CLEAN WATER OXYGEN TRANSFER TESTS

AYLESBURY STW AERATION SYSTEM

INDEX

1. PURPOSE AND SCOPE

In order to satisfy the oxygen requirements associated to the treatment process selected for the AYLESBURY STW, Suprafilt has been required to supply fine bubble aeration equipment suitable for the application and capable of meeting such process requirements.

Asesoría Técnica y Control (ATC) has been commissioned the conduction of a series of shop scale Clean Water Oxygen Transfer Tests on three Suprafilt-SSI 9” EPDM membrane diffuser aeration grids representative of the aeration system to be installed at the AYLESBURY STW aeration lanes.

This document includes all the information regarding the tests conducted, the testing equipment and procedures followed, and the final results obtained for the different systems and conditions tested.

All tests were conducted by Ian Trillo and Jerónimo Cantón (ATC) during the period Sept. 7th-11th 2004 at Aesoría Técnica y Control´s test facilities in Terrassa (Barcelona). Tests consducted on Sept.7th were witnessed onsite by Mr. Jonathan Lord (Suprafilt). Tests conducted on Sept.7th and 9th were witnessed onsite by Ms. Angela Barugh (Thames Water).

2. DESCRIPTION OF TESTING PROCEDURES AND EQUIPMENT

Shop Scale Clean Water Oxygen Transfer Tests are carried out by ASESORÍA TÉCNICA Y CONTROL’s personnel in ATC´s clean water testing facilities in Terrassa, Barcelona (Spain) following the procedures included in the ASCE Standard ‘A Standard for the Measurement of Oxygen Transfer in Clean Water’ (ANSI/ASCE 2-91).

2.1 SUMMARY OF METHOD

The test method is based upon removal of dissolved oxygen from the water volume by addition of chemicals followed by reaeration to near the saturation level. The dissolved oxygen inventory of the water volume is monitored during the reaeration period by measuring dissolved oxygen concentrations at several determination points selected to best represent the tank contents.

The data obtained at each determination point are then analyzed by a simplified mass transfer model to estimate the apparent mass transfer coefficient, K_La, and the steady state dissolved oxygen saturation concentration, C^*_∞. The basic model is given by

$$\mathbf{C = C^*_\infty - (C^*_\infty - C_0)\ exp(-K_L a_t)}$$

Where:

C = dissolved oxygen concentration, mg/l

C^*_∞ = determination point value of the steady DO concentration at time approaches infinity, mg/l,

C_0 = DO concentration at time zero, mg/l, and

K_La = determination point value of the apparent volumetric mass transfer coefficient, 1/hr.

Nonlinear regression is employed to fit the above equation to the DO profile measured at each determination point during reaeration. In this way, estimates of K_La and C^*_∞ are obtained at each determination point. These estimates are adjusted to standard conditions (20°C water temperature, zero DO concentration and one atmosphere) and the standard oxygen transfer rate (SOTR) is obtained as the average of the products of the adjusted determination point K_La values, corresponding adjusted determination point C^*_∞ values, and the tank volume.

$$\mathbf{SOTR = K_La_{20}\,(C^*_{\infty 20})\,V}$$

Where

K_La_{20} = determination point value of Kla corrected to 20°C;

$C^*_{\infty 20}$ = determination point value of steady-state DO concentration corrected to 20°C and a standard barometric pressure of 1.00 atmospheres;

V = liquid volume of test water in the test tank when the aerator(s) is turned off.

Oxygen transfer efficiency (OTE) refers to the fraction of the mass of oxygen in an injected air stream dissolved into the test fluid under given conditions. The standard oxygen transfer efficiency (SOTE) is the oxygen transfer efficiency corrected to standard conditions (20°C water temperature, zero DO and 1.00 atmospheres) and may be calculated for a given flow of air by

$$\mathbf{SOTE = SOTR / W_{02}}$$

Where:

W_{02} = mass flow of oxygen in the air stream, mass/time (Kg/hr).

2.2. DESCRIPTION OF THE TEST BASIN

Asesoría Técnica y Control´s (ATC) clean water test tank is an industrial (Shop) scale rectangular concrete tank, 7 metres long by 4 metres wide, with a total height of 7.5 metres. The tank dimensions are such that it is possible to represent a section of a full scale aeration system, thereby ensuring results are applicable to real full-scale conditions.

The compressed air fed to the aeration system is produced by means of a positive displacement blower (Aerzener Machine Factory GM 25S Delta Blower). For the purpose of testing, airflow to the basin is controlled using a control valve to by-pass to the atmosphere a portion of the compressed air stream in order to allow feeding of the desired amount of air to the aeration system.

The air distribution system to the test tank includes an Endress+Hauser Prowirl 77 vortex flowmeter for flow measurement. For each test run, flow to the test basin was adjusted to +/- 2% of the target airflow value by opening or closing the by-pass valve to control the amount of air fed to the system. During tests, airflow readings (flow, line pressure and line temperature), are taken manually every 5 minutes and the average flow for the duration of each test run is used for system performance calculations.

2.3. AERATION EQUIPMENT

Tests have been conducted on three different Suprafilt-SSI 9” EPDM membrane disc diffuser systems representative of the aeration system proposed for Zones 1,3 and 5 of the AYLESBURY STW aeration lanes.

As shown in Figures 2a-2c, the layouts adopted for testing consisted in full floor coverage systems equipped with 108, 72 and 49 diffusers installed on 110 mm PVC headers connected to the air feed pipe through a 110 mm PVC manifold.

After installation of the aeration system on the tank bottom support railings, the height of the diffusers over the tank bottom was of 25 cm.

1 BLOWER
2 FLOW CONTROL VALVE
3 MANOMETER
4a FLOWMETER
4b ORIFICE PLATE
5 THERMOMETER
6 AIR SUPPLY
7 AERATION GRID

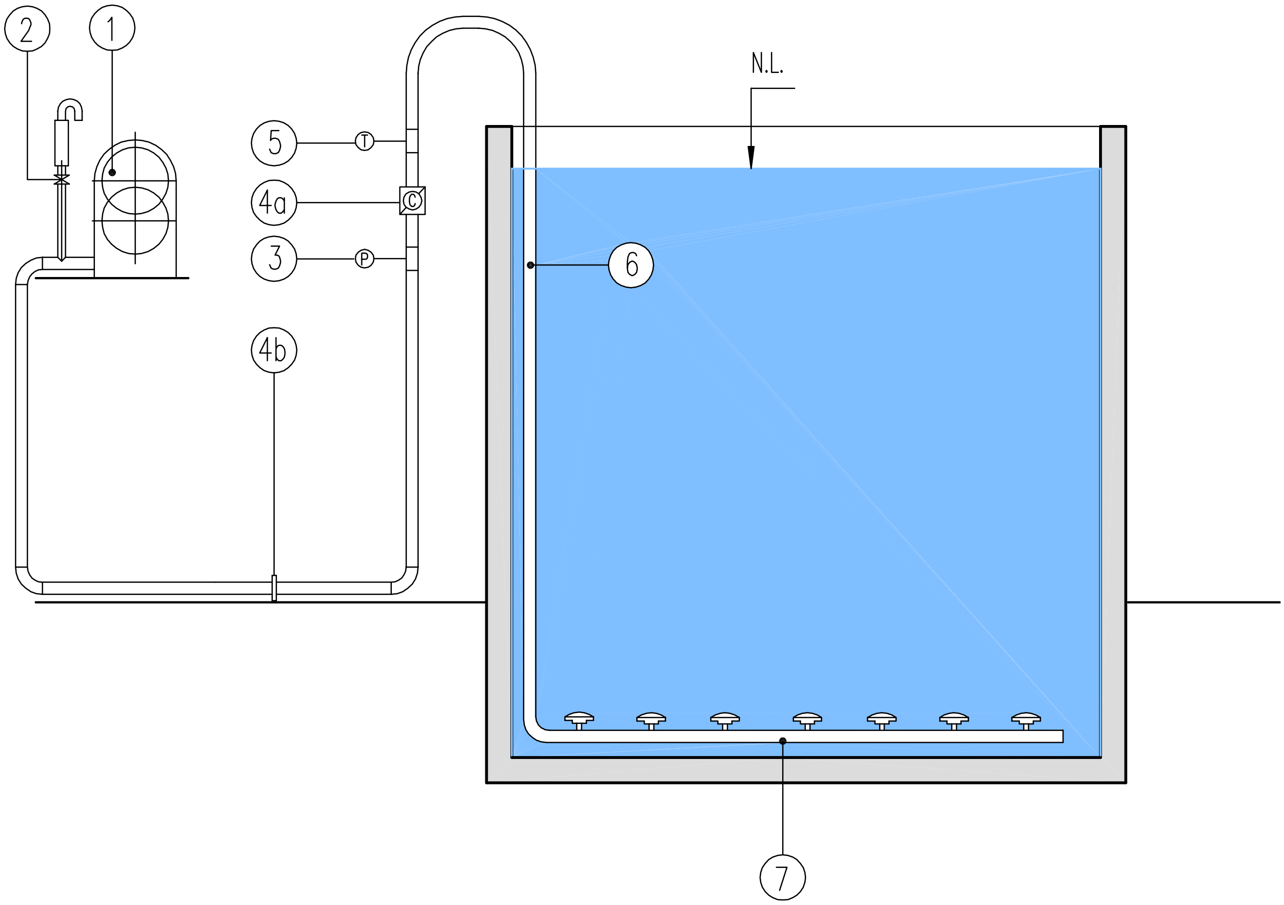
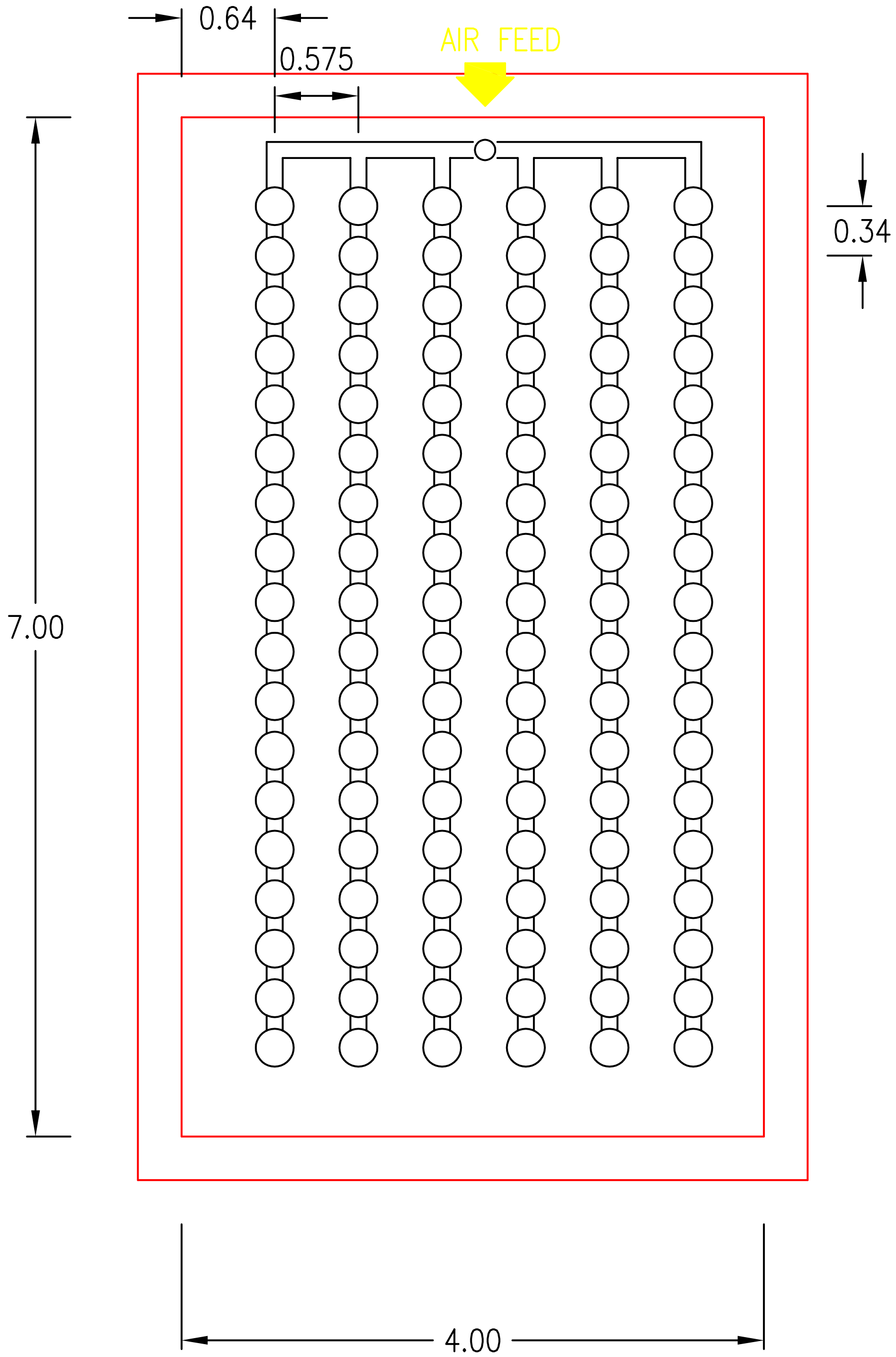
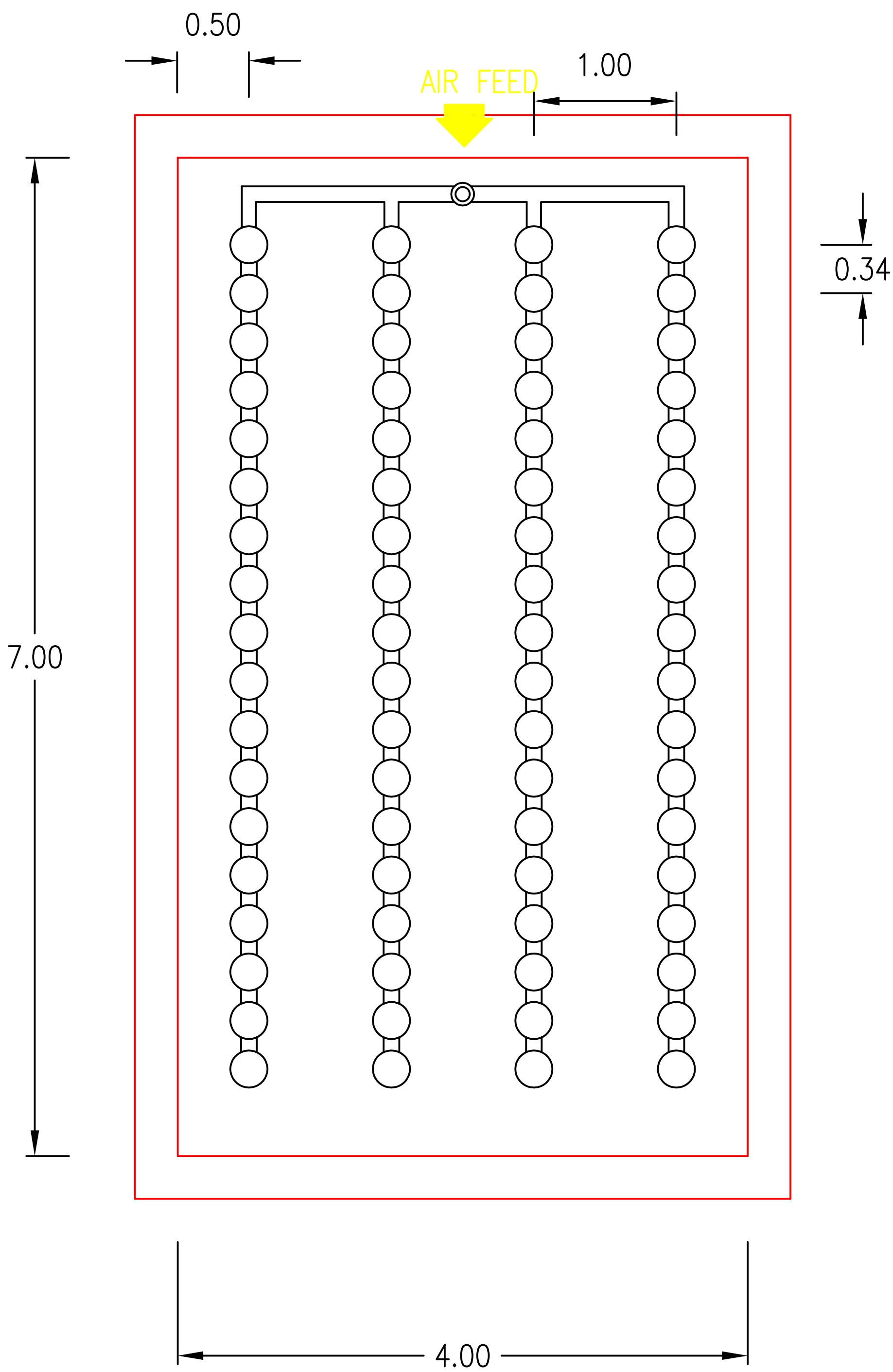


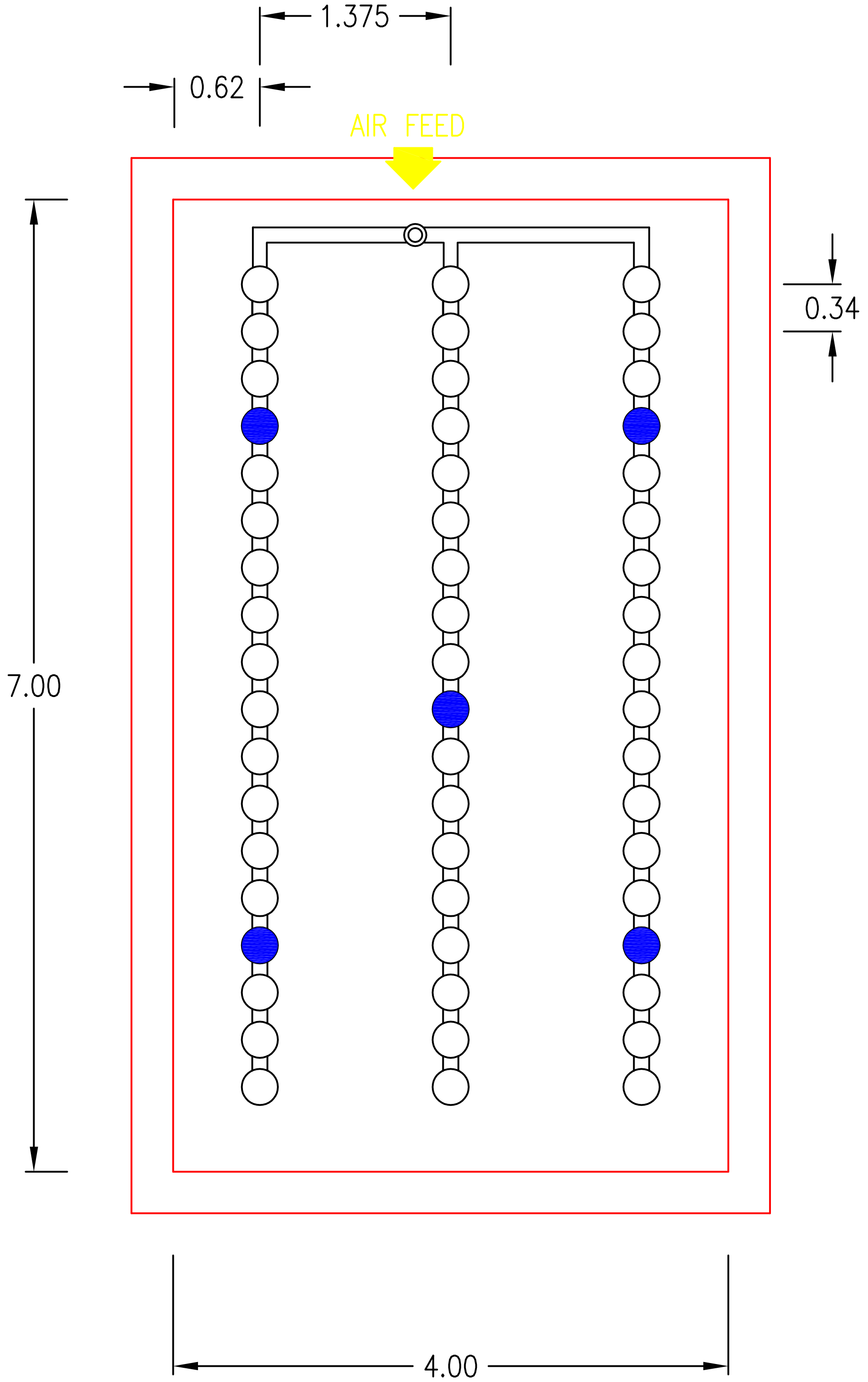
Fig. 1 SCHEMATIC OF TESTING TANK AND CONTROL DEVICES



GRID 1 – ZONE 1 (108 Active Diffusers)



GRID 2 – ZONE 3 (72 Active Diffusers)



GRID 3 – ZONE 5 (49 Active Diffusers)

● – Blocked Diffuser Holder

3. TEST PROCEDURE

The tests have been conducted following the procedures described in the ASCE Standard ANSI/ASCE 2-91 'A Standard for the Measurement of Oxygen transfer in Clean Water'.

Public supply drinking water from the area (Les Fonts, Mina Pública de Terrasa) was used to fill the test tank to the water depth specified for the tests. Multiple tests were conducted in the same water checking the conductivity did not exceed 2500 μS.

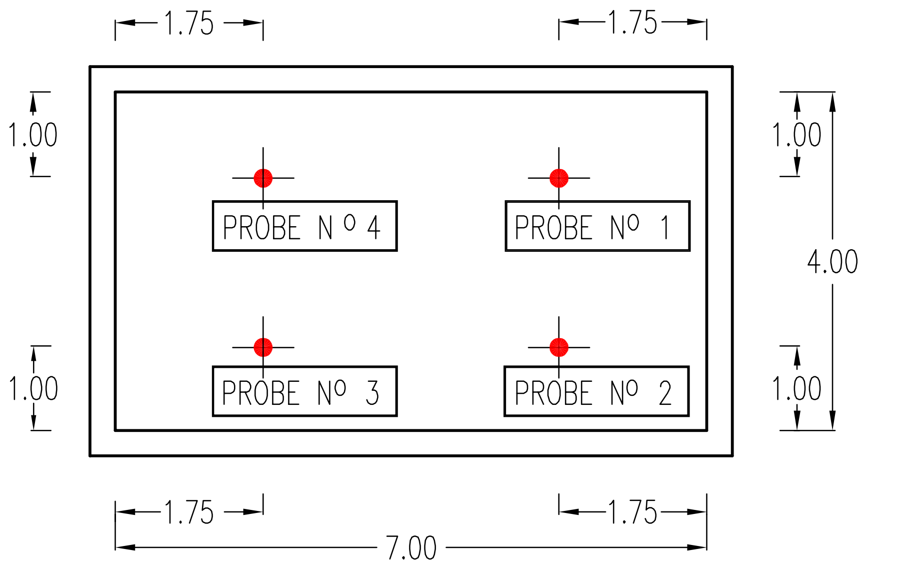
3.1. DEOXYGENATION

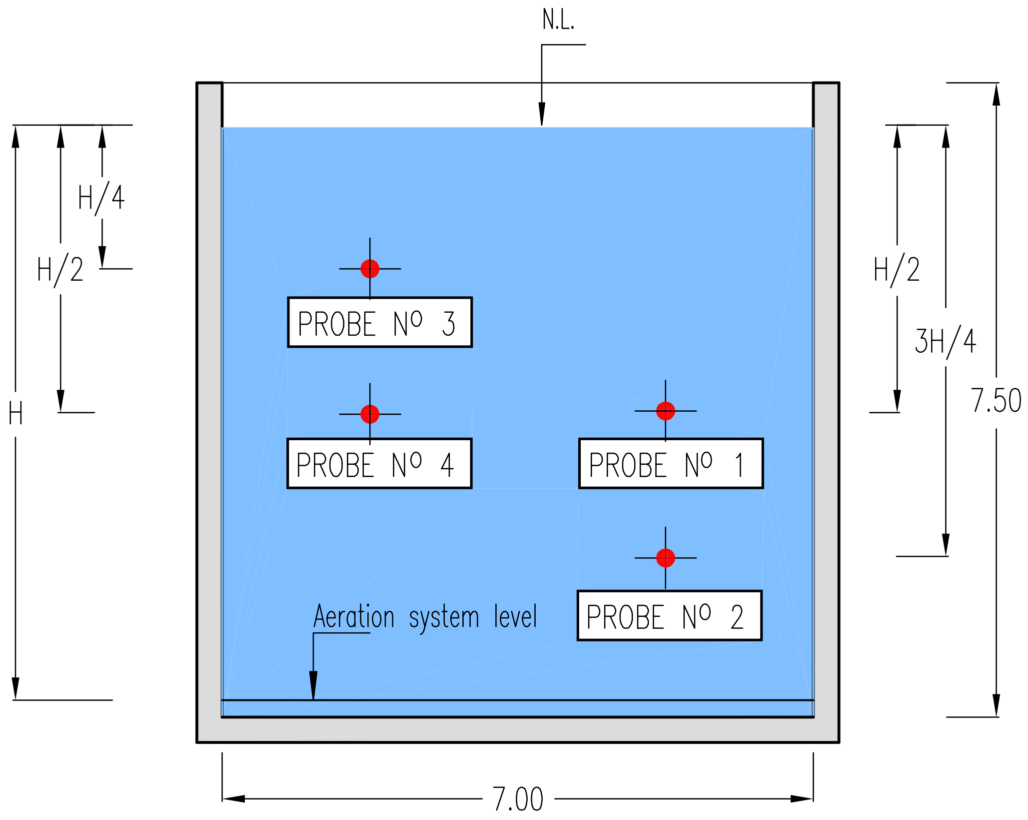
Deoxygenation of the test water volumes was achieved by addition of technical grade (98%) Anhydrous Sodium Sulphite in excess of the stoichiometric amounts required for the removal of all DO present in the test water using Cobalt II Chloride · 6H20 as a catalyst. To allow good catalisation, a minimum free cobalt concentration of 0,30 mg/l is maintained in the test volume. Cobalt catalyst was added to each batch of fresh water as a solution with the aeration system turned on at least one hour before the first addition of Sodium Sulphite to allow adequate mixing. Sodium Sulphite in excess of stoichiometric amounts required for DO depletion is added as a solution prepared beforehand in a separate mixing tank by pumping over the tank surface with a flexible hose. The aeration system was kept in operation at the desired test flow at all times, even during sulphite addition procedures.

3.2 MEASUREMENT OF DISSOLVED OXYGEN

Determination of DO concentrations in the different areas of the test tank is accomplished by means of four Yellow Springs Instruments YSI 52 membrane DO probes. Precision, accuracy and response time of such probes is adequate for the application of the testing method used.

TOP VIEW





CROSS SECTION

Fig. 3 LOCATION OF DO PROBES IN TEST TANK

Location of DO probes in the test volume is represented in the attached drawing (Figure 3). Such distribution has been adopted to ensure good sampling of the test contents and representativity of the data collected. Calibration of probes was done by comparison with an independent DO measurement method (Winkler method). Winkler tests for probe calibration were conducted in the Terrassa STW laboratory located within walking distance of the test tank. At the beginning of each test day, three water samples from the saturated test water will be taken and analysed for Dissolved Oxygen concentration. The average of the three determinations was used to calibrate probes.

Data registration was done automatically connecting all probes to a laptop computer, and readings of the DO v/s time data points were taken at variable time intervals depending on the specific requirements of each test. The interval between readings was adjusted so that between 50 and 100 data points were obtained for each test run.

3.3 DATA ANALYSIS

The data collected from each test is prepared for analysis following the truncation criteria contained in the applied standard and is analysed for Kla and C* values using the non linear regression method.

Parameter values for each individual probe and test run are obtained and used for system performance calculations. Kla and C* values are corrected to standard temperature and pressure conditions using the expressions included in the applied standard and SOTE (Oxygen Transfer Efficiency at 20ºC, 1 atm) values are them calculated to establish comparison with guarantee values. Calculations and acceptance criteria included in ANSI/ASCE 2-91 are applied for the purpose of system performance evaluation.

4. TEST PROGRAM AND CONDITIONS

The test program and system operating conditions for the AYLESBURY STW aeration tests included a total of 12 test runs as listed in the following test programme:

Aeration Grid	Test Runs	Test Ref.	Operating Airflows	Water Depth, m
Aylesbury STW Grid 1 –Zone 1	4	1a,1b,1c 1d	3 at max airflow 1 at avg airflow	5.329
Aylesbury STW Grid 2 –Zone 3	4	2a,2b,2c 2d	3 at max airflow 1 at avg airflow	5.329
Aylesbury STW Grid 3 –Zone 5	4	3a,3b,3c 3d	3 at max airflow 1 at avg airflow	5.329

- Sm3/h is volumetric airflow expressed at 20ºC and 1 atm absolute pressure.

5. TEST DATA AND RESULTS

The following tables include basic test conditions and results for the 6 test runs conducted. Detailed listing of full test data and conditions, together with individual probe C* and Kla values, both in test and standard conditions, for each probe and test run are included in Annex 3.

TABLE A: TEST CONDITIONS AND RESULTS

TEST	DATE	GRID	AIRFLOW (Sm3/hr)	W. TEMP. (ºC)	VOLUME (m3)	SOTE (%)
1MAX1	7/9	1	223.2	22.3	149.5	33.93
1MAX2	7/9	1	228.1	22.4	149.5	34.72
1MAX3	7/9	1	225.4	22.5	149.5	35.98
1AVG	7/9	1	179.1	22.6	149.5	35.79
2MAX1	9/9	2	146.9	22.2	149.2	32.43
2MAX2	9/9	2	148.9	22.3	149.2	33.52
2MAX3	9/9	2	146.5	22.4	149.2	34.12

TEST	DATE	GRID	AIRFLOW (Sm3/hr)	W. TEMP. (ºC)	VOLUME (m3)	SOTE (%)
2AVG	9/9	2	119.5	22.6	149.2	35.97
3MAX1	11/9	3	96.8	22.7	149.2	32.94
3MAX2	11/9	3	98.4	22.8	149.2	32.69
3MAX3	11/9	3	96.4	22.9	149.2	33.05
3AVG	11/9	3	77.6	23.0	149.2	33.02

From the data presented, one may observe that average Standard Oxygen Transfer Efficiencies measured for Grids 1,2 and 3 at maximum airflow conditions are of 34.87, 33.36 and 32.89 % respectively.

6. PERFORMANCE GUARANTEE VALUES

The Oxygen Transfer Rate requirements for each aeration zone are established in the Aylesbury STW tender documents and summarised in the following Table (Total airflow per tank at maximum normal conditions is of 2703 Sm3/hr):

ZONE	% Flow	Zone Flow, Sm3/hr	Required SOTR, kgO2/hr	Equivalent SOTE, %
1	27	729.8	69.6	34.43
3	17	459.5	41.0	32.21
5	11	297.3	25.7	31.20

*Equivalent SOTE calculated as the ratio of required SOTR to input mass flow of oxygen (=Zone Flow x O2 content per Sm3/hr = Zone Flow x 0.277 kgO2/Sm3).

7. CONCLUSIONS

This document includes all the information relative to the series of Clean Water Oxygen Transfer Tests conducted by Asesoría Técnica y Control on different EPDM 9” disc aeration systems representative of the systems to be supplied by Suprafilt for installation in Zones 1, 3 and 5 of the AYLESBURY STW aeration lanes.

During the series of tests conducted, Standard Oxygen Transfer Efficiencies (SOTE,%) of 34.87, 33.36 and 32.89 % have been measured for the aeration systems to be installed in Zones 1, 3 and 5 respectively when operating at maximum airflow per diffuser conditions.

Project tender documents required SOTE performances of 34.43, 32.21 and 31.20 % for the three aeration zones considered when operating at the same water depth and airflow per diffuser conditions.

Therefore, it may be concluded that results obtained in the present series of tests show aeration system performances between 1.3 and 5.4% in excess of performance guarantee requirements.

Barcelona, September 16th 2004

The Engineer in Charge of the Testing

Ian Trillo

Asesoría Técnica y Control, S.A.

ANNEX 1

WATER QUALITY

ANNEX Nº1: CLEAN WATER CHARACTERÍSTICS

SOURCE: Mina Pública de Terrassa

QUALITY PARAMETERS

PARAMETER	*VALUE*
pH	7,7
Total Dissolved Solids (mg/l)	750
Conductivity (uS/cm)	1.160
Alcalinity (mg/l)	246
Hardness (mg/l CaCO3)	424
Oxydability (mg O2/l)	1,94
Salt Contents (mg/l):	
Fe	< 1
Mn	<1
Cu	<40
Zn	<40

ANNEX 2

TEST CONDITIONS

GRID 1 TEST CONDITIONS

TEST REF.	1MAX1	1MAX2	1MAX3	1AVG
DATE	Sept.7	Sept.7	Sept.7	Sept.7
BAROMETER, mbar	999	999	999	999
WATER DEPTH, m	5.34	5.34	5.34	5.34
DIFF. SUBMERGENCE, m	5.09	5.09	5.09	5.09
WATER TEMPERATURE, ºC	22.3	22.4	22.5	22.6
VOLUME,m3	149.52	149.52	149.52	149.52
COBALT DOSE, gr	181			
SULPHITE DOSE, kg	25	25	25	25
CONDUCTIVITY,µS/cm				
TARGET AIRFLOW,Sm3/hr				
DIFF.PRESSURE, mbar	-	-	-	0.97
AIRFLOW (flowmeter), m3/hr	170.3	173.7	172.2	-
LINE TEMPERATURE, ºC	67	66	67	65
LINE PRESSURE, bar	0.54	0.54	0.54	0.54
AIRFLOW, Sm3/hr	223.22	228.09	225.45	179.11

GRID 2 TEST CONDITIONS

TEST REF.	2MAX1	2MAX2	2MAX3	2AVG
DATE	Sept.9	Sept.9	Sept.9	Sept.9
BAROMETER, mbar	1001	1001	1001	1001
WATER DEPTH, m	5.33	5.33	5.33	5.33
DIFF. SUBMERGENCE, m	5.08	5.08	5.08	5.08
WATER TEMPERATURE, ºC	22.2	22.3	22.4	22.6
VOLUME,m3	149.24	149.24	149.24	149.24
COBALT DOSE, gr	185			
SULPHITE DOSE, kg	25	25	25	25
CONDUCTIVITY,µS/cm				
TARGET AIRFLOW,Sm3/hr				
DIFF.PRESSURE, mbar	0.65	0.67	0.65	0.97
AIRFLOW (flowmeter), m3/hr	-	-	-	-
LINE TEMPERATURE, ºC	63	64	65	63
LINE PRESSURE, bar	0.535	0.535	0.535	0.535
AIRFLOW, Sm3/hr	146.91	148.93	146.48	119.49

GRID 3 TEST CONDITIONS

TEST REF.	3MAX1	3MAX2	3MAX3	3AVG
DATE	Sept.11	Sept.11	Sept.11	Sept.11
BAROMETER, mbar	995	995	995	995
WATER DEPTH, m	5.33	5.33	5.33	5.33
DIFF. SUBMERGENCE, m	5.08	5.08	5.08	5.08
WATER TEMPERATURE, ºC	22.7	22.8	22.9	23.0
VOLUME,m3	149.24	149.24	149.24	149.24
COBALT DOSE, gr	182			
SULPHITE DOSE, kg	25	25	25	25
CONDUCTIVITY,µS/cm				
TARGET AIRFLOW,Sm3/hr				
DIFF.PRESSURE, mbar	0.28	0.29	0.28	0.18
AIRFLOW (flowmeter), m3/hr	-	-	-	-
LINE TEMPERATURE, ºC	58	59	61	58
LINE PRESSURE, bar	0.53	0.53	0.53	0.53
AIRFLOW, Sm3/hr	96.80	98.36	96.36	77.61

ANNEX 3

EXPERIMENTAL DATA, DATA ANALYSIS AND REGRESSION CURVES

The CD-Rom attached to the present report includes the following files and information:

- **AYLESBURYData.xls**:This file includes all the DO v/s Time data collected for each individual probe during each individual test run. Data is organised in such a way that each spreadsheet is named after the aeration Grid Type (1 through 3) to which data correspond. Each spreadsheet includes four different data sets named after the corresponding test run (max1 to max3 and avg) as a function of airflow and run number.

- **Files GxMAXy and GxAVG**:For each of the test runs considered, files GxMAXy and GxAVG include regression curves and fitting residuals for all DO probes, Kla and C* values for each individual probe both under test conditions and standard conditions, truncation levels used in parameter estimation, and SOTR and SOTE values for each test.

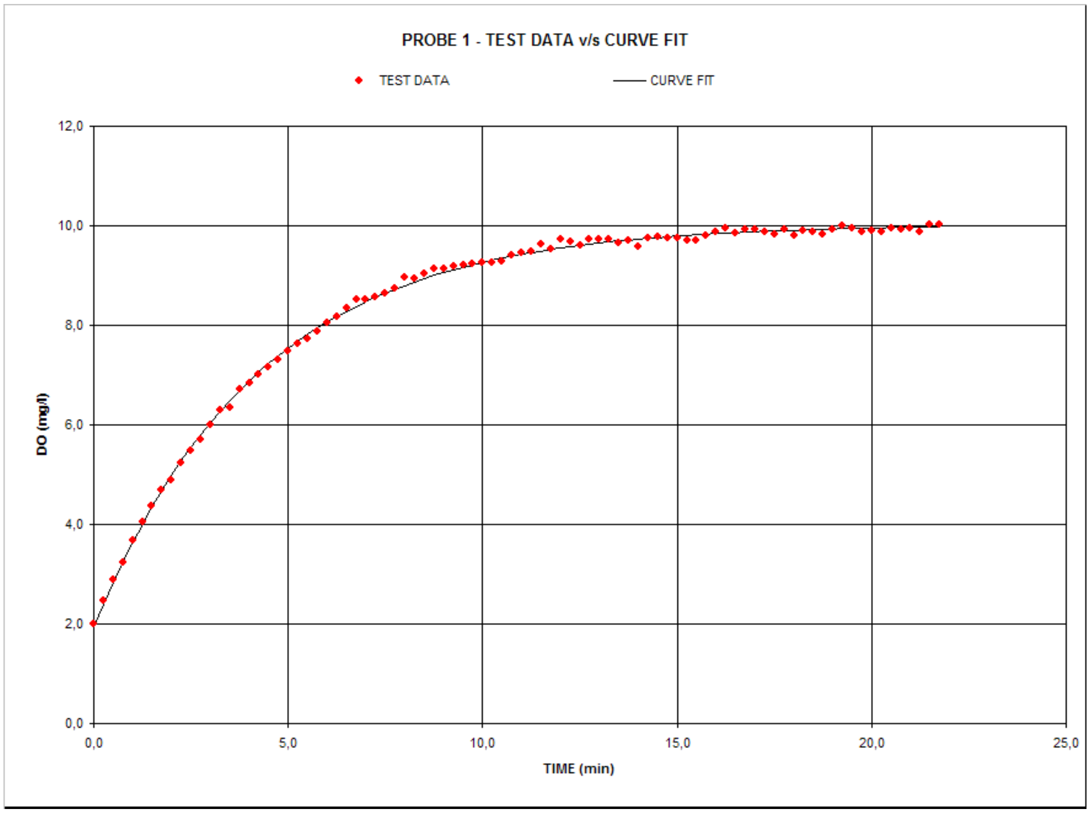
  By way of example, the following pages are a printout of the information included in file G1MAX1, corresponding to the first run conducted at maximum airflow (MAX1) for aeration Grid Type 1.

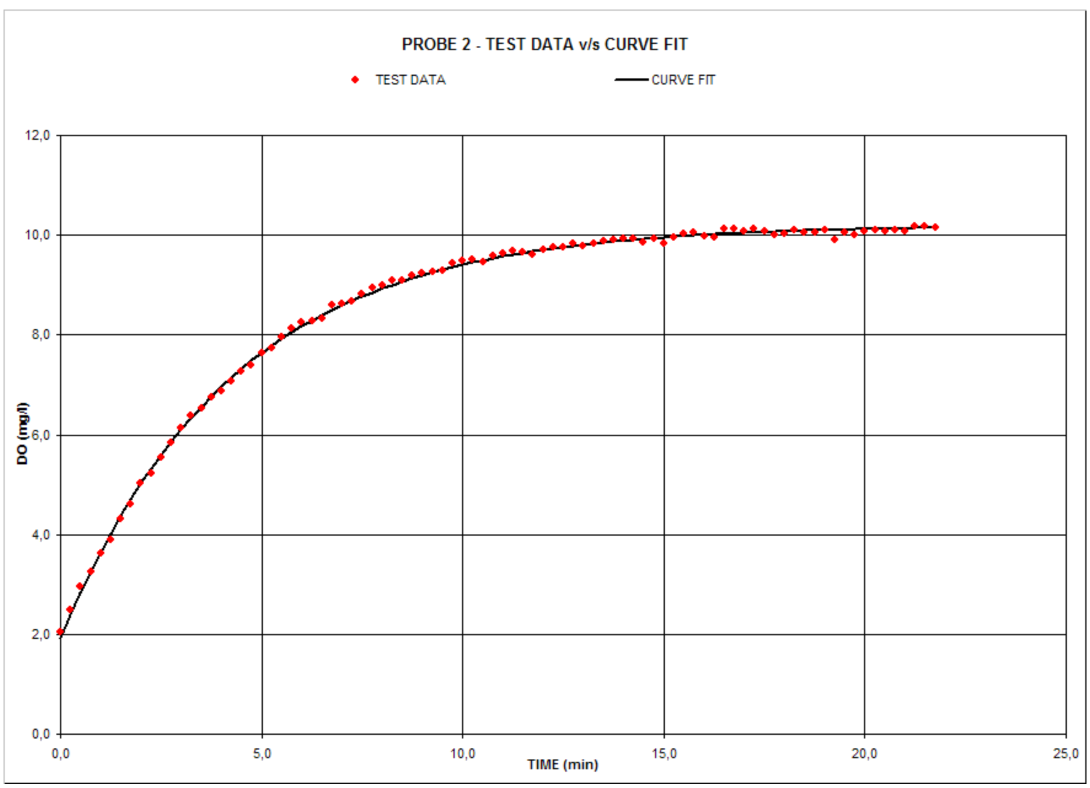
AYLESBURY STW			G1MAX1
WATER DEPTH	5,34	m	
TANK VOLUME	149,52	m3	
WATER TEMPERATURE	22,3	C	
BAROMETER	999	mbar	
AIRFLOW	223,22	Sm3/h	

TEST CONDITIONS	KLA	C*	TRUNC.L
PROBE 1	14,15	10,03	20
PROBE 2	14,09	10,20	20
PROBE 3	13,59	10,05	20
PROBE 4	13,51	10,21	20
AVERAGE	13,833	10,120	

STANDARD CONDS.	KLA	C*	KLA·C*
PROBE 1	13,39	10,62	142,20
PROBE 2	13,34	10,80	144,01
PROBE 3	12,87	10,64	136,88
PROBE 4	12,79	10,80	138,18
AVERAGE	13,098	10,713	140,31

OXYGEN TRANSFER RATE	20,98	KGO2/HR
SOTE	33,93	%


PROBE 1 - TEST DATA v/s CURVE FIT
TEST DATA
CURVE FIT
DO (mg/l)
TIME (min)
0,0
2,0
4,0
6,0
8,0
10,0
12,0
5,0
15,0
20,0
25,0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TEST DATA
CURVE FIT
DO (mg/l)
TIME (min)
0,0
2,0
4,0
6,0
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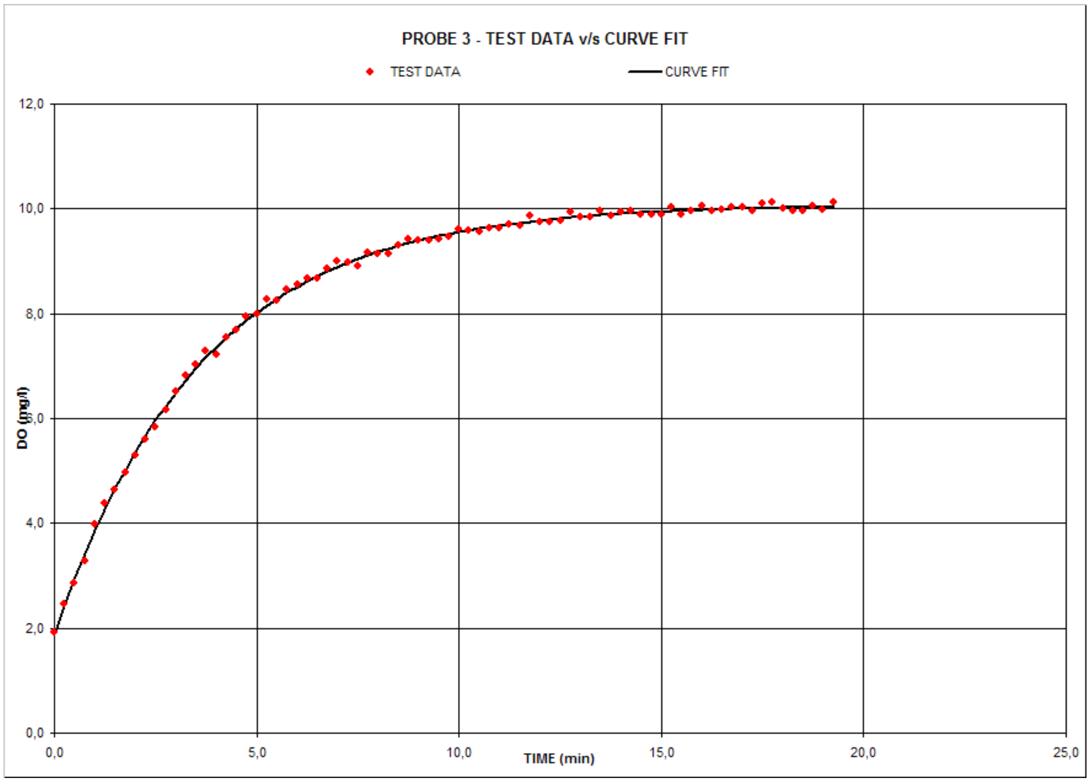
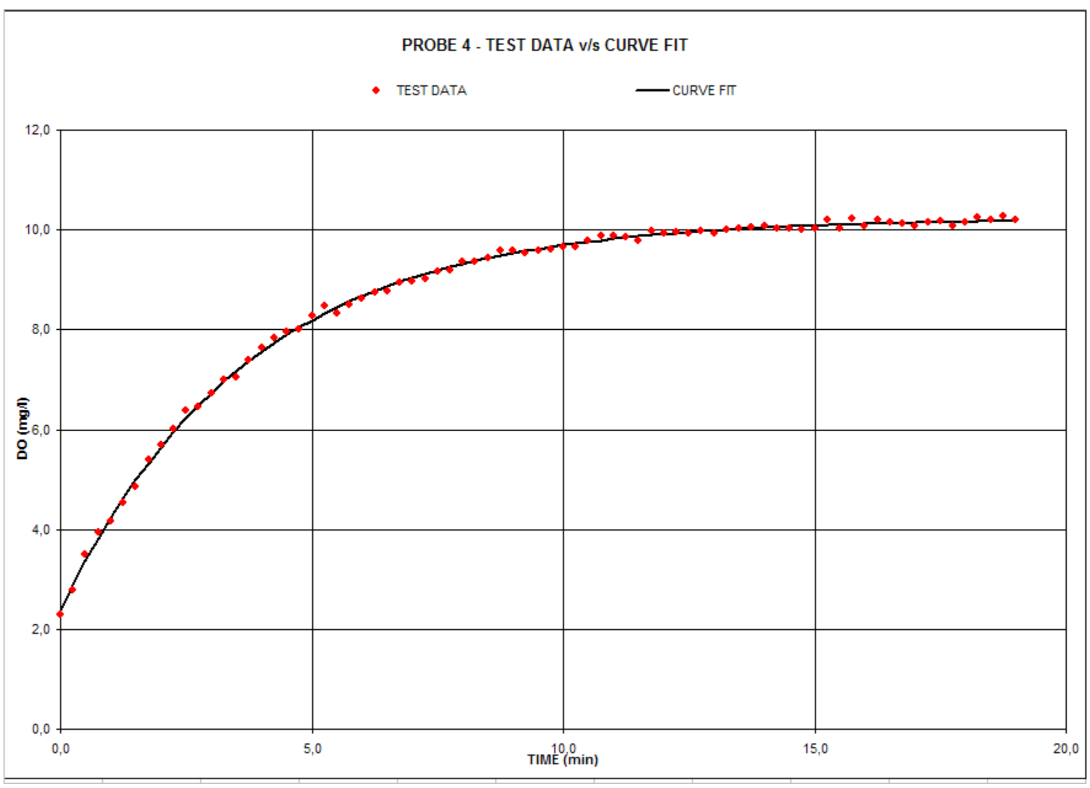
15,0
20,0
25,0


PROBE 3 - TEST DATA v/s CURVE FIT
TEST DATA
CURVE FIT
DO (mg/l)
TIME (min)
12,0
10,0
8,0
6,0
4,0
2,0
0,0
5,0
10,0
15,0
20,0
25,0


PROBE 4 - TEST DATA v/s CURVE FIT
TEST DATA
CURVE FIT
DO (mg/l)
TIME (min)
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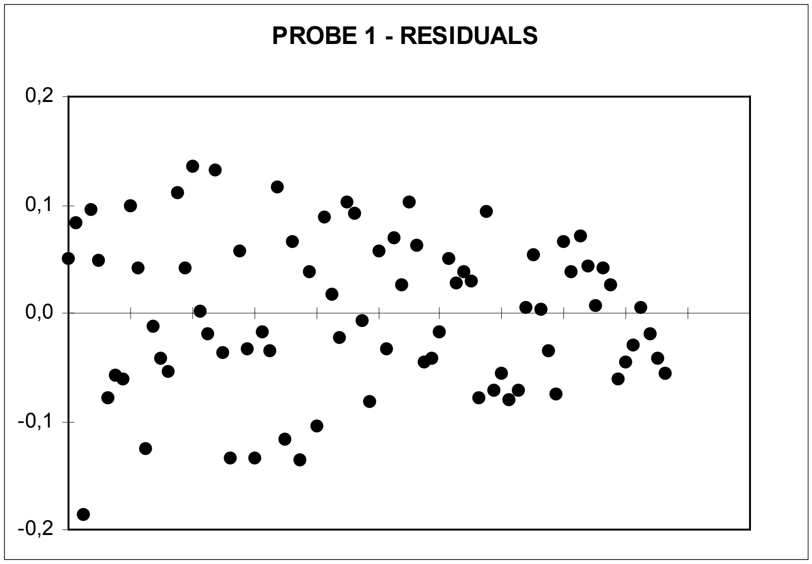
10,0
8,0
6,0
4,0
2,0
0,0
5,0
10,0
15,0
20,0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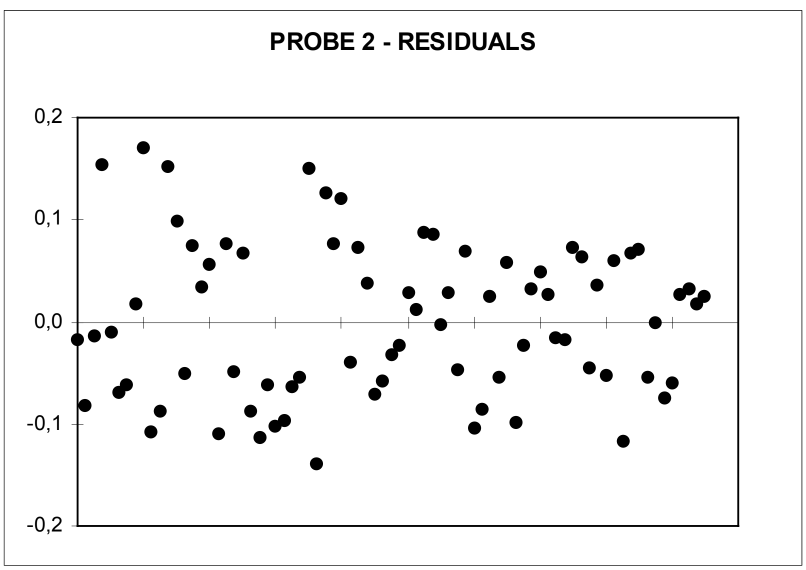
0,1
0,0
-0,1
-0,2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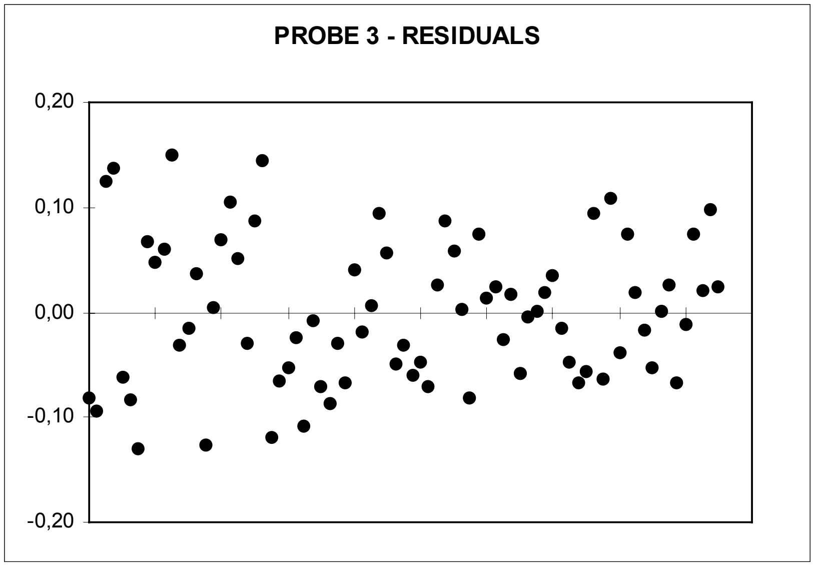
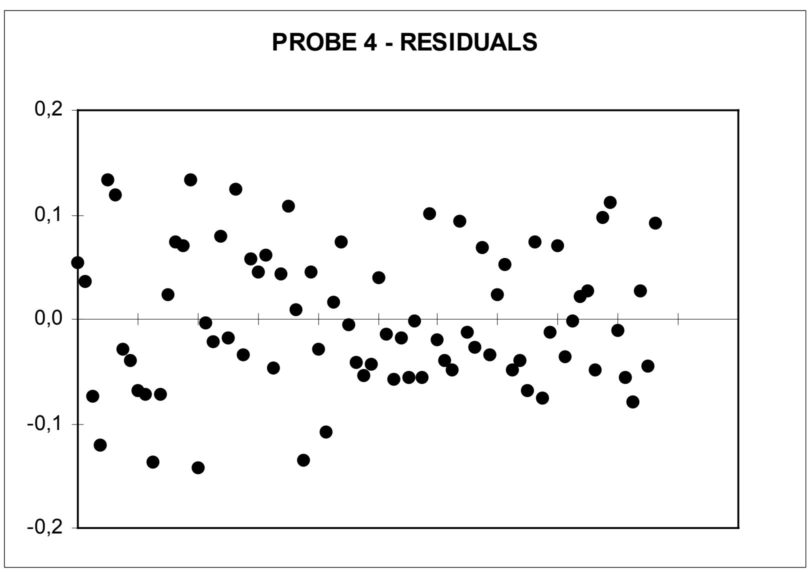
0,2
0,1
0,0
-0,1
-0,2


PROBE 3 - RESIDUALS
0,20
0,10
0,00
-0,10
-0,20


PROBE 4 - RESIDUALS
0,2
0,1
0,0
-0,1
-0,2

ANNEX 4

CALCULATION EXAMPLE

CALCULATIONS

The data obtained at each determination point is analysed by a mass transfer model to estimate the apparent volumetric mass transfer coefficient and the steady-state DO saturation concentration. The model is based an the expression.

$$C = C\infty^{*} - (C\infty^{*} - C_0) \exp(-K_L a \cdot t)$$

where:

C = DO concentration, mL^{-3}

$C\infty^{*}$ = determination point value of the steady-state DO saturation concentration as time approaches infinity, mL^{-3}

C_0 = DO concentration at time zero, mL^{-3}

K_{La} = determination point value of the apparent volumetric mass transfer coefficient, t^{-1}, defined so that

$K_L a$ = rate of mass transfer per unit volume/ $(C\infty^{*} - C_0)$

m = mass, L = length, t = time, f = force

Non-linear regression is employed to fit this equation to the DO profile measured at each determination point during reoxygenation. In this way, estimates of $K_L a$ and $C\infty^{*}$ are obtained at each determination point. These estimates are adjusted to standard conditions, and the standard oxygen transfer rate (mass of oxygen dissolved per unit time at a hypothetical concentration of zero DO) is obtained as the average of the products of the adjusted determination point $K_L a$ values, the corresponding adjusted determination point $C\infty^{*}$ values, and the tank volume.

$$SOTR\ (KgO_2/h) = \Sigma\ K_L a_{2oi} \cdot C\infty^{*}_{i} \cdot Vi$$

The SOTR value shall be determined by correcting the values of K_La and $C^*\infty$ for each determination point to standard conditions by:

$$K_La_{20} = K_La\theta^{(20-T)}$$

$$C^*_{\infty 20} = C^*\infty \left(\frac{1}{\tau\Omega}\right)$$

where:

K_La = determination point value of apparent mass transfer coefficient

K_La_{20} = determination point value of K_La corrected to 20°C

θ = empirical temperature correction factor, usually taken to be 1.024 unless proven to have a different value for the aeration system and tank tested.

$C^*\infty$ = determination point value of steady-state DO saturation concentration

$C^*_{\infty 20}$ = determination point value of steady-state DO saturation concentration corrected to 20°C and a standard barometric pressure of 1.00 atm (101 kPa)

τ = temperature correction factor

= C^*_{st} / C^*_{s20}

C^*_{st} = tabular value of dissolved oxygen surface saturation concentration, mL^{-3}, at the test temperature, a standard total pressure of 1.00 atm and 100% relative humidity.

C^*_{s20} = tabular value of dissolved oxygen surface saturation concentration mL^{-3}, at 20°C, a standard total pressure of 1.00 atm and 100% relative humidity

Ω = pressure correction factor,

= P_b / P_s

P_b = barometric pressure at test site during test

P_s = standard barometric pressure of 1.00 atm (101 kPa) and

T = water temperature during test, °C

The Standard Oxygen Transfer Efficiency is calculated by referring the measured SOTR to the oxygen input to the system.

$$\text{SOTE (\%)} = \frac{\text{SOTR (Kg/h)}}{\text{WO}_2\text{ (Kg/h)}} \times 100$$

where WO_2 = mass flow of oxygen in air stream

= Qs · 0,277 (Qs = airflow rate at standard conditions)

Example:

Following is a calculation example for test G1MAX1, where estimation of K_La and C^*_∞ values in test conditions using non-linear regression of the field data yielded the following values:

PROBE	K_La	C^*_∞
1	14.15	10.03
2	14.09	10.20
3	13.59	10.05
4	13.51	10.21

Correction to standard conditions (20°C, 1 atm) is done by application of the following expressions:

$K_La_{20} = K_La \cdot 1.024^{(20-T)} = 0.947 \cdot K_La$ for test temperature of 22.3°C

$C^*_{\infty 20} = C^*_\infty \left(\frac{1}{\tau\Omega}\right)$, $\tau = \frac{8.694}{9.092} = 0.956$

$$\Omega = {Pb}/{Ps} = \frac{999}{1013} = 0.986$$

= 1.0609 C^*_∞ for a test water temperature of 17.5 and barometric pressure of 1004 mbar.

K_La_{20} and $C^*_{\infty 20}$ corrected values would therefore be as follows:

PROBE	K_La	$C^*\infty$
1	13.40	10.64
2	13.34	10.82
3	12.87	10.66
4	12.79	10.83

and the calculated SOTR (KgO_2/h):

SOTR (KgO_2/h) = $\Sigma\ K_La_{20} \cdot C^*_{\infty 20} \cdot Vi$

where Vi = V/4 for the selected probe location = 37.38 m3

SOTR (KgO_2/h) = V/4 (13.40*10.64+13.34*10.82+12.87*10.66+12.79*10.83)

$= 37.38\ m^3\ (562.62 gO_2/m^3 \cdot h) = 21.03\ kgO_2/h$

Once SOTR is determined, and knowing the total airflow to the basin is of 260.39 Sm^3/h, the calculated SOTE (%) would be:

$$\text{SOTE (\%)} = \frac{21.03 KgO2/h}{223.22 Sm3/h \cdot 0{,}277 KgO2/Sm3/h} \cdot 100 = 34.01\%$$

Differences with respect to data presented in the body of the document (33.93%) may be explained by the number of decimal points considered in this manual calculations.

ANNEX 5

ORIFICE PLATE AIRFLOW CALCULATIONS

AIRFLOW CALCULATIONS

When using a calibrated orifice plate, airflow at reference condition may be calculated using the following expression..

$$Q = Q\,cal \cdot \sqrt{\frac{Tcal}{Pcal \bullet \Delta pcal}} \bullet \sqrt{\frac{Ptest \bullet \Delta ptest}{Ttest}}$$

Where:

Q cal = Airflow during calibration (Sm^3/h)

T cal = Line temperature during calibration (K)

P cal = Line absolute pressure upstream of orifice late during calibration (bar)

Δp cal = Pressure differential across orifice plate during calibration, (mbar)

Tline = Line temperature during test (K)

Pline = Line absolute pressure upstream of orifice during test (bar)

Δp line = Pressure differential across orifice plate during calibration (mbar)

According to the orifice plate calibration sheet provided, airflow during test will be computed as follows:

$$Q\,(Sm^3/h) = 600 \cdot \sqrt{\frac{(273+70)}{1{,}7 \bullet 10}} \bullet \sqrt{\frac{Pline \bullet \Delta pline}{Tline}}$$

EXAMPLE:

For test run G3MAX1, Δp = 0.28, Tline = 58ºC, Patm = 995 and Pline=0,530. Therefore,

$$Q\,(Sm^3/h) = 600 \cdot \sqrt{\frac{(273+70)}{1.7 \cdot 10}} \cdot \sqrt{\frac{1.525 \cdot 0.28}{(273+58)}} = 96.799$$