“2001” OXYGEN TRANSFER REPORT: CLEAN WATER TESTING

(In accordance with latest ASCE standards)

for

AIR DIFFUSION SYSTEMS
SUBMERGED FINE BUBBLE DIFFUSERS

on

MARCH 7, 8, 9, & 10 in 2001
TESTING DEPTHS
In feet: 5, 10, & 15
In meters: 1.52, 3.05, & 4.57

By
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NOMENCLATURE

AE*	Aeration efficiency; mass of oxygen transferred per unit energy at process conditions (lb-O2/hp-hr or kg-O2/kW-hr)
KLA	Mass transfer coefficient (hr^{-1})
OTE	Oxygen transfer efficiency; oxygen transfer efficiency at process conditions (mass %)
OTR	Oxygen transfer rate; oxygen mass transfer rate at process conditions (lb-O2/hr or kg-O2/hr)
SAE	Standard aeration efficiency; mass of oxygen transferred per unit energy at standard conditions (lb-O2/hp-hr or kg-O2/kW-hr)
SCFM	Airflow in standard cubic feet per minute
SCFH	Airflow in standard cubic feet per hour
SOTE	Standard oxygen transfer efficiency; oxygen transfer efficiency at standard conditions (mass %)
SOTR	Standard oxygen transfer rate; oxygen mass transfer rate at standard conditions (lb-O2/hr or kg-O2/hr)
Wire horsepower	Horsepower consumed by the aeration system, including all electrical and mechanical inefficiencies; equal to power draw from the electrical service
Delivered Blower Horsepower*	Horsepower consumed by the blower in a diffused aeration system, to overcome all pressure drops, and excluding electrical and mechanical efficiencies; must be divided by the motor, blower, coupling etc. efficiencies to equal wire horsepower
ADS	Air Diffusion Systems, a John Hinde Company, 28846-C Nagel Ct, Lake Bluff, IL, 60044, (moving in 2002 to Gurnee, IL), www.airdiffusion.com
LWA1.5	Aeration tubing, designated as Linear Weighted Aeration, which uses a single row of slits on1.5” centers.
LTC	Aeration tubing, designated as Linear Triple Cut Weighted Aeration, which uses three rows of slits on 1.5”centers.

ADS, LWA1.5 and LTC are trademarks of John Hinde Company.

* Consult the ASCE, *Measurement of Oxygen Transfer in Clean Water***,** for more information on oxygen transfer protocols.

INTRODUCTION

The Air Diffusion Systems (**ADS**) fine bubble aeration system (originally created by J. Nelson Hinde in 1965, and now owned by John N. Hinde,) was tested in clean water at their manufacturing facility in Lake Bluff, Illinois on March 7 to 10, 2001. The goal of the testing was to determine the oxygen transfer efficiency as a function of diffuser submergence.

The **ADS** system is used in lagoons and other applications requiring only a low air flow rate. The tubing is composed of a virgin polyethylene (containing>2% Carbon Black) with surgically processed air release slits. The slits are manufacturing using a proprietary process, but are simply called "slits" in the rest of the report, but refer to proprietary process. The encapsulated lead wire-keel located underneath the tubing, provides the necessary ballast to keep the tubing submerged. The tubing is typically installed in parallel rows (tapered grid coverage) across bottom width of the lagoons to provide aeration. **ADS** also supplies the tubing in 48" diameter coils to provide greater aeration in a small area. The application of the system to only low rate processes has generally precluded oxygen transfer testing as typically performed on aeration systems for high rate applications, such as the activated sludge process. The details of the process application are beyond the scope of this report, and their literature should be consulted for further information.

Most clean water testing is performed today using the clean water standard developed by the American Society of Civil Engineers (ASCE, 1984, 1991). This standard uses a procedure that requires the test water (tap water) to be deoxygenated and then reaerated with the test diffusers at the appropriate airflow rate (The airflow is quite small; less then 0.05 SCFM total air for "LTC".) For typical **ADS** applications, the time required to reaerate the tap water is quite lengthy, making testing expensive. Also, the application of the system to lagoons often means that the geometry of the water body is a very large and not well simulated in test tanks.

The tests were performed in accordance with the ASCE Standard is so far as possible. The Standard was created for full-scale testing and not small scale testing as performed in this project. The Standard urges that similar geometries be used for testing and design. Obviously this is not possible in general applications to lagoons; however the tests were conducted at depths representative of full-scale application of the **ADS** System. Other differences exist because of the small scale. The Standard suggests using six dissolved oxygen (DO) probes and requires at least four operating probes for data analysis. Only three probes were used for 10 and 15-foot test depths. Two probes were used at the 5-foot depth. It was not possible or necessary to use six probes for the column. The data were analyzed in strict adherence to the Standard; the non-linear estimation procedure was used and the time to complete the test (~ $4/K_LA$ or 98% of equilibrium) was always followed. Power was calculated using the adiabatic blower compression method, as opposed to being measured with a wattmeter.

TEST DESCRIPTION

Testing was performed in a clear acrylic column with an 8.75-inch internal diameter by 16 feet maximum depth. The depth of the column was varied by filling with tap water to the appropriate depth. Small sections of aeration tubing were placed across the diameter of the column at the bottom. The tubing uses slits parallel to the length of the tubing to create orifice for aeration (see ADS literature for more information).

Figure 1 is a schematic diagram of the test column (unnecessary details are omitted). A more detailed diagram and photographs are included in the Appendix. Three DO meters with probes set at various depths in the column were used to measure DO concentrations. The DO probes, which used mixing heads, were attached to YSI model 58 and 57 DO meters. A pumped sampling port is shown near the bottom of the column. The pumped sample was used to obtain water samples for calibration, and was not operating during actual testing. A ladder was used to access the top of the column. Liquid height was manually set with a tape measure with gas flow turned off, and checked between tests. The column was filled with Lake Bluff tap water, which uses Lake Michigan as its source. For the 10 and 15-foot water depths, three probes were used, and were set at 25, 50 and 75% of the water depth. For the 5-foot depth, only two probes were used and were set at 33 and 66% of water depth.

Two types of ADS Aeration Tubing were tested: Single-Cut LWA1.5 & Triple-Cut LTC. Figure 2 (supplied by John Hinde) shows the internal arrangement of the aeration tubing. Two slit patterns were investigated in this test. The first type, designated as LWA1.5, uses a single slit at the top of the tubing on 1.5-in centers. This test allowed 6 slits to be used in the 8.75-inch column diameter. The second slit pattern, designated as LTC, uses three rows of slits; the top row is complimented by two rows on the sides, rotated +/- 90 degrees from the top. The slit spacing is 1.5 per inch, which becomes 0.5 per inch if all three sides are considered. This test allowed 14 slits to be used across the 8.75-inch diameter column. The column was equipped with a sparge ring, also composed of ADS tubing, around the circumference of the column. The sparge ring was used to deoxygenate the column with nitrogen gas. Its diameter and geometry have no bearing on test results.

The test water was first deoxygenated using sodium sulfite. Cobalt chloride was dissolved in the tap water to catalyze the deoxygenating reaction. Later analysis showed the cobalt concentration as 0.301 mg/L (as Co). The sulfite was dissolved in tap water and poured from the top of the column. At 15 feet water depth, the decrease in DO concentration revealed very slow mixing, and the sulfite remaining at the top of the column. To avoid mixing problems, nitrogen gas was used instead. Nitrogen gas was released at the bottom at high flow rate. Sulfite addition was not evaluated at the 5 and 10 water depths.

Air pressure and temperature were measured with a mercury manometer and thermometer. Airflow was measured with Dwyer Visi float VFA and VFB meters, which have accuracies of ± 5% (VFA) and ± 3% (VFB) of full scale. Corrections to standard conditions for airflow (760 mm Hg, $25^{o}C$) were made using the manufacturer's recommended procedure (ratios of the square roots of the actual temperature and pressures to standard pressure and temperature). The DO probes were calibrated at the beginning of each day (testing occurred over three days) and checked periodically during the sequence of tests. Probes were calibrated using air calibration and checked using the Winkler Azide procedure as referenced by the

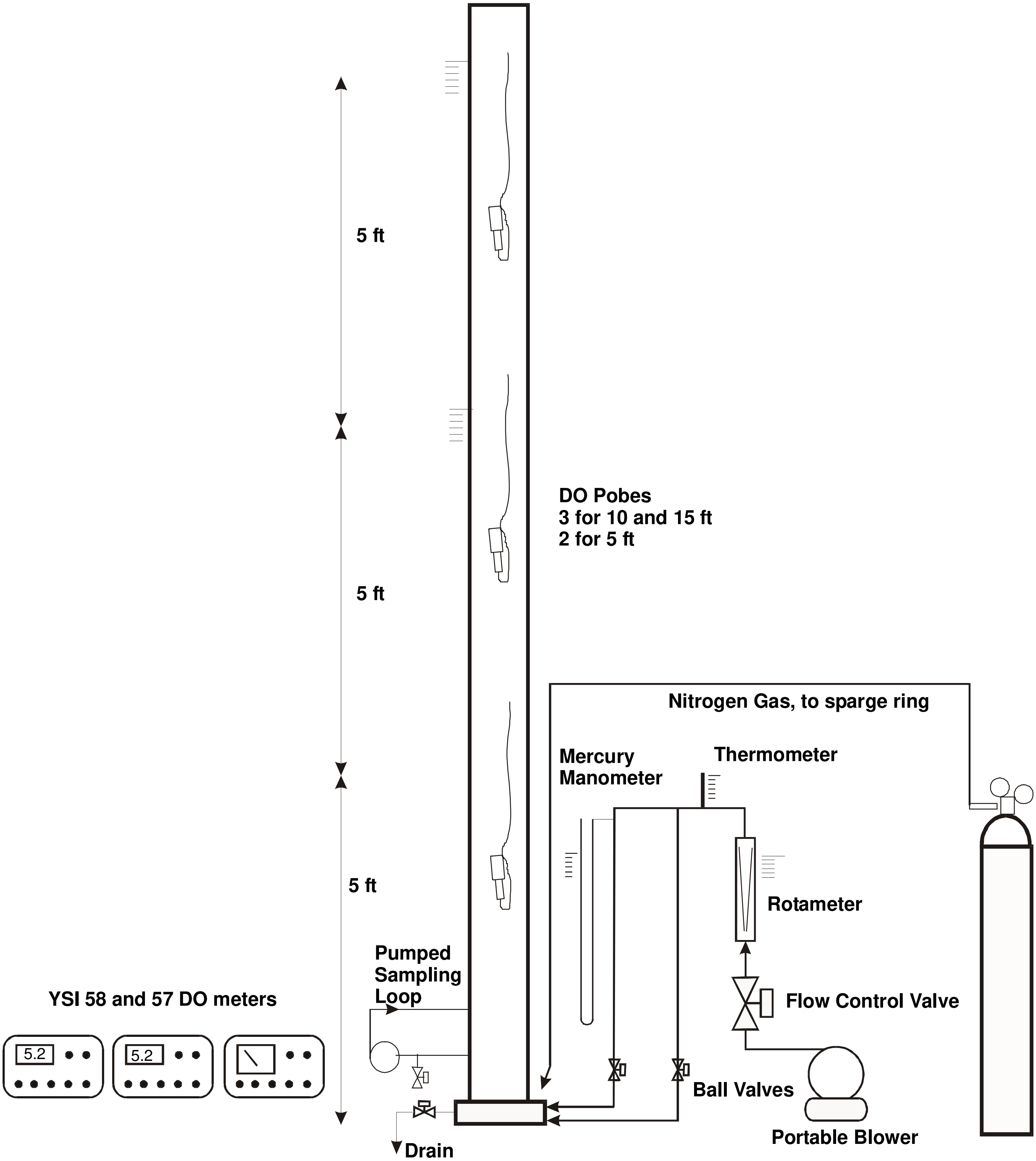


Figure 1. Test Column (8.75 inch ID) Schematic Diagram, showing DO meters and measuring instruments.

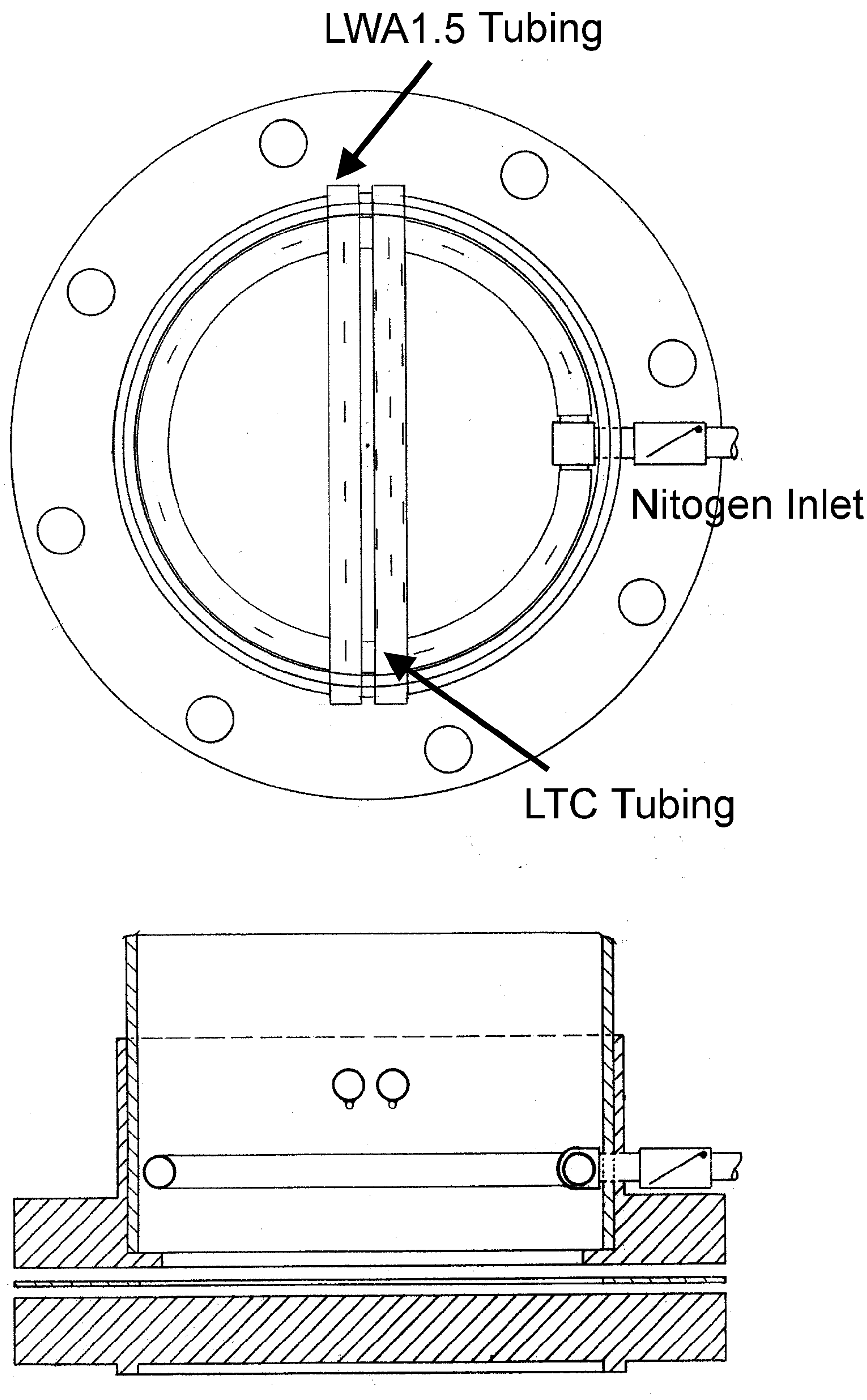


Figure 2. Details of the air diffusion tubing (drawing supplied by John Hinde)

ASCE standard. Water temperatures were also measured with the YSI probes, which were within 0.1 ^{o}C of each other, and were the same as a mercury thermometer.

Nitrogen gas was used to purge DO from the column. After approximately 10 to 15 minutes purging, the column DO decreased to 0.5 to 0.6 mg/L. At this point the nitrogen purge was stopped and the airflow was started. A portable oil-less air compressor was used to supply the air. The airflow was preset before starting the test to minimize adjustments in the test. The airflow was reset at the beginning of the test and was stable so that further adjustments during the test were not necessary.

Data collection was begun as soon as all three probes showed positive DO increase. Generally this was within several minutes of ending the nitrogen purge. A stopwatch was used to record time. The DOs were recorded manually. The interval for recording was initially every 30 seconds, which continued until five minutes elapsed time. After five minutes, the interval was increased to every minute until ten minutes elapsed time. After ten minutes, recording was performed every two minutes, which continued to 20 minutes elapsed time, when recording frequency was decreased to every four minutes. Tests were conducted to $4/K_LA$ minutes or longer, which required some tests to continue for two hours.

Tests were performed first at 15 feet, then 10 feet and finally at 5 feet side water depth. Three tests were performed at the design flow rate for each orifice configuration, which is 0.003375 SCFM per slit (0.203 SCFH per slit). The three tests provide a measure of the precision of testing, which is needed for the ASCE Standard. The airflow rate for the LTC "Triple-Cut" tubing was 0.0472 SCFM (2.83 SCFH) for 14 Slits and for LWA1.5 "Single-Cut" tubing was 0.0203 SCFM (1.22 SCFH) for the 6 slits. To determine the impact of airflow rate on transfer efficiency, the LTC was tested at 50% and 200% of the design flow rates. The LWA1.5 was tested only at the design flow rate

All data was analyzed using the ASCE Standard recommended procedures. In fact, the example Visual Basic/Excel program referenced in the Standard was used (available for download at fields.seas.ucla.edu).

TEST RESULTS

Figure 3 shows Standard Oxygen Transfer Rates (SOTE, as defined by the ASCE Standard, which is the mass transfer efficiency at standard conditions: 0 mg/L DO, 20^{o}C, tap water, 760 mm Hg, etc.) for LWA1.5 tubing. The efficiency is approximately 3% per foot of water depth or approximately 9.8% per meter of water depth. The replicate test results at the 5-foot depth are so similar that the 3 symbols appear as a single symbol. At the 15-foot depth, greater variation is observed, which will be discussed later. The straight line on Figure 3 is a best-fit, least squares regression of the test results. It is provided for convenience in scaling for different depths.

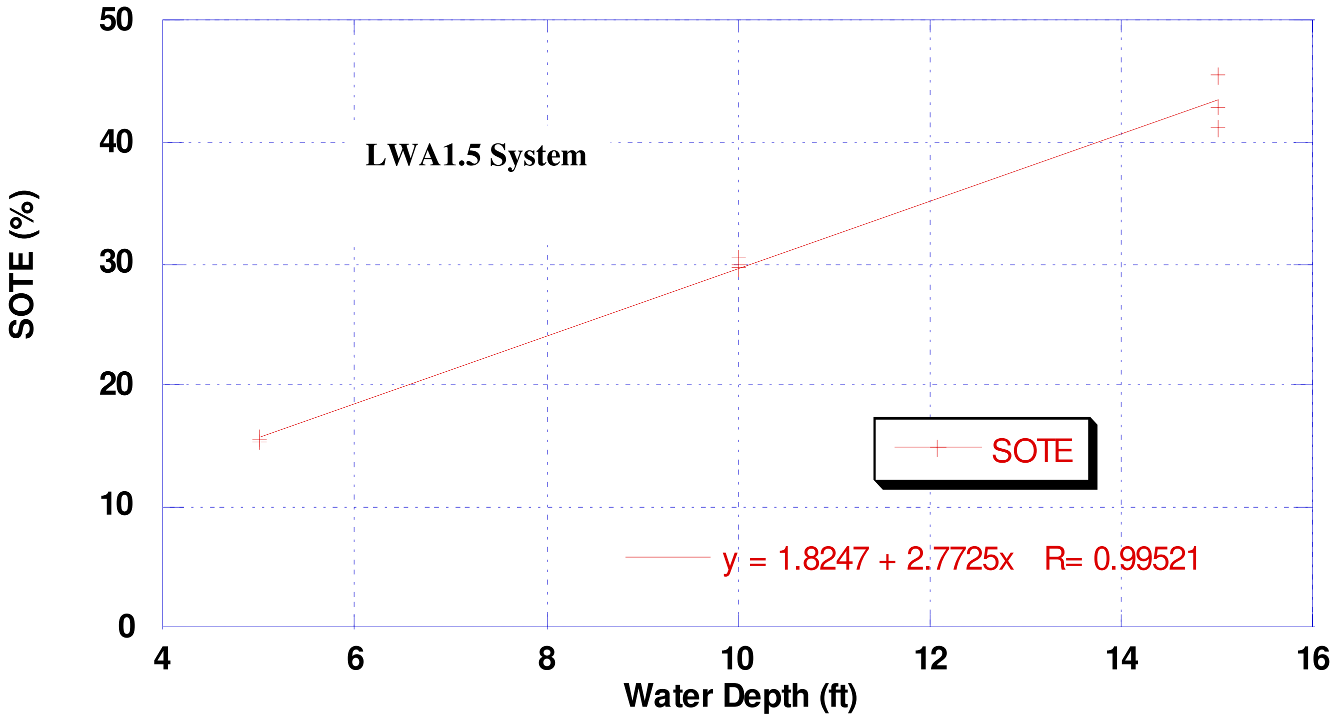


Figure 3**:** Standard Oxygen Transfer Efficiency (SOTE) versus Water Depth for the LWA1.5 system at the standard airflow rate (**above**).

Figure 4: Standard Transfer Efficiency (SOTE) versus Water Depth for LTC system (**below**).

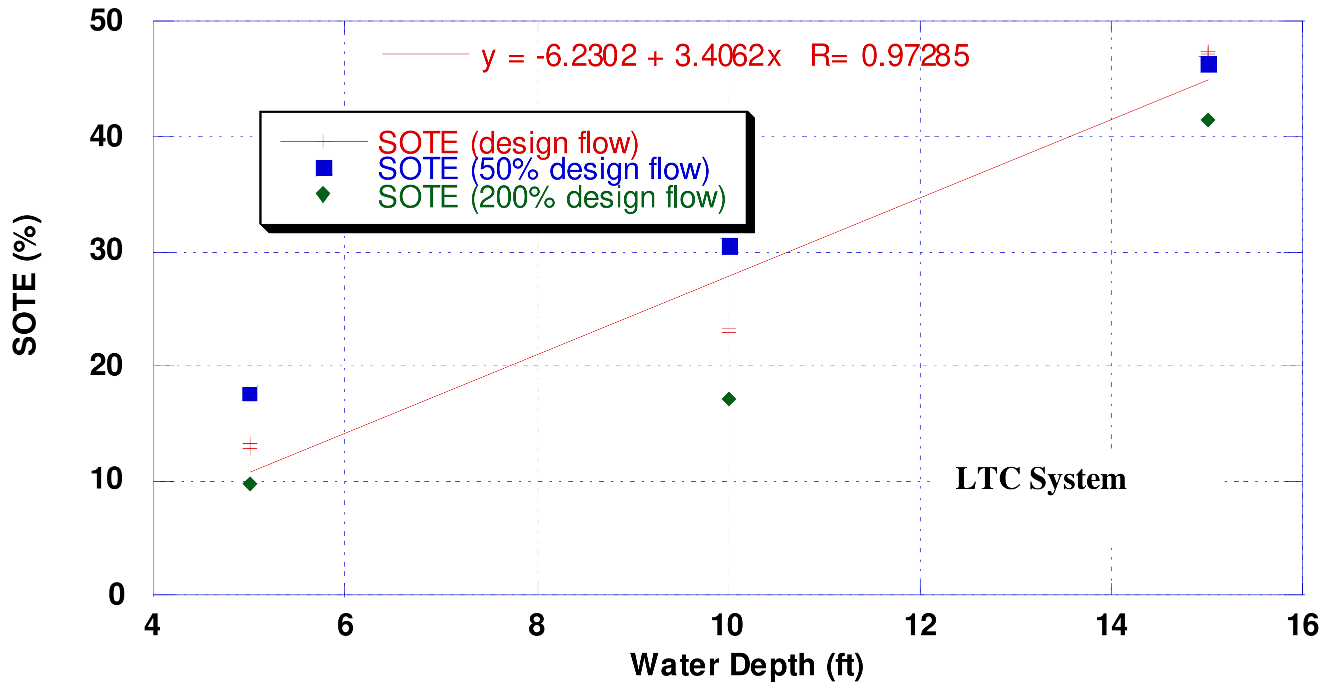


Figure 4 shows the SOTE for LTC tubing. The middle line (+ symbols) is the test result at the design flow rate. The diamonds and squares are results at the high (200% of design) and low (50% of design) airflow rates. As expected the efficiency at the lower airflow rate increased and decreased at the higher airflow rate. 15-foot depths do not follow the pattern. This is similar to the increased variability in the LWA1.5 test, and will be discussed later.

It is important to translate the transfer efficiencies into standard aeration rates. Standard aeration rates (SAE) represents the mass of oxygen transferred per unit of energy consumed. SAEs typically reported in units of lb-O2/hp-hr or kg-O2/kW-hr. The power basis is usually wire power consumption, meaning the actual electrical power consumed by the blower motor. Other power units are possible, such as "water" or "brake" power, which indicates the power consumption of only a portion of the aeration system. For example, waterpower neglects line losses and blower and motor inefficiencies. Waterpower is useful when the design engineer wishes to consider alternative piping systems different motors, blowers or gearboxes with different efficiencies. The ASCE Standard defines the term "delivered blower power," which refers to the power that must be supplied by a blower to overcome diffuser, line and static pressure losses. It must be calculated by the adiabatic compression formula. Delivered blower power can be converted to wire power by dividing by the combined blower, motor and coupling efficiencies. Care must be used in defining the types of power, especially if units other than wire power are used.

In full scale aeration testing, the actual power consumed would have been measured using a recording wattmeter or similar instrument. In this way, the SAE could have been directly measured in terms of wire power. In small scale testing, as performed in this study, measured power is not representative of full-scale results. This occurs because the flow measuring equipment, small vessels or tubing, or blowers, are not representative of full-scale results. Therefore it is better to calculate SAE based upon transfer efficiency, pressure losses, including diffuser orifice losses, and expected blower/motor efficiency. The SAEs found in this report are calculated on the basis of wire power for scenarios using 60%, 70% or 80% combined motor/blower efficiency, and for delivered bower power, is used. This information is provided to allow scaling of results. The delivered power SAEs should be multiplied by the combined blower/motor efficiency, expressed as a fraction. The actual SAE should be estimated by the designer as a function of the selected blower/motor's efficiency, site-specific line losses, system pressure and ambient temperature.

Figure 5 shows pressure drops measured during selected tests. The pressures were measured close to the diffuser, where the line losses are close to zero. The "LTC" system results are more useful in that they show the pressure drop for a range of slit flow rates. Data are available for only one flow rate for the "LWA1.5" system. Note that the pressure drop for the LTC system has different characteristics than the LWA1.5 system. This may be due to the surgical cutting technique, which is "ADS" proprietary procedure. Note also that the slit pressure drop does not behave as a fixed orifice, where pressure drop should be proportional to approximately the 1.5 power of the flow rate. This indicates that the slits are opening slightly (changing their area) at increased flow rates. The pressure drop data can be used with system characteristics, such as water depth and line losses, to calculate SAE.

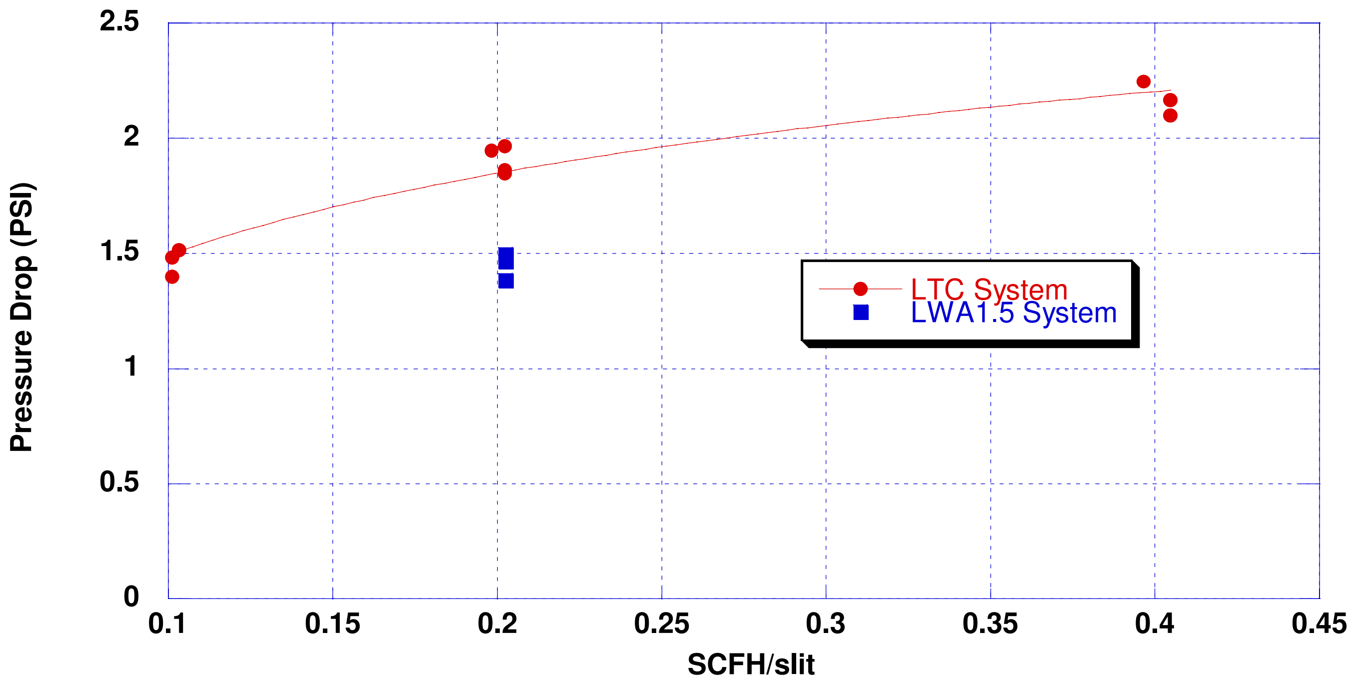
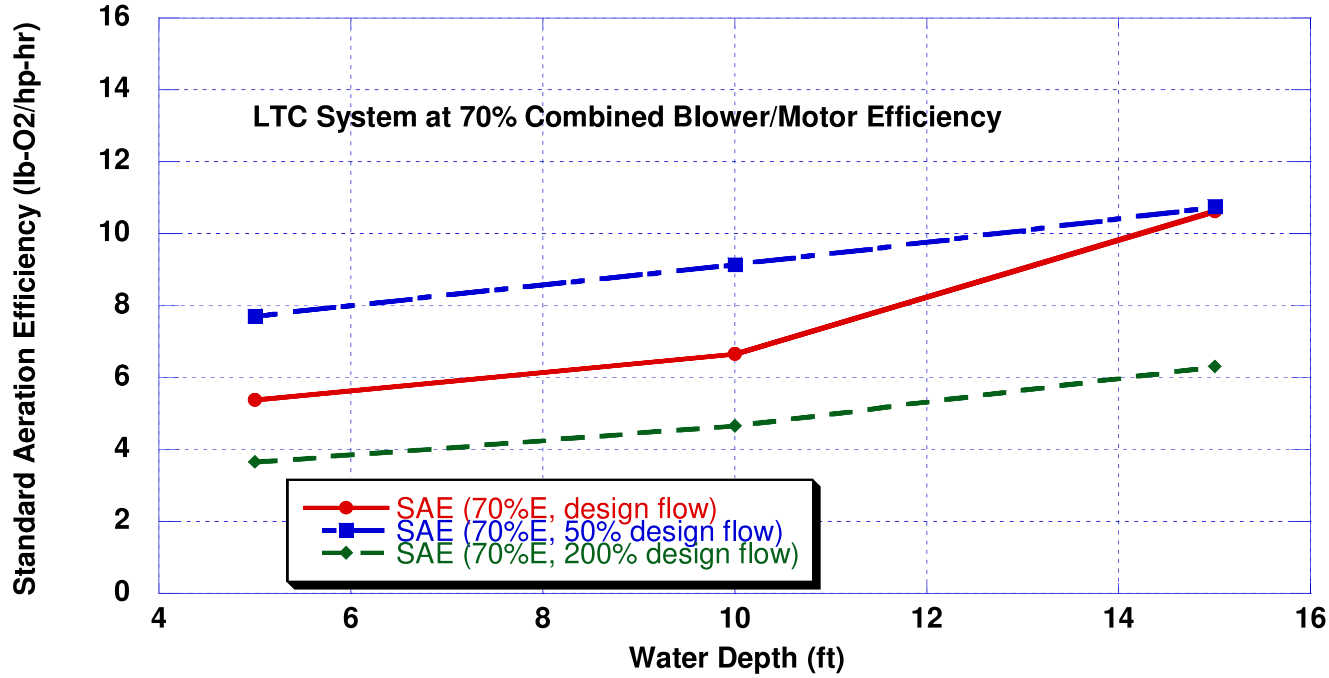


Figure 5. Pressure drop versus airflow per slit

Using the adiabatic blower horsepower formulas (see the ASCE Standard) and assumed line losses (0.5 PSI), with measured orifice losses and the Standard Oxygen Transfer Rate (SOTR), the SAE was calculated. The SOTR is defined in the ASCE standard and is the mass of oxygen transferred per unit time at standard conditions. It is calculated by multiplying the SOTE and the air flow rate, with the appropriate conversion factors. The SOTR is also calculated by the Visual Basic program. Figure 6 shows the calculated SAE's for the test results at the design flow conditions for each depth at 20^{o}C ambient air temperature.

Figure 6 shows the SAEs calculated with for the LWA1.5 configuration as a function of water depth. These were calculated with the slit pressure drops shown in Figure 4, 0.5 PSIG line losses and 70% combined blower/motor efficiency. The calculation is linear with respect to blower/motor efficiency, which means the values in the figure can be scaled up or down to match different blower/motor efficiencies. To account for pressure drop differences, the adiabatic formula must be resolved.

Figure 7 shows similar calculations but for the "LTC" system. In this case only the results at 70% are reported. The different lines represent different airflow rates per slit. The SAEs at the 15-foot water depth show an anomalous pattern with is discussed in the next section.



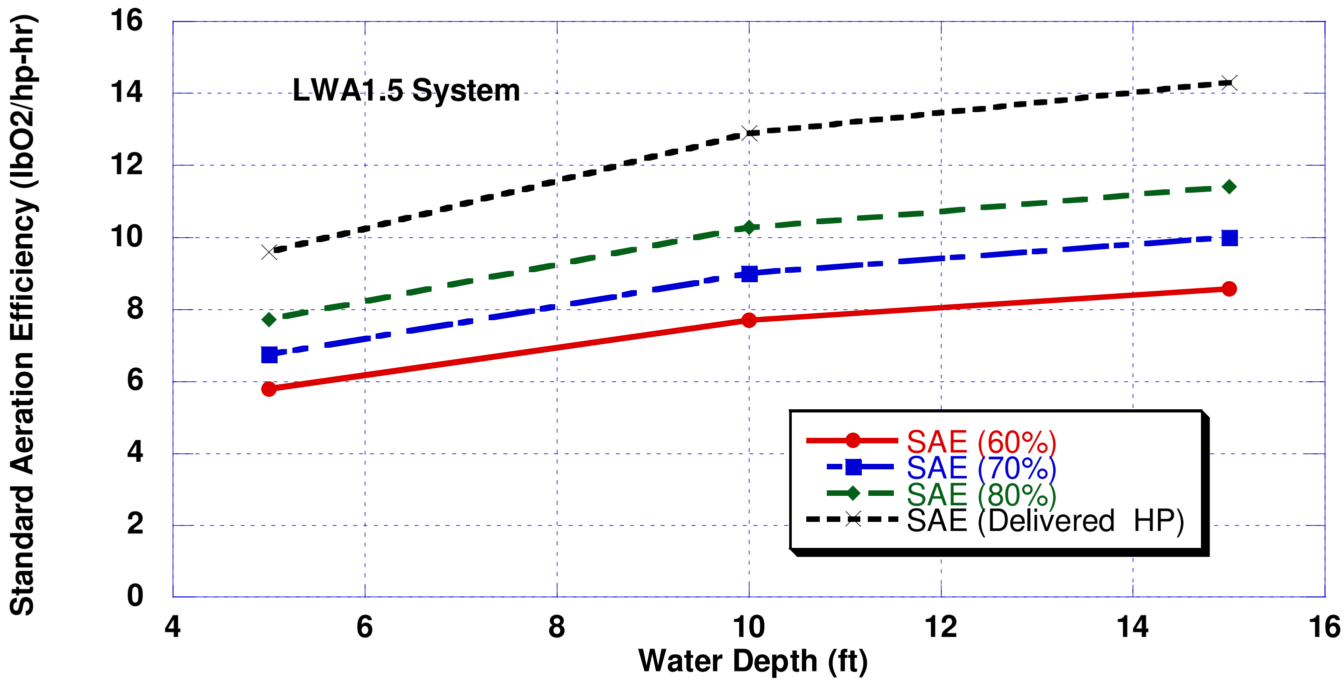


Figure 6. Standard aeration efficiency as a function of water depth and blower/motor efficiency for the LWA1.5 system (**top**)
Figure 7. Standard aeration efficiencies as a function of water dept and flow rate for the LTC system (**bottom**).

Table 1. Summary of Test Results

Test	Water Depth (ft)	Diffuser Slits	Air Flow (SCFM)	K_LA (hr^{-1})	C^*_∞ (mg/L)	SOTE (%)	SOTR (lb/hr)	de (ft)	SAE (60%)	SAE (70%)	SAE (80%)	SAE (delivered power)
4	15	14	0.0236	2.73	10.61	46.3	0.0113	5.6	9.2	10.8	12.3	15.4
1	15	14	0.0472	5.52	10.67	47.1	0.0230	5.8	9.1	10.6	12.2	15.2
2	15	14	0.0472	5.53	10.67	47.1	0.0230	5.8				
3	15	14	0.0472	5.49	10.79	47.4	0.0232	6.2				
5	15	14	0.0944	6.76	10.75	29.1	0.0285	6.1	5.4	6.3	7.2	9.0
12	10	14	0.0236	2.86	10.04	30.5	0.0075	3.5	7.8	9.2	10.5	13.1
9	10	14	0.0472	4.35	10.08	23.3	0.0114	3.6	5.7	6.7	7.6	9.5
10	10	14	0.0472	4.34	10.06	23.2	0.0114	3.5				
11	10	14	0.0472	4.27	10.06	22.9	0.0112	3.6				
13	10	14	0.0944	6.33	10.13	17.1	0.0167	3.8	4.0	4.7	5.3	6.7
23	5	14	0.0236	3.38	9.560	17.6	0.0043	1.7	6.6	7.7	8.8	11.0
20	5	14	0.0472	5.27	9.489	13.3	0.0065	1.5	4.6	5.4	6.2	7.7
21	5	14	0.0472	5.24	9.473	13.2	0.0065	1.4				
22	5	14	0.0472	5.08	9.526	12.9	0.0063	1.6				
24	5	14	0.0944	7.45	9.525	9.7	0.0095	1.6	3.2	3.7	4.2	5.3
6	15	6	0.02025	2.01	10.94	41.1	0.0086	6.8	8.6	10.0	11.4	14.3
7	15	6	0.02025	2.23	10.93	45.5	0.0095	6.7				
8	15	6	0.02025	2.11	10.90	42.9	0.0090	6.6				
14	10	6	0.02025	2.42	10.18	30.6	0.0064	4.0	7.7	9.0	10.3	12.9
15	10	6	0.02025	2.35	10.16	29.6	0.0062	3.9				
16	10	6	0.02025	2.37	10.17	29.9	0.0063	3.9				
17	5	6	0.02025	2.64	9.504	15.6	0.0033	1.5	5.8	6.8	7.7	9.6
18	5	6	0.02025	2.61	9.507	15.4	0.0032	1.5				
19	5	6	0.02025	2.61	9.463	15.4	0.0032	1.4				

Notes:

1. SAEs calculated from measured slit pressure losses, 0.5 assumed line losses, hydrostatic pressure, 20^oC ambient temperature and the indicated blower/motor efficiencies. SAE (delivered power) ignores the blower/motor inefficiencies and must be multiplied by the efficiencies (as a fraction) to convert the SAE to a wire horsepower basis.
2. de – effective depth, see the ASCE Standard
3. For 10 and 15-foot water depths, the results shown are the averaged results from three probes. For 5-foot water depths, two probes were used.
4. Replicate (3) tests were performed at the design slit flow rate. The SAEs are averaged for these tests and only the averages are tabulated.

DISCUSION

The results presented so far are more or less as expected by the manufacturer, with the exception of the results at 15 feet with the "LTC" system at the low airflow rate. There are two phenomena that influence the results at this depth. The first is column mixing and the second is gas-side oxygen depletion.

It was observed during sulfite addition at 15 feet water depth that the upper portion of the column did not mix well with the lower portion. (The small testing airflow of less then 0.05 SCFM for the LTC and 1/3 as much for LWA1.5 may be the reason). The DO probes also showed stratification during tests at 15 feet water depth. The DO stratification is detected by the different equilibrium DO concentrations (C^*_∞, the final DO established by the aeration system) and the effective depth (depth at which the hydrostatic pressure of the water column equals the increase in C^*_∞ over the surface saturation DO concentration). The increased variability in the results of the LWA1.5 system at the 15-foot water depth is also probably due to this effect.

The second issue is gas-side oxygen depletion. Gas-side depletion refers to the decrease in oxygen partial pressure as the bubbles rise through the water column. As the bubbles rise, oxygen is transferred but no net nitrogen is transferred. This results because the nitrogen concentration in the column is constant, since there are no reactions that consume dissolved nitrogen. All diffused aeration systems will experience gas-side depletion as the water depth increases. More efficient systems encounter gas-side oxygen at lower depths. Coarse bubble diffusers may not experience gas-side depletion until 50 feet or more of depth. Fine pore systems experience gas side depletion at lower depths, but typically not below 20 feet. Fine pore diffuser systems using full floor coverage typically have transfer efficiencies form 2 to 2.5% per cent per foot (SOTE/ft), depending on the gas flow rate and diffuser density. The system being tested here has closer to 3% SOTE/ft, and it is not surprising that gas side depletion occurs at lower depths.

The lack of complete mixing does not interfere with the ASCE procedure. It has been shown (Boyle et al., 1989) in oxidation ditches and other non-ideal geometries that the different mixing/transfer areas are properly measured if a sufficient number of probes are used.

A second issue is the extrapolation of column results to full-scale results. It has been shown by the author (Stenstrom and Redmon, 1996) and others that column or test tank results do not always translate to full-scale results, even if the applications are at identical depths. The primary reason occurs because of upwelling liquid velocity.

As bubbles rise through a water column, the drag they impart on the water creates currents in the water column. As the number of bubbles increases, greater liquid velocities occur. If the air bubbles are not uniformly spaced across the tank bottom, a significant upwelling velocity will be created. This upwelling velocity sweeps the bubbles from the water column at a faster rate than in quiescent water, which reduces their contact time and opportunity for oxygen transfer. Therefore the SOTE is reduced. This phenomenon is the major reason that coarse bubble "spiral roll" or "cross roll" systems have such poor efficiency. A coarse bubble grid system, which is free of upwelling velocities, will transfer at approximately 1% SOTE/ft. A spiral or cross roll system may only transfer at 0.4% SOTE/ft. The stratification of the column at 15 feet means that bubble rise rate in the tests described in this report did not produce upwelling velocities.

The application of the ADS aeration system to low loading rates in lagoons using the design air flow per slit, should not create upwelling velocities. If the system is used for other conditions or air flows higher the design airflow per slit, reduced efficiencies may result.

It is also important to note that the SAE is not constant for various water depths. Generally, subsurface systems are thought to have relatively constant SAE over a range of water depths. This occurs because the increased power to compress the air released at greater depth is compensated by the increased transfer that occurs over the greater bubble rise time.

In most situations, the line losses and orifice losses are a function of airflow rate only, and do not change with aeration system depth. The slit pressure drop for the "LWA1.5" system is 1.5 PSI at the design flow rate. If line losses of 0.5 PSI exist, then the fixed pressure drops are 48%, 32% and 24% of the total system pressure at 5, 10 and 15 feet water depth, respectively. This varying percentage accounts for the changing SAE over depth. The slit pressure drop for LTC system is ~2.0 PSI at design flow. If line losses of 0.5 PSI exist, then the fixed pressure drops are 52%, 35% and 26% of the total system pressure at 5, 10 and 15 feet water depth, respectively. Other diffused aeration systems exhibit similar trends, although they may be less pronounced. The **ADS** system has high slit pressure drop (~ 1.5 PSI to 2.0 PSI) compared to fine pore diffusers (~ 0.5 PSI) or coarse bubble spargers (~0.25 PSI) in order to create small bubbles that produce its high efficiency. The high slit pressure drop has the advantage of helping maintain even air distribution when used in lagoons, which often have uneven depths.

SUMMARY

The **ADS** aeration system was tested in two slit configurations in an 8.75-inch diameter column at 5, 10 and 15 feet water depth. The methods used were the same as the ASCE Standard, in so far as they can be applied to a column test. The result suggest approximately 3% SOTE/ft at the design airflow per slit at depths of 15 feet or less. The calculated SAEs at 70% combined motor/blower efficiency were 10.0, 9.0 and 6.75 lb-O_2/hp-hr at 15, 10 and 5 foot water depth, respectively, for LWA1.5 system. For the LTC system, the SAEs were 10.6, 6.7 and 5.4 lb-O_2/hp-hr at 15, 10 and 5-foot water depth at the design flow rates.

Results of previous tests were reviewed. Most are not applicable to the new ADS system or were conducted before the ASCE Standard. However, one test, conducted in a 65,000-gallon tank using LWA1.5 tubing on 2.5-foot tubing centers at 14 feet submergence and the same airflow per slit, showed nearly identical SOTE.

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APPENDIX

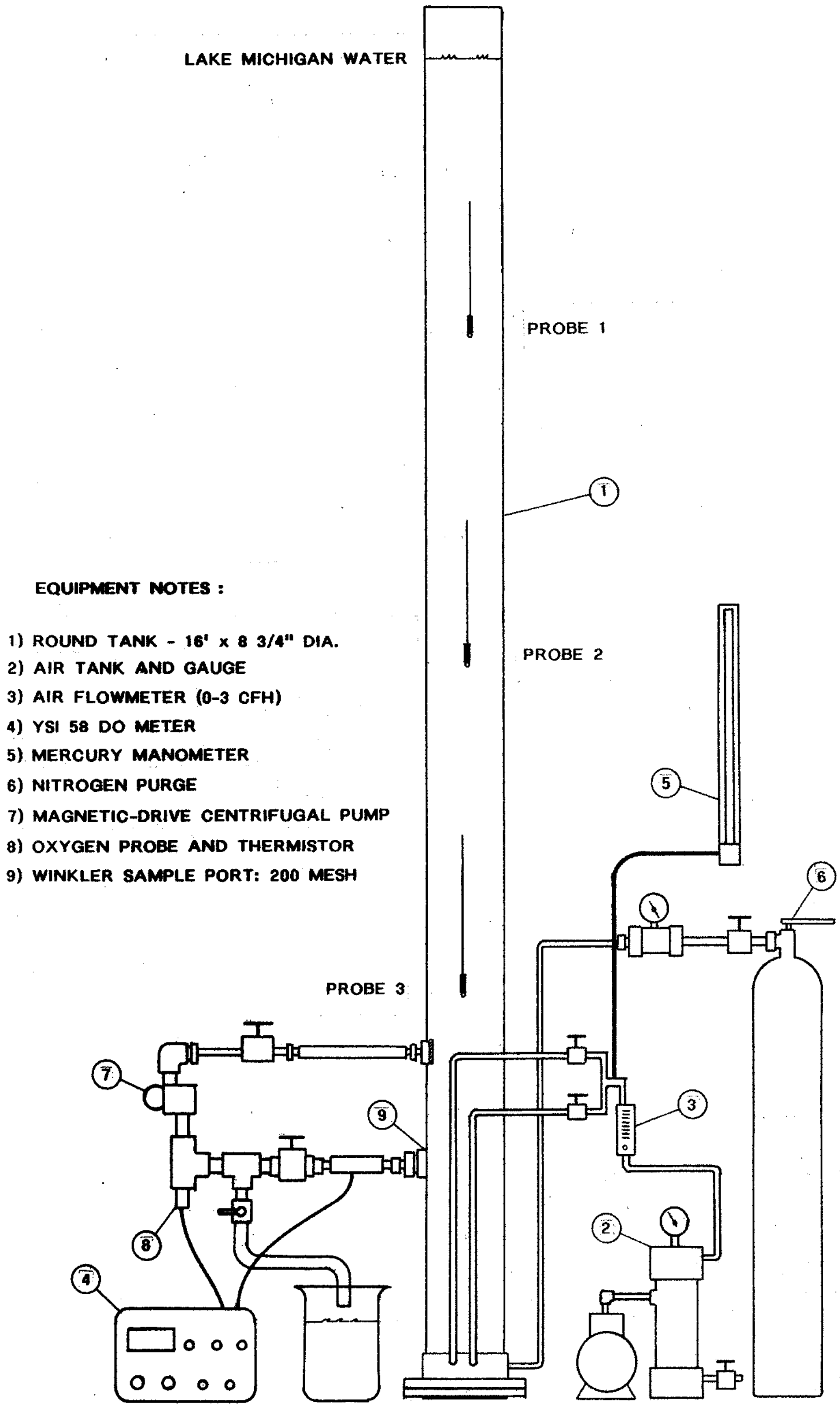
COMPARISON TO PREVIOUS TESTS

In order to better understand the performance of the "ADS" system, pervious test reports as conducted by leading Testing Agencies for John and Nelson Hinde were supplied by the company and reviewed by the author. Some of the previous tests were performed in tanks as opposed to columns. The test reports were obtained from ADS. All the tests either predate the present ASCE Standard or did not use the Standard.

The oldest report is entitled "Oxygen Transfer Tests of Hinde AIR-AQUA System" and authored by V.W. Bacon, R.T. Balmer and R.G. Griskey (the authors were associated with the University of Wisconsin, Milwaukee). Tests were conduced in a 31,000-gallon tank (34.3 ft long by 6 ft wide by 24 ft deep). These tests were made using the old-style Hinde tubing, and are not applicable to the current system.

The second report is entitled "Air-Aqua Certified Oxygen Transfer Tests" and authored by K.L. Murphy of the Ontario Ministry of the Environment, and is dated January 6, 1981. The tests were conducted in a concrete tank 26 feet long by 24 feet wide with 14 feet maximum water depth. Tubing was placed along the bottom of the tank, parallel to the length. Tests were run with tubing on 2.5-foot centers at 5, 10 and 14 feet water depth. Tests were also performed on 10 centers at 10 feet water depth. Tests were performed at a variety of airflow rates. Results were analyzed using the log-deficit procedure using surface, mid-depth and calculated (e.g., best fit) estimates for C^*_∞. These results cannot be reanalyzed using the ASCE Standard Method, since the Standard also requires the data to be collected in a specific manner. However, the results using the best-fit method most closely approximate the ASCE results. The reported efficiencies at standard conditions are 41.6%, 30.3% and 16% at 14, 10 and 5 feet water depth. The corresponding results obtained in the column is this test were 43% at 15 feet, 30.0% at 10 feet and 15.4% at 5 feet. This is good agreement. These results suggest that the column results can be extrapolated to other geometries if the circulating velocities are not created because of the change.

The third report was authored by F. J. Winter of the North Shore Sanitary District and dated October 8, 1986. The tests were performed in a column and experimental setup virtually identical to the one used in this test. The data appear to have been carefully collected, and were analyzed using the log deficit procedure with a best-fit equilibrium value. Single reaeration tests were performed at 5, 8, and 11 feet. The DO concentrations versus time data are contained in the report. A reanalysis of their data confirms their calculations of the mass transfer coefficients and C^*_∞. The calculated transfer efficiencies are in error. Their report contains the correct equations and procedures, but for unknown reasons the efficiencies were too great. They reported 58 % efficiency at 11 feet. A reanalysis of their raw data yields 34.8%. The differences at 8 and 5 feet were 38% versus 22.9% and 30.7% versus 17.7%. The reanalyzed results are roughly comparable to the results obtained in this study (34.8% at 11 feet versus 30% at 10 feet – this study, and 17.7% at 5 feet versus 15.4% - this study). Obviously, the results of this study should not be used.


LAKE MICHIGAN WATER
PROBE 1
PROBE 2
PROBE 3
EQUIPMENT NOTES :
1) ROUND TANK - 16' x 8 3/4" DIA.
2) AIR TANK AND GAUGE
3) AIR FLOWMETER (0-3 CFH)
4) YSI 58 DO METER
5) MERCURY MANOMETER
6) NITROGEN PURGE
7) MAGNETIC-DRIVE CENTRIFUGAL PUMP
8) OXYGEN PROBE AND THERMISTOR
9) WINKLER SAMPLE PORT: 200 MESH
1
2
3
4
5
6
7
8
9

Picture 1. The column is in the center of the picture with the DO probes, nitrogen cylinder (black), and ladder clearly visible. The other tank, green aquarium and equipment were not part of the test.

Picture 2. The three DO probes (2 YSI 58's, 1 YSI 57) are in the foreground. Column was being stripped with nitrogen when the picture was taken.

Picture 3. A large volume of nitrogen was used to strip the DO. A probe is visible behind the bubble swarm.

Picture 4. This picture shows the column and DO probe during aeration. The bubble density is much less than during nitrogen stripping.

Picture 5. This picture, taken at slow shutter speed, shows the air release and bubble trajectories. Both LWA 1.5 and LTC tubing were operating during the picture. (Picture supplied by John Hinde).