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Project Summary

Aeration Equipment Evaluation: Phase I – Clean Water Test Results

Fred W. Yunt and Tim 0. Hancuff

An oxygen transfer performance evaluation was conducted on submerged air aeration systems at the Joint Water Pollution Control Plant of Los Angeles County Sanitation Districts (LACSD). The non-steady state clean water test procedure was used. Systems chosen for evaluation represented various submerged generic aeration devices including several types of both fine and coarse bubble diffusers. Jet aerators and static aerators were also tested.

Seven manufacturers, representing seven different aeration systems, participated in the study. An eighth system utilized historically in many LACSD treatment plants and throughout the country was tested to provide a reference point. All testing was conducted in the same outdoor tank using identical procedures in order to standardize test conditions.

The results of this study indicated that, of the systems tested, fine bubble diffusion equipment transferred oxygen most efficiently in clean water. Jet aerators transferred oxygen more efficiently than static aerators and other coarse bubble systems but not as efficiently as fine bubble diffusers. Because the values of wastewater correction factors (alpha and beta) are dependent on the type of aeration device tested, the relative performance of one aerator to another in wastewater may be different than observed in these clean water tests.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Analysis of clean water test data for various submerged aeration devices is the first step toward defining the oxygen transfer performance of such equipment. While clean water test results indicate general trends in an aeration system's oxygen transfer performance, they do not necessarily reflect that system's performance under process conditions. The logical second step, therefore, is an oxygen transfer evaluation of selected submerged aeration equipment in mixed liquor under field operating conditions.

A comparison of the data generated by the above two types of tests provides an estimation of the wastewater alpha correction factor. The alpha factor typically is less than unity and results in lower oxygen transfer rates in process waters than in clean (tap) waters. The value of alpha varies with wastewater characteristics, process operating conditions such as SRT and the F/M loading rate, type of aeration equipment (bubble size), aeration system layout, aeration tank geometry, the degree of prior treatment received (e.g., the alpha factor has a higher value at the effluent end than the influent end of a plug flow aeration tank), and the relative state of aerator cleanliness. The last factor refers primarily to fine bubble (fine pore) diffusers, which tend to clog or foul with time in mixed liquor operation. Because partially fouled diffusers generally transfer less oxygen than clean diffusers, the term apparent alpha factor rather than alpha factor is used when comparing the mixed liquor and clean water oxygen transfer performance of diffusers that are operating with an indeterminate degree of fouling.

Since clean and process water oxygen transfer performance can vary widely, it was considered essential to undertake a two-phase test program. The first phase, which is the subject of this report, included only clean water testing. Several fine and coarse bubble submerged aeration systems were tested in the same tank under the same operating conditions. Based on the results of these tests, the three systems with the highest oxygen transfer rates were selected for further oxygen transfer testing under process water conditions.

The clean water tests were conducted in the Districts' Joint Water Pollution Control Plant in Carson, CA. The subsequent process water (mixed liquor) tests were carried out in parallel trains at LACSD's Whittier Narrows Water Reclamation Plant in El Monte, CA. The results of the process water testing will be presented in a follow-on report.

The three major objectives of this project were to:

- evaluate the clean water oxygen transfer performance of various generic types of submerged aeration equipment under identical testing conditions and using identical testing methods,
- demonstrate the effects of changing water depth and operating power levels on aeration equipment performance, and
- evaluate the two most highly regarded oxygen transfer data analysis methods currently in use.

Project Outline

This study was devised as an evaluation of distinct generic types of submerged aeration equipment; it was not intended to be an evaluation of various manufacturers' equipment of the same generic type. Due to the large variety of fixed orifice coarse bubble diffusers on the market, however, more than one example of this generic type was tested. The aeration equipment tested is summarized in Table 1.

System H, FMC Corporation's coarse bubble Deflectofuser* (sparger), was not included in the initial scope. It was added at a later date and tested only at the 4.6-m (15-ft) water depth because of its widespread use at that depth both nationwide and in the Districts' treatment plants.

The tests were conducted at water depths of 3.0 m (10 ft), 4.6 m (15 ft), 6.1 m (20 ft), and 7.6 m (25 ft). A range of nominal power densities was evaluated at each depth. The manufacturers, with the exception of FMC Corporation for their Deflectofuser system, were given the choice to test at one of the following two ranges of power options:

Option 1: 13.2, 26.3, and 39.5 nominal W/m^3 (0.5, 1.0, and 1.5 nominal hp/1,000 ft^3),

Option 2: 7.9, 13.2, and 26.3 nominal W/m^3 (0.3, 0.5, and 1.0 nominal hp/1,000 ft^3).

It was hoped that each manufacturer would select the range that was most typical of its equipment's application in mixed liquor. All manufacturers tested chose Option 1 with the exception of the Norton Company, which selected Option 2. The 3 to 1 range in power for both options was intended to demonstrate the aeration equipment's ability to handle diurnal variations representative of typical process loading patterns.

The manufacturers were responsible for designing the layout of their equipment subject to the constraints of this study. Each manufacturer was allowed, if desired, to change its equipment configuration at each depth tested. It was required, however, that the same configuration be used for all tests at a given depth.

Test Facility

An outdoor, all-steel, rectangular aeration tank located at the LACSD Joint Water Pollution Control Plant with dimensions of 6.1 m x 6.1 m x 7.6 m sidewater depth (SWD) (20 ft x 20 ft x 25 ft) was used for all tests. Prior to the start of this project, the tank was steam cleaned and all exposed metal surfaces were coated with coal tar epoxy. Potable water was used in all clean water tests conducted in this study. Average characteristics of the supplied water were: total dissolved solids = 500 mg/L, pH = 8.25, hardness = 225 mg/L as $CaCO_3$, and turbidity <0.1 turbidity units.

The air delivery system used for this project consisted of a Roots Model RAS-60 rotary positive blower driven by a 56-kW (75-hp) electric motor. System air was filtered by an Air Maze DA dry-type filter. A 1-m^3 (35-ft^3) pulsation dampening tank was also included in the system between the blower and the airflow measurement elements. System air rate was adjusted by bleeding off excess air at the blower.

Test Procedures

The basic clean water test procedure employed was the non-steady state method. This method uses sodium sulfite to deoxygenate the clean water and cobalt chloride to catalyze the reaction Samples were withdrawn from the tank and collected in BOD bottles and chemically fixed for later dissolved oxygen (DO) measurement by the Iodometric (Winkler) method.

Airflow Measurements

Airflow measurements were made with two different primary flow elements: an orifice plate and an Annubar. Dual flow measurements were taken to ensure greater accuracy. Furthermore, to provide acceptable accuracy over the wide range of flow rates encountered, two different

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Table 1. Description of Aeration Systems Subjected to Clean Water Testing

System	*Description*	*Manufacturer*
A	*Fine bubble ceramic dome diffusers applied in a total floor coverage configuration*	*Norton Company*
B	*Fine bubble plastic tube diffusers applied in a dual aeration configuration (Pearlcomb)*	*FMC Corporation*
C	*Jet aerators*	*Pentech-Houdaille Industries, Inc.*
D	*Static tube aerators*	*Kenics Corporation*
E	*Variable orifice coarse bubble diffusers*	*C-E Bauer of Combustion Engineering, Inc.*
F	*Fixed orifice coarse bubble diffusers*	*Sanitaire - Water Pollution Control Corporation*
G	*Fixed orifice coarse bubble diffusers*	*Envirex, Inc.*
H	*Fixed orifice coarse bubble diffusers (Deflectofuser) [tests conducted at a 4.6-m (15-ft) depth only]*	*FMC Corporation*

sized air lines were used, both with appropriately sized orifice plates and Annubar equipment.

DO Sample Collection

Sample Locations

Water samples to be analyzed by the Winkler method were collected from four locations in the aeration tank. Two vertical sampling "stacks" were employed, each with two sampling locations. Submersible sample pumps were installed in the first stack at mid-depth and at 0.6 m (2.0 ft) off the bottom of the tank; the second stack had submersible pumps installed at mid-depth and 0.6 m (2.0 ft) below the surface of the tank. The heights of the pumps were adjustable for proper placement at the various water depths evaluated.

Sample Collection Procedure

Samples for DO analysis were pumped through plastic tubing by submersible pumps from the aeration tank to the sampling station where samples were collected in BOD bottles. Copper discharge nozzles for the four pumped samples were mounted on a plywood board to enable one operator to control the four samples simultaneously.

An attempt was made to collect approximately eight samples for the Winkler analysis between 20% and 80% saturation, although additional samples were taken below 20% and above 80% saturation. Sample water was pumped continuously to purge the BOD bottles until the desired time, "t," after which the sampling device was withdrawn and the BOD bottles stoppered. If necessary, 1 or 2 sec were allowed before stoppering the BOD bottles to allow any small air bubbles to rise to the surface and escape. The overflow water from the BOD bottles was caught in a 208-L (55-gal) tank and continuously pumped back to the aeration tank.

Sampling Rates

The submersible pumps for the Winkler samples were sized so a BOD bottle could be filled three to five times in 15 sec (0.06 to 0.10 L/sec = 1.0 to 1.6 gpm). This was done to ensure adequate displacement of the water in the BOD bottle and to minimize the detention time in the sample lines (approximately 10 sec). All pump rates and sample line lengths were maintained equal so that the samples from the various locations would represent the same time "t."

DO Measurements

The official DO measurements were made by the Winkler method on captured samples. The azide modification of the Winkler titration method was used with alkali-iodide-azide reagent #2 as stated in Standard Methods. This reagent was selected because it reportedly reduced the volatility of iodine and thus provided a more accurate DO measurement. Samples were set up immediately after capture and titrated within 1.5 hr. The thiosulfate used for the titrations was standardized once each day.

Deoxygenation Procedure

Cobalt chloride was used as a catalyst in the deoxygenation reactions. It was added once at a dosage of 0.1 mg/L as cobalt ion to each batch of test water. The chemical crystals were added to the mix tank and allowed to dissolve for at least 30 min prior to discharging the solution into the aeration tank. After cobalt addition to the aeration tank, at least another 30 min was allowed prior to the start of the first test.

Anhydrous sodium sulfite was used to deoxygenate the water prior to the start of each test. The amount of sodium sulfite added was approximately 1.5 times the stoichiometric requirement for oxygen removal. The salt was dissolved in approximately 379 L (100 gal) of water prior to the start of each run. The brine addition to the tank was accomplished within a 2-min period. The solution was pumped equally into the four tank quadrants through a 4-hose addition system. Distribution was, therefore, as even and rapid as possible. The chemical mix tank and delivery hoses were immediately flushed with tap water to wash all residual sodium sulfite into the aeration tank.

A decision was made to discard each water batch after the accumulated sodium sulfite concentration had reached 1,000 mg/L. At that time, samples were taken for laboratory analyses to determine the chemical properties of the "post-test" water. Analyses were also conducted prior to using a water batch to determine the "pre-test" condition. These measurements included pH, alkalinity, hardness, sulfate, total dissolved solids, cobalt, iron, and manganese.

Aerator Power Determinations

In addition to power for an air supply, aeration equipment may also require power for a mixer or a pump. Of the eight systems evaluated in this study, only the jet aeration system required pump power in addition to the power for the air supply. Power determination is discussed in detail in the full Project Report, and equations are given for calculating air nominal power, air delivered power, air brake power, air wire power, pump delivered power, pump brake power, and pump wire power. All power requirements used in this report to calculate aeration efficiencies (kg or lb O_2 transferred per kWh or hp-hr of electricity consumed, respectively) were based on wire power.

Analysis Methods

The transfer of gas into a liquid can be described by the two-film theory proposed by Lewis and Whitman (Principles of Gas Adsorption, Ind. Eng. Chem., 16:1215, 1924), expressed as follows:

$$dC/dt = K_La_t\,(C^*-C) \quad (1)$$

where:

dC/dt = oxygen transfer rate per unit volume, mg/L/hr

K_La_t = overall volumetric mass transfer coefficient for test conditions, hr^{-1}

C^* = DO saturation value, mg/L

C = DO concentration, mg/L

This is the differential form of the basic equation and states that the oxygen transfer rate per unit volume is directly proportional to the DO deficit (C^* - C). The oxygen transfer rate, dC/dt, is a function of many variables, including the type of aerator, the aeration tank geometry, the nature of the liquid, and the liquid temperature. Equation 1 was originally developed to describe oxygen transfer in small, shallow containers. It has been generalized to the case of large, deep aeration basins that are completely mixed. If complete mixing is not achieved, the use of Equation 1 to define the oxygen transfer capabilities of an aeration system may lead to significant errors.

All data analysis methods share one common trait; they define an analytical procedure to calculate oxygen transfer rate. This always includes the fundamental determination of both the volumetric mass transfer coefficient, K_La_t, and the DO saturation value, C^*.

Eight data analysis methods were originally planned to be incorporated in the Project Report. A computer program was developed to analyze data using all eight methods. It was later decided, however, to include only the analysis results in the Project Report of the two most highly regarded methods. The two methods the Districts considered to be the most highly regarded were 1) the log-deficit model with a measured equilibrium, hereinafter referred to as the equilibrium method, and 2) the transformed integrated form of the basic equation, hereinafter referred to as the exponential method.

The equilibrium method is described by the following equation:

$$\ln(C^*-C) = K_La_t(t/3600) + \ln(C^*-C_i) \qquad (2)$$

where:

C_i = initial DO concentration, mg/L
t = time in sec

The conversion factor of 3600 is utilized to make compatible the units of K_La_t in hr^{-1} and t in sec.

The equation for the exponential method is given below:

$$C = C^* - (C^*-C_i) \exp[-K_La_t (t/3600)] \qquad (3)$$

The two methods of analysis are different in the ways the error structure of the data is handled and the saturation value is obtained. The exponential method provides estimates of three parameters, K_La_t, C^*, and C_i. It uses the entire data set to estimate C^*. The equilibrium method involves a log transformation of the data, such that the latter measurements of C in a test run are weighted more heavily than the early measurements. This method utilizes a measured saturation value obtained from a few data points at equilibrium conditions and, thus, provides an estimation of only a single parameter, K_La_t. Both methods assume the same model (Equation 1), and if all the data fit this model exactly, no differences would exist between the respective estimates of the parameters. In general, however, the exponential method is the preferred procedure because it does not require long aeration times to obtain an accurate estimate of C^* and it provides more accurate estimates of K_La_t if the test data do not precisely fit the basic model. The exponential method is the basis of the recommended ASCE Standard for Measurement of Oxygen Transfer in Clean Water (ASCE, ISBN 0-87262-430-7, New York, NY, July 1984).

Test Results

Overview

To utilize clean water test data intelligently, it is essential that the limitations of the test be realized. Clean water data alone cannot be used to predict oxygen transfer performance in mixed liquor. To relate clean water oxygen transfer results to anticipated aerator performance in mixed liquor, two correction factors are required. The first factor, alpha (α), is the oxygen transfer coefficient correction factor. The second factor, beta (β), is the oxygen saturation correction factor. These correction factors are applied to the basic aeration equation as follows:

$$dC/dt = \alpha K_La_t(\beta C^* - C) \qquad (4)$$

Only with accurate alpha and beta factors, used in conjunction with clean water data, can successful prediction of oxygen transfer performance in activated sludge be achieved. As previously mentioned, the alpha factor, the ratio of wastewater K_La to clean water K_La, can vary widely as a function of several site-specific considerations. For the type of equipment tested during this study, alpha factors from 0.35 to 0.95 have been reported. Beta factors of 0.96 to 0.99 are common for municipal wastewaters.

Since aeration equipment oxygen transfer efficiency is usually highly dependent on test medium characteristics, it is common to specify equipment compliance requirements on the basis of clean water tests. Because a clean water test is repeatable, it may be used to demonstrate general trends in aeration performance with regard to airflow rates, diffuser location, tank geometry, and other parameters. When the aerator's alpha and beta factors are known for a particular wastewater, clean water tests also provide meaningful data for activated sludge aeration system design. Even then, the process flow regime used can have a significant effect on alpha. For example, alpha will tend to approach a constant value throughout a completely mixed aeration tank, whereas it will increase from inlet to outlet of a plug flow tank as the influent wastewater becomes progressively more treated.

Tabular Data

The Project Report contains 16 tabular summaries of the test data, two each for the eight aeration systems tested. One table for each system contains the results of the exponential method of data analysis, the other the results of the equilibrium method of analysis. Only one table (Table 2) is presented in this Summary, a comparison of the exponential method and equilibrium method analysis results for the Norton fine bubble dome diffuser system.

Information provided in the first four columns of Table 2 identifies and characterizes the tests. Results of the exponential method of analysis are summarized in columns 5 through 9. The last five columns summarize the results of the equilibrium method of analysis. The K_La_{20} values shown are the overall volumetric mass transfer coefficients at a standard water temperature of 20°C, while the C^*_0 numbers are the DO saturation values at 20°C and a standard barometric pressure of 1.00 atmosphere. Standard oxygen transfer efficiency (SOTE), standard delivered aeration efficiency (SDAE), and standard wire aeration efficiency (SWAE) data represent actual field determined clean water values corrected to standard conditions of 20°C, 1 atmosphere, 0 mg/L DO, and 36% relative humidity.

The data in Table 2 indicate close agreement in test results between the two data analysis methods for the Norton system. Similar agreement was observed for the other seven aeration systems. The average ratios of K_La_{20} (exp. method)/K_La_{20} (equil. method) and SWAE (exp. method)/SWAE (equil. method) were 0.990 and 0.995, respectively, for all eight systems encompassing 100 test runs. For the K_La_{20} ratio, the maximum value for any one run was 1.10, while the minimum ratio was 0.88. For the SWAE ratio, the maximum and minimum run values were 1.06 and 0.93 respectively. The close agreement in these results indicates that the test data fit the basic model (Equation 1) extremely well for all eight systems.

Graphical Data

A total of 15 graphs are presented in the Project Report comparing the oxygen transfer performance of the various aeration systems. Four of these 15 graphs are presented in this Project Summary to illustrate key representative results of the entire test program. SOTE and SWAE are shown as functions of water depth for the middle nominal power density in Figures 1 and 2, respectively. In Figures 3 and 4, SOTE and SWAE are graphed, respectively, against delivered power density for the 4.6-m (15-ft) water depth. This water depth was selected because many municipal treatment plants around the country use aeration tanks with a similar depth.

The middle nominal power density data plotted in Figures 1 and 2 represent a power level of 26.3 W/m^3 (1.0 hp/1,000 ft^3) for all aeration equipment except Norton. Norton selected a middle power density of 13.2 W/m^3 (0.5 hp/1,000 ft^3)

The data points at the four water depths tested are connected by straight

Table 2. *Summary of Results for Exponential and Equilibrium Methods: Norton Fine Bubble Diffusers*

Date	Water Depth (ft)	Delivered Power Density@ (hp/1000 ft^3)	Air-Flow Rate (scfm)	Exponential Method: K_La_{20}† (hr^{-1})	Exponential Method: C^*_o (mg/L)	Exponential Method: Standard Oxygen Transfer Efficiency (%)	Exponential Method: Standard Aeration Efficiency§ (lb O_2/hp-hr) Delivered	Exponential Method: Standard Aeration Efficiency§ (lb O_2/hp-hr) Wire	Equilibrium Method: K_La_{20}‡ (hr^{-1})	Equilibrium Method: C^*_o (mg/L)	Equilibrium Method: Standard Oxygen Transfer Efficiency (%)	Equilibrium Method: Standard Aeration Efficiency§ (lb O_2/hp-hr) Delivered	Equilibrium Method: Standard Aeration Efficiency§ (lb O_2/hp-hr) Wire
3/24/78	25	0.28	73.8	5.34	11.42	49.48	13.44	8.22	5.36	11.42	49.60	13.47	8.24
4/21/78	10	0.57	125.8	11.31	9.81	21.30	12.10	7.40	11.64	9.72	21.72	12.34	7.55
4/24/78	10	0.32	73.9	7.17	9.88	23.20	13.95	8.53	7.18	9.88	23.21	13.96	8.54
4/25/78	15	0.31	74.5	6.41	10.24	32.03	13.37	8.18	6.22	10.36	31.40	13.10	8.01
4/26/78	15	0.54	126.0	9.87	10.45	29.71	11.98	7.33	9.92	10.40	29.70	11.98	7.33
4/27/78	15	1.24	253.4	17.66	10.60	26.61	9.33	5.71	17.95	10.53	26.87	9.42	5.76
5/04/78	20	0.51	126.9	9.47	11.12	39.81	12.72	7.78	9.57	11.08	40.10	12.81	7.83
5/05/78	20	1.15	256.1	16.39	11.02	33.80	9.68	5.92	16.33	10.97	33.94	9.71	5.94
5/08/78	25	1.16	272.4	14.61	11.67	37.16	9.11	5.57	14.72	11.66	37.42	9.18	5.61
5/09/78	25	0.50	127.5	8.54	11.65	46.69	12.46	7.62	8.42	11.73	46.36	12.37	7.57
5/10/78	20	0.30	76.3	6.07	11.33	43.55	14.17	8.66	6.21	11.25	44.27	14.40	8.81
5/15/78	10	1.37	248.3	19.30	10.17	19.14	8.94	5.47	19.93	10.07	19.58	9.15	5.59
5/16/78	20	0.30	75 .0	5.82	11.44	42.85	13.96	8.54	5.85	11.40	42.88	13.97	8.54

@ The delivered horsepower numbers are based on the adiabatic compression equation. Standard ambient conditions of 20°C, 14.70 psia, and 36% relative humidity have been used. Blower inlet and discharge pressures were determined in accordance with Equations 4 and 6 from the full report.
† Based on the exponential model analysis using Winkler data.
‡ Based on the equilibrium model analysis using Winkler data.
§ The wire horsepower used in this analysis is related to delivered horsepower by a blower efficiency of 0.70, a coupling efficiency of 0.95, and a motor efficiency of 0.92 (an overall or combined efficiency of 0.612).

lines in Figures 1 and 2 for five of the seven systems represented. For the Kenics and Sanitaire Systems, however, discontinuous lines are shown. It was felt that equipment configuration changes at the different depths strongly influenced the results of these two systems; consequently, only points for the same configuration layout are connected for Kenics and Sanitaire.

It is apparent in Figure 1 that increases in water depth produced increases in SOTE for each manufacturer configuration tested. The three highest curves represent the ceramic dome and plastic tube fine bubble diffusers and the jet aerators. The coarse bubble aeration equipment tested is represented by the lower curves. The variable orifice coarse bubble diffuser SOTE curve is at the bottom of the coarse bubble diffuser band.

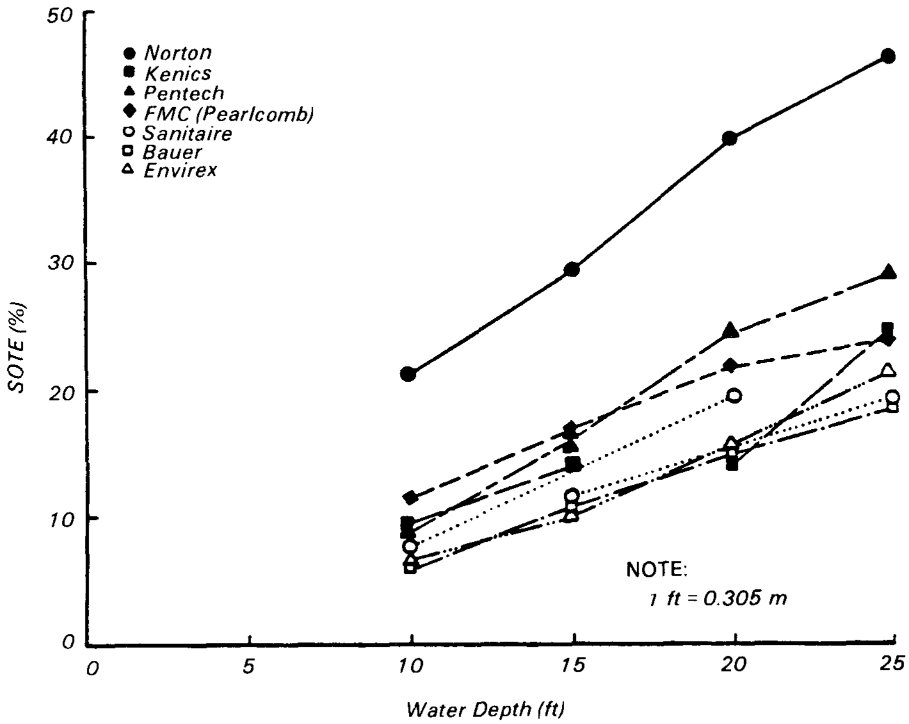

Figure 1. *Comparative plot of SOTE vs. water depth at middle power density tested.*

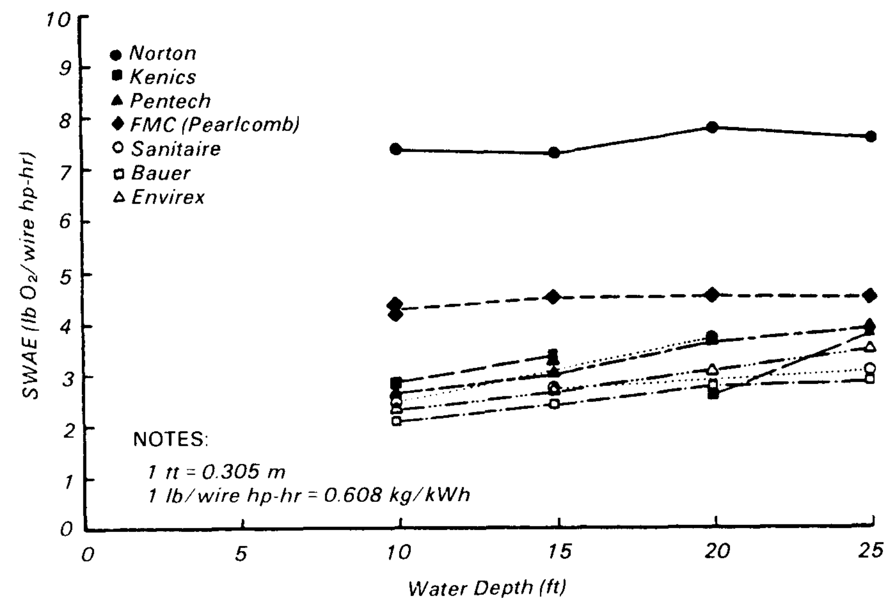

Figure 2. *Comparative plot of SWAE vs. water depth at middle power density tested.*

The data in Figure 2 indicate that the effects of increasing water depth on SWAE depend on the generic type of aeration equipment tested. While the fine bubble diffusers appear to have been relatively unaffected by changes in water depth, SWAE improved with increasing water depth for the coarse bubble diffusers, static aerators, and jet aerators. The two highest curves represent the two fine bubble diffuser systems, while the jet aerators, static tube aerators, and coarse bubble diffusers generally grouped together in the lower band of curves. The variable orifice diffuser results again were the lowest.

The jet aeration system's SWAE values are lower in relation to the SWAE's of the coarse bubble aeration systems than would be expected based on the comparative SOTE values of the two types of equipment. This is most likely due to the need for two prime movers (blower and pump) to operate the jet aerators versus only one (blower) to operate any of the other systems evaluated.

As seen in Figure 3, the aeration equipment producing fine bubbles – Norton, FMC Pearlcomb, and Pentech – exhibited peak oxygen transfer efficiencies at the lowest delivered power density for the 4.6-m (15-ft) water depth. Equipment that produces coarse bubbles generally showed the opposite trend, with peak valves occurring at the greatest delivered power density. The curves for most of the equipment are relatively straight with the exception of the jet aeration system. The order in SOTE values, from highest to lowest, is as follows: Norton, Pentech, FMC Pearlcomb, and Kenics, followed by the other coarse bubble systems clustered closely together. Similar trends and orders were observed at the other water depths studied, with the exception that the Kenics static tube aerator SOTE fell within rather than above the coarse bubble curve band.

Five of the systems demonstrated little variation in SWAE for the 4.6-m (15-ft) water depth over the range of delivered power densities evaluated (Figure 4). The systems that did exhibit significant variation over this range – Norton, FMC Pearlcomb, and Pentech – all generate small bubbles. Both Norton and FMC produced their peak SWAE values at the lowest delivered power density, while for Pentech, the peak SWAE occurred at the middle delivered power density. From highest to lowest, the order in SWAE values is Norton; FMC Pearlcomb; Kenics; Pentech; FMC Deflectorfuser, Envirex, and Sanitaire grouped together; and Bauer. The impact of two prime movers on the energy consumption of the jet aeration system in relation to its relative high SOTE values is again clearly evident. The Norton and FMC Pearlcomb systems also generated the highest SWAE values at the other depths tested.

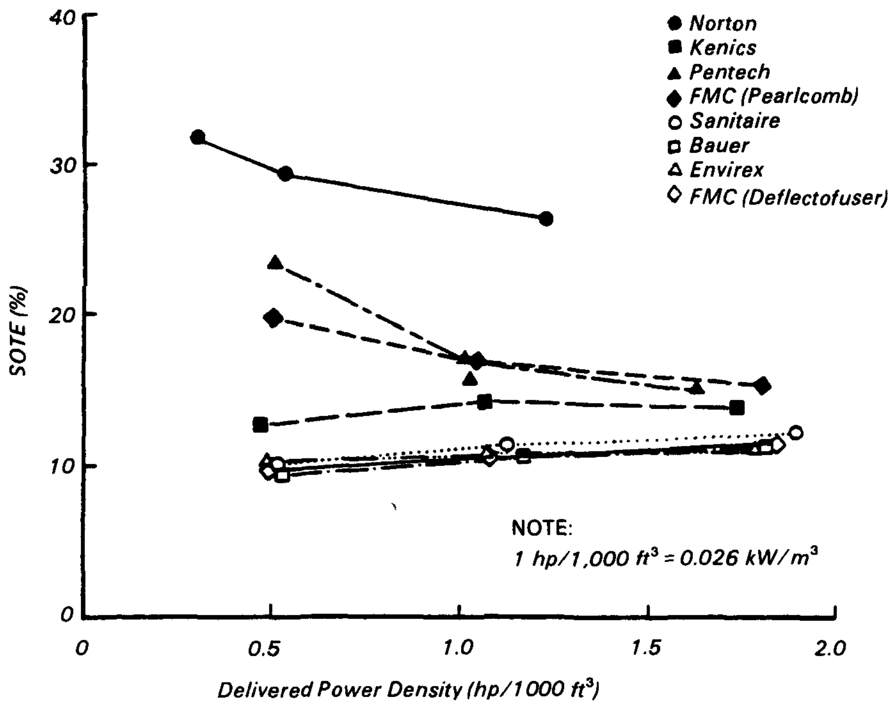

Figure 3. Comparative plot of SOTE vs. delivered power density at 15-ft water depth.

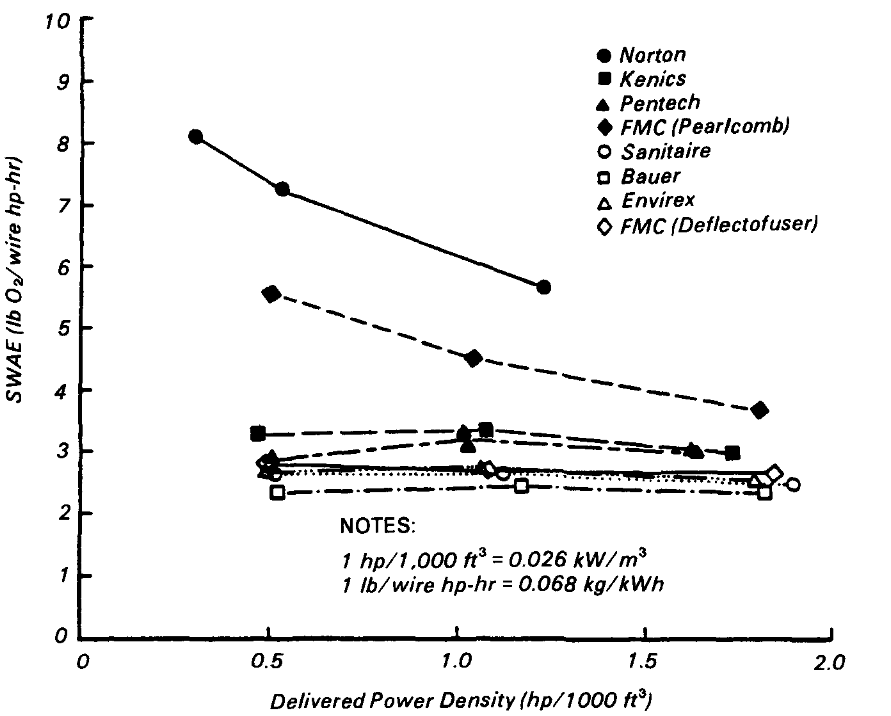

Figure 4. Comparative plot of SWAE vs. delivered power density at 15-ft water depth.

Conclusions

This clean water study provided considerable insight into oxygen transfer performance characteristics of various submerged aeration devices. The following conclusions were reached:

- For a given water depth and delivered power density, the SWAE's of the fine bubble dome diffusers (Norton) in a total floor coverage mode were substantially better than those of any other system tested.
- For a given water depth and delivered power density, the SWAE's of the fine bubble tube diffusers (FMC Pearlcomb) in a dual aeration mode were substantially better than those of either the jet aerators (Pentech) or the various coarse bubble devices (Kenics, Sanitaire, Envirex, FMC Deflectofuser, and Bauer).
- For a given water depth and delivered power density, the SWAE's of the jet aerators were usually better than those of the various coarse bubble diffusers (with the exception of the Sanitaire fixed orifice coarse bubble diffusers in a total floor coverage mode).
- For a given water depth, delivered power density, and with similar configurations, the SWAE's of the various coarse bubble diffusers were similar.
- For a given configuration and water depth, SWAE decreased significantly with increasing delivered power density for the fine bubble tube diffusers, reached a mid-point maximum value for the jet aerators, and exhibited very little change for the coarse bubble diffusers.
- For a given configuration and delivered power density, the SWAE values of the fine bubble diffusers were relatively unaffected by increases in water depth and usually increased significantly for the other aeration devices with the exception of the static tube aerators at the upper water depths.
- For a given water depth and delivered power density, the SOTE's of the fine bubble dome diffusers in a total floor

coverage mode were substantially better than those of any other system tested.

- For a given water depth and delivered power density, the SOTE's of the fine bubble tube diffusers in a dual aeration mode and the jet aerators were similar and significantly better than those of the various coarse bubble diffusers.
- For a given water depth and delivered power density, the SOTE's of the various coarse bubble diffusers were very similar when installed in similar configurations.
- For a given configuration and water depth, SOTE decreased significantly for the fine bubble diffusers and jet aerators with increasing delivered power density and usually increased slightly for the various coarse bubble diffusers (with the exception of the static tube aerators, where SOTE was not significantly affected by changes in delivered power density).
- For a given configuration and delivered power density, SOTE increased substantially with increasing water depth for all systems tested.
- The use of a total floor coverage configuration with the Sanitaire fixed orifice coarse bubble diffusers appeared to improve the performance of this system significantly.
- With the exception of the Sanitaire system, the changes in aerator configuration selected by the manufacturers at different water depths did not appear to result in significant changes in oxygen transfer performance.
- The exponential and equilibrium methods of clean water data analysis provided nearly identical results under the conditions of this study. Based on 100 test analyses, the average ratio of the SWAE obtained with the exponential method to the SWAE obtained with the equilibrium method was 0.995, with a standard deviation in the ratio of 0.0169.

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Fred W. Yunt and Tim O. Hancuff are with the County Sanitation Districts of Los Angeles County, Los Angeles, CA 90607.
***Richard C. Brenner** is the EPA Project Officer (see below).*
The complete report, entitled "Aeration Equipment Evaluation: Phase I - Clean Water Test Results," (Order No. PB 88-180 351/AS; Cost: $25.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Water Engineering Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

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