LAST COPY

Review and Evaluation of the Contractors' Oxygen Transfer Test Reports for the Total Barrier Oxidation Ditches at South Hill, Virginia

by

Peer Review Panel

William C. Boyle

Hugh J. Campbell, Jr.

Michael K. Stenstrom

July 10, 1987

TABLES OF CONTENTS

I. INTRODUCTION

To evaluate the applicability of the ASCE Clean Water Standard[1] and selected process water test procedures to a circulating oxidation ditch configuration, Peer Consultants, Inc. selected three peer review panelists to assist the City of Opelika, Alabama, its consultants, and interested equipment manufacturers in developing an oxygen transfer field test program for the Total Barrier Oxidation Ditch (TBOD).[2] Both clean and process water testing were envisioned. The Peer Review Panel was charged with the following tasks:[3]

1. Review proposed project scope-of-work and attend a review meeting in Opelika, Alabama.

2. Prepare a consensus summary report discussing technical feasibility, modifying the proposed scope-of-work, and recommending modifications to existing test procedures as needed.

3. Review and evaluate the Project Engineer's clean water testing plan and recommend changes as necessary.

4. Witness clean water testing, providing advice and recommendations to resolve on-site disputes, and alert the Project Engineer if non-acceptable test methodologies were being used.

5. Review and evaluate the Project Engineer's process water testing plan and recommend changes as necessary.

6. Witness process water testing, providing advice and recommendations as necessary. Prepare a report summarizing clean and process water test results, reconciling

differences, identifying problems and corrective actions, evaluating the accuracy of the various tests, and estimating apparent alpha factors.

7. Review and evaluate the Project Engineer's draft final project report and attend a meeting in Atlanta, Georgia, to discuss review comments with all interested project participants.

During the initial meeting at Opelika, the scope-of-work and test program were expanded to include testing of a second TBOD facility at South Hill, Virginia. Previous reports were provided by the Peer Review Panel for Tasks 1 to 6. This report also relates to Task 6 and is the summary of the Peer Review Panel's evaluation of the test program for the TBOD's at South Hill, Virginia. A previous report was issued for Task 6 for Opelika, Alabama.[4]

II. TESTING PROGRAM

A. PROGRAM OVERVIEW

The testing program for the TBOD aeration system involved two sites: Opelika, Alabama, and South Hill, Virginia. Aeration testing was to be done in both clean water and process water situations. In the clean water programs, three different test methodologies were proposed: 1) the ASCE non-steady state sulfite method, 2) the krypton/tritium radiotracer technique, and 3) a procedure utilizing a dissolved oxygen mass balance across the aeration unit (the so-called "delta DO" approach). For the process water situations, two approaches were recommended: 1) the "off-gas" technique and 2) the krypton/tritium radiotracer method. All parties agreed not to conduct radiotracer tests at South Hill for process water conditions. Table 1 summarizes the overall testing strategy by site and method.

Table 1

Overview of the EPA Aeration Testing Program for the TBOD Systems

Test Site	Clean Water	Process Water
Opelika	ASCE Tracer DO Mass Balance	Off-Gas Tracer
South Hill	ASCE Tracer DO Mass Balance	Off-Gas

B. SOUTH HILL TESTING PROGRAM

The aeration testing program at South Hill was performed in two phases. The clean water test program was completed during July, 22-25, 1986. Process water testing was performed during the periods of November 11-14, 1986, and May 20-22, 1987. Table 2 summarizes the test conditions for the clean water tests and the second set of process water tests. The conditions and test procedures for the clean water and second process water tests are consistent with recommendations outlined in a letter from the Peer Review Panel to BCM Converse, dated June 3, 1986.[5]

Results from the first process water test are not included in this report due to a series of difficulties with the test procedures. The first set of process water tests was performed on Ditch 1 (Ditch 1 is closest to the control room) in the belief that it was identical to Ditch 2 where the clean water tests were performed. During the process water tests, it was discovered that the turbine in Ditch 1 flooded at much lower gas flow rates than were obtained in clean water testing. A problem in measuring gas flow rates further complicated the test procedure. A rain storm just prior to the test produced very low BOD wastewater. These factors, combined with the transients associated with transferring the mixed liquor from Ditch 2 to Ditch 1 and raising the water level from its normal mid-depth position to the maximum depth, produced non-steady state biological conditions. As a result of these problems, the Peer Review Panel decided not to evaluate the results of the first set of process water tests.

Analyses of the ASCE method for the clean water tests are discussed in a technical report issued to BCM Converse by Philadelphia Mixers, dated October 3, 1986. Philadelphia Mixers did not perform the DO mass balance procedure. The radiotracer analyses are discussed in a technical report issued to BCM Converse by Law Environmental Services dated October 1986.

Table 2

Test Conditions

Test Run No.	Date	Time	Total Turbine Horsepower (whp)	Total Blower+ Horsepower (whp)	Total Air++ Flow (SCFM)	Total Horsepower (whp)
Clean Water*						
T	7/22/86	1:00 PM	44.9	15.7	415 (486)	60.6
1**	7/22/86	4:30 PM	44.9	15.7	415 (486)	60.6
2**	7/23/86	9:30 AM	22.1	6.9	188 (234)	29.0
3	7/23/86	4:15 PM	44.9	15.7	415 (486)	60.6
4	7/24/86	9:00 AM	22.1	6.9	188 (234)	29.0
Process Water***						
1P	5/21/87	9:40 AM	20.5	6.9	185	27.4
2P	5/21/87	1:20 PM	47.6	15.7	402	63.3

* Witnessed by Drs. Boyle and Campbell.
** Radiotracer test performed.
*** Witnessed by Drs. Boyle and Stenstrom.
\+ Adiabatic calculations using 60% combined efficiency.
\++ Flow data were sent to Fluidic Techniques, Inc. who calculated the flow rates shown for the clean water test, which are reported at 0% relative humidity. See text for further discussion. Values in parentheses are revised flow rates provided to R. Brenner - EPA by Philadelphia Mixers following issuance of their clean water test report.

Ewing Engineering Company documented off-gas testing results and analysis for the first process water tests in their report to BCM Converse dated February 20, 1987, and for the second process water tests in their addendum, dated July 2, 1987. All of these reports are reviewed in the following sections, and this review is accompanied by an independent data analysis by the Peer Review Panel for each test program and test method.

III. CLEAN WATER TEST RESULTS

Clean water tests were conducted in Ditch 2 at the South Hill wastewater treatment plant. The tests were conducted by Philadelphia Mixers, Innova-tech, Gerry Shell Environmental Services (GSEE), and Law Environmental Services (Law). This section will briefly critique the tests conducted by these four groups and will be followed by an analysis of the clean water test data by the Peer Review Panel.

A. PHILADELPHIA MIXERS, INNOVA-TECH, GSEE

1. Oxygen Transfer Tests

The clean water tests were conducted in accordance with the ASCE Standard Measurement of Oxygen Transfer in Clean Water.[1] In general, the test procedures were acceptable with respect to the Standard; however, the Peer Review Panel notes several deficiencies in reporting methods and for DO, power, and gas flow measurements.

A trial test run was performed by Philadelphia Mixers on July 22, 1986. This test was witnessed by the Peer Review Panel, and the results are included in the Philadelphia Mixers report. Since the values of K_LA were comparable to a replicate test run, these data were analyzed and accepted as a valid test for the study. A final test run (Test Run 5) was performed at a low water level and was not witnessed by the Peer Review Panel. These data are not included in this report.

Sodium sulfite was dissolved prior to being introduced into the ditch. The Peer Review Panel concurs with opinions expressed previously that sodium sulfite needs to be thoroughly mixed in the ditch prior to testing for these types of systems. At South Hill (as at Opelika), this was accomplished by introducing the dissolved sulfite over several circulation times, followed by several additional circulations after sulfite addition to insure proper blending.

There is no tabulation of the cobalt concentrations that were observed at the end of the test series (see ASCE 6.3.3). Furthermore, there is no indication of the total dissolved solids concentration at the end of the test series (see ASCE 6.3.3).

DO concentrations were monitored with six DO meters connected to multipen recorders. Additionally, samples were collected using BOD bottles followed by Winkler titrations. These samples were not officially used in estimating oxygen transfer but were used to check and calibrate probe results.

Philadelphia Mixers' values of SOTR and $C^*_{\infty 20}$ are shown in Table 3. The values of K_LA, C_o, and C^*_∞ were estimated by a nonlinear least squares program that performs the analysis as outlined by ASCE.[1] Their report did not provide adequate information to determine if the timing criteria and data truncation stipulated by ASCE 6.8.3.3 were followed. All tests were run so that the DO concentration approximated 98% of C^*_∞ ($4/K_LA$, ASCE 6.8.4) at the test conclusion.

In reviewing the Philadelphia Mixers' data, the Peer Review Panel found that the spatial variation of average determination point K_LA_{20} values fell within ± 10% of the mean values as described by ASCE 8.2.1, indicating that the probe locations effectively described the oxygen

Table 3

Philadelphia Mixers Summary of Clean Water Test Results

Test No.	SOTR ($lb\ O_2/hr$)	$C^*_{\infty 20}$ + (mg/L)
T	93	11.3
1	95	11.5
2	52	11.2
3	99	11.2
4	59	11.7

\+ $C^*_{\infty 20}$ values were not included in Philadelphia Mixers' test report. The values shown were calculated from their SOTR's, temperatures, and pressures in accordance with the ASCE Standard.

transfer capability of the ditch. In addition, for the three replicate tests at high air flow and the duplicate tests at low air flow, the estimates of $K_L A_{20}$ fell within ±15% of the mean values as specified in ASCE 8.2.2.

Accurate estimates of flow in the ditch were critical to the accuracy of the DO mass balance procedure. Flow was measured at discrete points within a ditch cross-section using a Marsh-McBirney magnetic flow meter. However, no test procedures or raw data are documented in the Philadelphia Mixers' report. A summary of ditch velocities is contained in the report without substantiating data.

2. Power and Gas Flow Measurements

Power and gas flow measurements were not taken in accordance with good practice. Turbine and blower power were measured with a single-channel Esterline Angus recording Wattmeter. Copies of the turbine power strip charts are presented in the appendices of Philadelphia Mixers' report and appear reliable. It was intended that blower power be measured with the same device; unfortunately, there were air leaks in the main air header and it was necessary to vent gas in various tests in order to avoid turbine flooding. Consequently, measured blower power is not meaningful and blower power can only be estimated from adiabatic calculations.

Gas flow measurements were made using an orifice plate supplied by Fluidic Techniques, Inc. Innova-tech and Philadelphia Mixers, assisted by GSEE, were responsible for calculating flow rates from raw data.

Power and gas flow rates are provided on page 8 of Philadelphia Mixers' report. After their report was issued, Philadelphia Mixers telephoned Mr. Richard Brenner, EPA Project Officer, and revised the blower power and gas flow rates. The gas glow rates reported by

Philadelphia Mixers also appeared to be greater than the blower was capable of producing. Later, during the first process water test program, a discrepancy in gas flow measurements appeared when turbine flooding occurred at what appeared to be inordinately low gas flow rates.

As a result of these uncertainties, the Peer Review Panel decided to review the procedure for determining gas flow rates from the orifice plate data. The orifice plate manufacturer[6] was asked to calculate flow rates from raw orifice plate data. The manufacturer reported a value of 415 SCFM for Test Run 1, which was significantly less than the 486 SCFM reported by Philadelphia Mixers. The Peer Review Panel decided to provide its own flow rate calculations, and the procedure is described in Appendix A. The Peer Review Panel's procedure agrees with the manufacturer's procedure within ±1 SCFM. The gas flow rates reported in Table 2 and throughout this report were calculated using the procedure in Appendix A.

Blower horsepower was calculated from these rates using the adiabatic gas compression equation using a 60% combined motor/blower efficiency, as follows:

$$bhp = \frac{w\,RT_1}{(550)(0.283)e}\left[\left[\frac{P_2}{P_1}\right]^{0.283} - 1\right]$$

where

w	=	weight flow of air, lb/sec
R	=	gas constant, 53.5
T_1	=	inlet temperature, °R
P_1, P_2	=	inlet and outlet pressure, psia
e	=	efficiency, 0.6

This procedure contrasts to the procedure used at Opelika, where the the Peer Review Panel calculated blower horsepower from RPM, pressure increase, and frictional horsepower according to the manufacturer's recommendations[7]. This approach was not possible at South Hill since there was a gas leak and venting was sometimes necessary.

3. Summary

In summary, the Philadelphia Mixers' tests were performed in a manner consistent with the intent of the ASCE Standard, although data collection and reporting procedures for DO, power, and gas flow measurements were inadequate. Philadelphia Mixers concluded that the results fell significantly below specified performance, but raised questions regarding the applicability of non-steady state test techniques to this TBOD. However, Philadelphia Mixers offered no support for the latter claim. This point will be addressed in detail later in this report.

B. LAW ENVIRONMENTAL SERVICES

Radiotracer tests were conducted simultaneously with clean water tests during Runs 1 and 2 (Table 2). Results of Law's data analysis are shown in Table 4. The Peer Review Panel concurs with Law's conclusion that the radiotracer analyses accurately describe aeration of water circulating in a TBOD. Results of this test should, therefore, accurately depict oxygen transfer in a plug flow oxidation ditch.

Of concern to the Peer Review Panel, however, was the absence of a correction to the K_{Kr}/K_{ox} ratio to account for the gas-side stripping that produces krypton partial pressure in the rising bubbles. This occurs in diffused air systems and has been documented by Baillod et al.[8] The ratio of 0.83 used by Law was developed for surface aeration and must be corrected. This correction is described in the Peer Review Panel analysis section and Appendix B. The net

Table 4

Radiotracer Oxygen Transfer Test Results - Clean Water
Law Environmental Services*

Test Run No.	Station	Temp. ($°C$)	K_{Kr_T} (min^{-1})	$K^{**}_{ox_T}$ (min^{-1})	$K_{ox_{20}}$ (min^{-1})
1	A	28	0.0226	0.0272	0.0225
	B	28	0.0232	0.0280	0.0231
	C	28	0.0242	0.0292	0.0241
	D	28	0.0213	0.0257	0.0212
2	A	27.5	0.0122	0.0147	0.0123
	B	27.5	0.0115	0.0139	0.0116
	C	27.5	0.0116	0.0140	0.0117
	D	27.5	0.0104	0.0125	0.0105

* Table 10 from Law.

** Calculated from $\frac{K_{Kr}}{K_{ox}} = 0.83$; $K_{ox} = K_L A$

result of this correction is to reduce this ratio (to values of 0.79 and 0.78, respectively, for Test Runs 1 and 2), thereby increasing the values of K_{ox} that appear in Table 4.

The tritium tracer results produced useful information on the mixing characteristics of the ditch. The "plug flow" character of the ditch was clearly delineated from the analysis of these data. The circulation times predicted by this analysis were about 9 minutes for Test Run 1 and approximately 14 minutes for Test Run 2.

C. PEER REVIEW PANEL APPRAISAL

1. ASCE Procedure

The Peer Review Panel's data analysis produced results very similar to Philadelphia Mixers' results, differing only by a few percent. The differences in results are due primarily to corrections in probe calibration. Unfortunately, not all the probes were calibrated at the beginning of each test. Winkler samples were collected at the conclusion of each run. The Peer Review Panel corrected probe calibrations by multiplying the indicated probe DO concentrations by the ratio of the final Winkler measured DO to probe measured DO concentrations. Alternatively, one can correct the value of $C^*_{\infty T}$ by multiplying by the same ratio. Either procedure does not bias the results as long as the probes are not malfunctioning (linearity is preserved) and the error is a true calibration error as opposed to probe drift.

Table 5 compares the Philadelphia Mixers and Peer Review Panel results. The data collected at South Hill were not as precise as those collected at Opelika. Although the precision was within the criteria set out in the ASCE Standard, the sum of squares errors* for South Hill were 2-4 times higher than those for Opelika.

* Note. Sum of squares error is the sum of the squares of the measured values minus the predicted values. This is an indicator of "goodness of fit."

Table 5

Comparison of Philadelphia Mixer and Peer Review Panel's ASCE Results

Test Run No.	Philadelphia Mixer Results SOTR ($lb\ O_2/hr$)	SAE** ($lb\ O_2/whp-hr$)	$C^*_{\infty 20}$ (mg/L)	Peer Review Panel Results SOTR ($lb\ O_2/hr$)	SAE ($lb\ O_2/whp-hr$)	$C^*_{\infty 20}$ (mg/L)	% Difference* SAE	$C^*_{\infty 20}$
T	93	1.53	11.3	90	1.47	10.6	3.4	6.6
1	95	1.56	11.5	95	1.56	11.4	0	0.9
2	52	1.77	11.2	53	1.82	11.6	-2.2	-3.4
3	99	1.63	11.2	99	1.63	11.5	0	-2.6
4	59	2.02	11.7	55	1.89	12.0	7.4	-2.5
Average			11.4			11.4	1.72	-0.2

* Percent Difference = 100 (Philadelphia Mixer - Peer Panel)/Peer Panel.

** Calculated from Philadelphia Mixer SOTR's, Philadelphia Mixer's measured turbine horsepower, and the Peer Review Panel's calculated blower horsepower.

2. Dissolved Oxygen Mass Balance Procedure

The DO mass balance procedure was used to calculate oxygen transfer in a manner identical to that used at Opelika.[4] The description of the procedure is not repeated here, but the results are reported later.

3. Radiotracer Procedure

The Peer Review Panel believes that the radiotracer procedure is currently the most accurate and precise method for assessing oxygen transfer in water and wastewater. Therefore, it serves as the referee method for all other test procedures. However, in order to provide accurate information on K_LA, it is necessary to correct the ratio $K_{Kr}/K_{ox} = 0.83$ to reflect the stripping of krypton that takes place during bubble rise. Baillod et al.[8] have developed a methodology for calculating a correction factor, and corrections were developed for all tests by the Peer Review Panel. Appendix B summarizes the procedure. In Test Runs 1 and 2, the correct ratio, K_{Kr}/K_{ox}, was 0.79 and 0.78, respectively. Table 6 shows the corrected values of K_{ox}.

4. Summary

Table 7 summarizes the SOTR's and the standard deviations of SOTR's for the radiotracer and ASCE methods as calculated by the Peer Review Panel. Also shown are the results of the DO mass balance procedure, applied to the data collected during the ASCE tests. The standard deviations represent the standard deviations of the SOTR's obtained from each probe or sampling station for the ASCE and radiotracer procedures, respectively. For the DO mass balance procedure (see Reference 4 for details), the standard deviation was calculated using all the points used in the analysis (typically 10 to 25).

Table 6

Radiotracer Oxygen Transfer Test Results
Peer Review Panel Corrections

Test Run No.	Station	Law* K_{Kr_T} (min^{-1})	Law* SOTR** ($lb\ O_2/hr$)	Peer Review Panel K_{ox_T}*** (min^{-1})	Peer Review Panel $K_{ox_{20}}$ (min^{-1})	Peer Review Panel SOTR** ($lb\ O_2/hr$)
1	A	0.0226	97	0.0287	0.0238	102
	B	0.0232	99	0.0294	0.0244	104
	C	0.0242	125	0.0307	0.0254	109
	D	0.0213	91	0.0276	0.0224	96
			103 ± 15			103 ± 5
2	A	0.0122	52	0.0157	0.0131	56
	B	0.0115	49	0.0148	0.0124	53
	C	0.0116	50	0.0149	0.0125	53
	D	0.0104	45	0.0134	0.0112	48
			49 ± 3			53 ± 3

* See Table 4 for $K_{ox_{20}}$; $K_{ox} = K_L A$

** SOTR = $K_{ox_{20}}$ x $C^*_{\infty_{20}}$ x tank volume x conversion factors

= $K_{ox_{20}}$ x 11.4 mg/L x 0.75 million gallons x 8.34 x 60

*** Corrected by $K_{Kr}/K_{ox} = 0.79$ for Test 1 and $K_{Kr}/K_{ox} = 0.78$ for Test 2 (Appendix B).

Table 7

Peer Review Panel's Comparisons of Different Methods (Clean Water)

Test Run No.	ASCE		Dissolved Oxygen Mass Balance			Radiotracer		
	SOTR ($lb\ O_2/hr$)	Std. Dev.*	SOTR ($lb\ O_2/hr$)	Std. Dev.*	% Difference with ASCE	SOTR ($lb\ O_2/hr$)	Std. Dev.*	% Difference with ASCE
T	90	4.4	88	6	-2.2			
1	95	3.0	101	5	+6.3	103	4.7	+8.4
2	53	3.0	43	3	-18.9	53	3.0	0
3	99	1.3	110	6	+11.1			
4	55	1.4	54	4	-1.8			

* Standard deviations for the ASCE and radiotracer methods are calculated using the results of each probe or sample locations. Standard deviations for the mass balance method are calculated using individual observations.

The estimates of SOTR by the different procedures were in close agreement. The results of the three methods are not practically different; however, the DO mass balance method exhibited much greater variability than the other two methods.

IV. PROCESS WATER TESTING

A. FIRST PROCESS WATER TESTING PROGRAM

The first set of process water tests was conducted on November 11-14, 1986. The original intent was to perform the process water tests on the same tank and turbine and at the same operating conditions that were used for clean water testing. Furthermore, the process water testing was to be performed in a stable, acclimated biological oxidation system operating at steady state conditions. Unfortunately, even though the test program was delayed several months to accomplish these goals, plant conditions were still not adequate.

The first process water tests were performed in Ditch 1 as opposed to Ditch 2 where the clean water tests were performed. During the process water testing it was discovered that the turbine in Ditch 1 flooded at much lower gas flow rates than the turbine in Ditch 2. This made it impossible to duplicate the clean water test conditions.

For these reasons, coupled with other test result discrepancies, the Peer Review Panel is in unanimous agreement in recommending that these test results not be included in the final EPA report. They are not representative of typical applications for the TBOD.

B. SECOND PROCESS WATER TESTING PROGRAM

A second set of process water tests was performed during May 20-22, 1987. Test conditions were satisfactory, and the tests were performed in the same ditch tested during the clean water testing program. Gas flow rates and blower power were calculated by the Peer Review Panel during the tests, and conditions very close to the clean water tests were obtained.

Smoke bombs were used to detect leaks in the fixed hood and revealed major gas leaks. An attempt was made to seal the leaks by caulking the seams where smoke appeared. Most leaks were stopped, although it was not possible to seal all leaks. These leaks resulted in less than 100% capture during off-gas testing, as noted later.

C. EWING ENGINEERING COMPANY

Ewing Engineering Company (Ewing) conducted two off-gas tests on May 21 and reported these results to BCM Converse in their addendum dated July 2, 1987. Earlier they reported their results of the first set of process water tests in a report to BCM Converse, dated February 28, 1987. As indicated previously, the first process water test results are not included in this report. The same procedures were used for off-gas analysis for the first and second process water tests and were identical to the procedures used at Opelika. These procedures have been discussed previously by the Peer Review Panel.[4]

Ewing used several techniques to estimate the driving force for correcting OTE's to αSOTE's at Opelika. At South Hill, they averaged the turbine inlet and exit DO concentrations, which the Peer Review Panel chose as the most accurate procedure in its Opelika evaluation report. Therefore, Ewing's analysis procedure for South Hill is identical to the procedure selected by the Peer Review Panel for Opelika.

Ewing's off-gas results are presented in Table 8.

Table 8

Summary of Off-Gas Results by Ewing Engineering
for South Hill, Virginia - May 21, 1987

Run	Applied Air Rate (SCFM) (% Balance)*	Mean Wt. OTE (%)	Actual Transfer Rate ($lb\ O_2/hr$)	αSOTE (%)	αSOTR ($lb\ O_2/hr$)
1P	185 (84.8)	16.0	31.0	22.5	43.5
2P	402 (89.7)	11.5	48.1	19.8	82.9

* % Balance is the air flow rate measured from the fixed and portable hoods divided by the blower air flow rate.

D. PEER REVIEW PANEL ANALYSIS

The Peer Review Panel agrees with the Ewing off-gas procedure, including the method used to correct OTE's to αSOTE's. The poor capture in both tests is unfortunate, but undoubtedly resulted from leaks in the fixed hood. Poor capture was noted in the first set of process water tests and must also have been due to fixed hood leaks. Testing with the smoke bombs was a valuable improvement in technique that was developed during the second process water test program.

Table 9 compares process water test results with clean water test results for South Hill.

V. SUMMARY AND CONCLUSIONS

A comprehensive evaluation of downdraft submerged turbines in a TBOD application was performed at South Hill, Virginia. The ASCE standard procedure was compared to the krypton radiotracer method and a non-standard DO mass balance procedure ("delta DO"). All three clean water methods produced similar results. The estimates of SOTR for the ASCE and radiotracer methods were not statistically different. Figures 1 and 2 show the SOTR's and SAE's, respectively, for all clean water tests as calculated by the Peer Review Panel. The precision of the DO mass balance procedure is much less than that of the other methods and, for this reason, is considered inferior.

The results of the first process water testing program at South Hill are not included in this report. As discussed in detail previously, the Peer Review Panel felt that the ditch under test was in a transient load condition, not representative of typical operation. Furthermore, the clean water conditions could not be duplicated. The turbine aerator in Ditch 1 flooded at much lower gas flow rates than the turbine in Ditch 2. It was not possible to duplicate clean water gas flow

Table 9

Process Water Test αSOTR
and α Calculations
Peer Review Panel

Run No.	Off-Gas* αSOTR ($lb\ O_2/hr$)	Off-Gas αSAE ($lb\ O_2/whp-hr$)	Equivalent Clean** Water SOTR ($lb\ O_2/hr$)	Calculated α
1P	43.5	1.59	54±1	0.81
2P	82.9	1.31	95±5	0.87

* From Table 8.

** From Table 5 (Peer Review Panel).

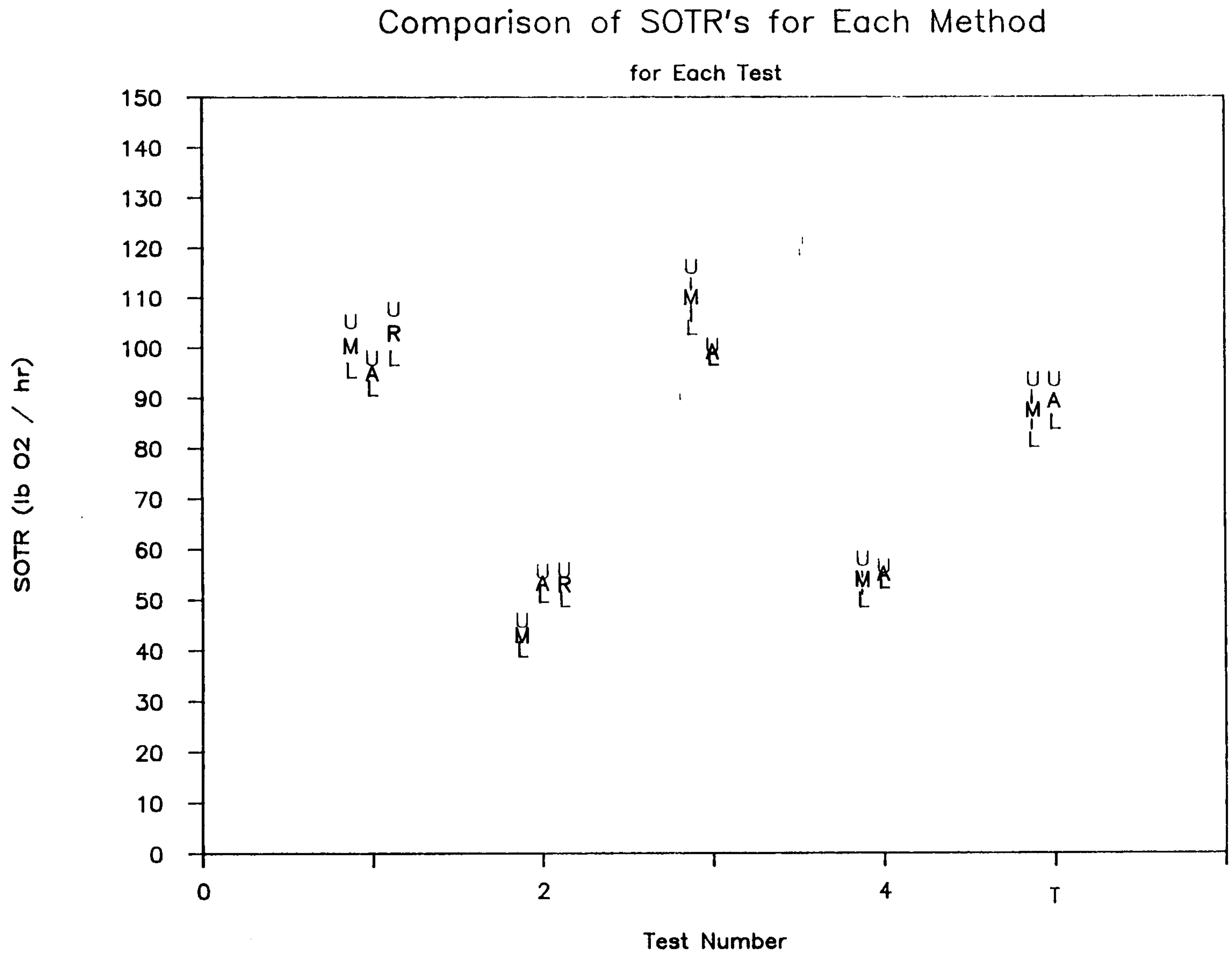

Fig. 1 Comparison of SOTR's for Clean Water (A = ASCE method, M = DO mass balance method, R = Radiotracer method, L = lower standard deviation, U = upper standard deviation. For the ASCE and radiotracer methods, the standard deviations when using the results of each probe or sample location, respectively. For the DO mass balance procedure, the standard deviation was calculated for all sequential data points, typically 10 to 25).

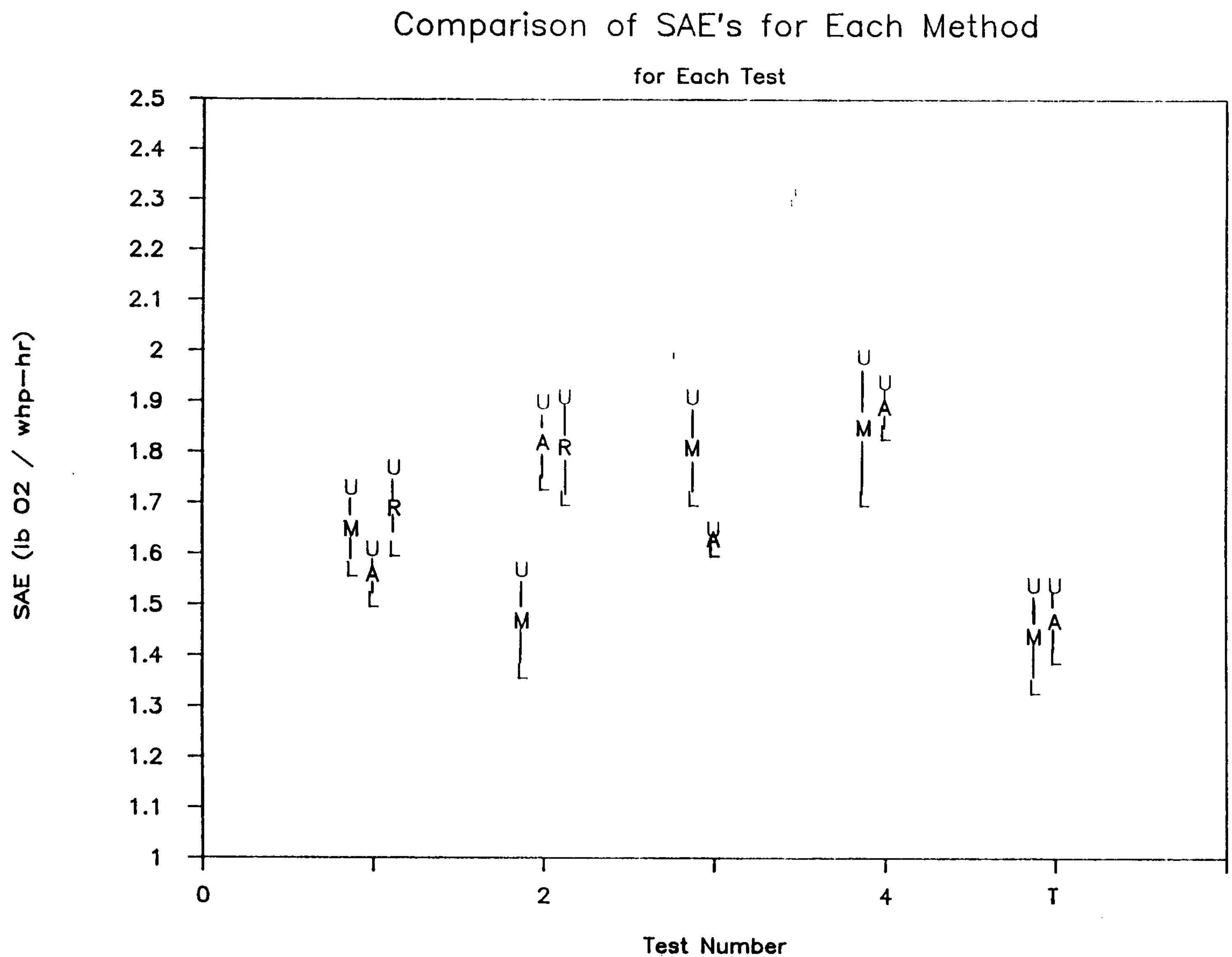

Fig. 2 Comparison of SAE's for Clean Water (A = ASCE method, M = DO mass balance method, R = Radiotracer method, L = lower standard deviation, U = upper standard deviation. For the ASCE and radiotracer methods, the standard deviations when using the results of each probe or sample location, respectively. For the DO mass balance procedure, the standard deviation was calculated for all sequential data points, typically 10 to 25).

rates in the first series of process water tests.

A brief summary of the clean water test results at both Opelika and South Hill is presented in Table 10 where values of SAE are presented for the different test conditions. In spite of the differences in equipment manufacturer and tank size and geometry, the energy efficiencies of the two aeration systems are similar.

The alpha factors calculated for the Opelika TBOD ranged from 0.66 to 0.77 with the majority of test results ranging from 0.70 to 0.77. The South Hill alpha factors ranged from 0.81 to 0.87. The Peer Review Panel believes that the differences in alpha factors for the two sites are partially attributable to plant loading. The instantaneous F/M ratio at Opelika during the process water test was 0.14 day^{-1} (MLSS basis), and the specific oxygen uptake rate (SOUR) was 7.3 mg O_2/g MLSS-hr. The instantaneous F/M ratio for South Hill during the second set of process water tests was 0.086 day^{-1}, and SOUR was only 3.5 mg O_2/g MLSS-hr. The F/M ratio and SOUR for South Hill are very low and are representative of typical extended aeration treatment systems. The corresponding values for Opelika are somewhat higher and more representative of systems operating in the lower portion of the conventional activated loading range.

The Peer Review Panel believes that the alpha factors reported in this document and their previous document[4] should be used with caution. They should not be extrapolated to higher rate systems. Alpha factors are valid only for the specific type of equipment, wastewater characteristics, and process conditions evaluated at a given point in time.

The ASCE standard clean water test procedure is a valid procedure for evaluating oxygen transfer performance in TBOD's and should also be valid for other types of oxidation ditches. Testing oxidation ditches is more difficult due to the "plug flow" characteristic of the ditches.

Table 10

Clean Water Test Results - Peer Review Panel ASCE Results

Test Run No.	Total Power (whp)	SOTE (%)	SAE (lb O_2/whp-hr)	Std. Dev.
Opelika				
1	165	22.0	1.64	0.06
2	165	22.9	1.72	0.03
3	164	24.2	1.80	0.04
3A	165	23.1	1.76	0.04
4	81	24.0	1.85	0.09
5	142	27.5	1.25	0.02
6	244	24.5	1.78	0.03
South Hill				
T	60.9	21.0	1.47	0.07
1	60.9	22.3	1.56	0.05
2	29.3	27.4	1.82	0.10
3	60.9	23.3	1.63	0.02
4	29.2	28.3	1.89	0.05

More care is required in introducing and mixing the sodium sulfite. Additionally, it is recommended that continuous DO monitoring be performed or frequent manual readings be taken for ditches. This increased frequency of DO measuring makes Winkler analysis impractical.

VI. REFERENCES

1. *A Standard for the Measurement of Oxygen Transfer in Clean Water*, ASCE, New York, New York, July 1984.

2. Letter from Dr. Lilia A. Abron-Robinson, Peer Consultants, Rockville, Maryland, to each Peer Review Panelist, January 15, 1986.

3. Letter from Richard C. Brenner, Project Officer, U.S. EPA, Cincinnati, Ohio, to all project participants, January 28, 1986.

4. Boyle, W.C., Campbell, H.J., and M.K. Stenstrom, "Review and Evaluation of the Contractor's Oxygen Transfer Test Reports for the Total Barrier Oxidation Ditches at Opelika, Alabama," February 28, 1987.

5. Peer Review Panel Report, "Evaluation of Oxygen Transfer Performance of Total Barrier Oxidation Ditches Equipped with Draft Tube Aerators, South Hill, Virginia - Summary Evaluation Report," June 3, 1986.

6. Personal Communication - Fluidic Techniques, Inc., Mansfield, Texas, March 31, 1987.

7. *Roots Rotary Blower Manual*, Roots-Dresser, Connersville, Indiana.

8. Baillod, C.R., Paulson, W.L., McKeown, J.J., and H.J. Campbell, Jr., "Accuracy and Precision of Plant Scale and Shop Clean Water Oxygen Transfer Tests," *JWPCF*, Vol. 58, No. 4, pp. 290-299, 1986.

9. Miller, R.W., *Flow Measurement Engineering Handbook,* McGraw-Hill Book Company, New York, 1983.

10. Cusick, C.F., *Flow Meter Engineering Handbook,* Fourth Edition, Honeywell Automation, Industrial Division, Washington, Pennsylvania.

VII. APPENDIX A

The procedures described by Miller[9] were used by the Peer Review Panel to calculate air flow rates from orifice plate data. Miller's Equation (i) from his Table 9.36 was used to calculate air flow rate as follows.

$$q_V = N_{V_\rho} \, S_m \, F_a \, F_{RD} \, F_y \, D^2 \sqrt{h_w} \, \frac{\sqrt{\rho_{f_1}}}{\rho_b} \tag{A1}$$

where

q_V	=	gas flow (SCFM)
N_{V_ρ}	=	units conversion factor
	=	5.982119
S_m	=	size factor, calculated below
F_a	=	orifice expansion factor
	=	1.0
F_{RD}	=	Reynolds number correction coefficient
	=	1.0
F_y	=	gas expansion factor
	=	0.992
D	=	pipe diameter (in.)
	=	6.125 inches (cast iron, schedule 40)
h_w	=	differential pressure (in.)
ρ_{f_1}	=	flowing gas density, (lbm/ft^3)
ρ_b	=	base gas density (lbm/ft^3)

The size factor, S_m, is calculated from Miller's Table 9.1, for D and D/2 taps as follows:

$$C_\infty = 0.5959 + 0.0312\,\beta^{2.1} - 0.184\,\beta^8 + 0.039\frac{\beta^4}{1-\beta^4} - 0.0158\,\beta^3 \tag{A2}$$

where

C_∞ = discharge coefficient at infinite Reynolds Number

β = ratio of orifice diameter to pipe diameter
= 3.092/6.065

= 0.50981

Next, a Reynolds correction to the discharge coefficient is calculated as follows:

$$C = C_\infty + \frac{b}{R_D^n} \tag{A3}$$

where:

C = discharge coefficient at operating Reynolds number

b = 91.71 $\beta^{2.5}$ (Miller's Table 9.1)

n = 0.75 (Miller's Table 9.1)

R_D = pipe Reynolds number

The size factor, S_m, can now be calculated from Miller's equation 9.77, as follows:

$$S_m = \frac{CY\beta^2}{\sqrt{1-\beta^4}} \tag{A4}$$

where:

Y = gas expansion factor (note, not the same as F_y, used previously)

The problem requires an iterative solution since the pipe Reynolds number must be known to solve Equation A3, which requires the flowing velocity, q_V/pipe area. A trial and error technique is used.

Example Problem:

Pipe temperature	=	129°F
h_w	=	9.55 in.
Pipe pressure	=	6.2 psig

Trial	Estimate for Reynolds Number	Calculated Gas Flow Rate (SCFM)	Calculated Reynolds Number
1	100,000	454.8	136,900
2	136,900	454.3	136,800
3	136,800	454.3	136,800

For these conditions, the manufacturer calculated 452.5 SCFM.

As a double check, Cusick's[10] method was also used. Using Cusick's procedure, a flow rate of 452.4 SCFM was calculated. Cusick's method was not used by the Peer Review Panel since it requires frequent interpolation from tables, which makes it awkward to use in the field.

VIII. APPENDIX B

Corrections to K_{Kr}/K_{ox} Ratio for Krypton Stripping

(See Baillod, et al.[8] and Opelika report for details[4])

Table 11 presents the results of the calculation of the apparent $K_{K_r/K_{ox}}$ ratios for the clean water tests at South Hill, VA. The entire test volume of 2832 m^3 was used in these calculations since K_{ox} was estimated for that volume. The values of K_{ox} were obtained from clean water tests, Test Runs 1 and 2.

Table 11

Parameters Used to Calculate Apparent K_{Kr}/K_{ox} Ratio at South Hill

Parameter	Clean Water Run 1	Clean Water Run 2
Temp, °C	28	27.5
M_o	32	32
M_a	29	29
M_{Kr}	83.8	83.8
$\rho_a Q_a$, kg/min	14.01	6.40
V, m^3	2832	2832
P_b, KPa	100.6	100.9
de,m	2.66	2.88
H_o, mg/L atm	37.9	38.3
H_k, mg/L atm	178.6	180.2
K_{ox}, min^{-1}	0.0268	0.0146
ϕ	0.121	0.0542
ϕ_k	0.0673	0.0301
$\frac{K_{Kr}}{K_{ox}}$	0.79	0.78