERFLOW SLUDGE			
SS	9293	9482	7909
VSS	Not assessed	Not assessed	Not assessed
6. DRINKING WATER*			
Hardness as $CaCO_3$			
Alkalinity as $CaCO_3$			
Total dissolved solids (TDS)			
Sulphates			
Chlorides			
Iron			
Manganese			

* The drinking water is supplied to the area served by the works.

PLANT PERFORMANCE DATA FOR YEAR ...1975-1976... (contd)

7. HYDRAULIC DATA	Annual average	Monthly average	
		Max	Min
Dry weather flowrate (m^3/d)	13,290	12,080	12,130
Average flowrate of influent (m^3/d)	13,690	12,160	11,940
Recycle rate (% of influent)	143	143	140
Flowrate of waste sludge (m^3/d)	69	137	62
8. LIQUOR TEMPERATURE (°C)		*	*
Raw sewage	Not assessed	Not assessed	Not assessed
Primary effluent	"	"	"
Mixed liquor	16.05	20.3	12.9
Final effluent	15.86	21.5	13.5

* Max and Min for the temperature data denote the months when the temperature is the maximum and minimum respectively. Please define the months:

Max ..August.......... Min ..April..........

≠ Experiments being conducted to reduce solids from an average of 10,000 mg/l to 3,500/4,000 mg/l.

CONSTRUCTION AND PERFORMANCE DATA FOR AERATION SYSTEM

Name of plant BASINGSTOKE SEWAGE TREATMENT WORKS.....................

	Section*			
	1	2	3	4
1. TANK DIMENSIONS	3 No. @	1 No. @	4 No. @	
Length (m)	79.25	79.25	79.25	
Width (m)	3.35	3.35	6.71	
Total depth (m)	2.36	2.51	2.51	
Operating depth (m)	2.36	2.51	2.51	
2. DIFFUSER LAYOUT†				
No of diffuses in row	275	275	275	
No of rows	4	4	8	
Spacing in rows (m)	0.3	0.3	0.3	
Spacing between rows (m)	0.76	0.76	0.76	
Distance from floor (m)	0.22	0.22	0.22	
3. AIR FLOW DISTRIBUTION (TOTAL)				
minimum air flow (m^3/s)				2.60
minimum power (kW)				87
average air flow (m^3/s)				4.04
average power (kW)				116
maximum air flow (m^3/s)				5.56
maximum power (kW)				160

* A section is each part of the aerator basin having a different diffuser arrangement or air flow per diffuser.

† Explanatory sketches showing diffuser layout may be drawn on the blank page overleaf.

AERATION SYSTEM DATA (cont)

4. DIFFUSER DATA:

Are all diffusers the same type (yes/no) ..YES.....................

Manufacturer(s) ..Norton................ Model No(s) Alundum.......

....

Description ("round dome, 12" square plate) ..Round................

....

Granulation or pore size ....150 microns...........................

Time in service (years) ....12..................................

5. BLOWER SYSTEM DATA:

Manufacturer .Geo. Waller............... Model No 2 No. 10", 1 No. 14", 1 No. 15", 1 No. 18"

Type .Rootes.................. Number of units ....5...

* Rated air flowrate .334 m^3/min at 0.34 kg/cm.............. pressure

Power demand at: Maximum air flow ..277 KVA........total elec. power

Minimum air flow .151 KVA.........total elec. power

Average air flow .200 KVA.........total elec. power

6. AIR CLEANING SYSTEM:

Please describe type (cyclone, electrostatic, etc) ....

Tilghman Ultra Filtration

....

7. CAPITAL COSTS:

Cost of air diffuser system, including in tank piping and fittings

Not available........ year ....

Cost of air cleaning equipment

Not available........ year ....

* 2 No. @ 2302 m^3/hour
1 No. @ 4605 "
1 No. @ 5098 "
1 No. @ 5709 "

AERATION SYSTEM DATA (cont)

Cost of air compressor equipment and appurtenances

Not available .... year ....

Total Wastewater Plant cost

.... year ....

8. ELECTRICITY CONSUMPTION

	YEAR				
	1	2	3	4	5
Consumption kWh/year	Est. 900,000	Est. 900,000	Est. 900,000	Est. 900,000	Actual 963,000

PLANT DESIGN DATA

Name of plant .BASINGSTOKE SEWAGE TREATMENT WORKS...................

Address ...Department of Water Pollution Control, Reading Road, Chineham, BASINGSTOKE, Hants.

Approximate year of construction ..1967..&..1971.(Extension).......

Year fine bubble aeration system installed ..As above..............

1. FLOWRATES (ACTUAL)

Dry-weather flowrate (m^3/d) ....16,783...........................

Annual-average flowrate (m^3/d) .18,580..........................

Peak monthly-average flowrate (m^3/d) ...28,229..................

Peak daily-average flowrate (m^3/d) .....40,900..................

Peak instantaneous flowrate to treatment (x DWF) ....600 litres/sec = DWF x 2.3....

2. AERATION DESIGN CRITERIA

Definition of design flowrate (average, DWF, etc) ....1 x DWF...........................

Type of plant (tapered aeration, etc) .Conventional............

Hydraulic conditions in tanks (plug flow, complete-mix etc) ....Plug Flow......................

Nominal retention time (h) of sewage in aeration tanks at design flowrate ....8.54 hours.........................

Recycle flowrate (%) of design flow ..100......................

Settled sewage:

Average BOD_5 (mg/l) ...157..................

Average NH_3-N (mg/l) ..34.8.................

Mixed liquor:

Average SS (mg/l)........4275.................

Average VSS (mg/l) ....Not assessed.........

Were any tanks designed for sludge reaeration (yes/no) ...Yes...

If yes, what is the volumetric proportion of the reaeration tanks ....8%........

3. CLARIFIER DESIGN CRITERIA

Definition of design flow (average, DWF, etc) ....1 x DWF..............................

Nominal retention time (h) of sewage in clarifier at design flowrate ....5.............................

Upward velocity (m/h) at design flowrate ....0.683...............................

Total length of weir(s) per tank (m) ..60.34...................

Number of tanks ....5......................................

Wall depth (m) ....1.52...................................

Diameter or length (m) .19.2 dia...............................

Width (m) ....-......................................

Location of inlet (centre or rim) ..Centre.....................

Location of weir(s) ......Perimeter............................

Type of sludge removal equipment ..Continuous hydrostatic......

....

Clarified effluent:

Average BOD_5 (mg/l) ....11.9...............

Average SS (mg/l) ......23.3..............

Underflow sludge:

Average SS (mg/l) ......7101...............

Average flowrate of waste sludge (m^3/d) ....228...............

APPENDIX B

PLANT SURVEY DATA

BASINGSTOKE

History and Background

Prior to the initiation of activated sludge treatment on the present site, wastewater from Basingstoke was treated at a 40.5-ha (100-ac) land treatment plant. Initially, it was planned to use the existing site and continue the practice of pumping wastewater to it. However, in 1960 it was decided to merge wastewater flows from several communities in the area. A downstream site, which would drain the service area by gravity, was selected adjacent to the River Loddon.

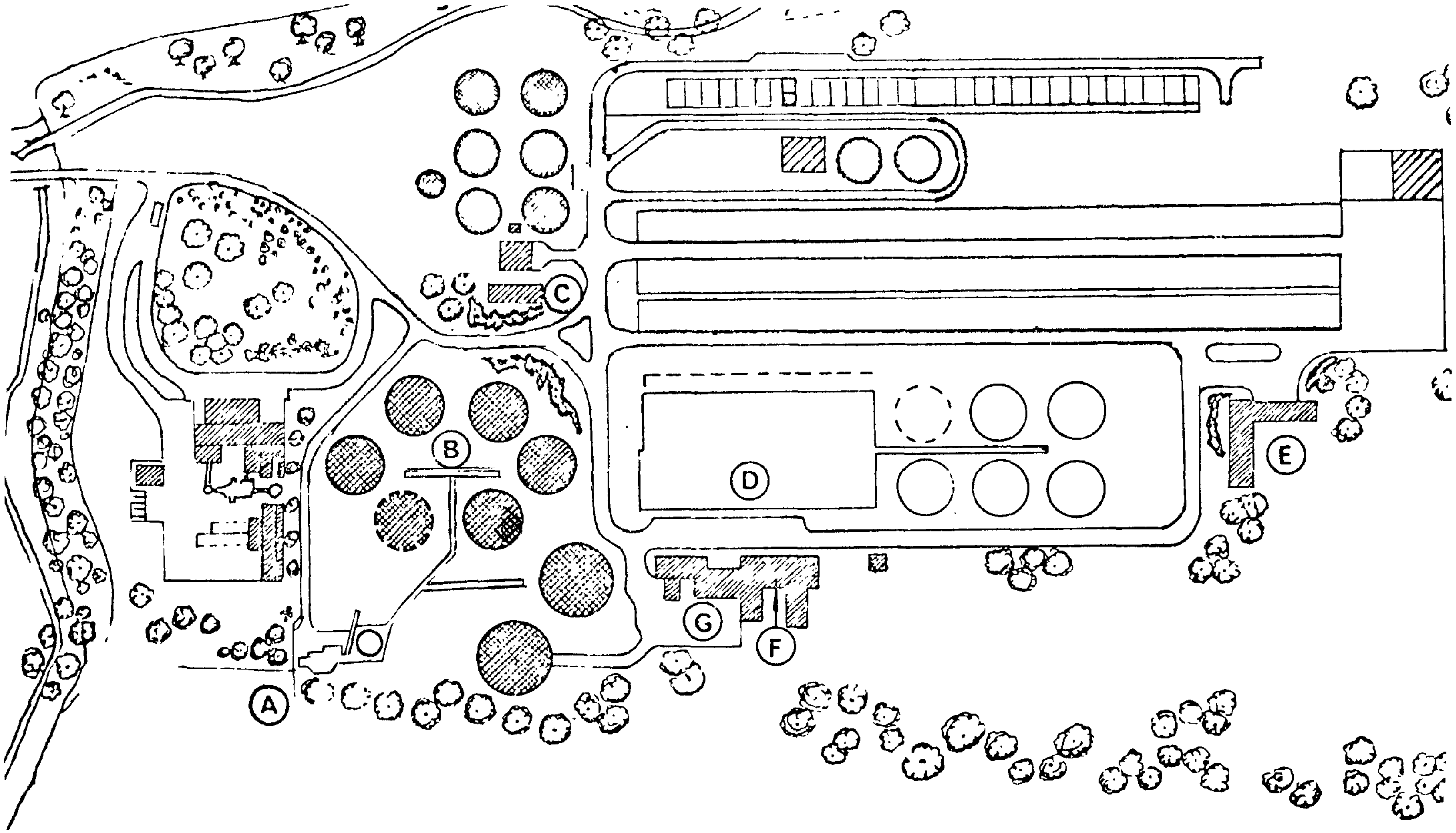
The activated sludge plant was constructed in three stages beginning in 1964. The first and second stages were designed to serve populations of 40,000 and 80,000, respectively. The second stage was completed in 1971. A final expansion, increasing plant size to a population equivalent of 96,000, was completed in 1976. The population currently being served is approximately 70,000. Figure B-1 shows the site plan at Basingstoke.

Plant Description

The Basingstoke wastewater treatment plant is a fine bubble diffused air activated sludge plant, with primary and secondary settling. In addition, the plant is provided with drum-type microstrainers and stormwater retention facilities owing to the very high discharge requirements of the River Loddon, a trout stream. Sludge is digested and disposed on land in liquid form. Facilities for sludge thickening and drying are also available at the plant. Table B-1 provides design details on the major plant elements.

In total, there are eight aeration basins in the activated sludge plant, the four smaller of which are 3.4 m (11 ft) wide; all are 79.2 m (260 ft) in length. Three of the smaller basins are designed to allow for flow in either direction. The other small basin is used exclusively for return sludge aeration. The four larger basins are for mixed liquor aeration only.

Dome distribution in all eight basins is symmetrical, with 1032 domes in each of the smaller basins and 2068 in each of the larger. A total of 708 domes are used for aerated primary effluent and mixed liquor channels. Each row of diffusers is laid lengthwise in the basin and has 275 domes; there are four rows in the smaller tanks and eight rows in the larger basins. Spacing



KEY:
- A. INLET WORKS
- B. PRIMARY SEDIMENTATION TANKS
- C. SLUDGE TREATMENT
- D. AERATION TANKS
- E. MICROSTRAINERS
- F. BLOWER AND POWER HOUSE
- G. AMENITY AND ADMINISTRATION BUILDING

Figure B-1. Basingstoke site plan.

TABLE B-1. BASINGSTOKE DESIGN DATA*

Stormwater Tanks	
2 Circular Tanks	
Diameter:	27.4 m+
Sidewater depth:	3.7 m
Floor slope:	2.5 degrees

Flow to tanks automatically controlled by No-flote controls and Rotork driven penstocks. Duty tank filled before it is shut down and flow diverted to standby tanks. Should tank fill and overflow, the first 4,546 m^3/day (1.2 mgd) is fed back to the aeration tanks. Any flow above 4,546 m^3/day (1.2 mgd) is irrigated on prepared grassland, collected, and discharged to the river, subject to the same standards as the final effluent.

Primary Sedimentation	
5 Circular Clarifiers	
Diameter:	20.3 m
Sidewater depth:	3.3 m
Floor slope:	5 degrees
Detention time:	6.3 hr @ DWF
Surface loading:	13.4 m^3/m^2/day @ DWF (330 gpd/ft^2)
Aeration Basins	
3 Dual Purpose Mixed Liquor/ Reaeration Tanks	3.4 m x 79.2 m x 2.4 m SWD (each tank)
1 Mixed Liquor Tank	3.4 m x 79.2 m x 2.4 m SWD
4 Mixed Liquor Tanks	6.7 m x 79.2 m x 2.4 m SWD (each tank)
Detention Time	8.5 hr @ DWF
Dome Distribution	
Small tanks:	1032
Large tanks:	2068
Final Sedimentation	
5 Circular Clarifiers	
Diameter:	19.2 m
Sidewater depth:	1.5 m
Floor slope:	30 degrees
Detention time:	5 hr @ DWF
Surface loading:	16.3 m^3/m^2/day @ DWF (400 gpd/ft^2)

* DWF = 22,700 m^3/day (6 mgd)
+ 1 m = 3.28 ft

between domes is 0.30 m (1 ft) and between rows 0.76 m (2.5 ft). The domes are installed 17 mm (8 in.) off the basin floor. Minimum air flow to the domes in the mixed liquor channels is 0.011 m^3/min (0.4 cfm).

Air supply is provided by five Rootes-type positive displacement blowers driven by electric motors. All are fixed speed but are sized to cover a range of outputs at 33.1 kN/m^2 (4.8 psi) as summarized below:

	Power		Output	
Blower No.	BHP	kW	cfm	m^3/min
1 & 2	60	45	1,362	38.4
3	110	82	2,724	76.8
4	125	94	3,015	85.0
5	125	94	3,373	95.1

The blowers are operated in various combinations to achieve the desired air flow rate as determined from manual D.O. measurements taken in the aeration tanks and the normal diurnal flow pattern.

Air cleaning is provided by three bag type dust collectors, each rated at 232 m^3/min (8200 cfm). Two units are normally in operation, with the third on standby.

Five circular final clarifiers, each 19.2 m (63 ft) in diameter, provide secondary settling. At the design flow rate of 22,700 m^3/day (6 mgd), the retention time is 5 hr and surface loading rate is 16.3 m^3/m^2/day (400 gpd/ft^2). The clarifiers have steeply sloped bottoms (30°) and shallow side water depths of 1.5 m (5 ft). Sludge is moved to the center withdrawal hoppers with simple chain type scrapers.

Performance

Influent and effluent data for the past 5 yr of operation at Basingstoke are presented in Table B-2. Plant personnel stated that the 1977/78 and 1978/79 data are the most representative of plant operations following the final expansion.

After correction of infiltration problems in 1975, causing an initial flow reduction, raw wastewater flow to this plant increased by nearly 50 percent from 1976 to 1979. Unlike most of the other plants visited, wastewater strength at Basingstoke has remained relatively constant, due apparently to the increasing industrial flow received at this plant.

Primary treatment performance was consistent over the period of study, decreasing influent BOD_5 by about 45 percent and influent suspended solids by about 67 percent. Secondary treatment, including final effluent microstraining, has also provided excellent performance, achieving 97-98 percent reductions in BOD_5 and 94-95 percent reductions in suspended solids. Detergent removals have consistently averaged 97-99 percent.

Monthly average hydraulic and influent BOD_5 loadings varied about ± 25 percent from the annual average. Of the total plant flow, 4-6 percent is derived from light industrial activities in the service area.

Reductions in ammonia nitrogen concentrations have averaged 96 percent, and the level of nitrate nitrogen in the final effluent has been constant to ± 10 percent.

TABLE B-2. BASINGSTOKE INFLUENT-EFFLUENT DATA SUMMARY

Parameter	Year*				
	78/79	77/78	76/77	75/76	74/75
Flow: mgd	4.91	4.25	3.97	3.62	4.65
m^3/day	18,600	16,100	15,000	13,700	17,600
Raw Wastewater: (mg/l)					
BOD_5	281	271	326	328	275
COD	658	634	695	700	573
TSS	372	356	363	378	310
TKN	45	45	54	54	45
NH_3-N	35	35	38	37	30
Detergent +	13	13	19	21	18
Primary Effluent: (mg/l)					
BOD_5	157	156	169	174	149
COD	323	342	366	366	308
TSS	114	112	126	121	111
TKN	43	45	46	47	43
NH_3-N	35	38	37	36	30
Detergent +	11	11	14	14	12
Final Effluent: (mg/l)					
BOD_5	3	3	3	3	4
COD	33	33	34	30	28
TSS	6	5	6	6	6
TKN	2.1	3.5	3.0	3.0	3.8
NH_3-N	1.3	2.4	1.1	1.0	1.7
NO_3-N	27	31	31	33	28
Detergent +	0.3	0.3	0.3	0.4	0.2

* Year begins April 1 and ends the following March 31.
\+ Detergent as manoxol OT (a proprietary ABS type compound).

MLSS levels have varied over the period of record from 4000-5000 mg/l. The F/M loading rate has averaged 0.08 kg BOD_5/day/kg MLSS. Based on Figure 1 in Section 5, 1.23 units of oxygen are required to remove each unit of BOD_5. Aeration efficiency, as calculated by the method of Section 5 and summarized in Table B-3, ranged from 1.08-1.20 kg O_2/kWh (1.78-1.97 lb/wire hp-hr). Based on data provided by plant personnel, a BOD_5 of 12 mg/l from the secondary clarifier, before microstraining, is assumed in computing BOD_5 removals.

Mixed liquor D.O., under most conditions, ranges from less than 10 percent of saturation in the first one-quarter of the aeration basin to 70-80 percent of saturation at the outlet end. The return sludge channel is aerated only to about 2 percent of saturation to promote denitrification.

TABLE B-3. BASINGSTOKE AERATION EFFICIENCY CALCULATIONS

Parameter	Year 78/79	77/78	76/77	75/76	74/75
BOD_5 Removed (kg/day)*+	2694	2317	2358	2218	2410
NH_3-N Removed (kg/day)*	623	566	544	481	504
NO_3-N Produced (kg/day)*	496	491	464	452	498
O_2 Required° (kg/day)*	5992	5283	5240	4796	5131
Power Consumed (kWh/day)°°	4989**	4440++	4440++	4440++	4440++
Aeration Efficiency:					
kg O_2/kWh	1.20	1.19	1.18	1.08	1.16
lb O_2/wire hp-hr	1.97	1.97	1.94	1.78	1.91

* 1 kg = 2.21 lb
\+ Assumes secondary effluent BOD_5 averaged 12 mg/l before microscreening.
° Calculated by the method of Section 5, assuming 1.23 units O_2 required/unit BOD_5 removed.
** Corrected for 5 percent of power used to aerate influent and effluent channels and to air lift return sludge.
++ Estimated value.
°° 1 kWh/day = 1.34 wire hp-hr/day.

The minimum mixing intensity or power input level at Basingstoke is 20.8 W/m^3 (0.80 wire hp/1000 ft^3), as shown in Table B-4. Maximum levels range to 106 percent above minimums. Plant personnel have not observed instances of inadequate mixing in any of the aeration basins.

Operation and Maintenance

Basingstoke is the only plant visited that operates a planned maintenance schedule (every 5 yr or less) for dome cleaning. Observation of the tanks in operation revealed that three of the eight tanks were experiencing possible dome plugging, as indicated by coarse bubbling. Pressure increase, if any, was not discernable, and plant personnel used D.O. levels to indicate the onset and degree of plugging.

TABLE B-4. BASINGSTOKE MIXING DATA

Parameter	Small Basin	Large Basin
Surface Area (m^2)*	265.5	531
Wetted Volume (m^3)+	627	1254
Diffuser Density (domes/m^2)°	3.89	3.89
Air Flow/Basin:**		
cfm	410	823
m^3/min	11.6	23.3
Air Flow/Area:**		
cfm/ft^2	0.144	0.144
m^3/m^2/min	0.044	0.044
Air Flow/Volume** (cfm/1000 ft^3)++	18.6	18.6
Minimum Power Imput:		
wire hp/1000 ft^3	0.80	0.80
W/m^3	20.8	20.8

* 1 m^2 = 10.8 ft^2
\+ 1 m^3 = 35.3 ft^3
° 1 dome/m^2 = 9.29 domes/100 ft^2
** Based on a minimum air flow rate of 0.011 m^3/min/dome (0.4 cfm/dome).
++ Same as m^3/1000 m^3/min.

The PI inspected fouled domes that had recently been removed for cleaning. It was determined that a white scale, apparently calcium carbonate, was building up on the domes and penetrating approximately 0.6 cm (0.25 in.) into the outer surface. Drinking water data for the plant revealed that hardness at 285 mg/l as $CaCO_3$ is similar to that of Oxford where the deposition problem has not been experienced. However, alkalinity at Basingstoke is 245 mg/l as $CaCO_3$, over two times the 111 mg/l level at Oxford.

To clean the carbonate fouled domes, Basingstoke personnel immerse the domes in a 10 percent solution of hydrochloric acid for 24 hr and follow with steam cleaning of each dome. Each batch of domes is checked after cleaning by testing a sample (2-4 domes) to determine headloss as compared to a new, unused dome.

Although plant personnel expressed satisfaction with this procedure, a subsequent discussion with the manufacturer of the domes cast some doubt on the validity of the cleaning process. It was the manufacturer's opinion that the procedure used at Basingstoke does not adequately clean the domes. They noted that the 3.4-6.9 kN/m^2 (0.5-1.0 psi) differential in pressure between one of the cleaned domes at Basingstoke and a new dome indicates that the domes are not fully cleaned by the process. It was their opinion that the domes should be refired to be fully cleaned.

Other problems with dome fouling have occurred in older sections of the plant that use cast iron manifolds on the tank floor. Rust formation in these mains, and resultant deposition on the interior surfaces of the domes, has caused some fouling in the past.

The maintenance supervisor at Basingstoke outlined the following procedure and manpower requirements for cleaning the domes in one of the larger tanks:

1. Empty and Clean Tank: 4 man days of work over a 3-4 day period. Work is hampered by lack of tank drains or cleanout sumps.

2. Remove Domes: Two men take 1 day for removal. A hoist or some other means of lifting the batches of domes should be provided.

3. Cleaning Domes: 2 man days to soak domes in 10 percent HCl, steam clean, and place in clean water bath.

4. Replacing Domes: 4 man days, over 2 days, to replace domes and check air manifolds and "hold-down" hardware. The large rubber gasket is replaced at each cleaning. O-rings in the dome hold-down bolts are checked and cleaned.

5. Final Checking: 1 man day over 1 day. Final effluent water is pumped into the basin to a depth of 15 cm (6 in.) over the domes and the air valve is partially opened. Domes are observed for leaks and pattern irregularity and repaired as needed.

The need for careful supervision of the reinstallation was emphasized by the supervisor to avoid over tightening of the dome hold-down bolts. About 2 percent of the domes are lost during the removal, cleaning, and replacement operations, mainly due to breakage during handling. The plant stocks 2000 spare domes plus rubber gaskets, plastic piping, hold-down bolts, and other hardware associated with the domes and air supply manifolds.

The bag filters are operated without a precoat and are cleaned by vigorous shaking of the bags once per year. Air quality in the vicinity of this plant is very good, resulting in only light loading of the filters. No problems have been experienced with this maintenance procedure or the bag filters.

BECKTON

History and Background

In 1864, wastewater handling at the site of the present Beckton treatment works began with the construction of a holding reservoir system. Wastewater collected from London was piped to the site and held in four large storage reservoirs, being discharged without treatment on the outgoing tide. This served as the principal wastewater disposal system for London until 1889 when manually cleaned primary sedimentation basins were added. In 1939, work was

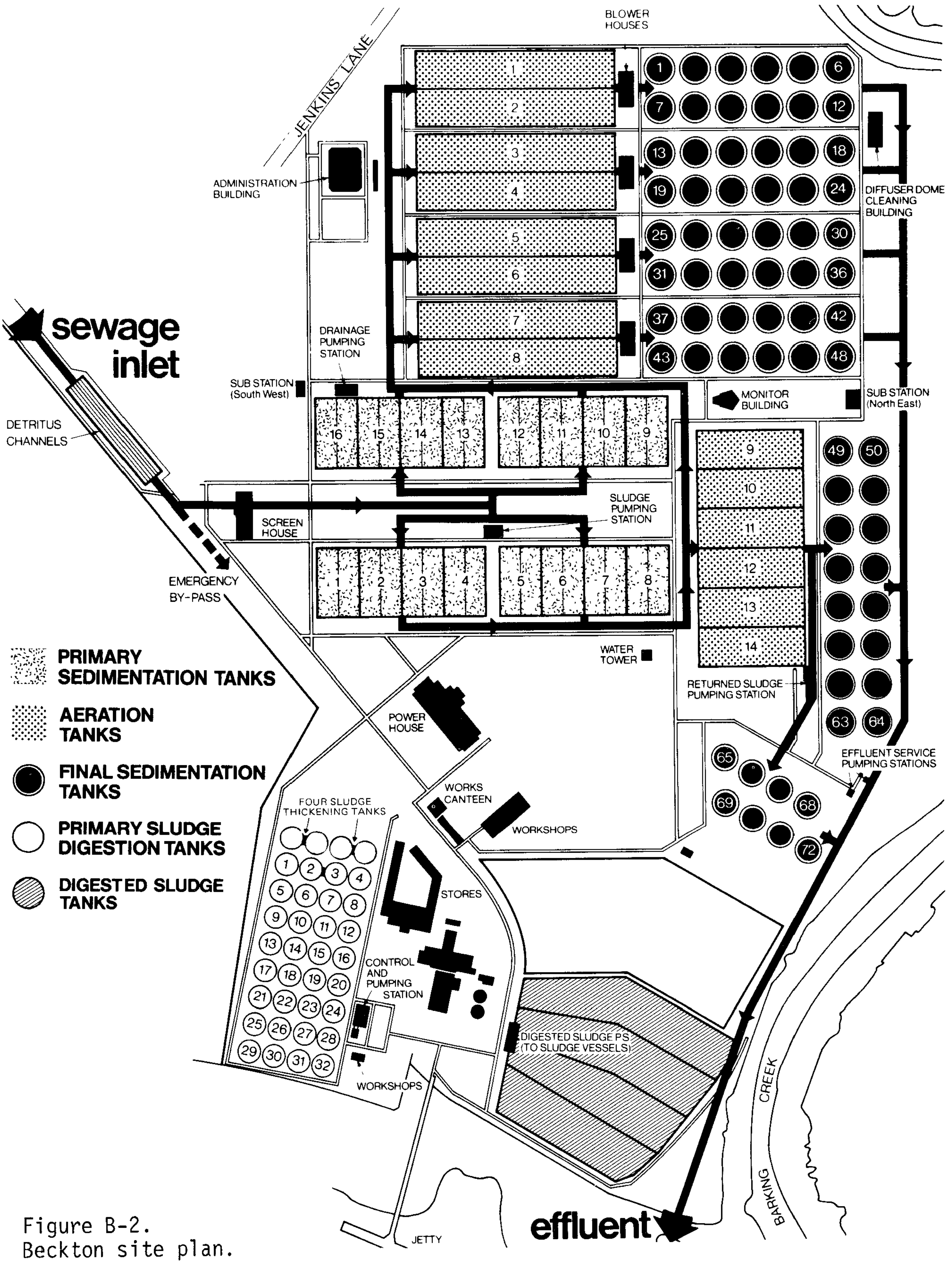


Figure B-2.
Beckton site plan.

completed on a mechanical aeration plant that treated 272,500 m^3/day (72 mgd), only a part of the flow. By 1955, screening and grit handling facilities had been added, along with eight mechanically cleaned primary sedimentation basins.

In 1959, a second 272,500-m^3/day (72-mgd) activated sludge plant was added, aerated by fine bubble diffusers. This equipment, dome diffusers mounted on cast iron piping manifolds that extended to all portions of the tank, was the precursor to the present day dome diffuser systems. The domes were manufactured by Activated Sludge Ltd., predecessor to Hawker-Siddeley Water Engineering Ltd., the current supplier in the United Kingdom.

At the conclusion of 1959 modifications, the plant provided secondary treatment to 50 percent of the DWF, the remainder being discharged to the Thames River with only primary treatment. In 1968, a program to provide secondary treatment for all flows received at Beckton was initiated, with completion coming in 1975. Presently, the plant is providing full secondary treatment for flows ranging from 999,200 m^3/day (264 mgd) up to 2,725,000 m^3/day (720 mgd). The presently served population is 2.4 million over a service area of 295 km^2 (114 mi^2). The service area encompasses most of London north of the Thames River. The site plan of the current facilities at Beckton is given in Figure B-2.

Plant Description

Table B-5 provides an overview of the design details of this plant, one of the largest activated sludge plants in the world. The activated sludge plant is divided into two portions:

- The 1959 plant, comprising aeration tank Nos. 9-14 and 24 secondary clarifiers.
- The 1975 plant, comprising aeration tank Nos. 1-8 and 48 secondary clarifiers.

The 1959 plant consists of full plug flow systems with eight separate channels for each tank. Wastewater flows through each channel in turn, for a total distance of 951 m (3120 ft). This plant was originally equipped with 15,000 diffusers per tank (1875 per channel). As part of the 1968 program, the 1959 plant was refitted with plastic air distribution piping and the number of domes per tank was increased to 18,000. The rehabilitated 1959 plant is rated at 454,200 m3/day (120 mgd).

The 1975 activated sludge plant, rated at 1,854,600 m^3/day (490 mgd), uses a single-pass modified plug flow process. Originally, each tank was equipped with 36,000 domes, distributed equally over the tank floor. In operating the plant, it was determined that maintenance of the minimum recommended air flow per dome, 0.014 m^3/min (0.5 cfm), led to extensive overaeration and substantial power wastage. D.O. profiles of the tanks under the normal operating conditions revealed that mixed liquor D.O. levels were near to saturation over about one-half of the tank length. Accordingly, a formal program to study the problem and make modifications was undertaken. The basic approach has been to remove domes from the tanks, thereby reducing required to-

TABLE B-5. BECKTON DESIGN DATA

Primary Sedimentation

16 Rectangular Tanks

Tank Nos. 1-8:	45.7 m+ x 79 m+ x 3.4 m+ SWD
Tank Nos. 9-16:	45.7 m x 77.4 m x 3.4 m SWD
Detention time:	4.1 hr @ DWF
Surface loading:	19.4 m^3/m^2/day @ DWF (477 gpd/ft^2)

Aeration Basins

14 Rectangular Tanks

Tank Nos. 1-8:	41.2 m x 223 m x 3.1 m SWD
Tank Nos. 9-14:	39 m x 119 m x 3.7 m SWD
Detention time:	7 hr @ DWF

Note: Tank Nos. 1-8 are single-pass plug flow.
Tank Nos. 9-14 are eight-pass plug flow.

Final Sedimentation

72 Circular Clarifiers

Tank Nos. 1-48:	Diameter	34.4 m
	Sidewater depth	3.7 m
	Floor slope	1:24
Tank Nos. 49-64:	Diameter	33.5 m
	Sidewater depth	3.5 m
	Floor slope	1:24
Tank Nos. 65-72:	Diameter	29 m
	Sidewater depth	2.9 m
	Floor slope	1:12
Average detention time:		5 hr @ DWF
Average surface loading:		19.9 m^3/m^2/day @ DWF (489 gpd/ft^2)

Blower System

Aeration Tank Nos 1-8:
4 blower houses, each with four 595-m^3/min (21,000-cfm) blowers driven by 582-kW (780-hp) motors. Rated pressure - 41.4 kN/m^2 (6 psi). Air cleaned by 4 electrostatic filters with fiberglass prefilters.

Aeration Tank Nos. 9-14:
5 blowers, each driven by a 716-kW (960-hp) gas turbines.
8 electrostatic air cleaners.

* DWF = 1,135,000 m^3/day (300 mgd)
\+ 1 m = 3.28 ft

tal plant air flows.

There are six aeration grids in each tank of the 1975 plant, occupying one-sixth of the tank length per grid and each supplied separately from the air header. A total of 5000 domes was removed from each of tank Nos. 3-8 initially. Because D.O. levels were still quite high, an additional 5000 domes were recently removed from tank No. 6 as a further experiment. Table B-6 provides the current dome configuration in the 1975 plant. Results of the experimentation are discussed below under "Performance".

TABLE B-6. DIFFUSER CONFIGURATION IN BECKTON 1975 ACTIVATED SLUDGE PLANT

Grid	Original Number of Domes per Tank	Current Configuration per Tank		
		Tank Nos. 1,2	Tank Nos. 3-5,7,8	Tank No. 6
1	6000	6000	6000	6000
2	6000	6000	6000	6000
3	6000	6000	5000	4000
4	6000	6000	5000	4000
5	6000	6000	4500	3000
6	6000	6000	4500	3000
	36000	36000	31000	26000
(Effluent)				

Air is supplied to the 1959 plant by five centrifugal blowers, each rated for 708 m^3/min (25,000 cfm) at 51.7 kN/m^2 (7.5 psi). Each blower is driven by a 716-kW (960-hp) gas turbine, which is normally fueled by methane gas from the plant's anaerobic digesters. Normally, three blowers are operated to supply 2226 m^3/min (78,600 cfm), drawing the equivalent of 1629 kW (2185 hp) against a pressure of 41.4 kN/m^3 (6 psi). Air cleaning is provided by eight electrostatic air cleaners.

The 1975 plant has four blower houses, each equipped with four electric motor driven centrifugal blowers and four electrostatic air filters. Each blower is driven by a 582-kW (780-hp), single-speed motor and is rated for 595 m^3/min (21,000 cfm) at 41.4 kN/m^3 (6 psi). At the minimum air flow of 0.017 m^3/min/dome (0.6 cfm/dome), the six blowers normally in service for six aeration tanks deliver 3738 m^3/min (132,000 cfm), drawing 3580 kW (4800 hp).

The plant makes extensive use of air lift pumping, which requires approximately 15 percent of the blower capacity of both the old and new plants. Minimum air flows to the domes are held at 0.017 m^3/min (0.6 cfm) to both the 1959 plant and the 1975 plant. During much of 1979, two of the newer activated sludge basins were not in service, being maintained as standby units.

Final clarifiers are of the circular type with rotory scrapers. The surface loading rate at design flow is 19.0 m^3/m^2/day (465 gpd/ft^2) for Nos. 1-48. Clarifier Nos. 49-64 are sized at 22.8 m^3/m^2/day (560 gpd/ft^2), and Nos.

65-72 are rated at 16.8 m^3/m^2/day (412 gpd/ft^2). Design flow for the clarifiers is 1,135,000 m^3/day (300 mgd), and peak flow is calculated as 2.4 x design flow. The design recycle rate is 70 percent of the average influent flow. Detention time is 5.2 hr at design DWF flow for clarifier Nos. 1-48 and 4.6 hr for clarifier Nos. 49-72. Sludge return for Nos. 1-64 is via air lift pumps; the older clarifiers (Nos. 65-72) use centrifugal pumps.

Beckton is one of the two plants visited that has a diffuser dome cleaning facility, consisting basically of an oil fired kiln, dome storage space, and handling equipment. The system, discussed further in Section 6, is intended to serve the dome cleaning needs of a number of Thames Water Authority plants.

Costs of the most recent plant modification, in 1969, stated at the rate of \$2 = £1 sterling, were \$2,472,000 for the aeration equipment and piping out of a total of \$46,000,000 for the wastewater treatment plant. Expansion of sludge digestion facilities added \$6,250,000 to the cost.

Performance

Table B-7 is a summation of the Beckton influent and effluent data for the years 1976 through 1979. Data for the 1975 plant was supplied by Beckton in response to the survey. Data for the 1959 plant is for 1977-1979 only and was developed from other material supplied. The data year at Beckton spans the period from April 1 to March 31 of the following year.

Primary sedimentation at this plant performed well, removing 55-59 percent of the influent BOD_5 and 70-73 percent of the influent suspended solids, with a detention time of about 4 hr and a surface loading rate that averaged 22.1 m^3/m^2/day (542 gpd/ft^2). With an F/M loading of 0.13 kg BOD_5/day/kg MLSS and a volumetric loading of 0.37 kg BOD_5/day/m^3 (23 lb/day/1000 ft^3), the total plant averaged 96 percent removal of BOD_5 and 94 percent removal of suspended solids over the 3-yr period. Influent detergent averaged 11.3 mg/l as maroxyl OT and was 94 percent removed through the process. Both sections of the plant performed similarly under similar loading conditions. Monthly average flows varied approximately $\pm$ 20 percent from annual averages. Daily flows can range up to 3 x DWF because of the extensive combined sewer system discharging to the plant. Only about 10 percent of the flow is industrial in origin.

Using the method discussed in Section 5 of this report, the aeration efficiency of the aeration equipment has been computed in Table B-8. For purposes of comparison, a similar computation made by the Beckton scientific staff is also shown in Table B-8. The new activated sludge plant (aeration tank Nos. 1-8) averaged 1.75 kg O_2/kWh (2.88 lb/wire hp-hr), with corresponding values of 2.14 and 3.52, respectively, for the old plant (aeration tank Nos. 9-14). Because power to the old plant cannot be measured directly, the accuracy of these data is not expected to be on a par with the new plant. Based on observations at other plants, it is not anticipated that the old plant would be significantly more efficient in oxygen transfer than the new plant. Rather, the data in this report indicate that multi-pass plug flow systems are less efficient as a whole than single-pass systems.

TABLE B-7. BECKTON INFLUENT-EFFLUENT DATA SUMMARY

Parameter	Year* Aeration Tank Nos. 1-8 78/79	77/78	76/77	Aeration Tank Nos. 9-14 78/79	77/78
Flow: mgd	176	178	181	104	88
1000 m^3/day	666	674	685	394	333
Raw Wastewater: (mg/l)					
BOD_5	169	230	237	169	230
COD	428	501	546	428	501
TSS	268	297	303	268	286
TKN	35	40	42	39	38
NH_3-N	22	24	26	22	24
Detergent+	14	9	12	14	9
Primary Effluent: (mg/l)					
BOD_5	96	105	115	96	100
COD	204	233	243	--	233
TSS	78	77	82	78	77
TKN	32	36	36	32	35
NH_3-N	23	25	27	24	25
Detergent+	11	7	8	--	--
Final Effluent: (mg/l)					
BOD_5	8	6	7	9	7
COD	55	49	53	--	49
TSS	17	11	15	19	16
TKN	3.6	3.1	3.2	3.9	3.2
NH_3-N	1.5	0.9	1.1	1.6	0.8
NO_3-N	18	23	21.2	17	22
Detergent+	0.5	0.2	0.3	--	--

* Year begins April 1 and ends the following March 31.
\+ Detergent as manoxyl OT (a proprietary ABS type compound).

Table B-9 lists minimum mixing power levels for the aeration tank configurations at Beckton. MLSS in all tanks is held in the range between 2600-3400 mg/l. The lowest power input is 6.8 W/m^3 (0.26 wire hp/1000 ft^3) in the last section of aeration tank No. 6. The highest power input at minimum air flow is 13.6 W/m^3 (0.52 wire hp/1000 ft^3) in all parts of aeration tank Nos. 1 and 2. The average air flow is about 30 percent higher than the minimum.

Surveys by plant personnel have verified that suspended solids are evenly distributed in all parts of the tank. Further verification will be carried out on the recently modified Tank No. 6.

Removal of domes to introduce an aeration taper has had some impact on the D.O. profile of the original configuration. Figure B-3 is a plot of D.O.

profiles for three tanks: unmodified (Tank No. 1), 5,000 domes removed (tank No. 8), and 10,000 domes removed (Tank No. 6). Tank No. 6 has a flatter profile than No. 1 or No. 8. Influent conditions were not quite the same on the two days of sampling, however, so a direct comparison between the three tanks is not totally accurate with these data. Data for tank Nos. 1 and 8, taken on the same day, indicate that the difference between the two is not large.

TABLE B-8. BECKTON AERATION EFFICIENCY CALCULATIONS

	Year					
	Aeration Tanks Nos. 1-8			Aeration Tanks Nos. 9-14		
Parameter	78/79	77/78	76/77	78/79	77/78	76/77
BOD_5 Removed (kg/day)*	58,700	66,700	74,200	34,500	31,200	NOT FULLY OPERATIONAL
NH_3-N Removed (kg/day)*	14,500	16,200	17,800	8,850	8,100	
NO_3-N Removed (kg/day)*	11,700	15,400	14,600	6,790	7,200	
O_2 Required+ (kg/day)*	115,116	146,855	138,470	73,405	69,540	
Power Consumed (kWh/day)°	74,520**	75,470	78,106	33,252	33,456	
Aeration Efficiency:						
kg O_2/kWh	1.54	1.95	1.77	2.21	2.08	
lb O_2/wire hp-hr	2.53	3.21	2.91	3.63	3.42	
kg EOL/kWh++	2.13	2.44	2.27	2.63	2.44	
lb EOL/wire hp-hr++	3.50	4.01	3.73	4.32	4.01	

* 1 kg = 2.21 lb

\+ Calculated by the method of Section 5, assuming 1.15 units O_2 required / unit BOD_5 removed.

° 1 kWh/day = 1.34 wire hp-hr/day

** 9 mo power data extrapolated to full year.

++ Calculations by Beckton staff:
EOL = 1.5 x BOD_5 removed + 4.5 NH_3-N & organic nitrogen removed

Other comments relating to plant performance are summarized as follow:

1. This plant is designed to treat all flows received to secondary standards. Unlike many of the plants visited, there are no storm water equalization facilities. The high ratio of peak flow to dry weather flow, 3:1, reduces the overall efficiency of operation.

2. Influent data reveal that average wastewater strength to the plant appears to be decreasing over time. This phenomenon was observed at other U.K. plants and may reflect increasing use of water-using ap-

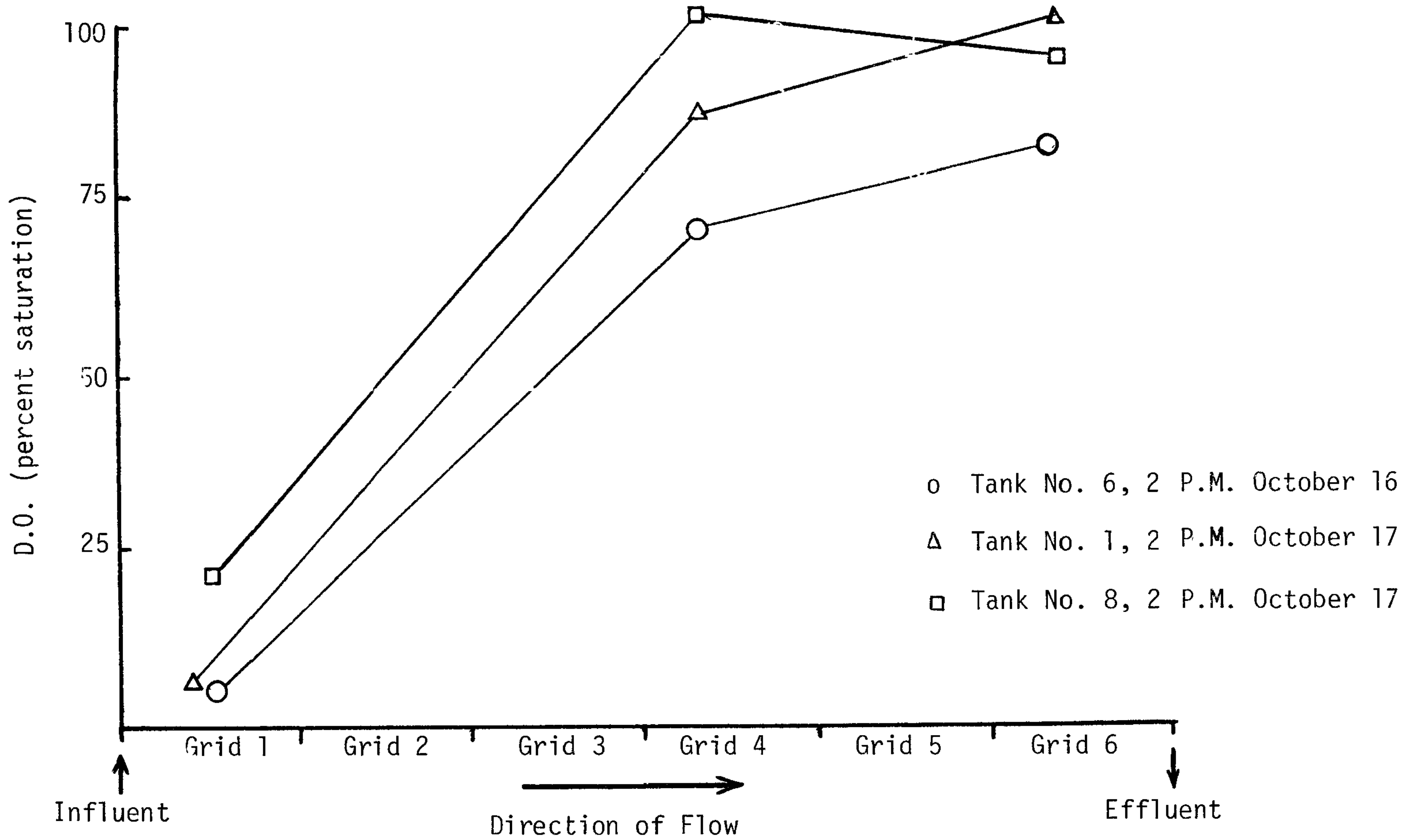


Figure B-3. Beckton D.O. profile comparison.

TABLE B-9. BECKTON MIXING DATA

Aeration Tank & Grid Nos.	Surface Area (1000 m^2)*	Wetted Volume (1000 m^3)+	Diffuser Density (domes/m^2)°	Air Flow/Section** (cfm)	Air Flow/Section** (m^3/min)	Air Flow/Area** (cfm/ft^2)	Air Flow/Area** (m^3/m^2/min)	Air Flow/Volume** (cfm/1000 ft^3)++	Minimum Power Input (wire hp/1000 ft^3)	Minimum Power Input (W/m^3)
Tanks 1, 2 (each tank):	9.2	28.5	3.91	23,400	663	0.24	0.072	23.3	0.52	13.6
Tanks 3-5,7,8 (each tank):	9.2	28.5	3.34	20,150	571	0.20	0.062	20.0	0.44	11.7
Grids 1,2	3.07	9.5	3.91	7,800	221	0.24	0.072	23.3	0.52	13.6
Grids 3,4	3.07	9.5	3.26	6,500	184	0.20	0.060	19.4	0.43	11.3
Grids 5,6	3.07	9.5	2.93	5,850	166	0.18	0.054	17.4	0.39	10.2
Tank 6:	9.2	28.5	2.83	16,900	479	0.17	0.052	16.8	0.37	9.8
Grids 1,2	3.07	9.5	3.91	7,800	221	0.24	0.072	23.3	0.52	13.6
Grids 3,4	3.07	9.5	2.60	5,200	147	0.16	0.048	15.5	0.34	9.0
Grids 5,6	3.07	9.5	1.95	3,900	110	0.12	0.036	11.6	0.26	6.8
Tanks 9-14 (each tank) (8 passes/tank)	4.64	17.2	3.88	15,000	425	0.30	0.092	24.7	0.41	10.9

* 1 m^2 = 10.8 ft^2
\+ 1 m^3 = 35.3 ft^3
o 1 dome/m^2 = 9.29 domes/100 ft^2
** Based on minimum air flow rates of:
0.018 m^3/min/dome (0.65 cfm/dome) for Tank Nos. 1-8
0.017 m^3/min/dome (0.6 cfm/dome) for Tank Nos. 9-14
++ Same as m^3/1000 m^3/min.

pliances such as those in common use in the United States. However, total flow at Beckton has remained relatively.

3. Beckton employs two basic final clarifier configurations. The older clarifiers, Nos. 65-72, have a floor slope of 1:12; the newer units, Nos. 1-64, have a floor slope of 1:24. Plant personnel indicated that the older units generally performed better and desludged more readily.

Operation and Maintenance

Experience with dome diffusers at the Beckton plant spans a period of 20 yr. The original domes, installed on cast iron mains in aeration Tank Nos. 9-14,performed satisfactorily, without cleaning. Minimum air flow was held at 0.017 m^3/min/dome (0.6 cfm/dome), and special care was taken to maintain positive air flow at all times and keep air distribution piping free of moisture. Pressure increased 4.2 kN/m^2 (0.6 psi) over the period before the plant was rehabilitated, but was increasing rapidly in the 2-yr period prior to rehabilitation.

In the newer plant, there have been a large number of failures of the uPVC strap which holds the piping to the floor mount. This problem was apparently caused by inadequate strength of the strap, a problem which has been corrected by the manufacturer. There have been no failures of the heavier hardware now supplied by the manufacturer.

Some dome cleaning has been carried out in the new activated sludge plant (aeration tank Nos. 1-8). The domes have been cleaned successfully in the plant's dome cleaning facility, and plant management is estimating a cleaning frequency not to exceed once every 10 yr.

The electrostatic air filters have generally performed satisfactorily. However, when fogs or freezing rains occur concurrent with near-freezing temperatures, the moisture freezes onto the prefilters, gradually diminishing air flow. The prefilters are now routinely removed when such conditions occur, and no further problems of this type have been encountered. The electrostatic filters require light cleaning (1 man hr) about every 8 days in the form of a washdown with hot water. Every 3 yr, an alkaline cleaning solution is sprayed on the dust collecting elements and washed off with hot water (2 man hr).

BEDDINGTON

History and Background

The site of the Beddington plant has been used for wastewater treatment for over 100 yr. From 1860-1902, the site was used for land treatment. From 1902-1912, primary sedimentation and trickling filters were added. By 1932, the flow had increased to 43,100 m^3/day (11.4 mgd) and an activated sludge plant and additional trickling filters were constructed.

In 1966, construction began on an entirely new activated sludge plant on the site. The plant, shown in Figure B-4, has 12 aeration tanks and 16 final

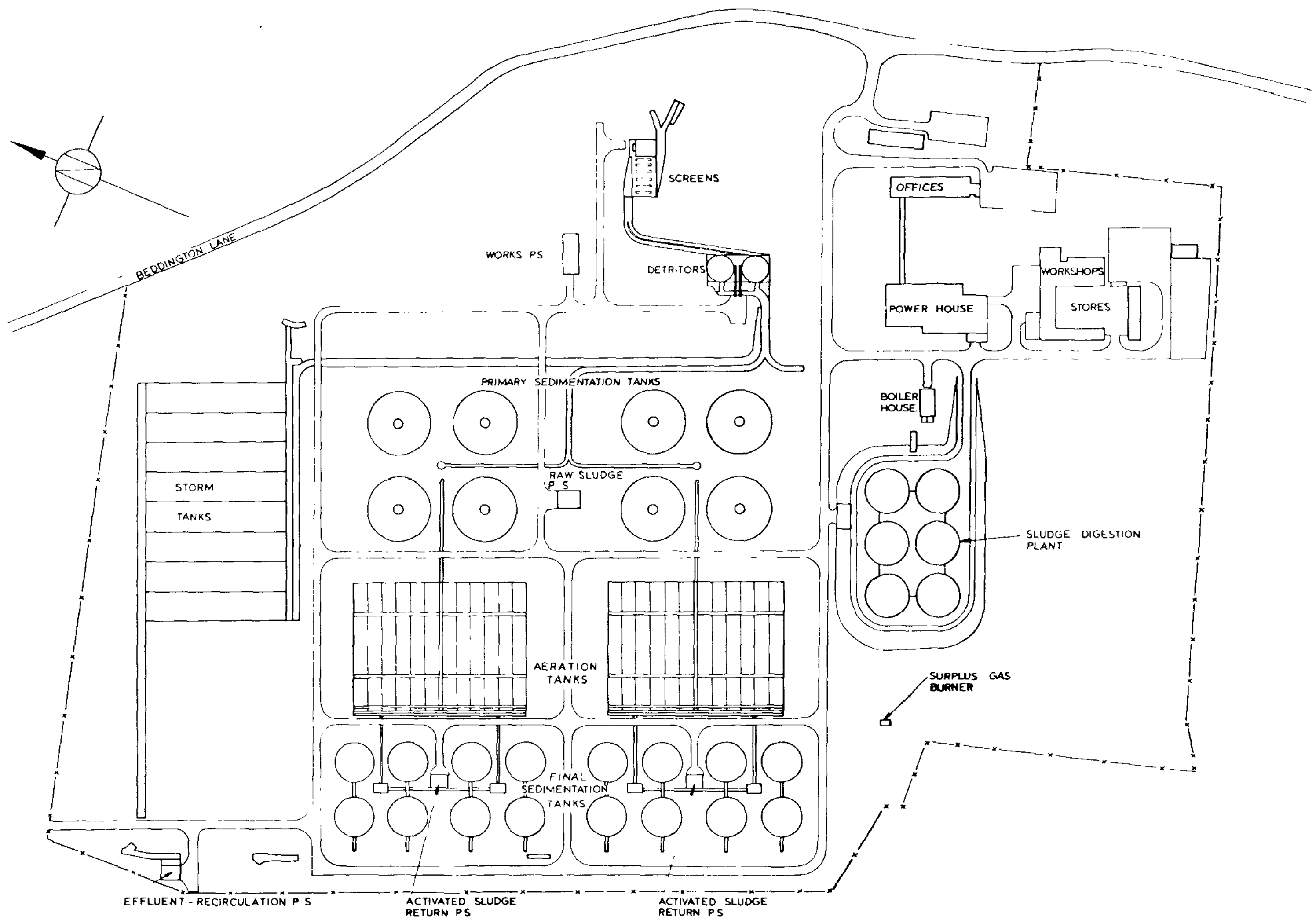


Figure B-4. Beddington site plan.

clarifiers. In mid-1978 it was necessary to add four additional aeration channels to reduce volumetric loading rates.

Plant Description

Plant design data are presented in Table B-10. Primary settling is provided by eight circular clarifiers, which have a retention time of 6.2 hr at the design DWF of 82,500 m^3/day (21.8 mgd). Flows up to 3 x DWF are passed directly through the plant. Excess flows are diverted to the stormwater retention tanks where solids are removed, and the settled overflow is returned to the process when flows decrease.

Of the 16 aeration basins, 12 have 3915 domes each equally distributed among two plug flow passes and four employ tapered aeration. The last half of each tapered second pass has 523 domes placed on four centrally located rows, causing a double spiral flow hydraulic regime to be set up (tapered aeration is discussed in Section 8). Primary effluent and mixed liquor channels are also dome aerated, consuming 11 percent of the air flow.

Air is supplied by six centrifugal blowers rated for 236 m^3/min (8330 cfm) at 37.9 kN/m^2 (5.5 psi). Normally, five units are operating, supplying 1081 m^3/min (38,163 cfm) at 27.6 kN/M^2 (4 psi). Air is cleaned by five bag filters using mixed cellulose and asbestos precoating.

The 16 final clarifiers are mated in sets of four to four sets of aeration basins. The clarifiers have steeply sloped hopper bottoms (30°) and shallow sidewater depth characteristic of many U.K. plants. Maximum surface overflow rate at 3 x DWF is 43.9 m^3/m^2/day (1078 gpd/ft^2).

Performance

Over the past 10 yr, the performance of this plant has been highly variable, due chiefly to problems with sludge handling and the impact of industrial wastes containing high strength organics and metal plating liquors. The industrial wastes caused several immediate problems:

1. An apparent depression of the alpha factor, resulting in lowered oxygen transfer efficiency.

2. Slime formation rapidly appeared on many of the domes in the 12 original tanks, leading to coarse bubbling and subsequent loss of oxygen transfer capacity.

In an effort to deal with these problems which span several years, step feeding of wastewater, refiring of domes in several of the tanks, and periodic draining and dome brushing were tried, with only limited success. In 1974, two additional, identical blowers were added, to allow for blower maintenance and supply peak air needs. To lower volumetric loadings from an average of 0.5 kg BOD_5/day/m^3 (31 lb/day/1000 ft^3) to 0.4 kg BOD_5/day/m^3 (25 lb/day/1000 ft^3) and to provide additional oxygen transfer capability, four additional aeration tanks were added in 1978. A summary of the annual data, from startup to the present was provided by plant personnel as shown in Table B-11. The

TABLE B-10. BEDDINGTON DESIGN DATA*

Stormwater Tanks

8 Rectangular Tanks	15.4 m+ 76.2 m+ x 2.8 m+ SWD
Total volume:	25,900 m^3
Detention time:	7.6 hr @ DWF

Primary Sedimentation

8 Circular Clarifiers	
Diameter:	32 m
Sidewater depth:	2.9 m
Detention time:	6.22 hr @ DWF
Surface loading:	12.2 m^3/m^2/day @ DWF (300 gpd/ft^2)

Aeration Basins

16 Rectangular Tanks (2 passes per tank)	7.3 m x 67 m x 2.4 m SWD (each pass)
Detention time:	10.7 hr @ DWF

Dome Configuration:

Aeration Tank & Section Nos.	Description
Tank Nos. 1-12 (2 passes/tank)	3915 domes, 9 rows, spaced 0.76 m (2.5 ft) between rows, 0.30 m (1.0) between domes, 0.25 m (0.8 ft) off floor

Tank Nos. 13-16

Section	Section Length (m)	No. Domes	No. Rows
1	16.75	637	13
2	16.75	676	13
3	16.75	534	10
4	16.75	545	10
5	16.75	449	8
6	16.75	434	8
7	16.75	269	4
8	16.75	254	4

Note: Sections 7 and 8 have 4 rows centered in the tanks.

Final Sedimentation

16 Circular Clarifiers	
Diameter:	20.4 m
Sidewater depth:	1.37 m
Floor slope:	30°
Detention time:	5.3 hr @ DWF
Surface loading:	14.6 m^3/m^2/day (359 gpd/ft^2)

* DWF = 82,500 m^3/day (21.8 mgd)

\+ 1 m = 3.28 ft

TABLE B-11. BEDDINGTON INFLUENT-EFFLUENT AND PROCESS LOADING DATA SUMMARY

Year	Primary Effluent (mg/l) BOD$_5$	COD	TSS	NH$_3$-N	Final Effluent (mg/l) BOD$_5$	TSS	NO$_3$-N	NH$_3$-N	MLSS (mg/l)	BOD$_5$ Loading 1000 kg/day (1000 lb/day)	Air Supply m^3/kg BOD$_5$ (ft^3/lb)	Air Supply l/l (ft^3/gal)	F/M Loading (kg BOD$_5$/day/kg MLSS)	Volumetric Loading kg BOD$_5$/day/m^3 (lb/day/1000 ft^3)	Sludge Return Rate (%)	Nominal Aeration Time (hr)
69/70	206	--	136	37	28	21	16	29	3651	12.1 (26.8)	5.1 (82)	12.3 (1.64)	0.12	0.44 (27.5)	--	--
70/71	228	--	169	36	35	37	10	30	2466	18.1 (39.9)	4.4 (70)	16.4 (2.19)	0.27	0.66 (41.2)	83.2	8.3
71/72	165	--	134	34	13	11	17	6.5	2391	13.3 (29.3)	7.8 (125)	21.5 (2.87)	0.20	0.48 (30.0)	89.2	8.2
72/73	174	--	146	38	11	11	25	4.6	2495	13.1 (29.0)	8.0 (128)	22.9 (3.06)	0.19	0.48 (30.0)	96.6	8.8
73/74	161	480	153	37	12	13	27	4.2	2398	13.0 (28.7)	7.9 (127)	21.8 (2.91)	0.20	0.47 (29.3)	94.9	8.2
74/75	124	392	123	30	9	11	23	3.5	2452	12.0 (26.5)	8.4 (135)	17.7 (2.37)	0.18	0.43 (26.8)	76.4	6.7
75/76	138	371	121	29	12	10	23	5.3	2346	12.4 (27.3)	8.0 (128)	18.3 (2.45)	0.19	0.45 (28.1)	75.4	7.2
76/77	175	433	133	36	17	8	21	9.7	2275	13.4 (29.5)	8.3 (133)	21.7 (2.90)	0.21	0.49 (30.6)	92.0	8.5
77/78	156	373	120	31	16	9	23	5.7	2270	13.8 (30.4)	7.8 (125)	20.3 (2.71)	0.22	0.50 (31.2)	80.3	7.5
78/79*+	149	--	105	29	12	7	24	4.3	2199	14.4 (31.8)	7.1 (114)	17.4 (2.33)	0.18	0.41 (25.6)	70.8	8.9

* Extensions commissioned - aeration tank volume increased to 36,000 m^3 (1,271,000 ft^3) (May/June).
\+ Sludge lagoon supernatant liquor returned to works inlet from August 1978.

plant has produced a partially nitrified effluent since 1971 even with the rapid increase in oxygen required to satisfy BOD_5 applied, which occurred in that year. Data are for April 1 to March 31 of following year.

Primary clarifier performance was reported by plant personnel for the last 5 yr. BOD_5 removal through the primaries has consistently averaged 50-55 percent; SS removal averaged 70-75 percent.

Based on plant performance data, with a power demand of approximately 50 kW (67 wire hp) at an air flow of 60 m^3/min (2128 cfm) per channel, average plant aeration efficiencies can be calculated as shown in Table B-12. The F/M loading has routinely been held to 0.2 kg BOD_5/day/kg MLSS, resulting in an estimated oxygen requirement of 1.06 kg O_2/kg BOD_5 removed. Over the nearly 10 yr of record, aeration efficiency has been remarkably consistent, if low, averaging 1.12 kg O_2/kWh (1.84 lb/wire hp-hr). The likely cause of the low efficiency is the impact of the industrial waste contribution on the oxygen transfer coefficient alpha (α). Also, the very shallow tanks (for diffused aeration) tend to reduce overall aeration efficiency (see Section 8).

Even though Beddington uses a high air flow rate per unit of organic loading in order to counter the poor oxygen transfer efficiency, the energy used for mixing is in the lower range among the plants visited (Table B-13). The relatively long detention time and large aeration tank volume in this plant offset the high air flows, resulting in relatively low power levels. Plant personnel reported all tanks were well mixed with no solids deposition problems. Under current operating conditions, air flow per dome averages 0.017 m^3/min (0.6 cfm).

Operation and Maintenance

Formation of slime on the surface of the aeration domes in zones of low D.O. has been the major maintenance problem at this plant since startup. The low oxygen transfer efficiency leads to low mixed liquor D.O., which then apparently causes slime to grow on the exterior of domes. Coarse bubbling results, further lowering mixed liquor D.O. and exacerbating the slime formation problem. At the time of the plant visit, coarse bubbling, indicating the presence of slime, was very much in evidence in the first one-half pass in the 12 basins with equally distributed domes. Only the first one-quarter pass in the tapered aeration basins exhibited coarse bubbling, and plant personnel noted that the tapered aeration process was less susceptible to the problem.

A review of the wastewater characterization data provided by the plant operator does not illuminate the source of the problem. COD/BOD_5 ratios average 2.5, not unusual in the United Kingdom. Influent BOD_5 strength, at 275-325 mg/l, is not excessive for English plants. The efficiency of primary sedimentation is normal. Surfactant levels, at 11-13 mg/l, are typical. Visually, the milky white industrial flow was markedly different from conventional municipal wastewater. Even after dilution with domestic flows from another sewer, the presence of this milky white waste was very apparent. Also, an irridescent oily slick was very much in evidence in the grit facility and primary clarifiers.

TABLE B-12. BEDDINGTON AERATION EFFICIENCY CALCULATIONS

Parameter	Year 78/79	77/78	76/77	75/76	74/75	73/74	72/73	71/72	70/71	69/70*
Flow: mgd	25.5	23.4	20.5	24.4	26.3	20.2	20.0	21.3	21.0	15.5
m^3/day	96,500	88,600	77,800	92,500	97,400	76,600	75,500	80,700	79,500	58,500
Air Supply:										
1000 ft^3/day	58,020	61,380	63,190	56,530	57,383	58,870	60,030	59,366	45,454	35,040
1000 m^3/day	1639	1734	1785	1597	1621	1663	1695	1677	1284	990
Power Consumed (kWh/day)+	21,500	22,760	23,420	20,950	21.270	21,820	22,240	22,000	16,850	12,990
BOD_5 Removed (kg/day)o	13,220	12,395	12,985	11,668	11,390	11,400	12,310	12,240	15,380	10,444
NH_3-N Removed (kg/day)o	2374	2250	2022	2230	2614	2500	2552	2226	453	456
O_2 Required** (kg/day)o	24,220	22,815	22,460	21,960	23,310	22,830	24,020	22,540	18,250	13,030
Aeration Efficiency:++										
kg O_2/kWh	1.19	1.05	1.01	1.11	1.16	1.09	1.14	1.08	1.25	1.05
lb O_2/wire hp-hr	1.96	1.73	1.66	1.82	1.91	1.79	1.87	1.76	2.05	1.73

* Partial year, October - March only.
\+ 1 kWh/day = 1.34 wire hp-hr/day
o 1 kg = 2.21 lb
** Calculated by the method of Section 5, assuming 1.06 units O_2 required/unit BOD_5 removed.
++ Assumes 11 percent of air (and power) used in aeration channels.

Initially, when slime occurred, domes were removed from the aeration basin and refired in the dome kiln at Mogden. It was soon determined that vigorous brushing with a concurrent high rate of air flow would remove the mostly external growths. Periodic draining of the tanks followed by brushing is now the procedure used to deal with this problem. The anticipated dome kilning cycle is once every 5-6 yr under current procedures.

TABLE B-13. BEDDINGTON MIXING DATA

	Tank No.				
	2-7, 10-15 (each tank)	1, 8, 9, 16			
Parameter		First Quarter	Second Quarter	Third Quarter	Final Quarter
Diffuser Density (domes/m^2)*	2.0	2.7	2.2	1.8	1.1
Air Flow/Section:					
cfm	2260	759	621	508	304
m^3/min	64	21.5	17.6	14.4	8.6
Air Flow/Area:					
cfm/ft^2	0.11	0.14	0.12	0.10	0.06
m^3/m^2/min	0.033	0.044	0.036	0.029	0.017
Air Flow/Volume (cfm/1000 ft^3)+	13.4	18.0	14.8	12.1	7.2
Average Power Input:					
wire hp/1000 ft^3	0.47	0.61	0.50	0.41	0.24
W/m^3	12.4	16.1	13.2	10.8	6.4

* 1 dome/m^2 = 9.29 domes/100 ft^2
\+ Same as m^3/1000 m^3/min.

LONG REACH

Plant Description

At Long Reach, a new activated sludge plant was constructed on the site of an older plant and was commissioned in 1978 (see Figure B-5). The new plant has eight rectangular primary tanks, each one 20.4 m x 64 m x 3.4 m SWD (67 ft x 210 ft x 11 ft). At the current average flow of 208,900 m^3/day (55.2 mgd), surface loading is 26.4 m^3/m^2/day (648 gpd/ft^2). The detention time is 4.2 hr.

Six, four-pass, plug flow aeration basins comprise the activated sludge plant. Each pass is 6 m x 80 m x 3.8 m SWD (20 ft x 262 ft x 12.5 ft). The dome diffusers are symetrically distributed in the first three basins. In the last basin, they are placed toward the center causing a double spiral roll

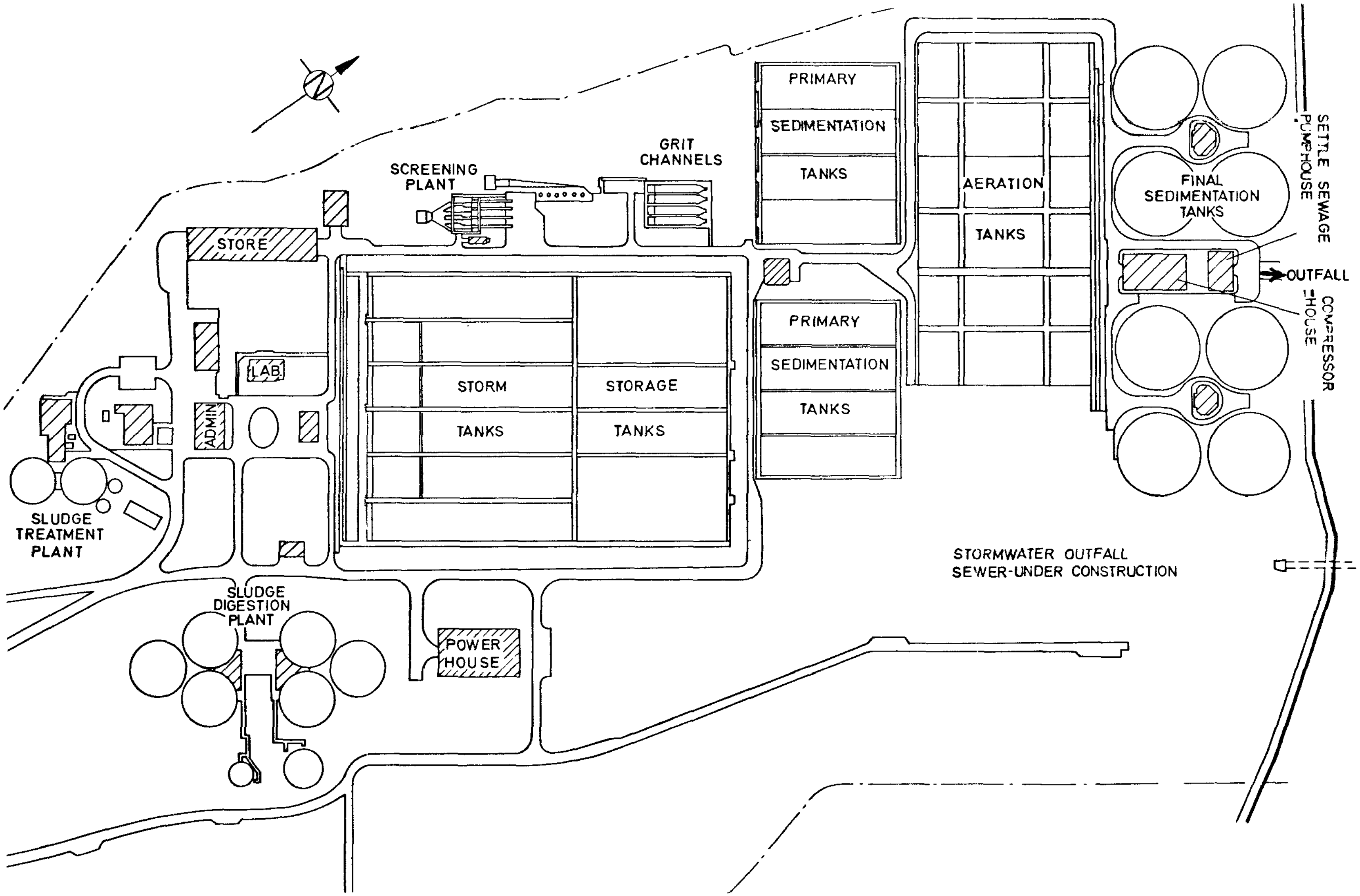


Figure B-5. Long Reach site plan.

mixing effect. Each four-pass aeration tank has 11,086 domes, distributed as follows:

Tank Pass	No. of Domes	No. of Rows
First Pass	3836	14
Second Pass	3068	11
Third Pass	2502	9
Last Pass	1680	6

Eight circular final clarifiers provide final settling. Each is 38.1 m (125 ft) in diameter with a sidewater depth of 3.1 m (10 ft) and 5 percent floor slope. Flow is unequally distributed to the clarifiers. The plant is divided into two sections, each with four clarifiers. However, there are four aeration basins on one side and two on the other. Thus, four clarifiers receive one-third of the flow; the other four receive two-thirds of the flow. Surface loadings are 15.1 m^3/m^2/day (371 gpd/ft^2) on one side and 30.2 m^3/m^2/day (742 gpd/ft^2) on the other. Detention times are 4.9 hr and 2.4 hr, respectively.

Air is provided by three 634-kW (850-hp) centrifugal blowers, capable of supplying 1593 m^3/min (56,250 cfm) at 40 kN/m^2 (5.8 psi). Coated bag filters precede the blowers.

Performance

One year's performance data, April 1, 1978-March 31, 1979 were reported by Long Reach, as follows:

TABLE B-14. LONG REACH INFLUENT-EFFLUENT DATA SUMMARY

Raw Wastewater: (mg/l)	
BOD_5	334
TSS	341
TKN	53
NH_3-N	33
Primary Effluent: (mg/l)	
BOD_5	180
TSS	113
TKN	45
NH_3-N	31
Detergent (manoxyl OT)	15
Final Effluent: (mg/l)	
BOD_5	20
TSS	30
TKN	35
NH_3-N	33
NO_3-N	1-2

Influent flow averaged 200,000 m^3/day (52.8 mgd) over the period of record. Power consumption averaged 15,000 kWh/day (20,115 wire hp-hr/day). The F/M loading averaged 0.3 kg BOD_5/day/kg MLSS and ranged from 0.27-0.34, with MLSS averaging 1700 mg/l. BOD_5 and SS removals through the primary clarifiers averaged 46 and 67 percent, respectively. BOD_5 and SS removals by secondary treatment averaged 89 and 73 percent, respectively. NH_3-N removal was negligible.

Based on the method of Section 5, with 0.97 units O_2 required/unit BOD_5 removed, aeration efficiency was calculated to be 2.07 kg O_2/kWh (3.40 lb/wire hp-hr). Mixed liquor D.O. is typically quite low, near 0.5 mg/l at the inlet, rising to 1-3 mg/l at the effluent.

Normally, Long Reach is able to generate all of its plant power needs from digester gas burned in dual fuel engines. Plant policy is to avoid the use of outside power; consequently, considerable effort has been devoted to optimizing the aeration process as a means of reducing power consumption. Air flow has been individually adapted to each pass of the aeration tank based on D.O. levels in that section.

Table B-15 provides mixing data for Long Reach, given an average air flow rate of 0.013 m^3/min/dome (0.45 cfm/dome). Because air flow per section has been adjusted to D.O., it is quite possible that domes in some sections have lower or higher air flow rates. Mixing power levels are more than adequate for suspension of solids based on experiences at the other plants visited.

Operation and Maintenance

This plant is the newest facility visited in the United Kingdom. Consequently, little O&M experience has been accrued. For the period of operation, there have been no apparent problems with either the aeration system or the air cleaning equipment. Observation of the tanks in operation indicated some coarse bubbling in the first 25 percent of the first pass, but it was not severe.

MOGDEN

History and Background

Wastewater was first treated in the new treatment plant at Mogden in late 1935. Full operation was commenced in mid-1936 with the completion of the plant, now the present day East works (and part of the West works), and an extensive collection system serving 427 km^2 (165 mi^2) and 1.05 million people. The original plant included a pumping station, screening and degritting, primary sedimentation, activated sludge treatment, final sedimentation, and stormwater tanks. Sludge was treated by anaerobic digestion, and a large power station was constructed to generate power and provide compressed air for the plant.

By 1961, the plant had been expanded with further construction of the West works to serve a population of 1.5 million and the activated sludge aeration basins, originally equipped with square diffuser stone aerators set in the basin floor, had been converted to dome diffusers mounted on cast iron

TABLE B-15. LONG REACH MIXING DATA

Aeration Basin	Surface Area (m^2)*	Wetted Volume (m^3)+	Diffuser Density (domes/m^2)o	Air Flow/Section**		Air Flow/Area**		Air Flow/Volume**	Average Mixing Power	
				(cfm)	(m^3/min)	(cfm/ft^2)	(m^3/m^2/min)	(cfm/1000 ft^2)++	(wire hp/1000 ft^3)	(W/m^3)
First Pass	480	1752	7.8	1719	48.7	0.33	0.10	27.8	2.23	58.7
Second Pass	480	1752	6.4	1374	38.9	0.27	0.08	22.3	1.78	46.9
Third Pass	480	1752	5.2	1119	31.7	0.23	0.07	18.2	1.45	38.2
Last Pass	480	1752	3.5	752	21.3	0.13	0.04	12.2	0.98	25.7

* 1 m^2 = 10.8 ft^2
+ 1 m^3 = 35.3 ft^3
o 1 dome/m^2 = 9.29 domes/100 ft^2
** Based on an average air flow rate of 0.013 m^3/min/dome (0.45 cfm/dome).
++ Same as m^3/1000 m^3/min.

mains. The entire plant, comprising the East and West works as presently constructed, is shown in Figure B-6.

Plant Description

The East works includes 12 primary settling basins (eight first-stage and four second-stage), 12 plug flow aeration basins each with four passes and divided into Battery A and Battery B, and 40 final clarifiers. Eight storm water retention basins are also located on the East works site. The West works includes four primary clarifiers, six plug flow aeration basins with four passes each, comprising Battery C, and 24 final clarifiers. Table B-16 summarizes the design data for both sides of the plant.

All of the aeration basins are equipped with dome diffusers mounted either on cast iron or the newer plastic air manifolds. A program of refitting basins with plastic piping is underway. Because Battery B has been fully changed over for 6 yr, Mogden has provided performance data for this battery covering the period 1974-1979.

Dome diffuser configuration in Batteries A, B, and the first three tanks of C is similar. The first pass of each tank has 2800 domes in five rows laid lengthwise along the 122-m (400-ft) long tanks. Spacing between domes is 20.3 cm (8 in.) and between rows 0.76 cm (2.5 ft). The other three passes of each aeration tank have 1750 domes each laid lengthwise in three rows with 20.3 cm (8 in.) between domes and 1.22 m (4 ft) between rows. Some of the three-row tanks have the original "ridge and furrow" tank floor, as described in Section 8. All tanks are operated in the plug flow mode with return sludge and primary effluent inlets at the head of the first pass.

Battery C has six tanks, four with dome configurations similar to Batteries A and B, one with all flat floors and one with all flat floors and a tapered dome configuation for experimentation. Battery C receives flow from the high level sewer only and thus tends to treat wastewater of different composition from that treated by the East works.

Final clarifiers at Mogden feature the steeply sloped (30°) floors and shallow side water depth (2.5 m = 8.2 ft) in widespread use in the United Kingdom. The 1978/79 flow to Battery B averaged 170,300 m^3/day (45 mgd) and varied between a maximum monthly flow of 196,800 m^3/day (52 mgd) and a minimum monthly flow of 143,800 m^3/day (38 mgd). Peak flow is 3 x dry weather flow.

Air for the entire plant is supplied by 10 centrifugal air compressors, six rated at 510 m^3/min (18,000 cfm) and four rated at 765 m^3/min (27,000 cfm). All blowers are driven by dual fuel digester gas/diesel fuel engines. Maximum system pressure is 42.7 kN/m^2 (6.2 psi). Air is cleaned by replaceable dual element filters. The outer filters are coarse fiberglass units. The inner filters are labyrinth box-type fine filters.

Mogden reports a construction cost of £32,937 ($65,874) for new domes and fittings and £22,100 ($44,200) for piping and labor, indexed to 1979, to retrofit a four-pass activated sludge unit. Cost of changing the air cleaning filters for Battery B is £700 ($1400) /yr.

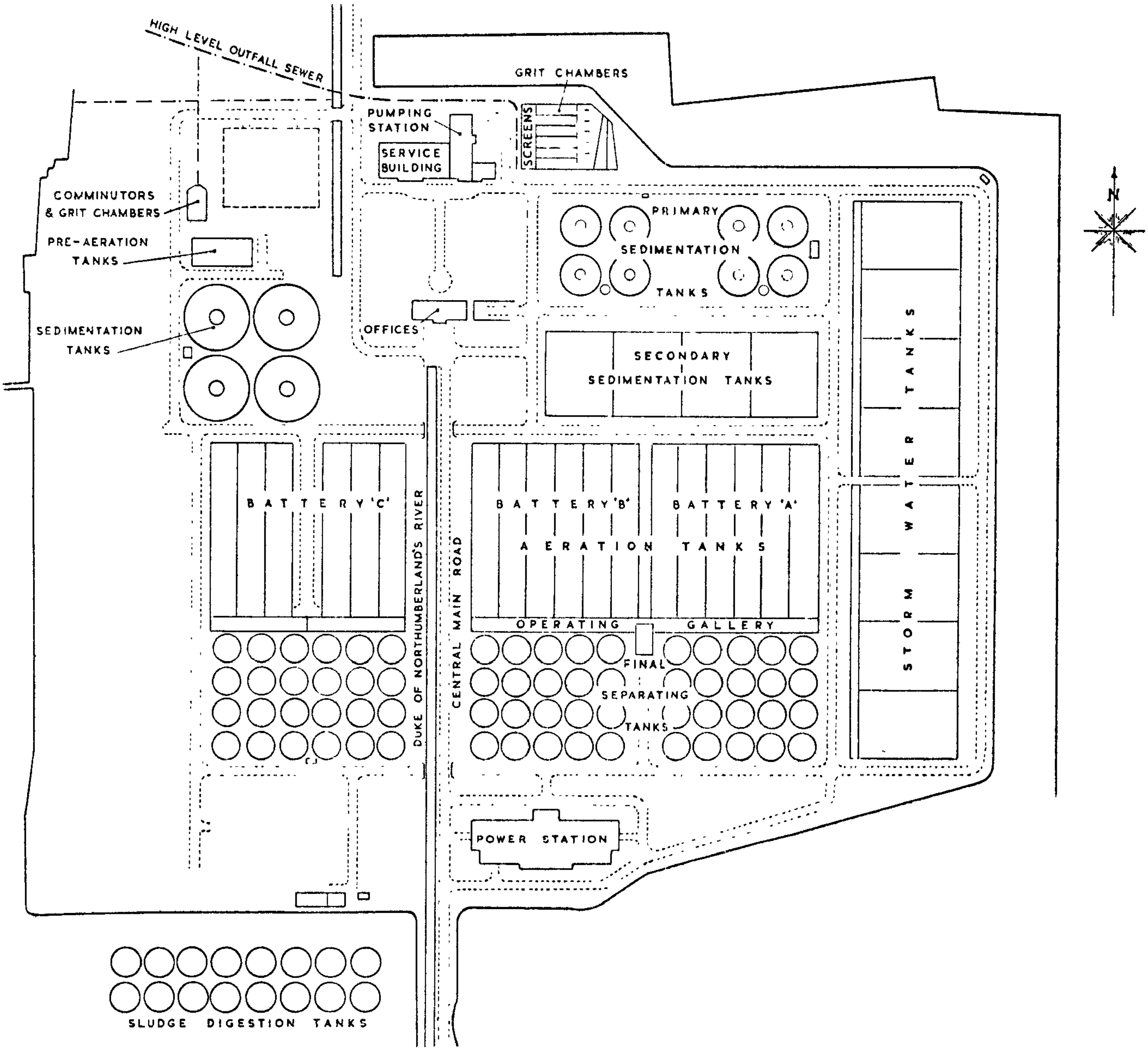


Figure B-6. Mogden site plan.

TABLE B-16. MOGDEN DESIGN DATA

EAST WORKS (DWF = 264,000 m^3/day = 70 mgd)

Stormwater Tanks

Flows exceeding 659,000 m^3/day (174 mgd) are diverted to adjacent stormwater tanks.

8 Rectangular Tanks	46 m* x 70 m* x 3.7 m* SWD
Detention time:	6.2 hr @ DWF (6 tanks in use)

Primary Sedimentation - Two Stage

8 Circular Clarifiers	
Diameter:	27.4 m
Sidewater depth:	3.4 m
Floor slope:	1:10
Detention time:	1.9 hr @ DWF
Surface loading:	55.2 m^3/m^2/day (1355 gpd/ft^2)
4 Rectangular Clarifiers	46 m x 61 m x 3.7 m
Detention time:	3.8 hr @ DWF
Surface loading:	24.0 m^3/m^2/day (589 gpd/ft^2)

Aeration Basins

12 Rectangular Tanks (4 passes per tank) (6 tanks per battery)	4.6 m x 122 m x 3.7 m SWD (each pass)
Detention time:	9.0 hr @ DWF

Final Sedimentation

40 Circular Clarifiers (20 per battery)	
Diameter:	18 m
Sidewater depth:	2.5 m
Floor slope:	30°
Detention time:	4.5 hr @ DWF
Surface loading:	22.3 m^3/m2/day (548 gpd/ft^2)

WEST WORKS (DWF = 132,000 m^3/day = 35 mgd)

Preaeration

2 Rectangular Tanks	6 m* x 40.8 m* x 3.7 m* SWD
Detention time:	30 min @ DWF

Primary Sedimentation

4 Circular Clarifiers	
Diameter:	42.6 m
Sidewater depth:	0.9 m
Detention time:	1.8 hr @ DWF
Surface loading:	23.0 m^3/m^2/day (564 gpd/ft^2)

Aeration Basins

6 Rectangular Tanks (4 passes per tank)	4.6 m x 122 m x 3.7 m SWD (each pass)
Detention time:	9.0 hr @ DWF

Final Sedimentation

24 Circular Clarifiers	
Diameter:	18 m
Sidewater depth:	2.5 m
Floor slope:	30°
Detention time:	5.4 hr @ DWF
Surface loading:	19.2 m^3/m^2/day (472 gpd/ft^2)

* 1 m = 3.28 ft

Performance

Performance data discussed herein are for Battery B only, although all sections of the plant performed similarly. Battery B data are the most representative as it was fully retrofitted with plastic piping between 1974-1979.

Primary sedimentation serving Battery B has averaged 53 percent removal of BOD_5 and 68 percent removal of suspended solids over the period of record (Table B-17). Secondary treatment averaged 91 percent removal of BOD_5, 91 percent removal of suspended solids, and 94 percent conversion or removal of ammonia nitrogen. Overall, the plant achieved average removals of 96 percent for BOD_5, 97 percent for suspended solids, and 93.8 percent for ammonia nitrogen through Battery B. Detergent was reduced an average of 97 percent through the process. Battery B flow averaged 166,500 m^3/day (44 mgd). Monthly average flow and BOD varied $\pm$ 15 percent from the annual average. Approximately 15 percent of the flow is derived from a variety of industrial sources.

TABLE B-17. MOGDEN INFLUENT-EFFLUENT DATA SUMMARY*

Parameter	Year+ 78/79	77/78	76/77	75/76	74/75
Flow:					
mgd	45.2	42.3	40.2	41.5	46.5
1000 m^3/day	171	160	152	157	176
Raw Wastewater: (mg/l)					
BOD_5	238	225	208	225	215
COD	542	511	--	--	--
TSS	311	292	291	299	281
NH_3-N	24	24	25	27	26
Detergent°	9.3	7.5	6.3	8.5	10.6
Primary Effluent: (mg/l)					
BOD_5	99	97	93	118	112
COD	228	228	--	--	--
TSS	96	90	99	92	94
NH_3-N	24	26	26	30	27
Detergent°	5.3	4.3	3.4	6.2	7.9
Final Effluent: (mg/l)					
BOD_5	8	12	10	8	6
COD	--	--	--	--	--
TSS	8	8	8	9	10
NH_3-N	1.3	1.7	1.6	1.9	1.3
NO_3-N	20	20	21	19	20
Detergent°	0.3	0.2	0.2	0.2	0.3

* For Battery B only.
\+ Year begins April 1 and ends the following March 31.
° As manoxyl OT (a proprietary ABS type compound).

Aeration efficiency is calculated for the 5 yr shown in Table B-18 and averaged 1.37 kg O_2/kWh (2.25 lb/wire hp-hr). In computing these efficiencies, constant power consumption in kWh was assumed over the 5-yr period. Plant personnel stated that the assumption was most accurate for 76/77, 77/78, and 78/79. They were unsure of 74/75 and 75/76 power consumption. The average aeration efficiency for the last 3 yr of 1.25 kg O_2/kWh (2.05 lb/wire hp-hr) is probably most representative of typical performance.

TABLE B-18. MOGDEN EFFICIENCY CALCULATIONS*

Parameter	Year 78/79	77/78	76/77	75/76	74/75
BOD_5 Removed (kg/day)+	15,560	13,600	12,620	17,270	18,660
NH_3-N Removed (kg/day)+	3830	3600	3480	3956	4365
NO_3-N Produced (kg/day)+	3437	3216	3162	2936	3538
O_2 Required°(kg/day)+	32,030	29,080	27,580	34,280	37,430
Power Consumed** (kWh/day)++	23,140	23,140	23,140	23,140	23,140
Aeration Efficiency:					
kg O_2/kWh	1.38	1.26	1.12	1.48	1.62
lb O_2/wire hp-hr	2.27	2.07	1.84	2.43	2.66

* For Battery B only.
\+ 1 kg = 2.21 lb
° Calculated by the method of Section 5, assuming 1.08 units O_2 required/unit BOD_5 removed.
** One-half of power consumption of Batteries A and B. Power assumed constant over 5 yr per plant operators.
++ 1 kWh/day = 1.34 wire hp-hr/day.

The relatively low efficiency at this plant is probably attributable to the substantial degree of excess aeration being practiced. Lack of hydraulic (wastewater flow) control and air flow control are principal contributors to this problem. Also, the extreme plug flow configuration and lack of tapered aeration mitigates against efficient use of the aeration process. D.O. reaches 70 percent of saturation in the third pass of the four-pass basins and can reach 100 percent at the exit of the last pass.

Mixing power levels at Mogden (Table B-19) are similar to those at the Beckton plant at 29 W/m^3 (1.10 wire hp/1000 ft^3) in the first pass and 18.5 W/m^3 (0.70 wire hp/1000 ft^3) in succeeding passes. Plant personnel stated that the tanks were adequately mixed, with the exception that a small snail which grows in the tanks at Mogden is deposited in large quantities under the domes and must be removed about once every 5 yr during routine tank cleaning.

TABLE B-19. MOGDEN MIXING DATA*

Parameter	First Pass	Other Passes
Surface Area (m^2)+	557.5	557.5
Wetted Volume (m^3)°	2174	2174
Diffuser Density (domes/m^2)**	5.02	3.14
Air Flow/Section:++		
cfm	2083	1306
m^3/min	59	37
Air Flow/Area:++		
cfm/ft^2	0.348	0.220
m^3/min/m^2	0.016	0.067
Air Flow/Volume++ (cfm/1000 ft^3)°°	27.3	17.0
Average Power Input: ***		
wire hp/1000 ft^3	1.10	0.70
W/m^3	29.0	18.5

* For Battery B only.
\+ 1 m^2 = 10.8 ft^2
° 1 m^3 = 35.3 ft^3
** 1 dome/m^2 = 9.29 domes/100 ft^2
++ Based on an operating air flow rate of 0.021 m^3/min/dome (0.75 cfm/dome).
°° Same as m^3/1000 m^3/min.
*** Assumes power apportioned between tanks in proportion to number of domes in each.

Operation and Maintenance

Mogden has operated 17.8-cm (7-in.) dome diffusers continuously since 1961, initially using domes mounted on cast iron mains. Rusting of the iron mains caused deposition of iron oxides on the inside of the domes. Prior to the retrofit of the tanks with plastic lines, which began in 1972, it was necessary to clean the domes about once each 6 yr. Battery B, which was fully converted by 1979, has not required cleaning since and is performing well. Very little coarse bubbling is occuring, mostly limited to the first one-third of the first pass, and there has been no pressure increase. There was some evidence of calcium carbonate deposition in domes that had been in service for 8 yr, but the amount was very light compared to that observed at Basingstoke.

In general, plant personnel expressed satisfaction with the equipment and its performance. Some failures of the plastic dome hold-down bolts had occurred, and the scientific staff was investigating alternative materials. The air filtration units are performing satisfactorily, requiring replacement of the filter elements once per year.

OXFORD

History and Background

Wastewater treatment for the City of Oxford began at Sanford-on-Thames, 8 km (5 mi) south of the City in the 1870's. Initially, the City's wastewater was land disposed on a "sewage farm" adjacent to a tributary of the Thames River. Increasing population progressively overloaded the facility, and, in 1957, it was replaced with an activated sludge system that employed mechanical surface aeration of the Simplex type.

In 1969, the 1957 plant was expanded with the provision of two additional primary clarifiers and four additional final clarifiers. A new treatment plant was constructed alongside comprised of three rectangular primary clarifiers, three rectangular storm/balancing tanks, eight diffused air activated sludge tanks, and three final clarifiers. The new works, sized for 15,000 m^3/day (3.96 mgd), was operated in parallel with the upgraded existing plant (Figure B-7).

By the early 1970's, it became apparent that the original activated sludge plant was reaching the end of its useful life and required substantial mechanical rehabilitation. Based on performance and maintenance studies, the decision was made to install diffused air aeration equipment. The work, currently under way, also includes refurbishment of the four original flat bottomed final clarifiers. Modifications will be completed by mid-1980. Separate contracts for further improvements in sludge handling and disposal are scheduled to follow this work.

Plant Description

Table B-20 summarizes basic design data for both sections of the Oxford plant. Wastewater flow is divided between the two activated sludge plants with 67 percent being treated in the 1957 plant and 33 percent in the 1969 plant. The 1957 plant was originally constructed with four aeration tanks of 10 aeration cells each. These tanks are presently being converted to diffused aeration with the addition of 168 dome diffusers per cell or 1680 per tank. The hopper bottoms of the individual aeration cells are being partially filled to provide a base for installing the dome diffusers, and the final operating depth will be 5 m (16.4 ft).

The 1969 plant was constructed with eight aeration tanks, each with 990 domes per tank. Seven of the units employ an equally distributed grid dome layout of nine rows spanning the length of the tank with 110 domes per row. The eighth unit was designed in the tapered aeration mode (still experimental in 1969) for the purpose of research. Dome configuration in tanks Nos. 2-8 is 0.30 m (1 ft) between domes and 0.76 m (2.5 ft) between rows. Dome diffuser configuration in tank No. 1 is as follows:

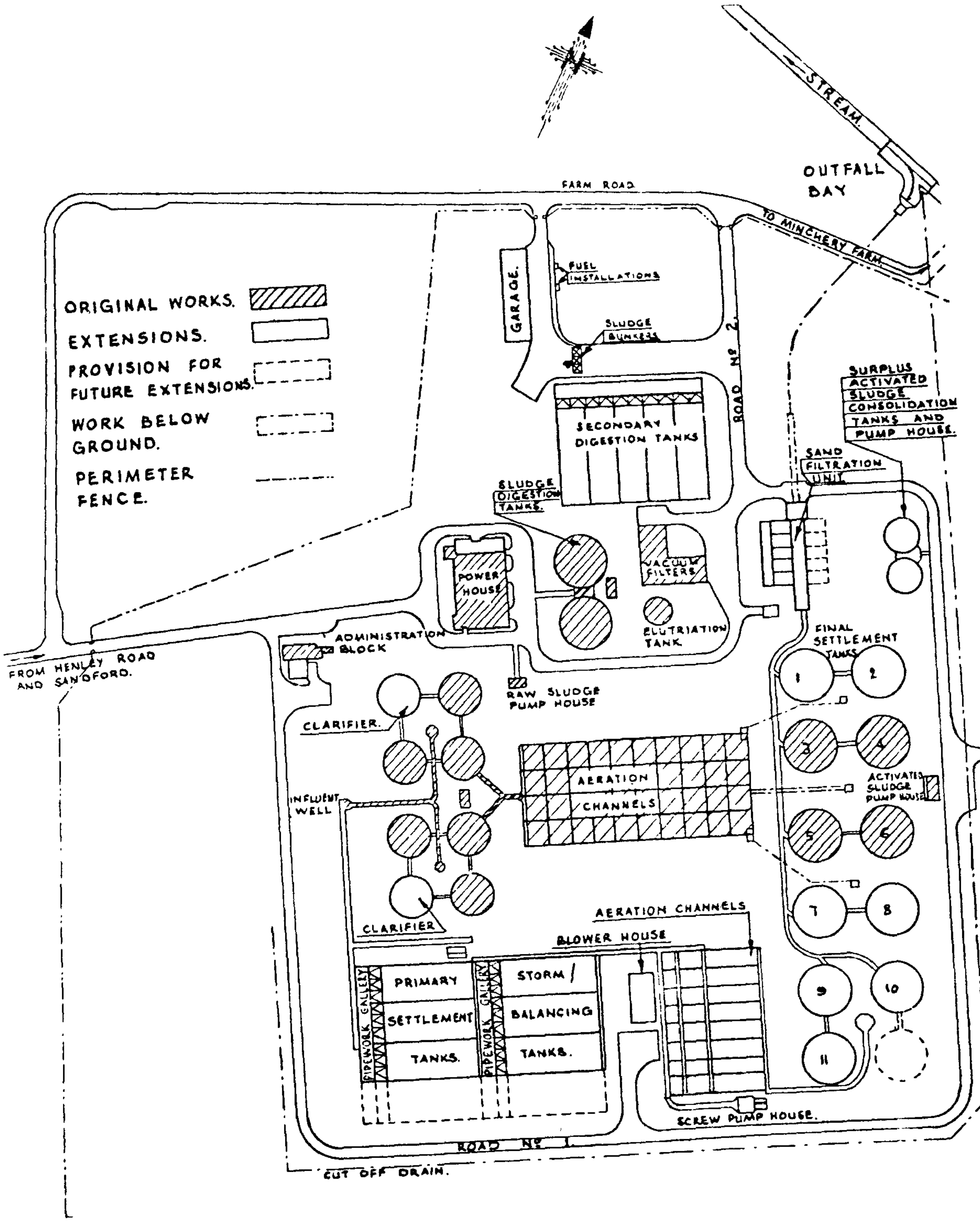


Figure B-7. Oxford site plan.

TABLE B-20. OXFORD DESIGN DATA

1969 PLANT (DWF = 15,000 m^3/day = 3.96 mgd)	
Stormwater Tanks	
3 Rectangular Tanks	15.2 m* x 45.6 m* x 3.3 m * SWD
Detention time:	11 hr @ DWF
Primary Sedimentation	
2 Circular Clarifiers	
Diameter:	18.3 m
Sidewater depth:	3.6 m
Detention time:	6.8 hr @ DWF
3 Rectangular Tanks	15.2 m x 45.6 m x 3.3 m SWD
Detention time:	10.9 hr @ DWF
Overall surface loading:	5.5 m^3/m^2/day (135 gpd/ft^2)
Aeration Basins	
8 Rectangular Tanks	6.9 m x 37.8 m x 2.4 m SWD
Detention time:	8.0 hr @ DWF
Final Clarifiers	
7 Circular Tanks	
Diameter:	24.4 m
Sidewater depth:	1.5 m
Floor slope:	30°
Detention time:	8.6 hr @ DWF
Surface loading:	10.3 m^3/m^2/day (253 gpd/ft^2)
1957 PLANT (DWF = 30,000 m^3/day = 7.92 mgd)	
Primary Sedimentation	
6 Circular Clarifiers	
Diameter:	18.3 m*
Sidewater depth:	3.6 m
Floor slope:	20°
Detention time:	6.8 hr @ DWF
Surface loading:	18.5 m^3/m^2/day (454 gpd/ft^2)
Aeration Basins	
4 Rectangular Tanks (10 cells each)	9.2 m x 9.2 m x 4.4 m SWD (each cell)
Wetted volume:	14,750 m^3+
Detention time:	11.7 hr @ DWF
Final Sedimentation	
4 Circular Clarifiers	
Diameter:	24.4 m
Sidewater depth:	3.6 m
Floor slope:	12°
Detention time:	10 hr @ DWF
Surface loading:	8.4 m^3/m^2/day (206 gpd/ft^2)
4 Circular Clarifiers	
Diameter:	24.4 m
Sidewater depth:	1.5 m
Floor slope:	30°
Detention time:	8.6 hr @ DWF
Surface loading:	10.3 m^3/m^2/day (253 gpd/ft^2)

* 1 m = 3.28 ft
+ 1 m^3 = 35.3 ft^3

Tank Section	Description	Percent of Domes
First quarter of tank 8.3 m (27.25 ft)	425 domes, 17 rows, 0.30 m (1 ft) between domes, 0.40 m (1.3 ft) between rows.	43
Second quarter of tank 9.4 m (31.0 ft)	270 domes, 9 rows, 0.30 m (1 ft) between domes, 0.76 m (2.5 ft) between rows.	28
Third quarter of tank 10.0 m (33.0 ft)	198 domes, 9 rows, first 1/3 at 0.30 m (1 ft) centers, last 2/3 at 0.61 m (2 ft) centers, 0.76 m (2.5 ft) between rows.	20
Last quarter of tank 9.9 m (32.5 ft)	90 domes, 3 rows in center, 0.30 m (1 ft) between domes, 0.76 m (2.5 ft) between rows.	9

The diffusers are placed 20 cm (8 in.) above the basin floor in all eight tanks. Air is distributed via a single main that enters the tank at mid-length and is split into feeders for each of the four grids.

Primary effluent is step fed, 50 percent at 8.2 m (27 ft) from the head of the aeration tank and 50 percent at 14.6 m (48 ft), into the seven tanks with equal dome spacing. The tapered tank is fed the full flow at 8.2 m (27 ft) from the head of the tank. Recycled activated sludge enters at the influent end of all eight tanks.

The renovated 1957 plant will be served by six Rootes-type positive displacement blowers, two of which are provided for standby. The standby blowers are fixed-speed, 93-kW (125-hp) units, operated at a maximum load of 78 kW (104 hp). The remaining four blowers are driven by variable-speed, direct-current thyristor drives and operate in the range of 48-75 kW (64-100 hp). The maximum operating pressure is 59.3 kN/m^2 (8.6 psi), and air flow ranges from 40-68 m^3/min (1400-2400 cfm) per blower.

Three positive displacement Rootes-type blowers, one fixed and two variable speed, provide air to the 1969 plant. The fixed-speed blower, used principally for standby, draws 57 kW (77 hp) at 41.4 kN/m^2 (6 psi) and delivers 78 m^3/min (2750 cfm). The variable-speed blowers are rated from 31-45 kW (42-60 hp) with an output ranging from 42-59 m^3/min (1500-2100 cfm).

The renovated 1957 plant will be equipped with a D.O. monitoring and control system. Four sensors will be provided for each tank, and a controller will blend the signals and control blower operation.

Air filtration in the renovated 1957 plant will be provided by three electrostatic air filters, each sized to precede two blowers. These filters were selected based on two factors:

1. The electrostatic units are substantially smaller than bag filters.

2. Use of the D.O. control system will cause wide variations in air flow rate. Bag filters are poorly suited to varying and cyclic (on/off) air flow conditions.

Air filtration in the 1969 plant is provided by two 85-m^3/min (3000-cfm) Tilghman-Wheelabrator bag filter units. The units require the use of a precoat, which is added immediately after cleaning. Formerly, an asbestos precoat was used, but a cellulose-based precoat is now applied when the units are cleaned.

Final clarifiers for the 1969 Oxford plant are of the circular, center-feed type and feature steeply sloped floors (30°) and shallow sidewater depth of 1.5 m (5 ft). Detention time at the design flow of 15,000 m^3/day (3.96 mgd) is 8.6 hr. The surface loading rate is 10.3 m^3/m^2/day (253 gpd/ft^2), not including a recycle flow of 75-100 percent of design flow. Settled sludge flows to the center of the clarifier aided by a simple rotating chain mechanism and is normally concentrated to 9000 mg/l when withdrawn.

Construction costs of the 1969 works totaled £1.3 million ($2.6 million), of which £47,000 ($94,000) was spent on diffusers, piping, blowers, and controls. The current 1957 plant renovation is costing £550,000 ($1.1 million), of which £42,700 ($85,400) is required for the diffusers and in-tank piping and installation.

Performance

Performance data were provided by the City of Oxford for the years 1974-75 to 1978-79 and are summarized in Table B-21. The data are for the 1969 works only and do not include the 1957 plant.

Primary treatment removed an average of 46.6 percent of the influent BOD_5 and 71.3 percent of the influent suspended solids. Secondary plant performance averaged near 93 percent BOD_5 removal and 85 percent suspended solids removal, with an average MLSS concentration of 5000-5500 mg/l and an F/M loading of 0.1 kg BOD_5/day/kg MLSS. Overall plant performance has consistently exceeded 95 percent removals of BOD_5 and suspended solids. Consistent nitrification has been achieved, with ammonia nitrogen removals exceeding 92 percent. Approximately 13 percent of the flow to this plant is derived from a variety of industrial sources. Monthly averages of volumetric loading vary approximately $\pm$ 20 percent from annual averages.

Aeration efficiency (Table B-22) as calculated by the method detailed in Section 5, ranged from 1.93-2.34 kg O_2/kWh (3.17-3.85 lb/wire hp-hr) over the 5-yr data base. Mixed liquor D.O. at Oxford is maintained at 20 percent of saturation at the outlet end of each aeration tank, a relatively low value when compared to the other plants visited. The purpose of this practice is twofold: first, to maximize aeration efficiency and, second, to create conditions at the tank inlet that are conducive to denitrification in the first 25 percent of the tank length. Substantial denitrification has been consistently achieved at Oxford over the last 2 yr. Plant operators expressed a strong belief that the creation of conditions conducive to denitrification in the first quarter of each tank improves effluent quality by suppressing denitrification in the final clarifiers and increases aeration efficiency.

TABLE B-21. OXFORD INFLUENT-EFFLUENT DATA SUMMARY

Parameter	Year* 78/79	77/78	76/77	75/76	74/75
Flow:					
mgd	5.34	4.61	3.75	4.19	5.07
m^3/day	20,200	17,400	14,200	15,900	19,200
Raw Wastewater: (mg/l)					
BOD_5	367	353	299	248	277
COD	927	881	695	608	641
TSS	480	475	376	364	352
TKN	--	--	--	59	62
NH_3-N	36	43	34	27	31
Primary Effluent: (mg/l)					
BOD_5	165	170	177	157	142
COD	349	364	363	352	317
TSS	112	130	112	119	106
TKN	--	--	--	45	50
NH_3-N	29	40	34	27	28
Final Effluent: (mg/l)					
BOD_5	7	13	14	10	13
COD	53	66	64	44	40
TSS	20	31	27	13	15
TKN	--	--	--	45	50
NH_3-N	2.6	3.3	2.8	1.4	2.4
NO_3-N	19	18	32	26	25

* Year begins April 1 and ends the following March 31.

Table B-23 summarizes mixing conditions in the 1969 plant. Tank Nos. 1-4 and 6-8 have a uniform diffuser density. The minimum power level utilized is 18.8 W/m^3 (0.71 wire hp/1000 ft^3). At the maximum air flow rate currently employed, the mixing power level is 29.2 W/m^3 (1.11 wire hp/1000 ft^3). Corresponding air flow rates are 0.013 m^3/min/dome (0.45 cfm/dome) and 0.020 m^3/min/dome (0.70 cfm/dome), respectively. The tapered aeration tank (No. 5) has a minimum mixing power level of 6.4 W/m^3 (0.24 wire hp/1000 ft^3) in the final section. This low power input is compensated for by placing the four diffuser lines in the center of the tank lengthwise creating a spiral roll condition in each half of the final section. Plant personnel stated that all of the tanks have been checked for adequate mixing and found to be satisfactory.

The renovated 1957 plant will also have a uniform distribution of domes, with a projected minimum air flow of 0.024 m^3/min/dome (0.83 cfm/dome). The maximum air flow rate will be 0.039 m^3/min/dome (1.38 cfm/dome).

TABLE B-22. OXFORD AERATION EFFICIENCY CALCULATIONS

Parameter	Year 78/79	77/78	76/77	75/76	74/75
BOD_5 Removed (kg/day)*	3195	2737	2317	2330	2475
COD Removed (kg/day)*	5797	5200	4247	4889	5313
NH_3-N Removed (kg/day)*	535	642	438	413	491
NO_3-N Produced (kg/day)*	380	321	460	411	482
O_2 Required+ (kg/day)*	4420	4949	4663	4501	5029
Power Consumed (kWh/day)°	2290	2108	2180	2331	2200**
Aeration Efficiency:++ kg O_2/kWh	1.93	2.34	2.14	1.93	2.29
lb O_2/wire hp-hr	3.17	3.85	3.52	3.17	3.76

* 1 kg = 2.21 lb
\+ Calculated by the method of Section 5, assuming 1.20 units O_2 required/ unit BOD_5 removed.
° 1 kWh/day = 1.34 wire hp-hr/day
** Estimated value.
++ Corrected for 10 percent of air supply used in aerated channels and elsewhere.

Operation and Maintenance

Oxford has operated the dome diffusers in the 1969 plant continuously for over 10 yr with no apparent loss of aeration efficiency and no dome cleaning. In the first 9 mo of operation, several domes had to be regasketed, but there have been no other failures of the domes, dome mountings, or plastic air piping in the tanks. Operating personnel at this plant have followed the following procedures since starting the 1969 plant:

1. Maintain minimum dome air flow rates near 0.014 m^3/min (0.5 cfm).

2. Scrupulously maintain air cleaning equipment.

TABLE B-23. OXFORD MIXING DATA

Aeration Tank & Section Nos.	Surface Area (m^2)*	Wetted Volume (m^3)+	Diffuser Density (domes/m^2)o	Air Flow/Section** (cfm)	Air Flow/Section** (m^3/min)	Air Flow/Area** (cfm/ft^2)	Air Flow/Area** (m^3/m^2/min)	Air Flow/Volume** (cfm/1000 ft^3)++	Minimum Power Input (wire hp/1000 ft^3)	Minimum Power Input (W/m^3)
Tanks 1-4, 6-8	261	639	3.8	445	12.6	0.16	0.048	19.9	0.71	18.8
Tank 5:										
Section 1	58	141	7.3	191	5.4	0.31	0.093	38.5	1.38	36.3
Section 2	65	161	4.1	120	3.4	0.17	0.051	21.6	0.77	20.4
Section 3	70	170	2.8	88	2.5	0.12	0.036	14.9	0.53	14.0
Section 4	68	167	1.3	40	1.14	0.06	0.018	6.8	0.24	6.4
1957 Plant										
(each cell)	83.7	369	2.0	74	2.1	0.15	0.047	10.7	0.38	10.1

* 1 m^2 = 10.8 ft^2
\+ 1 m^3 = 35.3 ft^3
o 1 dome/m^2 = 9.29 domes/100 ft^2
** Based on a minimum air flow rate of 0.013 m^3/min/dome (0.45 cfm/dome).
++ Same as m^3/1000 m^3/min.

3. Immediately repair air leakage to prevent infiltration of mixed liquor into aeration piping.

4. Operate aeration blowoff manifold valves once per month to clean lines of condensation.

Oxford uses coated bag filters for air cleaning. The 85-m^3/min (3000-cfm) units require cleaning approximately every 5 yr. Cleaning is scheduled on the basis of headloss across the filters. When clean, the headloss averages 5.1-7.6 cm H_2O (2-3 in.). Cleaning is scheduled when headloss exceeds 12.7 cm (5 in.). Mechanical performance of the two bag filters has been satisfactory, and there have been no breakdowns.

RYEMEADS

History and Background

The treatment plant at Ryemeads discharges to the River Lee and is part of the Middle Lee Regional Drainage Scheme. The plant receives wastewater from existing communities and New Towns to the north of London. Because treated effluent is discharged to the river only 16 km (10 mi) above the intakes to a substantial portion of London's drinking water supply, effluent standards are very high and the treated wastewater is passed through a series of lagoons prior to final discharge to the river.

The Ryemeads plant was built in three stages, beginning in 1956 with the startup of the first stage (Figure B-8). Stage 2 was completed in 1965. The final stage, consisting of four, four-pass plug flow aeration tanks and six circular final clarifiers, was completed in 1970.

Plant Description

All three stages of the plant are designed on a similar basis. Common primary treatment, with 6 hr detention time at DWF and a 12-m^3/m^2/day (295 gpd/ft) overflow rate, is provided by 12 rectangular clarifiers measuring 51.2 m x 17.4 m x 3.3 m SWD (168 ft x 57 ft x 10.75 ft) (DWF = 36,300 m^3/day = 9.6 mgd). Seven of the clarifiers handle the normal plant flow. Two are used for daily flow equilization and three for stormwater retention. Flow is then split among the three stages of the plant. Because the third stage is fully modernized, employing domes on plastic air distribution lines in a tapered configuration, performance data have been provided for this section only. Other parts of the plant are currently being modernized, replacing cast iron air lines with plastic piping (Table B-24).

In 1976, denitrification in the form of an anoxic zone in the first 40 percent of the first pass of each aeration tank was added. Mixing was provided by five 2.2-kW (3-hp) paddle stirrers in this zone. (Later investigations proved that mixing could be maintained by operating three of these.) Table B-24 summarizes design data for Stage 3 before and after this modification. Basically, domes removed from the first 40 percent of the first pass were installed in the second and third passes.

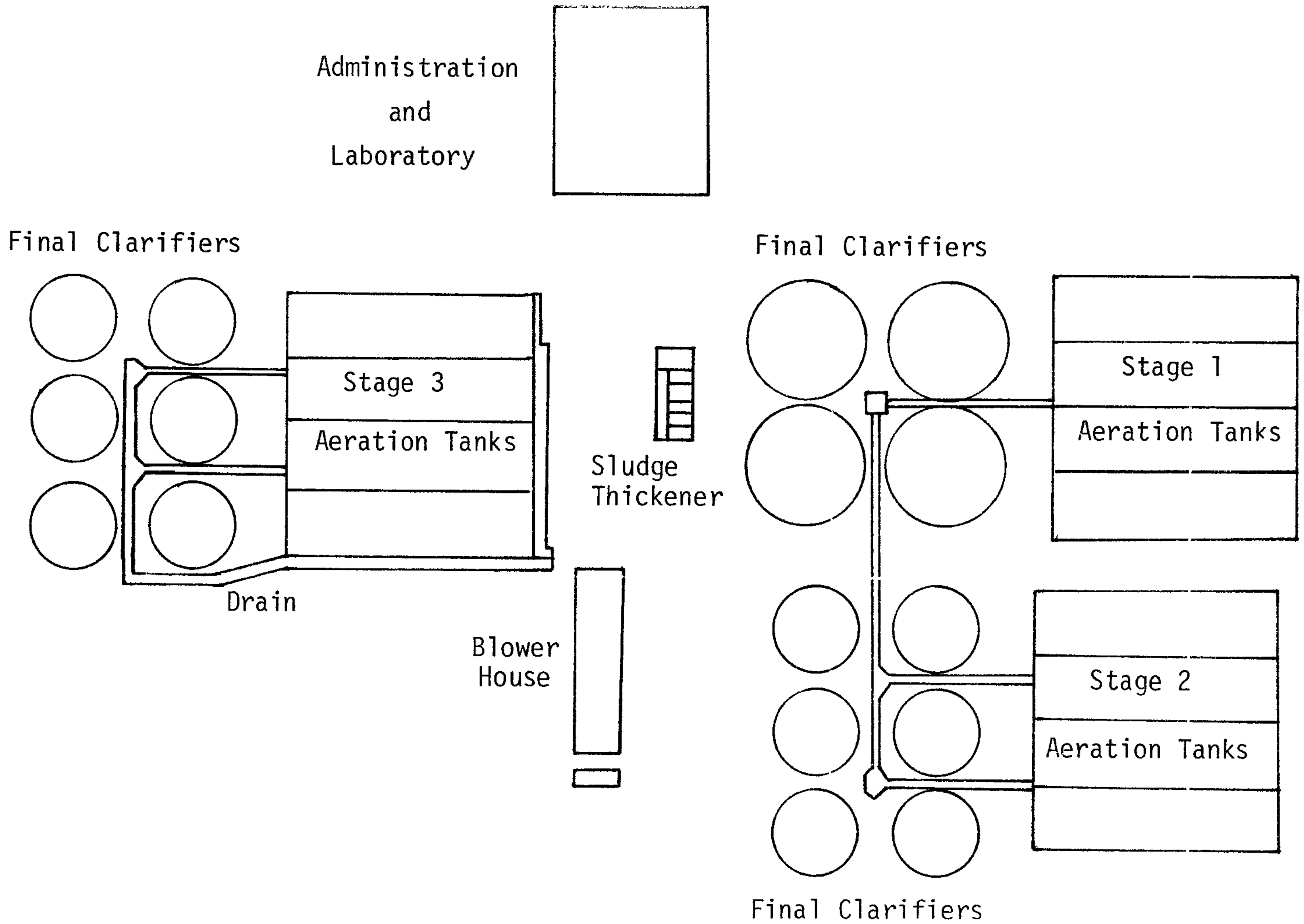


Figure B-8. Ryemeads site plan (secondary system)

TABLE B-24. RYEMEADS DESIGN DATA*+

Aeration Basins		
4 Rectangular Tanks (4 passes per tank)	4.27 m° x 70 m° x 3.1 m° SWD (each pass)	
Detention time:	9.6 hr @ DWF	
Diffuser Configuration:		
	PRE-JULY 1976	CURRENT
First Pass	Symmetrical, 9 rows, 150 domes/row, 0.47 m between domes, 0.43 m between rows.	First 28.7 m, no domes (5 equally spaced stirrers). Last 41.3 m. 9 rows, 90 domes/row, same spacing as before.
Second Pass	Two sections, each 35 m long. First has 9 rows, 75 domes/row, spaced like first pass. Second section, 5 rows, 120 diffusers/row, 0.3 m between domes, 0.7 m between rows.	Same as pre-July 1976.
Third Pass	Symmetrical, 5 rows, 120 domes/row, 0.6 m between domes, 0.7 m between rows.	Symmetrical, 5 rows, 220 domes/row, 0.3 m between domes, 0.7 m between rows.
Fourth Pass	Same as third pass.	Symmetrical, 5 rows, 140 domes/row, 0.5 m between domes, 0.7 m between rows.
TOTAL DOMES		
First Pass	1350	0 + 810
Second Pass	675 + 600	675 + 600
Third Pass	600	1100
Fourth Pass	600	700
	3825	3885
Final Sedimentation		
6 Circular Clarifiers		
Diameter:	22 m	
Sidewater depth:	1.3 m	
Floor slope:	30°	
Detention time:	7.5 hr @ DWF	
Surface loading:	15.8 m^3/m^2/day (389 gpd/ft^2)	

* For Stage 3 only.
\+ DWF = 36,300 m^3/day (9.6 mgd)
° 1 m = 3.28 ft

Air supply for Stage 3 is provided by three variable-vane centrifugal blowers with a shaft output that varies from 89-242 kW (120-325 BHP). The units will deliver 210 m^3/min (7400 cfm) at the normal operating pressure of 49 kN/m^2 (7.1 psi). Air cleaning is provided by five electrostatic air filters out of a total of 12 connected to a common duct. Approximately 6 percent of the air supply is used for the domes that are mounted in the primary effluent and mixed liquor channels.

Final clarifiers are of the type recommended by the diffuser manufacturer and feature a steep floor slope and a shallow sidewater depth. A single chain scraper moves sludge to the center hopper. Sludge recycle rates average 75-100 percent.

Performance

Data was provided for Stage 3 for the period January 1974-December 1978. However, considerable modification of Stage 3, with variable operation of two to four aeration tanks, took place in 1975 and 1976. Accordingly, these data have been deleted in this analysis. All four units were operated in 1974, 1977, and 1978, and influent and effluent data for these 3 yr are summarized in Table B-25.

The wastewater received by the Ryemeads plant is fairly strong and contains about 10 percent (by flow) industrial wastes from metal finishing, malting, and pharmaceutical industries. Over the period 1974-1978, the influent BOD_5 concentration declined by approximately 25 percent, reflecting growth in the contributing New Towns and the use of more water by the new inhabitants. BOD_5 removal has consistently averaged 53-56 percent in the primary system and 96-97 percent in the secondary system. Approximately 75-77 percent of the influent suspended solids are removed in the primary plant and 88-91 percent in the activated sludge process. Overall, the plant removed an average of 98 percent each of the BOD_5 and suspended solids in the raw wastewater. Ammonia nitrogen removal exceeded 99 percent. Monthly average flows and BOD_5 loadings varied about $\pm$ 20 percent from annual averages. Influent detergent (as manoxyl OT) averaged 10-15 mg/l and was 95 percent removed through the process. The stable flow and BOD_5 loadings to the Ryemeads plant reflect the relatively new collection system serving the plant.

Aeration efficiency computations are shown in Table B-26, based on data for Stage 3 only. MLSS averaged 4500-5000 mg/l, and the F/M loading rate averaged 0.08 kg BOD_5/day/kg MLSS. Using the method of Section 5, 1.22 units O_2 were estimated to be required per unit of BOD_5 removed and the aeration efficiency ranged from 1.04-1.14 kg O_2/kWh (1.71-1.87 lb/wire hp-hr). D.O. levels in the aeration tanks average 20 percent of saturation in the first pass, reaching 50-60 percent of saturation by the end of the second pass and 90-100 percent of saturation in the effluent from the final pass. These elevated levels are likely the main cause of the relatively poor aeration efficiency at this plant. Plant personnel indicated that these D.O. concentrations were the by-product of maintaining total plant air flows to keep dome air flow rates from falling below 0.014 m^3/min (0.5 cfm). Unlike Beddington and Hartshill, there is no indication that alpha factors are depressed at this plant.

TABLE B-25. RYEMEADS INFLUENT-EFFLUENT DATA SUMMARY

Parameter	Year 1978	Year 1977	Year 1974
Flow: mgd	10.45	11.9	10.1
m^3/day	39,600	44,880	38,200
Raw Wastewater: (mg/l)			
BOD_5	310	341	403
COD	698	749	--
TSS	490	483	430
NH_3-N	32	33	35
Primary Effluent: (mg/l)			
BOD_5	144	152	178
COD	299	308	--
TSS	117	109	105
TKN	44	51	48
NH_3-N	33	32	36
Final Effluent: (mg/l)			
BOD_5	5	6	5
COD	42	45	--
TSS	10	13	12
NH_3-N	0.2	0.3	0.2
NO_3-N	22	21	28

Mixing power levels have been calculated for the various pass configurations at Ryemeads and are shown in Table B-27. These data are calculated for minimum air flows and indicate that mixing power levels are well into the middle range of the plants surveyed. Maximum air flow rates range up to 100 percent higher than minimums. The nitrification section is mixed at a power level similar to the balance of the first aeration pass. Plant personnel reported no settling of solids in any of the aeration tanks.

Operation and Maintenance

Ryemeads has operated dome diffuser systems continuously since 1956 when Stage 1 was constructed. Stage-1 and-2 diffusers have required cleaning every 5-6 yr. Problems have been experienced with rust fouling of the diffusers in Stage 1, owing to the use of cast iron air distribution mains in the original plant. These mains are now being converted to uPVC pipe.

Considerable coarse bubbling was observed in the first pass of the aeration tanks in Stage 3 at the time of the plant visit. Plant personnel were uncertain as the causes of this, but it appeared to be a manifestation of the slime growth problem experienced at other plug flow plants.

TABLE B-26. RYEMEADS AERATION EFFICIENCY CALCULATIONS*

Parameter	Year 1978	Year 1977	Year 1974
BOD_5 Removed (kg/day)+	5483	6548	4923
NH_3-N Removed (kg/day)+	1258	1423	1328
NO_3-N Produced (kg/day)+	870	942	1068
O_2 Required°(kg/day)+	10,010	11,594	9892
Power Consumed (kWh/day)**	9640	10,732	8640
Aeration Efficiency:			
kg O_2/kWh	1.04	1.08	1.14
lb O_2/wire hp-hr	1.71	1.78	1.87

* For Stage 3 only.
\+ 1 kg = 2.21 lb
° Calculated by the method of Section 5, assuming 1.22 units O_2 required/unit BOD_5 removed.
** 1 kWh/day = 1.34 wire hp-hr/day

Plant maintenance workers estimated a cost of £ 1.50 ($3.00) each to remove, fire in a kiln, and replace domes in the tanks at Ryemeads, including 5-10 percent handling loss. They noted that the domes did not return to full oxygen transfer efficiency after the cleaning operation, but apparently lost 10-25 percent efficiency. Ryemeads domes are refired in the kiln at Beckton. The plant spends approximately £ 12,000/yr ($24,000/yr) for diffuser maintenance and cleans diffusers about once every 6 yr. A total of £ 35,000/yr ($70,000/yr) is being spent on the diffuser system, including retrofitting of cast iron air supply piping when a tank is removed from service for cleaning.

The electrostatic air filters have performed satisfactorily, requiring hot water washing every 3-4 mo. Approximately once every 2 yr, each air cleaner is dismantled and washed in a mild phosphoric acid solution. The job requires two men working 8 days to complete.

COALPORT

History and Background

The Coalport treatment plant was completed in 1970, serving a combination of existing villages and New Town areas. The plant was constructed on a former industrial site and is designed for expansion in step with New Town development. The construction cost in 1970 was £ 1.3 million ($2.6 million) for the facilities shown in Figure B-9.

TABLE B-27. RYEMEADS MIXING DATA

Pass	Surface Area (m^2)*	Wetted Volume (m^3)+	Diffuser Density (domes/m^2)o	Air Flow/Section** (cfm)	Air Flow/Section** (m^3/min)	Air Flow/Area** (cfm/1000 ft^2)	Air Flow/Area** (m^3/1000 m^2-min)	Air Flow/Volume** (cfm/1000 ft^3)++	Minimum Power Input (wire hp/1000 ft^3)	Minimum Power Input (W/m^3)
First Pass:										
First Section[oo]	122	372	0	0	0	0	0	0	0	0
Second Section	177	538	4.6	403	11.4	213	65	21.3	1.12	29.5
Second Pass:										
First Section	150	455	4.6	335	9.5	210	64	20.9	1.12	29.5
Second Section	150	455	4.6	300	8.5	187	57	18.6	0.99	26.1
Third Pass	299	910	3.7	547	15.5	171	52	17.1	0.90	23.7
Fourth Pass	299	910	2.3	350	9.9	108	33	10.9	0.52	13.8

* 1 m^2 = 10.8 ft^2
\+ 1 m^3 = 35.3 ft^3
o 1 dome/m^2 = 9.29 domes/100 m^2
** Based on a minimum air flow rate of 0.014 m^3/min/dome (0.5 cfm/dome) and current tank configurations in Stage 3 only.
++ Same as m^3/1000 m^3/min.
oo With three mixers operating at 2.2 kW (3 hp) each.

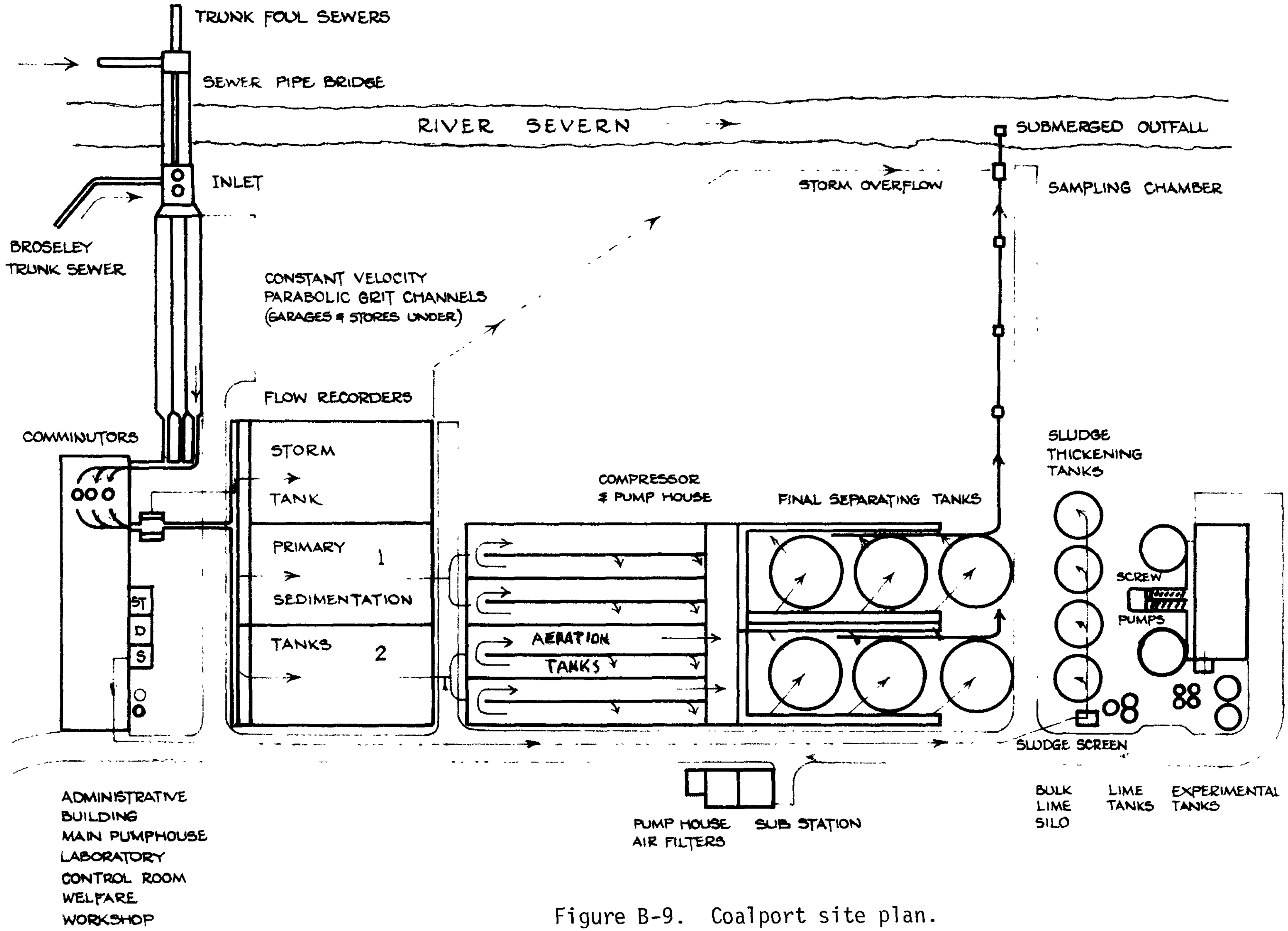


Figure B-9. Coalport site plan.

Plant Description

The Stage I plant at Coalport includes two rectangular primary sedimentation tanks, one stormwater overflow tank, four two-pass plug flow aeration tanks, and six circular final clarifiers. Designed for a DWF of 17,700 m^3/day (4.68 mgd), it is currently receiving about 67 percent of that flow. The primary tanks measure 53.2 m x 18.8 m x 2.8 m SWD (175 ft x 62 ft x 9 ft). The surface loading at DWF is 8.6 m^3/m^2/day (212 gpd/ft^2) with a current average loading of about 5.8 m^3/m^2/day (141 gpd/ft^2).

The aeration tanks each measure 65 m x 4.6 m x 3.4 m SWD (213 ft x 15 ft x 11 ft) and have 830 domes, symmetrically distributed. Air is distributed 60 percent to the first pass and 40 percent to the second pass. Twenty percent of the wastewater flow is fed at the head of the first pass, along with the return sludge. The balance is fed 21.7 m (71 ft) from the head of the first pass. The final clarifiers are each 14.9 m (49 ft) in diameter with a sidewater depth of 2.7 m (8.9 ft). The floor slope is 30°. The detention time and surface loading at DWF are 6 hr and 16.9 m^3/m^2/day (414 gpd/ft^2), respectively.

Air is supplied by four Waller two-speed centrifugal blowers after filtration through two bag type air filters, each of which is sized to handle the full air flow. The bag filters are precoated with an asbestos coating and require cleaning every 2 yr.

Performance

Staff of Severn Trent Water Authority at Coalport provided plant performance data for 1978/79, as shown below:

TABLE B-28. COALPORT INFLUENT-EFFLUENT DATA SUMMARY

Average Flow:	mgd	3.24
	m^3/day	12,300
BOD_5:	(kg/day)*	
	Load imposed	1927
	Load removed	1820
NH_3-N:	(kg/day)*	
	Load imposed	354
	Load removed	341
TSS:	(kg/day)*	
	Load imposed	1198
	Load removed	1125

* 1 kg/day = 2.21 lb/day

Influent flow averaged 12,300 m^3/day (3.24 mgd). BOD_5 to the aeration basin averaged 157 mg/l and influent NH_3-N averaged 29 mg/l. The F/M loading averaged 0.14 kg BOD_5/day/kg MLSS and ranged from 0.11-0.20. MLSS averaged 2500 mg/l. Monthly loadings varied about ± 25 percent from annual averages. Flow to this plant is mostly domestic with some light industrial contributions. BOD_5 and suspended solids were removed on an average of 94 percent each through the combined primary and secondary processes.

Based on an average aeration power consumption of 3047 kWh/day (4086 wire hp-hr/day), aeration efficiency averaged 1.08 kg O_2/kWh (1.78 lb/wire hp-hr), with 1.13 units oxygen required/unit BOD_5 removed. This is on the low side of the plants surveyed but can probably be accounted for by high mixed liquor D.O. The plant operators noted that, even with the uneven air distribution, aeration D.O. was normally quite high in the second pass of the two-pass system. Previously, the plant had been operated at even lower flows with all four aeration basins in operation. A change in management resulted in cutting out one basin to improve aeration efficiency.

Based on an average air flow rate of 158,640 m^3/day (5600 x 10^3 ft^3/day), air flow per dome is 0.9 cfm (0.025 m^3/min) in the first pass and 0.6 cfm (0.017 m^3/min) in the second. Plant operators limit minimum air flows to 0.5 cfm (0.014 m^3/min) in the second pass. Based on this minimum air flow rate, mixing data for the Coalport plant are given in Table B-29. Coalport's power input at minimum air flow is typical among the surveyed plants.

TABLE B-29. COALPORT MIXING DATA

Parameter	First Pass	Second Pass
Air Flow/Basin:*		
cfm	777	519
m^3/min	22.0	14.7
Air Flow/Area:*		
cfm/ft^2	0.23	0.16
m^3/min/m^2	0.07	0.05
Air Flow/Volume* (cfm/1000 ft^3)+	13.2	8.8
Minimum Power Input:		
wire hp/1000 ft^3	25	16.7
W/m^3	0.95	0.63

* Based on a minimum air flow rate of 0.014 m^3/min/dome (0.5 cfm/dome).
\+ Same as m^3/1000 m^3/min.

Operation and Maintenance

Coalport has accrued 9 yr of continuous operating experience with very few problems. Aeration tanks are routinely cleaned once every year. Inspection of the empty tanks revealed no evidence of scale build-up or solids deposition. Some coarse bubbling was noticeable at the inlet and one-third point feed zone, being most severe in the latter. This can most likely be attributed to the growth of slime on the domes in the feed zones. Air filters have performed satisfactorily, with no non-routine maintenance required.

COLESHILL

History and Background

The Coleshill treatment plant, shown in Figure B-10, was constructed in three stages. The first stage was commissioned between 1931 and 1934 and was one of the first activated sludge plants in the world. The second stage, a nearly identical duplicate of Stage 1, was constructed between 1939 and 1942, along with additional final clarifiers for the first stage. The capacity of the two stages then was 11,400 m^3/day (3 mgd).

The original concept was to develop this plant as five identical stages. Rapid increases in flow due to population growth and industrial expansion forced reconsideration of this approach, and the final stage was designed as a 54,500 m^3/day (14.3 mgd) dome diffuser activated sludge plant. The first two stages were then removed from service to be renovated by 1971 and reopened when flows increased further.

The third stage was constructed and opened by sections in the period 1968-1971. Excess sludge from the new plant was initially handled in existing facilities. In 1976, construction of a sludge incineration plant serving both Coleshill and Minworth was started on an adjacent site.

Plant Description

Described herein and detailed in Table B-30 are the basic design parameters for the third stage plant at Coleshill.

Primary settling is provided by eight rectangular clarifiers providing 8 hr of detention time at the DWF of 54,100 m^3/day (14.3 mgd). Primary settling is sized to accept flows up to 3 x DWF, with excess flows going to the stormwater overflow tanks.

The eight aeration tanks are coupled individually to the eight final clarifiers. Return sludge from each clarifier is individually pumped to its associated aeration basin, with provision for cross connection should either an aeration basin or a clarifier be taken out of service. Detention times at DWF in the aeration basins and final clarifiers are 12 hr and 6 hr, respectively. The maximum surface loading (3 x DWF) is 38.9 m^3/m^2/day (954 gpd/ft^2).

Initially, the aeration tanks were equipped with 3100 domes each. In an effort to improve plant performance by introducing intentional denitrification, domes have been removed from five of the tanks, Nos. 1, 2, and 6-8, to create anoxic zones at the influent ends, similar to those at Minworth. Tank Nos. 1 and 2 now have 2186 domes each; Tank Nos. 6-8 have 2153 domes each. The remaining tanks have 3100 domes each and were not in service at the time of the plant visit. These tanks remain in the initial configuration whereby 50 per-

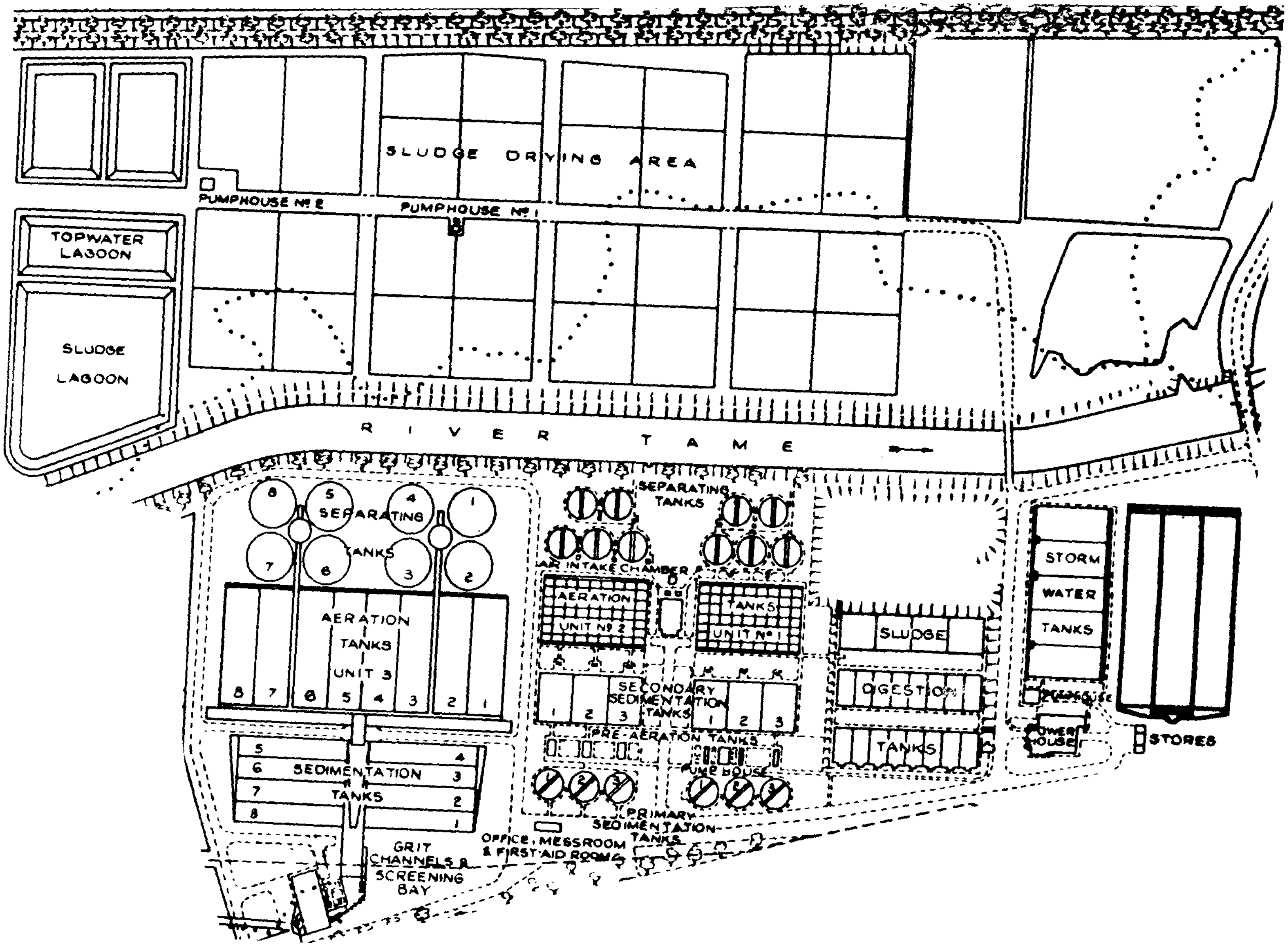


Figure B-10. Coleshill site plan.

TABLE B-30. COLESHILL DESIGN DATA*+

Stormwater Tanks

3 Rectangular Tanks	20 m° x 105 m° x 3.2 m° SWD
Total volume:	192,650 m^3**

Primary Sedimentation

8 Rectangular Clarifiers	10.7 m x 61 m x 3.5 m SWD
Detention time:	8 hr @ DWF
Surface loading:	10.3 m^3/m^2/day (253 gpd/ft^2)

Aeration Basins

8 Rectangular Tanks	18.3 m x 64 m x 2.9 m SWD
Detention time:	12 hr @ DWF

Diffuser Configuration:

Aeration Tank & Section Nos.	Tank Section Length (m)	No. of Domes	Diffuser Density (domes/m^2)++
Tank Nos. 1,2,6-8:			
Section 1	16.5	206	0.7
Section 2	4.9	394	4.4
Section 3	42.7	1586	2.0
Tank Nos. 3-5:			
Section 1	21.3	1538	3.9
Section 2	42.7	1562	2.0

Final Sedimentation

8 Circular Clarifiers	
Diameter:	26 m
Sidewater depth:	2.4 m
Floor slope:	20°
Detention time:	6 hr @ DWF
Surface loading:	13.0 m^3/m^2/day @ DWF (318 gpd/ft^2)

* For Stage 3 only.
\+ DWF = 54,100 m^3/day (14.3 mgd)
° 1 m = 3.28 ft
** 1 m^3 = 35.3 ft^3
++ 1 dome/m^2 = 9.29 domes/100 ft^2

cent of the domes are concentrated in the first one-third of the tank, with the remaining 50 percent distributed equally across the last two-thirds of the tank floor.

Air supply is provided by 16 56-kW (75-hp) Rootes type blowers, each rated at 45.3 m^3/min (1600 cfm). Two blowers are matched to each aeration tank, with provision for cross connection when units are out of service. Two bag filters, located at either end of a common feed duct for the blowers, provide filtered air.

Performance

In an effort to improve plant performance and reduce secondary settling problems, this plant has been operated experimentally in several modes over the last few years. A problem with denitrification occurs in the secondary clarifiers. This is caused by high concentrations of ammonia in the plant influent and production of a nitrified effluent, resulting in frequent episodes of poor effluent quality, particularly during the summer months. To improve energy efficiency, as well as reduce denitrification problems, Tank Nos. 1, 2, and 6-8 were modified by removing domes from the first 15+ m (50+ ft) (Table B-30), creating anoxic zones where denitrification could occur. Tank Nos. 3-5 were placed on a standby and the loading increased to the other tanks to reduce the detention time and increase the F/M loading from 0.05 to 0.1 kg BOD_5/day/kg MLSS. MLSS were maintained in the range of 3000-3500 mg/l.

Performance data were provided by plant personnel for the period September 1, 1978 to August 30, 1979, as follows:

Average Flow	51,200 m^3/day (13.5 mgd)
BOD_5 Removed	146 mg/l
NH_3-N Removed	30 mg/l
Denitrification	1000 kg/day (2205 lb/day) NO_3-N removed
Air Flow/Dome	0.025 m^3/min (0.88 cfm)
Power Consumed	6130 kWh/day (8220 wire hp-hr/day)

Based on the above figures, aeration efficiency and mixing parameters have been computed as shown in Table B-31. In the present configuration, the plant is one of the more energy efficient visited and is significantly more energy efficient than the Minworth plant, even though both plants have similar configurations and similar volumetric loadings. Plant personnel indicated a belief that aeration efficiency was increased substantially when flow was concentrated in five of the eight tanks. Mixed liquor D.O. ranges from 0.0 mg/l in the anoxic zones to 2-4 mg/l at the effluent end of the aeration tanks.

Operation and Maintenance

Plant personnel reported no major problems with the dome diffuser equipment or air filters. Similar O&M procedures to those at Minworth are followed. Tanks are cleaned and domes are checked annually. Air filters require cleaning once per year as well. Coleshill reported no significant settling of suspended solids in the aeration basin, even in the lightly mixed anoxic zones. Coarse bubbling of the air from partially blocked domes was most noticeable in

TABLE B-31. COLESHILL AERATION EFFICIENCY CALCULATIONS AND MIXING DATA

AERATION EFFICIENCY CALCULATIONS

BOD_5 Removed (kg/day)*	7480
NH_3-N Removed (kg/day)*	1537
NO_3-N Produced (kg/day)*	1000
O_2 Required+ (kg/day)*	13,005
Power Consumed (kWh/day)°	6130
Aeration Efficiency:	
kg O_2/kWh	2.12
lb O_2/wire hp-hr	3.49

MIXING DATA

Air Flow (Tanks 6-8)**	cfm	m^3/min
Anoxic Zone	191	5.4
First Aeration Zone	307	8.7
Second Aeration Zone	1391	39.4
Air Flow/Area**	**cfm/ft^2**	**m^3/m^2/min**
Anoxic Zone	0.056	0.017
First Aeration Zone	0.37	0.113
Second Aeration Zone	0.17	0.052
Air Flow/Volume**	**cfm/1000 ft^3++**	
Anoxic Zone	6.0	
First Aeration Zone	38.6	
Second Aeration Zone	17.5	
Average Power Input	**wire hp/1000 ft^3**	**W/m^3**
Anoxic Zone	0.22	5.7
First Aeration Zone	1.40	36.9
Second Aeration Zone	0.63	16.7

* 1 kg = 2.21 lb

\+ Calculated by the method of Section 5, assuming 1.20 units O_2 required/unit BOD_5 removed.

° 1 kWh/day = 1.34 wire hp-hr/day

** Based on an average air flow rate of 0.025 m^3/min/dome (0.88 cfm/dome).

++ Same as m^3/1000 m^3/min.

the anoxic zones and the immediately downstream aeration zones.

FINHAM

History and Background

The Finham Plant, shown in Figure B-11, was constructed over a period of years, beginning in 1932 with the startup of a 13,600-m^3/day (3.6-mgd) trickling filter plant. Numerous additions were made over the years, including activated sludge pretreatment systems for both the North and South works. The South activated sludge plant began operation in 1955 with fine bubble aeration using 10-cm (4-in.) ceramic domes. No air filtration was provided, and considerable problems with diffuser clogging were encountered. In 1963, the aeration system was converted to coarse bubble diffusers. The coarse bubble system performed satisfactorily but was replaced in 1974 by a dome diffuser fine bubble aeration system to improve oxygen transfer and remedy mechanical failures. Air filtration, employing two-element air filters, was added to the blower facility.

The North activated sludge plant was added in 1963 as a pretreatment stage to the North works trickling filters. It was initially equipped with coarse bubble aeration, which has remained in service to the present. Plans are being made to retrofit this plant with fine bubble equipment in the future.

Plant Description

Influent wastewater enters at opposite ends of the site, where it is screened and degritted. Stormwater overflow tanks are located at each inlet works as well. Both lines feed to a common splitter box for diversion to either the North or South works. Each plant has three primary clarifiers, each 35 m (115 ft) in diameter and with a sidewater depth of 3.7 m (12 ft). All of the flow receives primary treatment; part of the flow is then diverted to activated sludge treatment to reduce organic loading on the trickling filter beds.

Table B-32 summarizes design details for the North and South activated sludge plants. The South works has six aeration basins, each with 800 dome diffusers distributed evenly on four longitudinal rows. Domes are spaced 0.30 m (1.0 ft) on centers with 4.9 m (1.6 ft) between rows. The normal operating configuration is one tank reaerating return sludge, four tanks aerating mixed liquor, and one tank on standby. The detention time at DWF is 3.5 hr. Four Rootes type air compressors supply air to the South plant. The blowers each deliver 46.7 m^3/min (1650 cfm) at 41.4 kN/m^2 (6.0 psi). Air cleaning is provided by two-element Vokes air filters mounted on a common intake manifold for each pair of blowers. Four prefilters and four high efficiency filters are provided for each paired intake manifold.

Three final clarifiers serve the South works, averaging 3.5-hr detention time at DWF. The clarifiers are equipped with steeply sloped (30°) floors and simple peripheral drive scrapers.

The North plant has four aeration basins, providing 1-hr detention time

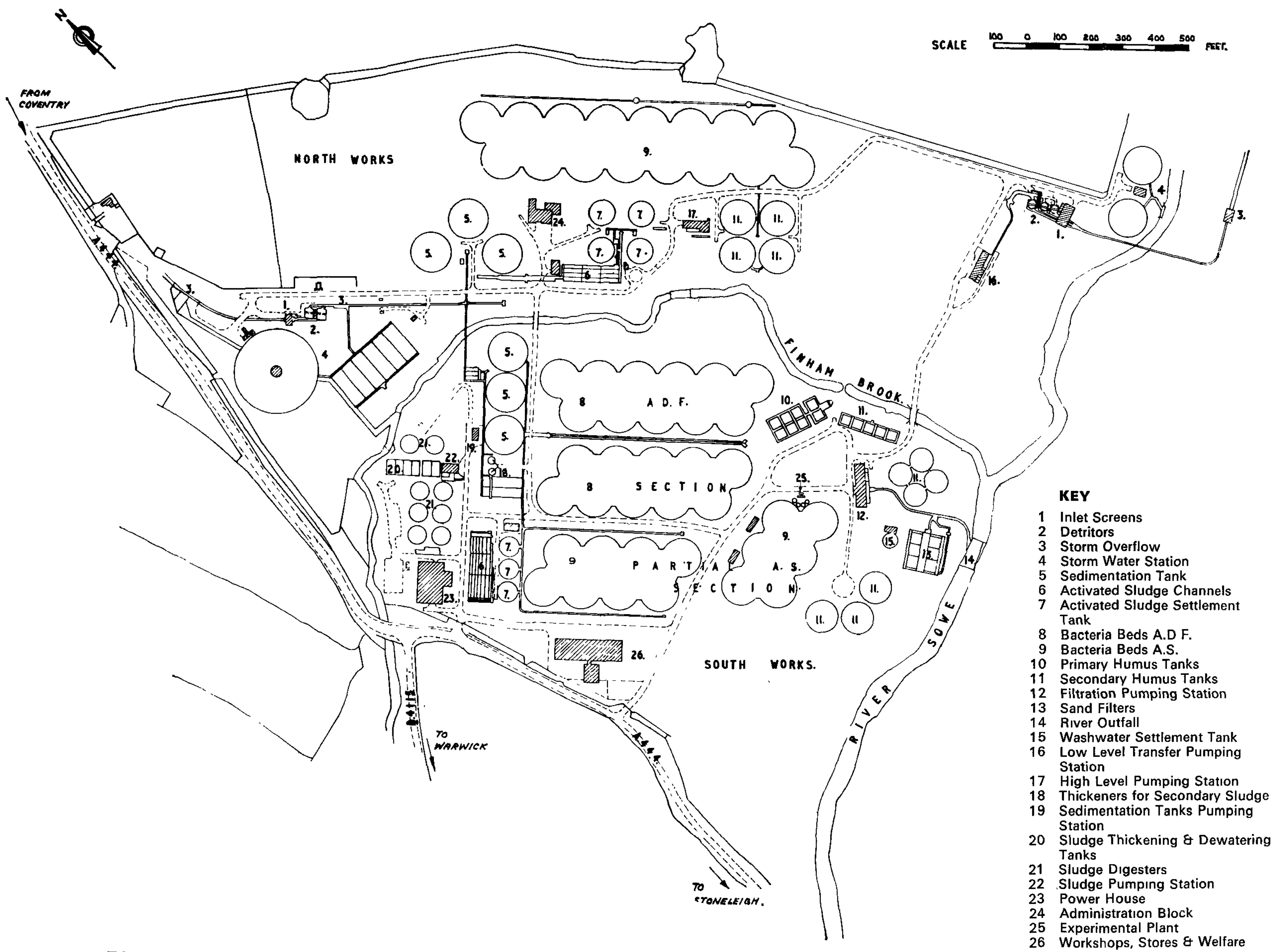


Figure B-11. Finham site plan.

at DWF. Air flow to the coarse bubble diffusers is tapered along the length of the tanks. Three of the tanks aerate mixed liquor; one is used for sludge reaeration.

Seven Rootes-type blowers provide air to the North works. Two units are rated at 28.3 m^3/min (1000 cfm); five are rated at 36.8 m^3/min (1300 cfm). Pressure at rated air flow for all seven blowers is 41.4 kN/m^2 (6.0 psi). No air cleaning is provided for this coarse bubble aeration system.

Four final clarifiers serve the North activated sludge plant with a detention time at DWF of 3.5 hr.

TABLE B-32. FINHAM DESIGN DATA

	South Plant*	North Plant+
Aeration Basins		
Number	6	4
Dimensions:		
Length (m)°	61.0	49.4
Width (m)°	3.0	3.0
Sidewater depth (m)°	3.6	3.8
Volume** (m^3)++	656	563
Detention Time°° (hr)	3.5	1.0
Final Clarifiers		
Number	3	3
Dimensions:		
Diameter (m)	18.5	23
Sidewater depth (m)	3.0	3
Detention Time°° (hr)	3.5	3.5
Surface Loading°° m^3/m^2/day	28.8	33.1
(gpd/ft2)	(707)	(813)

* DWF = 22,700 m^3/day (6.0 mgd)
\+ DWF = 54,500 m^3/day (14.4 mgd)
° 1 m = 3.28 ft
** Each tank.
++ 1 m^3 = 35.3 ft^3
°° At DWF.

Performance

Data for the year beginning April 1, 1978, and ending March 31, 1979, was provided for both sections of this plant, as shown in Table B-33. Because the activated sludge plants are used for pretreatment at Finham, F/M loading rates are high; 0.45 kg BOD_5/day/kg MLSS in the South works and 1.80 kg BOD_5/day/kg MLSS in the North plant. Finham South averages 50 percent removal of BOD_5 in the primary and 72 percent removal in secondary for an overall removal averaging 90 percent. Finham North removes 42 percent of the BOD_5 in the primary section and 65 percent in the secondary for an overall removal of approximately 80 percent. Suspended solids removal is similar in the two plants, and the North plant removes about 18 percent of the influent ammonia nitrogen.

TABLE B-33. FINHAM INFLUENT-EFFLUENT DATA SUMMARY*

Parameter	Finham South	Finham North
Flow: mgd	7.5	11.4
m^3/day	28,300	43,000
Raw Wastewater: (mg/l)		
BOD_5	321	258
COD	812	632
TSS	475	315
NH_3-N	29	28
Detergent+	10	11
Primary Effluent: (mg/l)		
BOD_5	162	150
COD	348	352
TSS	128	133
NH_3-N	28	28
Detergent+	10	11
Final Effluent: (mg/l)		
BOD_5	32	53
COD	118	147
TSS	40	50
NH_3-N	26	23
Detergent+	5	8
MLSS (mg/l)	2500	2000

* For the data year beginning April 1, 1978, and ending March 31, 1979.
\+ Detergent as manoxyl OT (a proprietary ABS type compound).

Calculated aeration efficiencies (Table B-34) seem to indicate that the fine bubble diffuser system (South plant) is performing only marginally better than the coarse bubble diffuser system (North plant). However, lacking mixed liquor D.O. data, and in view of the rough estimates used for power, it is possible that figures for both plants are seriously in error. Also, the method of analysis, derived for more lightly loaded plants, may seriously overstate oxygen requirements for the heavily loaded North plant.

At an average total system air flow rate of 140 m^3/min (4960 cfm), the average air flow rate per dome in the South plant approximates 0.035 m^3/min/dome (1.24 cfm/dome). This is well within the range required for efficient performance. Mixing power input is moderately high at 36 W/m^3 (1.37 wire hp/1000 ft^3). Diffuser density is more typical at 4.3 domes/m^2 (39.9 domes/100 ft^2). The air flow per unit volume is 42.7 m^3/1000 m^3/min in the South plant. By comparison, mixing power input in the North plant is 51.5 W/m^3 (1.96 wire hp/1000 ft^3) and the air flow per unit volume is 50.4 m^3/1000 m^3/min.

TABLE B-34. FINHAM AERATION EFFICIENCY CALCULATIONS

Parameter	Finham South	Finham North
BOD_5 Removed (kg/day)*	4680	4171
NH_3-N Removed (kg/day)*	56.6	215
O_2 Removed+ (kg/day)*	4920	4180
Power Consumed° (kWh/day)**	2800	2784
Aeration Efficiency:		
kg O_2/kWh	1.76	1.50
lb O_2/wire hp-hr	2.89	2.47

* 1 kg = 2.21 lb
\+ Calculated by the method of Section 5, assuming 0.88 units O_2 required/unit BOD_5 removed for Finham South and 0.78 units O_2 required/unit BOD_5 removed for Finham North.
° Estimated data.
** 1 kWh/day = 1.34 wire hp-hr/day.

Operation and Maintenance

The Finham plant staff reported very few maintenance problems with the dome diffuser plant. Since 1974, it has only been necessary to repair several small air distribution line leaks and to change the air filter elements every 18 wk at a total cost of less than £ 1500 ($3,000/yr). An inspection of the air filters indicated that they are trapping exhaust mists from the dual fuel engines that are located in the blower room along with the air intakes. It is likely that providing an outside intake might significantly reduce fouling of the air filters, lowering the annual cost of changing filter elements.

HARTSHILL

History and Background

The Borough of Nuneaton established treatment works in 1871, opening a primary sedimentation plant, assisted by chemical coagulation, on the site of the present day St. Mary's Road pumping station. In 1901, steam driven pumps were installed at St. Mary's Road to pump wastewater 4 km (2 1/2 mi) to the Hartshill site. There, the wastewater was given primary treatment followed by trickling filtration. Subsequent expansions were carried out at Hartshill in 1920, 1939, and 1973, when the fine bubble dome diffuser activated sludge plant was added. A site plan for the current works at Hartshill is presented in Figure B-12.

Plant Description

Screening and grit removal are carried out at the St. Mary's Road pumping station, which is also provided with three stormwater overflow basins, totalling 7592 m^3 (268,100 ft^3) in volume.

The design DWF is 24,500 m^3/day (6.46 mgd) based on a population of 80,500. The treatment works are designed to treat 3 x DWF, and extensions can be made to treat 104,500 m^3/day (27.6 mgd) from a population of 100,000, the works pipelines, channels, etc., having been sized for this flow. The preliminary treatment works at St. Mary's Road is designed to receive a maximum flow of 227,000 m^3/day (60 mgd) and to pump to Hartshill Sewage Treatment Works a maximum of 78,700 m^3/day (20.8 mgd), the remaining storm sewage being given partial treatment before discharge to the River Anker. The partial treatment is designed to produce an effluent with a suspended solids concentration not exceeding 150 mg/l.

Table B-35 provides design details for the settling basins, aeration process, and blower system at Hartshill. The plant is comprised of three primary clarifiers, six aeration basins, two sludge reaeration basins, and eight final clarifiers. Each aeration basin has 740 domes in the inlet half and 520 domes in the outlet half. The reaeration basins have about 400 domes apiece.

Aeration basin dome configuration consists of 16 longitudinal rows equally spaced on the tank floor, with 30.5 cm (1 ft) between domes in the first half of the tank and 42.7 cm (1.4 ft) in the second half.

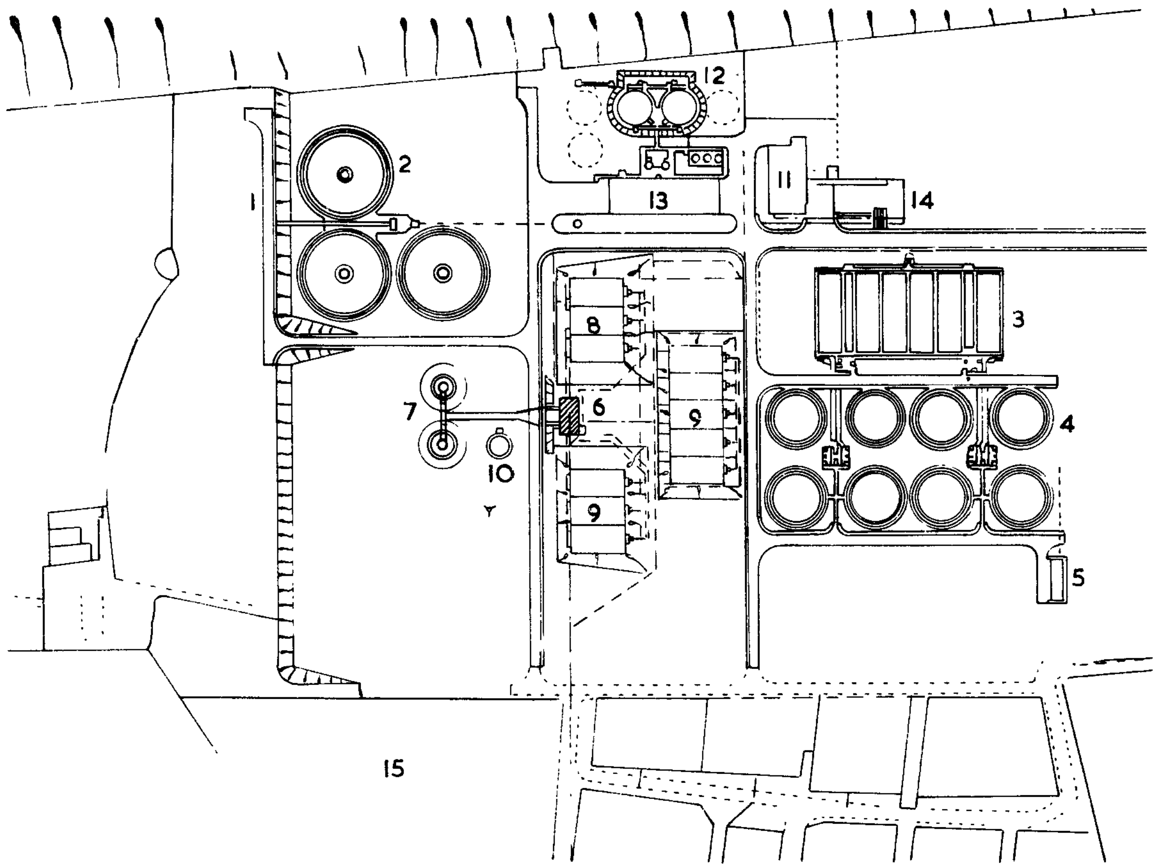
Air supply is provided by three positive displacement (Rootes-type) air blowers, two variable and one fixed speed. Air is drawn from a common air duct supplied by three electrostatic air cleaners, any two of which can supply the maximum air flow demand.

The final clarifiers have steeply sloped floors (30°) and shallow sidewater depths, 1.37 m (4.5 ft), characteristic of many dome diffuser activated sludge plants in the United Kingdom.

Performance

Meaningful long-term performance data were not available for this plant due to the effects of variable industrial loading, principally rendering wastes. However, performance can be estimated from current monthly average loading conditions, as shown below:

Flow	21,700 m^3/day (5.73 mgd)
BOD_5 Removed	330 mg/l



KEY

1.	WORKS INLET	9.	SECONDARY DIGESTION TANKS
2	PRIMARY SETTLEMENT TANKS	10.	GAS HOLDER
3.	ACTIVATED SLUDGE PLANT	11.	COMPRESSOR HOUSE AND WORKS DRAINAGE PUMPING STATION
4.	FINAL SETTLEMENT TANKS	12.	ELUTRIATION TANKS
5.	EFFLUENT PUMPING STATION	13.	SLUDGE PRESS HOUSE
6	SLUDGE PUMPING STATION	14.	ADMINISTRATION BUILDING
7.	PRIMARY SLUDGE DIGESTION TANKS	15.	SLUDGE STORAGE LAGOON
8.	CONSOLIDATION TANKS		

Figure B-12. Hartshill site plan.

TABLE B-35. HARTSHILL DESIGN DATA*

Stormwater Tanks		
3 Circular Tanks		
Diameter:	25.3 m+	
Sidewater depth:	4.4 m+	
Floor slope:	6°	
Total volume:	7952 m^3°	
Detention time:	7.5 hr @ DWF	
Primary Sedimentation		
3 Circular Clarifiers		
Diameter:	27.4 m	
Sidewater depth:	3.0 m	
Floor slope:	7.5°	
Detention time:	6.3 hr @ DWF	
Surface loading:	14.2 m^3/m^2/day (348 gpd/ft^2)	
Aeration Basins		
6 Aeration Tanks	9.2 m x 27.4 m x 3.2 m SWD	
2 Reaeration Tanks	3.0 m x 27.4 m x 3.2 m SWD	
Overall detention time:	5.5 hr @ DWF	
Diffuser Configuration:		
	No. of Domes	Diffuser Density (domes/m^2)**
Aeration Tanks:		
First 1/2	740	5.9
Second 1/2	520	4.1
Reaeration Tanks:	400	4.9
Final Sedimentation		
8 Circular Clarifiers		
Diameter:	17.4 m	
Sidewater depth:	1.4 m	
Floor slope:	30°	
Detention time:	59 hr @ DWF	
Surface loading:	13.0 m^3/m^2/day (318 gpd/ft^2)	

* DWF = 24,500 m^3/day (6.46 mgd)
\+ 1 m = 3.28 ft
° 1 m^3 = 35.3 ft^3
** 1 dome/m^2 = 9.29 domes/100 ft^2

NH_3-N Removed	40 mg/l
MLSS	4000 mg/l
Air Flow	211 m^3/min (7440 cfm)
Power Consumed	9,600 kWh/day (12,874 wire hp-hr/day)

Aeration efficiency calculations and mixing data based on these figures are presented in Table B-36. The influent wastewater strength at Hartshill is quite high, ranging from 500-700 mg/l BOD_5 due to the varying contribution of the rendering waste, which is often shock loaded into the system. Nitrification, as a result, tends to be variable. Because of a high loading rate of ammonia nitrogen, 50-70 mg/l, the plant experiences periodic episodes of denitrification with resultant sludge blanket flotation in the final clarifiers.

The apparent aeration efficiency at this plant falls in the lower range among the plants visited at 1.11 kg O_2/kWh (1.82 lb/wire hp-hr). Possible causes for the low efficiency may include the variable strength of the wastewater, which could depress the alpha factor, and the relative shallowness of the tanks.

The relatively low oxygen transfer efficiency at this plant necessitates relatively high air flow requirements, placing mixing power levels in the upper range of the plants surveyed. Observation of the tanks, verified by plant personnel, indicated that the aeration basins were well mixed. D.O. ranged from 20-80 percent of saturation, tending toward the higher level at the aeration tank exits. Plant operators try to keep D.O. levels fairly high as an aid in suppressing denitrification and absorbing shock loads from the rendering plant.

Operation and Maintenance

The dome diffusers at Hartshill have been in service since 1973 with no instances of failure or cleaning. Observation of the tanks, however, revealed substantial coarse bubbling in the front third of the aeration tanks, probably caused by the high volumetric loading of this area of the plug flow tanks and concomitant biological fouling of the dome exteriors (see Section 6). Blower pressure has remained steady over the period at about 37.9 kN/m^2 (5.5 psi).

The electrostatic air filters have performed well, requiring light washing every several weeks and a more thorough caustic wash annually. At start-up, problems with deterioration of the air filter grids caused by vibration from the air compressors were experienced. Pulsation of the air compressors set up a pulsing action in the air flow that damaged the air filter internals. To solve the problem, individual air dampeners were added at the inlet of each compressor.

MINWORTH

History and Background

TABLE B-36. HARTSHILL AERATION EFFICIENCY CALCULATIONS AND MIXING DATA

AERATION EFFICIENCY CALCULATIONS		
BOD_5 Removed (kg/day)*	7164	
NH_3-N Removed (kg/day)*	868	
O_2 Required+ (kg/day)*	10,682	
Power Consumed (kWh/day)°	9600	
Aeration Efficiency:		
kg O_2/kWh	1.11	
lb O_2/wire hp-hr	1.82	
MIXING DATA		
Air Flow**	cfm	m^3/min
Aeration Tanks:		
First 1/2	657	18.6
Second 1/2	583	16.5
Reaeration Tanks	353	10.0
Air Flow/Area**	cfm/ft^2	m^3/m^2/min
Aeration Tanks:		
First 1/2	0.53	0.16
Second 1/2	0.46	0.14
Reaeration Tanks	0.39	0.12
Air Flow/Volume **	cfm/1000 ft^3++	
Aeration Tanks:		
First 1/2	46.4	
Second 1/2	41.1	
Reaeration Tanks	38.6	
Average Power Input	wire hp/1000 ft^3	W/m^3
Aeration Tanks:		
First 1/2	3.35	88.2
Second 1/2	2.36	62.0
Reaeration Tanks	2.73	71.8

* 1 kg = 2.21 lb

\+ Calculated by the method of Section 5, assuming 0.97 units O_2 required/unit BOD_5 removed.

° 1 kWh/day = 1.34 wire hp-hr/day

** Based on an average air flow rate of 0.025 m^3/min/dome (0.88 cfm/dome).

++ Same as m^3/1000 m^3/min.

Wastewater treatment at Minworth began in the late 1800's with the utilization of the site for land application. During the period from 1905-1921, six large rectangular trickling filters were constructed on the site, providing a total bed area of 17 ha (42 ac).

By the end of World War II, the treatment system, comprising Minworth and four other plants, was overloaded and it was decided to concentrate service at Minworth, modernizing that plant and gradually shutting down the other plants. By 1952, 3.2 ha (8.0 ac) of the trickling filters had been upgraded along with the provision of improved sludge handling facilities. The period 1960-1970 saw extensive construction to improve interceptor sewers and major rehabilitation and expansion of the Minworth plant. In 1971, the activated sludge plant was completed and the plant was substantially completed as shown in Figure B-13.

Plant Description

Primary settling for the entire plant is provided by 10 rectangular tanks, each 76.2 m x 48.8 m x 3.0 m SWD (250 ft x 160 ft x 10 ft) with 7.5 hr detention time at the current average flow of 272,500 m^3/day (72 mgd). Surface loading at DWF is 7.2 m^3/m^2/day (177 gpd/ft^2). These are supplemented by six stormwater tanks with a total volume of 69,000 m^3 (2.44 million ft^3).

Twelve aeration tanks and 24 final settling tanks comprise the activated sludge plant at Minworth. Design parameters are shown in Table B-37.

TABLE B-37. MINWORTH DESIGN DATA

Aeration Basins

12 Rectangular Tanks (3 groups of 4 each)	18.3 m* x 178 m* x 3.0 m* SWD
Detention time:	14.5 hr @ DWF with 1 tank out of service

Diffuser Configuration:

Section	Length (m)	No. of Domes	Diffuser Density (domes/m^2)+
First 1/6	29.7	756	1.4
Second 1/6	29.7	3375	6.2
Final 2/3	118.6	6750	3.1

Final Sedimentation

24 Circular Clarifiers

Diameter:	27.4 m
Sidewater depth:	2.1 m
Floor slope:	19.5°
Detention time:	6 hr at DWF
Surface loading:	10.8 m^3/m^2/day (265 gpd/ft^2)

* 1 m = 3.28 ft

\+ 1 dome/m^2 = 9.29 domes/100 ft^2

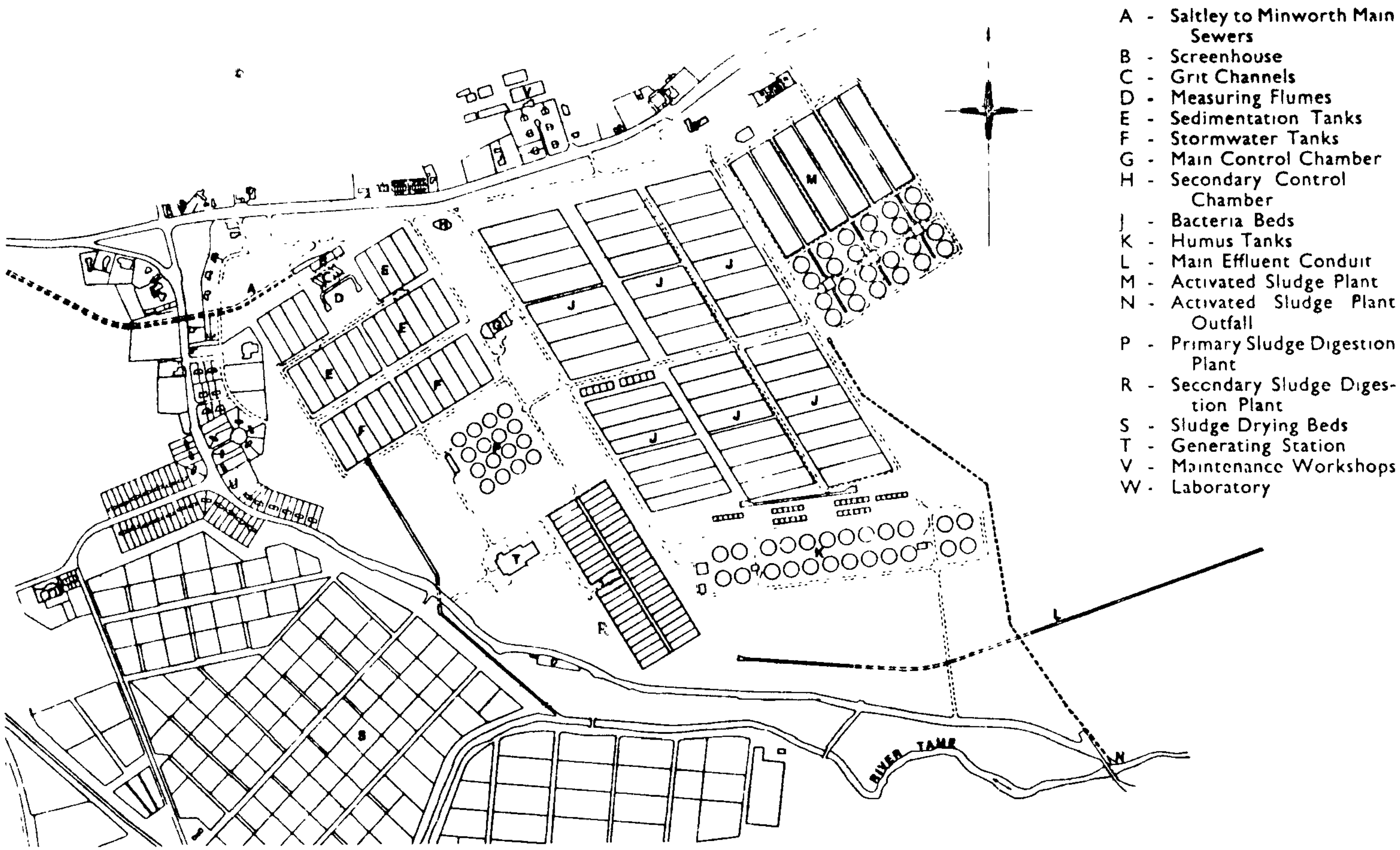


Figure B-13. Minworth site plan.

Diffuser domes are spaced on 0.61-m (2-ft) centers in the first one-third of each aeration tank and 1.22-m (4-ft) centers in the final two-thirds of each tank. To promote denitrification and reduce aeration power, most of the first grid of 2600 domes in each tank have been turned off, essentially halving the aeration zone in the first one-sixth of each tank.

Air is supplied by eight centrifugal blowers, as follows:

2 - 336 kW (450 hp), 326 m^3/min (11,500 cfm)
2 - 410 kW (550 hp), 411 m^3/min (14,500 cfm)
4 - 485 kW (650 hp), 496 m^3/min (17,500 cfm)

Air filtration is provided by bag filters.

Performance

Performance data for the secondary system were provided by Minworth personnel for the year ending December 1978 and are summarized below:

TABLE B-38. MINWORTH INFLUENT-EFFLUENT DATA SUMMARY

Average Flow:	274,000 m^3/day (72.4 mgd)
BOD_5: (mg/l)	
Influent	142
Effluent	6
COD: (mg/l)	
Influent	353
Effluent	13
TSS: (mg/l)	
Influent	144
Effluent	13
NH_3-N: (mg/l)	
Influent	21
Effluent	2.6
NO_3-N: (mg/l)	
Influent	1.9
Effluent	16
MLSS (mg/l)	3400 (avg.)

Secondary removals in 1978 averaged 96 percent for BOD_5, 91 percent for suspended solids, and 87 percent for NH_3-N. Average air flow was 1189 m^3/min (42,000 cfm) for the 12 tanks with 8360 active domes in each for an air flow rate of 0.011 m^3/min/dome (0.4 cfm/dome). The average F/M loading for 1978 was 0.9 kg BOD_5/day/kg MLSS. About 17 percent of the flow to this plant is industrial in origin from chemical, metal finishing, and food processing sources.

Table B-39 summarizes aeration efficiency calculations and mixing data for the aeration process at Minworth. Aeration efficiency falls in the middle range of the plants visited, at 1.71 kg O_2/kWh (2.81 lb/wire hp-hr). Mixing power levels are similar to that of the Beckton plant with the exception of the first section. Plant personnel stated that when the tanks are given an annual cleaning, some solids deposition, 20-30 cm (8-12 in.), is evident in this zone. Little deposition occurs in other parts of the tank.

Operation and Maintenance

Dome diffusers have been in continuous operation at Minworth since 1971. The only maintenance procedure routinely used is an annual aeration tank cleaning and brushing of the domes. There have been a few failures of the air supply piping connections and hold-down bolts. Air cleaning equipment is routinely cleaned on an annual basis.

STRONGFORD

While visiting plants of the Severn Trent Water Authority, a brief visit was made to the works at Strongford. The original plant, dating back to the 1930's, was recently expanded with the addition of a second parallel plant using fine bubble dome diffusers in 1973. At that time, the original plant was converted to dome diffusers as well. The new plant was equipped with four single-pass basins per aeration tank, 1950 diffusers per basin. Each new basin is 108 m x 9.1 m x 3.0 m SWD (354 ft x 30.0 ft x 10.0 ft). The domes are uniformly distributed with the exception that the first 27 m (88 ft) of each tank has 10 lines of domes on 0.46-m (1.5-ft) centers. The remaining segment of each tank has eight lines with domes on 0.46-m (1.5-ft) centers.

The old plant has 10 two-pass plug flow aeration tanks, each sized 64 m x 2.7 m x 3.0 m SWD (210 ft x 9.0 ft x 10.0 ft). These extremely narrow tanks are only moderately tapered with approximately 30 percent of the 800 domes (per two-pass tank) installed in three rows in the first half of the first pass. The balance of each tank has two rows of domes on 0.37-m (1.2-ft) centers.

Several problems have combined to severely reduce oxygen transfer efficiency at this plant. Typically, the plant has been designed for future rather than present flows and, thus, was underloaded at startup. Adding to this is the waste discharged from extensive pottery and china making operations at Stoke on Trent. The clay material in the effluent from these operations acts like a coagulating agent, significantly improving primary clarifier performance. Primary BOD_5 and suspended solids removals of 70-80 percent are common at this plant. A plant performance evaluation conducted by Hawker-Siddeley in 1976 and repeated in 1978 indicated that mixed liquor D.O. approached saturation in most of the plant for 16-20 hr/day. Using the data provided in this Hawker-Siddeley evaluation, aeration efficiency in the new plant was estimated at 1.49 kg O_2/kWh (2.45 lb/wire hp-hr) by the method of Section 5 for the new plant. The average aeration efficiency could vary substantially from this estimate, however, as the computation was based on a single day grab sampled analysis.

TABLE B-39. MINWORTH AERATION EFFICIENCY CALCULATIONS AND MIXING DATA

AERATION EFFICIENCY CALCULATIONS

BOD_5 Removed (kg/day)*	37,182
NH_3-N Removed (kg/day)*	4932
NO_3-N Produced (kg/day)*	3726
O_2 Required+ (kg/day)*	65,577
Power Consumed (kWh/day)°	38,360
Aeration Efficiency:	
kg O_2/kWh	1.71
lb O_2/wire hp-hr	2.81

MIXING DATA

Air Flow**	cfm	m^3/min
First 1/6 of Tank	109	3.1
Second 1/6 of Tank	1144	32.4
Final 2/3 of Tank	2291	64.9

Air Flow/Area**	cfm/ft^2	m^3/m^2/min
First 1/6 of Tank	0.020	0.006
Second 1/6 of Tank	0.197	0.060
Final 2/3 of Tank	0.098	0.030

Air Flow/Volume**	cfm/1000 ft^3++
First 1/6 of Tank	4.8
Second 1/6 of Tank	28.4
Final 2/3 of Tank	11.5

Average Power Input	wire hp/1000 ft^3	W/m^3
First 1/6 of Tank	0.10	2.6
Second 1/6 of Tank	1.02	26.8
Final 2/3 of Tank	0.51	13.4

* 1 kg = 2.21 lb

\+ Calculated by the method of Section 5, assuming 1.21 units O_2 required/unit BOD_5 removed.

° 1 kWh/day = 1.34 wire hp-hr/day

** Based on an average air flow rate of 0.011 m^3/min/dome (0.40 cfm/dome).

++ Same as m^3/1000 m^3/min.

Plant personnel expressed satisfaction with the maintenance performance of the dome diffuser systems and electrostatic air filters. The dome diffusers have performed satisfactorily for 6 yr without requiring cleaning. There was no evidence of coarse bubbling in any of the aeration tanks, not surprising when the very low F/M loading rate of 0.05-0.08 kg BOD/day kg MLSS is considered.

PLANTS IN THE NETHERLANDS

The Dutch are best known for their development and application of oxidation ditch treatment and horizontal rotor mechanical aeration. Until recently, there were no fine bubble aeration plants in Holland. A few plants had medium bubble Brandol tube aerators, but virtually all Dutch plants are mechanically aerated. Recently, several activated sludge plants using dome diffusers were constructed, including Holten-Markelo and Steenwijk.

Holten-Markelo

The Holten-Markelo plant shown in Figure B-14 is a small plant serving about 25,000 people. Design population is 50,000, and the plant is currently very underloaded. To compensate, only one of the two aeration basins is in service. Each basin has two passes and operates in the plug flow mode. The 734 diffusers per tank are tapered with 34 percent in the first half pass, 25 percent each in the second and third half passes, and 16 percent in the final half pass. For the one aeration basin (two passes) in use, air flow averages 30 m^3/min (1064 cfm) distributed equally among the domes. Each pass is 30.0 m x 6.6 m x 4.0 m SWD (98.4 ft x 21.6 ft x 13.0 ft). Mixing data are shown below in Table B-40.

TABLE B-40. HOLTEN-MARKELO MIXING DATA

Section*	Domes per Section*	Diffuser Density (domes/m^2)+	Air Flow per Section*°		Air Flow per volume° (cfm/1000 ft^3)**
			cfm	m^3/min	
1	368	1.9	184	5.2	13.3
2	276	1.4	138	3.9	10.0
3	276	1.4	138	3.9	10.0
4	184	0.9	92	2.6	6.7

* One section = one half pass
\+ 1 dome/m^2 = 9.29 domes/100 ft^2
° Based on an assumed minimum air flow rate of 0.014 m^3/min/dome (0.5 cfm/dome).
** Same as m^3/1000 m^3/min.

The above data represent minimum air flow rates. In reality, air flow rates are averaging 0.28-0.42 m^3/min/dome (1.0-1.5 cfm/dome). Considerable research

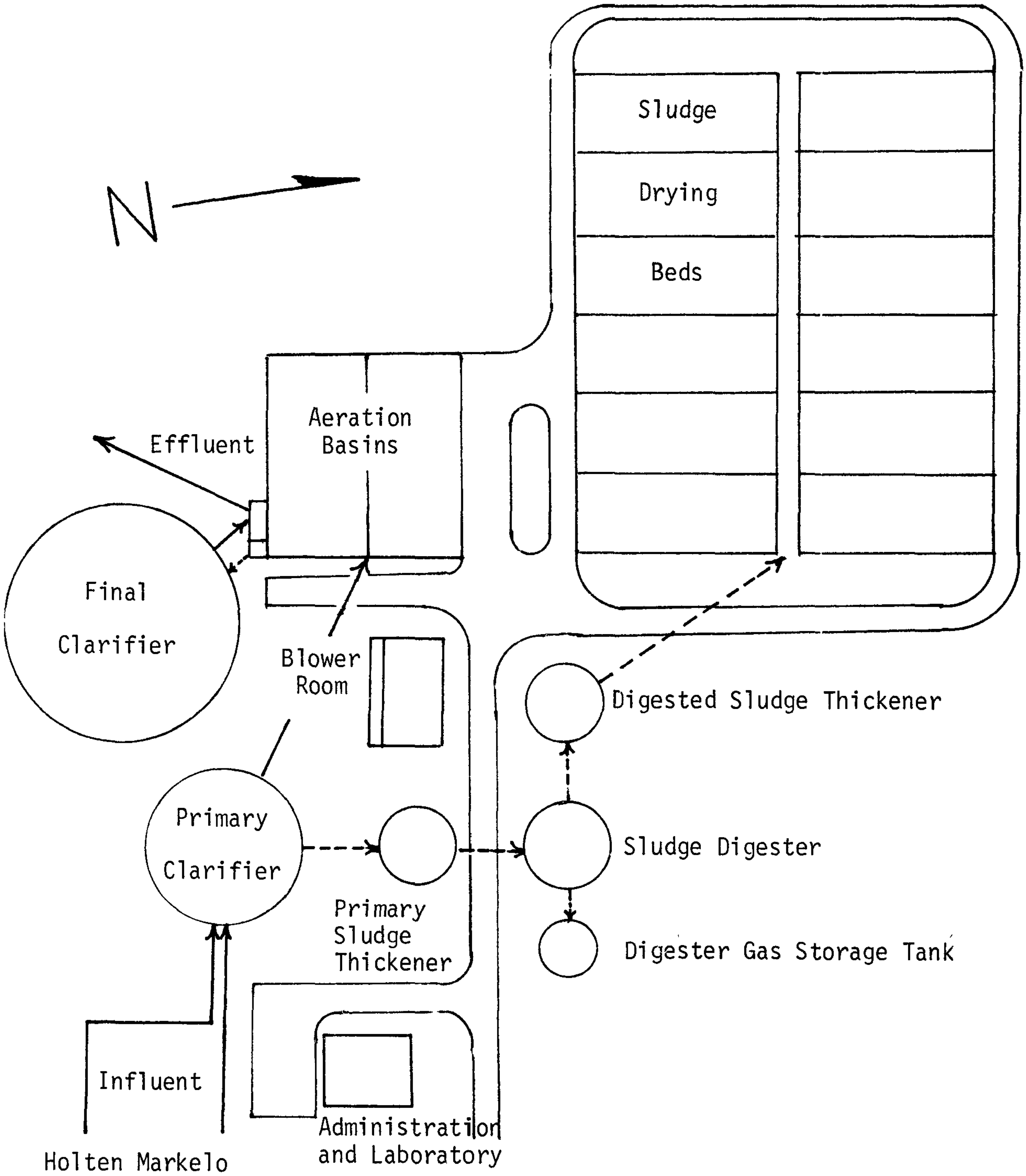


Figure B-14. Holten-Markelo site plan.

has convinced Dutch designers that the domes should be operated at air flow rates substantially higher than those recommended by Hawker-Siddeley. This plant was designed on the basis that minimum nighttime flows (and oxygen demand) would correspond to the minimum air unit dome flow rate of 0.014 m^3/min (0.5 cfm). Consequently, dome density is low and average air flow rates are relatively high when compared to English practice.

Recently, plant personnel began experimenting with an anoxic zone by severely restricting air flow to the first grid. The plant normally produces a nitrified effluent, and it is believed that the anoxic zone will reduce energy costs as well as improve performance in the final settling tank.

Air supply is provided by a centrifugal blower driven by a gas engine that burns a mixture of about 65 percent sludge gas and 35 percent pipeline gas. Plant personnel could not estimate power consumption (kWh). Consequently, aeration efficiency could not be calculated.

Primary clarifier design is much more typical of U.S. practice than that of the English plants. The diameter of the single unit is 24.0 m (78.7 ft), and the sidewater depth is 2.0 m (6.6 ft). At the maximum influent flow rate of 21,800 m^3/day (5.76 mgd), the detention time is 2 hr and the surface loading rate is 48.0 m^3/m^2/day (1178 gpd/ft^2). At the average influent flow rate, the surface loading is 28.8 m^3/m^2/day (707 gpd/ft^2).

The secondary clarifier is designed for a maximum hourly surface loading of 24.0 m^3/m^2/day (589 gpd/ft^2) and a 2.5-hr detention time. It is circular, 34 m (112 ft) in diameter and has a sidewater depth of 2.5 m (8.2 ft). Both the primary and secondary clarifiers are equipped with stainless steel wipers and scraper mechanisms.

The plant was started up in 1978 and officially commissioned in 1979. There have been no equipment failures in either of the aeration basins; however, at the time of the plant visit, there was considerable coarse bubbling in the second aeration grid, probably due to the growth of slime in the zone following the anoxic zone. The electrostatic air filters were providing satisfactory service.

Steenwijk

The plant at Steenwijk was the first major dome diffuser plant constructed in The Netherlands. It was commissioned in late 1976 and has two two-pass aeration basins that are laid out in a tapered configuration. Design flow is 54,100 m^3/day (14.3 mgd), and the influent flow in 1978 averaged 44,700 m^3/day (11.8 mgd) $\pm$ 30 percent. The primary and secondary clarifier design basis is the same as that used at Holten-Markelo.

Three motor driven multi-stage centrifugal blowers, one for each aeration tank and one standby, provide air for the process. The two-pass aeration basins have four aeration grids with 800, 560, 560, and 438 domes, respectively. This is the same percentage distribution as that of Holten-Markelo. The dimensions of each aeration pass are 100 m x 6.7 m x 4.0 m SWD (328 ft x 22 ft x 13.1 ft).

Steenwijk reported the following performance data for 1978:

Raw Wastewater
BOD_5 : 312± 74 mg/l
NH_3-N : 52± 12 mg/l

Primary Effluent
BOD_5 : 102± 19 mg/l
NH_3-N : 25± 3 mg/l

Final Effluent
BOD_5 : 12± 7 mg/l
NH_3-N : 12± 12 mg/l
NO_3-N : 11 mg/l

An average of 4860 kg (10,714 lb) BOD_5 and 702 kg (1548 lb) NH_3-N were removed daily at this plant in 1978. The average power consumption was 14,100 kWh/day (18,908 wire hp-hr/day), and the F/M loading was 0.11 kg BOD_5/day/kg MLSS. No air flow data were reported. Based on the method of Section 5, with 1.18 kg O_2 required/kg BOD_5 removed, the aeration efficiency was 0.62 kg O_2/kWh (1.02 lb/wire hp-hr). The computation was based on total power consumed for all purposes at this plant. No breakdown of power use was available. If aeration consumes 80 percent of the electrical power, a typical level, the aeration efficiency would be 0.78 kg O_2/kWh (1.28 lb/wire hp-hr), still quite low. Personnel from the Zuiveringschap-West Overijssel Authority, the authority that operates the plant, noted that the plant is somewhat underloaded and mixed liquor D.O. is high.

Ilsink and Brandse reported clean water aeration efficiencies of 3.3-3.7 kg O_2/kWh (5.4-6.1 lb/wire hp-hr) at a water temperature of 10°C (50°F) and a pressure of 760 mm Hg (14.7 psi) for Steenwijk.[20]

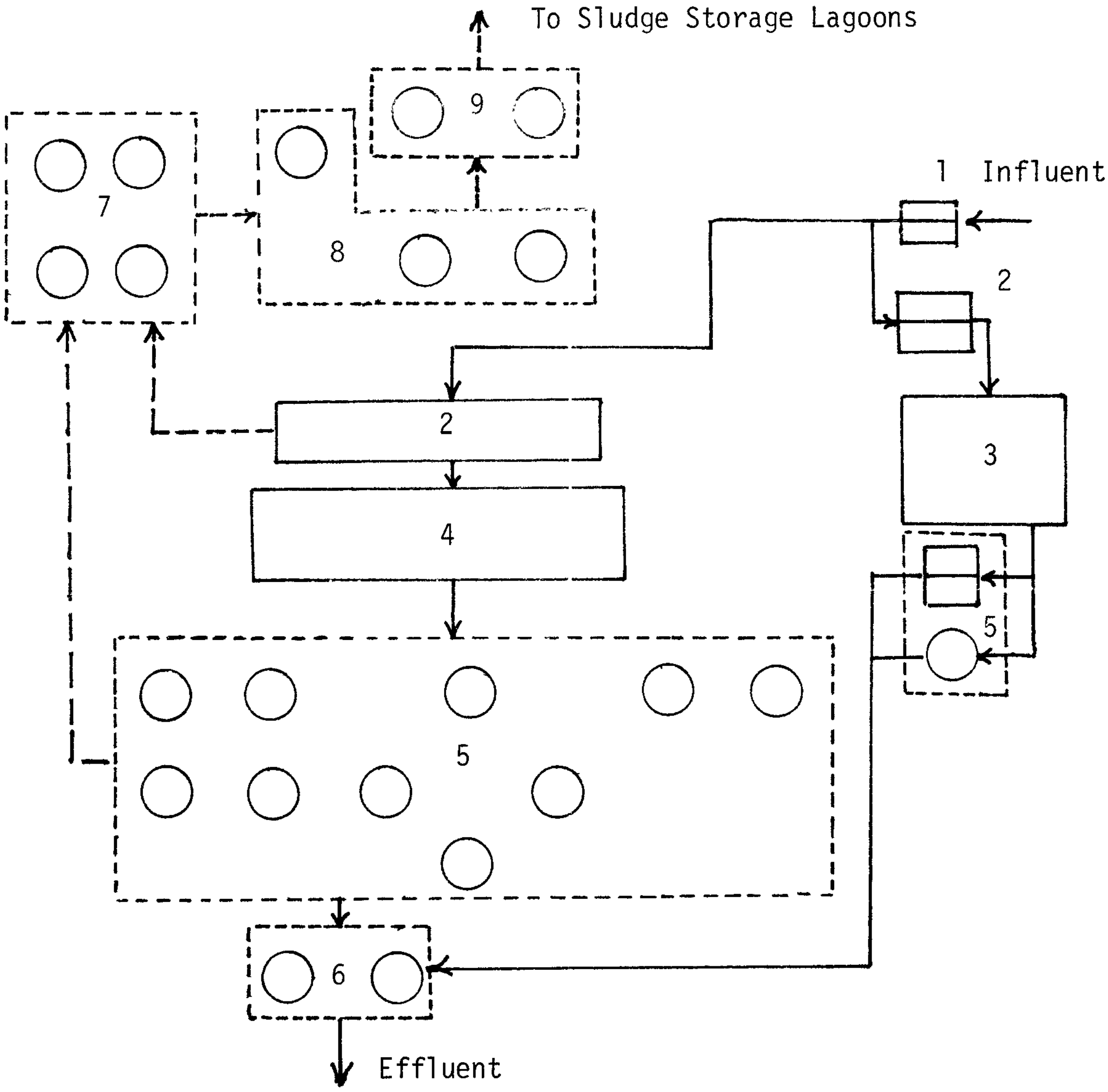
The aeration equipment at Steenwijk has accumulated about 3 yr of operating time. There have been no failures of the equipment, and plant personnel report no apparent loss of aeration efficiency over the period.

MADISON, WISCONSIN

History and Background

The Nine Springs Wastewater Treatment Plant serves the City of Madison, Wisconsin, and many of the surrounding suburban communities. The original plant was constructed in 1928 and provided primary treatment followed by trickling filters. The plant has been expanded five times, the last in 1977. By 1985, the plant will be further modified to provide nitrification and effluent polishing.

The current facilities, depicted in Figure B-15, are rated at 219,500 m^3/day (58 mgd) and treated 132,500 m^3/day (35 mgd) in 1978. Flow to the trickling filter plant accounted for about 14 percent of the total flow treated.



KEY

1. GRIT CHAMBERS
2. PRIMARY CLARIFIERS
3. TRICKLING FILTERS
4. AERATION TANKS
5. FINAL CLARIFIERS
6. CHLORINE CONTACT
7. SLUDGE THICKENERS
8. SLUDGE DIGESTERS
9. DIGESTED SLUDGE THICKENERS

Figure B-15. Madison site plan.

Plant Description

Prior to the 1977 modification, the activated sludge plant at Madison was wholly coarse bubble aerated. To increase organic loading capacity and to study the performance of dome diffusers under actual operating conditions, aeration tank Nos. 1-6 were retrofitted with dome diffusers arranged in a grid fashion. Aeration tank No. 7 was later equipped with fine bubble tube diffusers that could be installed utilizing the existing spiral roll manifolds without need for major piping modifications. The remaining basins remained in their original coarse bubble spiral flow aeration mode. No modifications were made to primary or secondary clarifiers. Air filtration was added to the blower system (see Table B-41 for design data).

The six aeration tanks with dome diffusers are divided into two sets of three-pass units and are tapered as shown in Table B-41. These can be operated in either the contact stabilization mode, using one tank for contact and two for reaeration, the plug flow mode using three passes, or a three-pass step feed mode. Two aeration grids are provided for each tank, and the domes are distributed fairly symmetrically in each grid. Spacing between domes is either 30.5 or 61 cm (12 or 24 in.). Spacing between rows varies, with pairing of six rows (12 total rows) plus two individual rows in the first pass, ten individual rows in the second pass, and nine individual rows in the final pass.

Five Rootes-type positive displacement blowers provide air for all 15 of the aeration tanks. One is driven by a digestor gas fueled engine; the other four are powered by electric motors. Normal operating pressure is 58.6 kN/m^2 (8.5 psi). Air cleaning is provided by a two-stage air filtration system. The first stage uses five automatically operated coarse fiberglass filters, each rated at 354 m^3/min (12,500 cfm). These roll-type units are automatically advanced by a photocell sensor and drive that, respectively, senses the opacity of the filter and periodically advances fresh medium onto the filtration frame. Five sets of final filters follow the prefilters, as described in Table B-41. A pressure gauge scaled between 0 and 5 cm H_2O (0 and 2 in.) reads headloss across the filters. They are to be changed when headloss approaches 5 cm (2 in.). After 2 yr of operation, the current reading on the gauge is 12.7 mm (0.05 in.).

Final settling is provided by 10 circular clarifiers of varying dimensions. At an average influent flow rate of 111,7000 m^3/day (29.5 mgd), the surface loading is 18.5 m^3/m^2/day (454 gpd/ft^2) and the detention time with 50 percent sludge recycle is 3.4 hr.

Madison reported installed costs of $282,000 for the dome diffusers and air distribution piping and $28,450 for the air cleaning system.

Performance

For purposes of comparison between types of aerators, aeration tank Nos. 1-6 and 7, 8, and 9 have been isolated from the general plant flow and operated as a unit. These tanks are dosed by primary clarifier Nos. 1-16 and final settling is carried out in clarifiers Nos. 1-10. Air flow to each tank

TABLE B-41. MADISON DESIGN DATA

Primary Sedimentation	
16 Rectangular Tanks	
Tank Nos. 1-2:	9.7 m* x 26.2 m* x 3.3 m* SWD
Tank Nos. 3-4:	(trickling filter plant)
Tank Nos. 5-6:	9.7 m x 31.1 m x 3.3 m SWD
Tank Nos. 7-16:	10.7 m x 26.8 m x 3.3 m SWD
Detention time (Tank Nos. 1-2 & 5-16):	1.44 hr @ 219,500 m^3/day (58 mgd)
Surface loading (Tank Nos. 1-2 & 5-16):	55.1 m^3/m^2/day (1354 gpd/ft^2) @ 219,500 m^3/day (58 mgd)
Aeration Basins	
15 Rectangular Tanks	
Tank Nos. 1-6:	9.1 m x 41.2 m x 4.7 m SWD
Tank Nos. 7-15:	9.8 m x 57.9 m x 5.3 m SWD
Aeration Equipment	
Tank Nos. 1-6:	Fine bubble dome diffusers
Tank No. 7:	Fine bubble tube diffusers
Tank Nos. 8-15:	Coarse bubble diffusers

Diffuser Configuration (Tanks Nos. 1-6)

Tapered aeration, 2 grids/tank.
3 tanks per unit. Can be operated as plug flow, contact stabilization, or step feed.

	No. Domes	No. Rows
First Pass:		
Grid No. 1	834	14
Grid No. 2	709	14
Second Pass:		
Grid No. 3	505	10
Grid No. 4	410	10
Third Pass:		
Grid No. 5	392	9
Grid No. 6	332	9

(continued on next page)

Final Sedimentation (Activated Sludge Plant)

10 Circular Clarifiers

Tank Nos. 1-4:	Diameter	23.7 m
	Sidewater depth	3.8 m
	Surface loading	18.5 m^3/m^2/day (454 gpd/ft^2) @ 111,700 m^3/day (29.5 mgd)
Tank Nos. 5-6:	Diameter	26 m
	Sidewater depth	3.8 m
	Surface loading	same as 1-4
Tank Nos. 7-10:	Diameter	32 m
	Sidewater depth	3.8 m
	Surface loading	same as 1-4
Detention time (all clarifiers):		3.4 hr @ 111,700 m^3/day (29.5 mgd) and 50% recycle

Blower System

5 Rootes-Type Positive Displacement Blowers

- No. 1: Engine driven, 312 m^3/min (11,000 cfm) @ 65.5 kN/m^2 (9.5 psi)
- No. 2,3: Single speed, 373 kW (500 hp) motor driven, 306 m^3/min (10,800 cfm) @ 65.5 kN/m^2 (9.5 psi)
- No. 4: Dual speed, 261-410 kW (350-550 hp) motor driven, 220-307 m^3/min (7760-10, 850 cfm) @ 65.5 kN/m^2 (9.5 psi)
- No. 5: Dual speed, 224-373 kW (300-500 hp) motor driven, 165-257 m^3/min (5840-9070 cfm) @ 65.5 kN/m^2 (9.5 psi)

Air Filter System

Primary Filters:

Automatic roll-type filter
5 sets
Each set rated 354 m^3/min (12,500 cfm) @ 152 m/min (500 ft/min) net velocity
Manufacturer - American Air Filter Company

Secondary Filters:

Dry disposable type - Biocell
5 sets
Each set has 8 filters each 0.3 m^2 (3.2 ft^2) in area:
2 sets also have 8 filters each 0.3 x 0.6 m (1.0 x 2.0 ft)
Other 3 sets also have 4 filters each 0.3 x 0.6 m (1.0 x 2.0 ft)
Manufacturer - American Air Filter Company

is measured periodically. Influent and effluent data summarized in Table B-42 for 1978 and 1979 are for this portion of the plant only.

TABLE B-42. MADISON INFLUENT-EFFLUENT DATA SUMMARY*

Parameter	Year 1979	Year 1978
Flow: mgd	14.5	15.7
m^3/day	54,900	59,400
Raw Wastewater: (mg/l)		
BOD_5	213	184
TSS	163	157
TKN	32	35
NH_3-N	17	18
Primary Effluent: (mg/l)		
BOD_5	156	138
TSS	79	88
TKN	29	28
NH_3-N	18	18
Final Effluent: (mg/l)		
BOD_5	19	23
TSS	12	13
TKN	14	16
NH_3-N	12	11
NO_3-N	1.5	2.3

* For that portion of the Madison plant comprised of primary clarifier Nos. 1-16, aeration tank Nos. 1-9, and final clarifier Nos. 1-10 only.

In 1978, the test plant was operated wholly in the contact stabilization mode. This was continued until August 15, 1979, at which time the test plant was briefly operated in the plug flow mode for 1 mo. After mid-September 1979, the test plant was changed over to step feed operation. The F/M loading was held at 0.26 kg BOD_5/day/kg MLSS in 1979 and 0.3 in 1978 to avoid nitrification. MLSS levels averaged 2000 mg/l in 1979 and 1500 mg/l in 1978. Peak monthly flows and BOD loads varied approximately $\pm$ 25 percent from annual averages. About 15 percent of the flow to the plant comes from food and milk processing plants.

By comparison to the plants visited in the United Kingdom, Madison's primary treatment system was considerably less effective, removing 25-27 percent of the influent BOD_5 and 44-48 percent of the influent suspended solids. This is probably related to the surface loading rate of 28.5 m^3/m^2/day (700 gpd/ft^2), which is considerably higher than the 12.2-20.4 m^3/m^2/day (300-500 gpd/ft^2) rate more typical in the United Kingdom.

Secondary treatment achieved average removals of 83 percent for BOD_5 and 85 percent for suspended solids in 1978. 1979 performance was comparable, averaging 88 percent and 76 percent removals, respectively. Overall removal efficiencies were 87 percent (BOD_5) and 92 percent (suspended solids) in 1978, with corresponding removals of 91 percent and 93 percent in 1979.

The two plants, coarse bubble and fine bubble, are operated in parallel, with 44 percent of the flow (and BOD_5 load) going to the coarse bubble aeration tanks. Air flow is split with 14.4 percent of total plant air directed to fine bubble tank Nos. 1-6 and 29.9 percent to coarse bubble tank Nos. 7-9. Power consumption for the total aeration system averaged 16,900 kWh/day (22,660 wire hp-hr/day) in 1978 and 21,150 kWh/day (28,360 wire hp-hr/day) in 1979. Based on these data, comparative aeration efficiencies for the two sections have been computed by the method of Section 5 in Table B-43. The results indicate that the fine bubble system

TABLE B-43. MADISON AERATION EFFICIENCY CALCULATIONS

	Fine Bubble*		Coarse Bubble+	
Parameter	1979	1978	1979	1978
Flow: mgd	8.1	8.8	6.4	6.9
m^3/day	30,700	33,300	24,200	26,100
BOD_5 Removed (kg/day)°	4207	3847	3306	3022
NH_3-N Removed (kg/day)°	160	231	125	154
O_2 Required** (kg/day)°	4768	4840	3744	3684
Power Consumed (kWh/day)++	3046	2431	6324	5047
Aeration Efficiency:				
kg O_2/kWh	1.54	1.96	0.58	0.72
lb O_2/wire hp-hr	2.53	3.22	0.96	1.18

* Comprised of aeration tank Nos. 1-6.
\+ Comprised of aeration tank Nos. 7-9.
° 1 kg = 2.21 lb
** Calculated by the method of Section 5, assuming 1.01 units O_2 required/unit BOD_5 removed in 1978 and 0.97 units O_2 required/unit BOD_5 removed in 1979.
++ 1 kWh/day = 1.34 wire hp-hr/day

was about 2.7 times more efficient than the coarse bubble system, with both showing somewhat higher aeration efficiencies in 1978. In both years, plant personnel operated the plant to hold maximum mixed liquid D.O. in the range of 2-4 mg/l. Since the plant was operated in the contact stabilization mode during all of 1978, with no operational changes, the 1978 data may be more accurate. As discussed in Section 6, these data correlate well with the relative aeration efficiencies determined in separate tests conducted at Madison in September 1978.

Mixing power levels for a minimum air flow rate of 0.014 m^3/min/dome (0.5 cfm/dome) have been calculated and are shown in Table B-44. Mixing power levels are comparable to that at many of the plants in the United Kingdom, reflecting similarities in design and operation procedures recommended by suppliers of dome diffusers in both the United States and the United Kingdom.

Operation and Maintenance

Madison has accrued 3 yr of maintenance history on dome diffusers and experienced little trouble until mid-1980. In 1978, it was necessary to drain several tanks to fix small air leaks and several manifolds that had pulled out of the concrete floor. A visual inspection in February 1980 of the six aeration tanks equipped with dome diffusers revealed only small zones, immediately adjacent to the raw wastewater feed points, where coarse bubbling was occuring, probably indicative of light slime growth. Concurrent with an increase in waste flow from a large dairy in early-1980, slime began to accumulate on the domes in all of the aeration tanks, particularly in the first and second passes. Efficiency decreased sharply in the late spring and it became necessary to dewater the tanks in June 1980 and steam clean the domes in place to remove the slime growths. Prior to steam cleaning, plant operators increased air flow and passed only return activated sludge through a set of tanks in an attempt to promote self cleaning as observed at Beckton. This did not significantly improve performance.

All of the aeration tanks had been cleaned and returned to service by mid-July. However, there was some indication that the diffusers had not fully come clean as a result of steam cleaning. This possibility was being investigated at the time of this writing and was not fully resolved.

Madison operators expressed great satisfaction with the air filtration equipment. Installed in 1977, it has performed well and required little maintenance since then. The coarse filter requires changing every 6 mo at a cost of $58 and consumes less than 1 man-hr to remove and replace the filter roll.

OTHER U.S. PLANTS VISITED

Four U.S. plants were visited during the course of the study:

- Madison, Wisconsin
- Glendale, California
- Fort Worth, Texas
- New York City (Tallman Island)

The Madison results have been detailed previously herein as it was the only U.S. plant visited that could provide complete performance data. Summarized below is the information obtained at the other U.S. plants visited.

TABLE B-44. MADISON MIXING DATA

Aeration Tank & Grid Nos.	Surface Area (m^2)*	Wetted Volume (1000 m^3)+	Diffuser Density ($domes/m^2$)o	Air Flow Section** (cfm)		Air Flow/Area** (cfm/ft^2)		Air Flow Volume** (cfm/1000 ft^3)++	Minimum Power Input oo (wire hp/1000 ft^3)	
				(cfm)	(m^3/min)	(cfm/ft^2)	(m^3/m^2/min)		(wire hp/1000 ft^3)	(W/m^3)
Tank 1 (first pass):										
Grid 1	91.8	0.433	9.1	417	11.8	0.42	0.128	27.3	1.28	33.7
Grid 2	91.8	0.433	7.7	352	10.0	0.35	0.106	23.0	1.08	28.4
Tank 2 (second pass):										
Grid 1	91.8	0.433	5.5	252	7.1	0.25	0.076	16.5	0.78	20.4
Grid 2	91.8	0.433	4.5	205	5.8	0.21	0.064	13.4	0.63	16.6
Tank 3 (third pass):										
Grid 1	91.8	0.433	4.3	191	5.4	0.19	0.058	12.5	0.59	15.4
Grid 2	91.8	0.433	3.6	166	4.7	0.17	0.052	10.8	0.51	13.4

* 1 m^2 = 10.8 ft^2
\+ 1 m^3 = 35.3 ft^3
o 1 $dome/m^2$ = 9.29 domes/100 ft^2
** Based on a minimum air flow rate of 0.014 m^3/min/dome (0.5 cfm/dome).
++ Same as m^3/1000 m^3/min.
oo Assumes compressor efficiency of 350 kWh per 10,000 cfm.

Glendale, California

To evaluate dome diffusers on a large scale, a 1-yr test was set up at the City of Los Angeles Glendale wastewater treatment plant. One aeration tank and two final clarifiers were isolated, and the aeration tank was fitted with 1570 dome diffusers on two grids. In operation, 57 percent of the air was directed to the first grid; the balance of 43 percent went to the second grid. This split resulted in equal air flows to individual domes in either grid. The aeration basin measured 9.7 m x 73.2 m x 4.9 m SWD (31.8 ft x 240 ft x 16.1 ft).

The results of the pilot study were reported by Egan[7] and have been discussed in detail in the body of this report. Basically, it was found that the fine bubble system removed 85-90 percent of the influent BOD_5 and suspended solids using 63 percent of the power required for the parallel coarse bubble, spiral roll aeration system. Reported operating conditions and performance for the fine bubble test system are as follows for the 10 mo. beginning August 1978.

Flow	11,360 m^3/day (3.0 mgd)
BOD_5: Influent	158 mg/l
Effluent	11 mg/l
MLSS	1500 mg/l
F/M Loading	0.35 kg BOD_5/day/kg MLSS
Sludge Recycle Flow Rate	50 percent of influent flow rate
Air Flow Rate	54.0 m^3/min (1907 cfm)
Power Consumed	13,152 kWh/day (17,637 wire hp-hr/day)

The performance of the coarse bubble system was similar, although the F/M loading at 0.25 kg BOD_5/day/kg MLSS was somewhat less than for the fine bubble system. The average power consumption of the coarse bubble system was 20,740 kWh/day (27,810 wire hp-hr/day).

Based on these limited data, performance data can be calculated as presented in Table B-45. The fine bubble system aeration efficiency was about 45 percent higher than for the coarse bubble system in this test. Mixing data indicate air flow rates and power levels typical of other dome diffuser plants.

A visual inspection of the dome diffuser system in operation revealed significant coarse bubbling in the first 20 percent of the tank. Plant personnel indicated that some problems were experienced at startup with several air blowoff lines that failed at the point of connection to the main grid. Also, several of the uPVC dome holddown bolts failed. Finally, there was a substantial problem with rust and scale from the plant's air supply lines being deposited in the air grid lines and within the dome housings. The test unit uses two-element disposable filters of the type described in Section 8.

Fort Worth, Texas

In 1978, the Fort Worth plant was expanded with the addition of four

TABLE B-45. GLENDALE AERATION EFFICIENCY CALCULATIONS AND MIXING DATA

AERATION EFFICIENCY CALCULATIONS

	Fine Bubble System	Coarse Bubble System
BOD_5 Removed (kg/day)*	1670	1670
kg O_2/kg BOD_5 Removed	0.93	1.0
O_2 Required (kg/day)*	1553	1670
Power Consumed (kWh/day)+	1460	2302
Aeration Efficiency:		
kg O_2/kWh	1.06	0.73
lb O_2/wire hp-hr	1.74	1.20

MIXING DATA°

Diffuser Density	(domes/m²)**	
First Grid	3.0	
Second Grid	1.6	
Air Flow	**cfm**	**m³/min**
First Grid	1087	30.8
Second Grid	820	23.2
Per Dome	1.2	0.034
Air Flow/Area	**cfm/ft²**	**m³/m²/min**
First Grid	0.34	0.104
Second Grid	0.18	0.055
Air Flow/Volume	**(cfm/1000 ft³)++**	
First Grid	21.2	
Second Grid	11.4	
Average Power Input	**wire hp/1000 ft³**	**W/m³**
First Grid	0.91	24.0
Second Grid	0.29	7.5

* 1 kg = 2.21 lb
\+ 1 kWh/day = 1.34 wire hp-hr/day
° For fine bubble system only.
** 1 dome/m^2 = 9.29 domes/100 ft^2
++ Same as m^3/1000 m^3/min.

dome diffuser activated sludge basins and additional final clarifiers to serve in parallel with an existing coarse bubble, spiral roll aeration system. The plant expansion program, to be completed in 1980, includes major modification of sludge handling facilities as well. The addition was designed for an average influent flow of 363,400 m^3/day (96 mgd) to be divided equally among the four basins.

Initially, each tank, measuring 31.7 m x 72.7 m x 3.2 m SWD (104 ft x 239 ft x 10.5 ft), was equipped with 13,314 dome diffusers, distributed in four equal-size grid areas as follows:

First Grid	4158
Second Grid	3276
Third Grid	3594
Fourth Grid	2286

In fitting the basins with domes, an experiment in optimization was set up. All basins were equipped with the same manifolds and dome fittings. However, basin No. 3 was fitted with only 7986 domes, distributed as follows:

First Grid	2178
Second Grid	2038
Third Grid	2004
Fourth Grid	1776

It was determined from this experiment that the modified aeration basin could treat the same amount of wastewater with a 25 percent reduction in air flow and with better control of mixed liquor D.O.

Several factors combined to make a performance evaluation of this plant impossible at this time. First, the continued construction on the site, with resulting system disturbance, cause the data to be highly scattered. In particular, major problems with sludge handling equipment have contributed to continued process upsets. Secondly, there has been a substantial turnover of key personnel at the plant. The new personnel have not had adequate time to become fully trained in plant operation or instrument maintenance.

The plant visit revealed a number of potentially serious problems (if not corrected) with the dome diffuser equipment. There were a number of substantial air leaks apparent in aerations basin Nos. 2 and 3. Several of the air blowoff lines were plugged, and one was apparently broken. The air leaks were likely of sufficient size to admit mixed liquor to the interior of the air distribution grid.

New York City (Tallman Island)

New York City's Tallman Island plant, located on the Hudson River, was originally constructed in 1939 as a coarse bubble aerated activated sludge plant. A major plant upgrading was carried out in 1977-1979, at which time a side-by-side test of dome diffusers, ceramic tubes, and coarse bubble diffusers was conducted. Influent flow, averaging 302,800 m^3/day (80 mgd), was divided between four four-pass step feed basins. Two of these are equipped with coarse bubble units mounted on a dual spiral flow configuration. One tank was equipped with fine bubble ceramic tube diffusers on the same manifolding as the coarse bubble units, and one tank was equipped with dome diffusers laid out in a symmetrical grid configuration with 6400 domes in the four passes.

In setting up this test, it was intended to gather side-by-side comparison data for use in all New York City plants. Accordingly, adequate instrumentation for performance measurement of each aeration tank set was provided when the plant was upgraded. However, equipment problems have been experienced and the equipment had not been accepted by the City at the time of the plant visit. Consequently, although influent and effluent data for the 1-1/2 yr of operation were available, they could not be correlated with either oxygen transfer or mixing performance.

In early 1979, environmental engineering students at Manhattan College carried out a short-term performance comparison between the coarse bubble and fine bubble equipment. Their data indicated that the coarse bubble equipment would require approximately twice the compressor power consumption to treat the same quantity of wastewater under the conditions encountered at Tallman Island. These findings correlate well with data from Madison, Wisconsin, and Glendale, California.

At the time of the plant visit, the aeration equipment was performing satisfactorily. There was some evidence of coarse bubbling immediately adjacent to two of the three-step feed inlets; however, it was not severe. Plant personnel indicated that the electrostatic air cleaning equipment was performing well.

System personnel report 1978 capital costs for the fine bubble dome diffuser aeration system of $880,000, including installation, plus $40,000 for the electrostatic air cleaner.

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