

**CLEAN WATER OXYGEN TRANSFER TESTS
NORTH COAST STW AERATION SYSTEM**

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1. PURPOSE AND SCOPE

In order to satisfy the oxygen requirements associated to the treatment process selected for the NORTH COAST STW, Suprafilt Ltd 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 9" Teflon membrane diffuser aeration grids representative of the aeration systems to be installed in Zones 1-3 of the NORTH COAST 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 March 13-17th at Asesoría Técnica y Control's test facilities in Terrassa (Barcelona).

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, $K_L a$, and the steady state dissolved oxygen saturation concentration, C^*_{∞} . The basic model is given by

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

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

$K_L a$ = 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 $K_L a$ 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 $K_L a$ values, corresponding adjusted determination point C^*_{∞} values, and the tank volume.

$$\text{SOTR} = K_{La20} (C^*_{\infty20}) V$$

Where

K_{La20} = determination point value of $K_L a$ corrected to 20°C;

$C^*_{\infty20}$ = 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

$$\text{SOTE} = \text{SOTR} / W_{O_2}$$

Where:

W_{O_2} = 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 both an Endress+Hauser Prowirl 77 vortex flowmeter and a calibrated orifice plate 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 four different Suprafilt Teflon membrane disc diffuser systems representative of the aeration system in Zones 1-3 of the NORTH COAST STW aeration lanes.

As shown in Figures 2a-2c, the layouts adopted for testing consisted in full floor coverage systems equipped with 126, 70 and 55 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

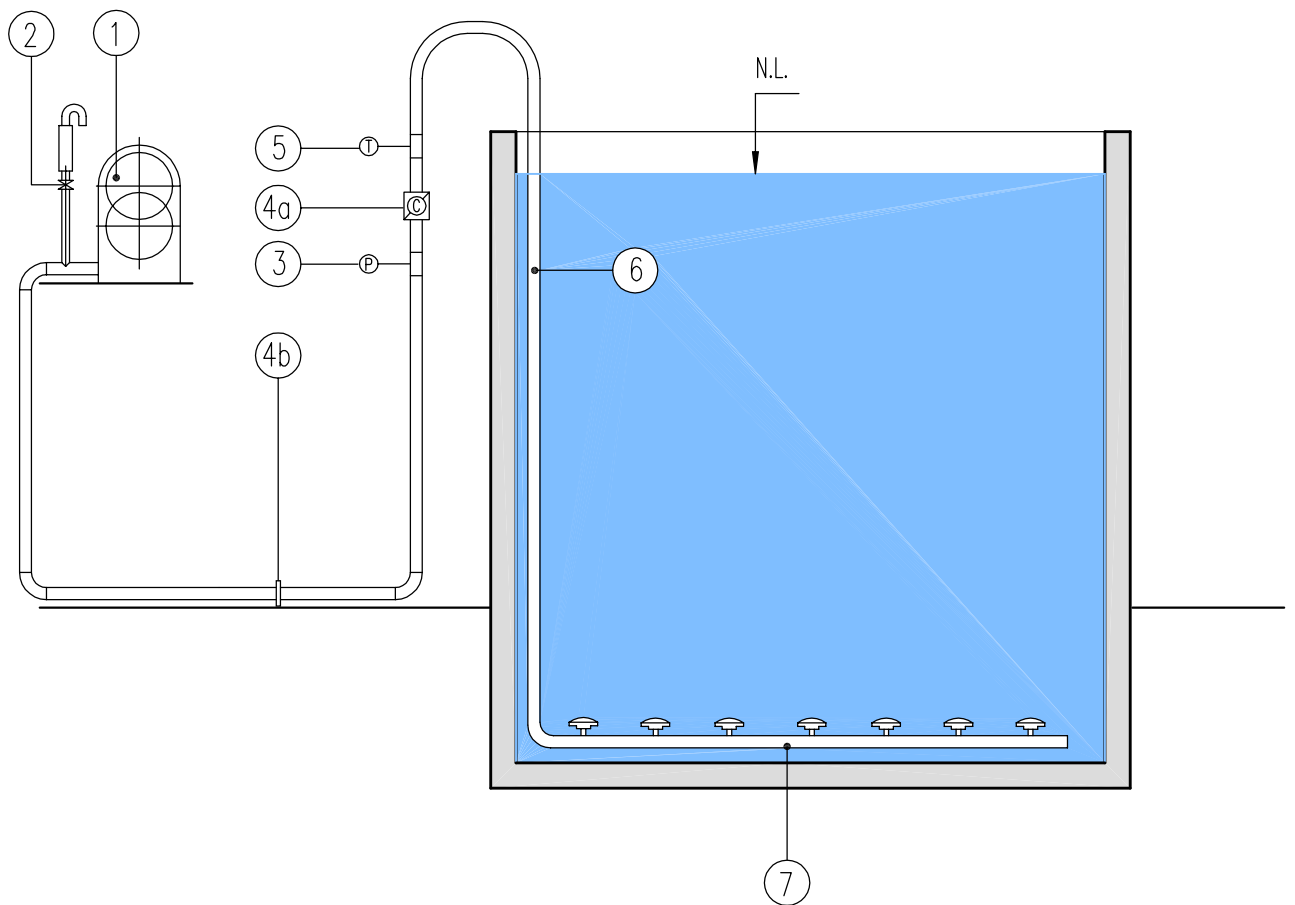
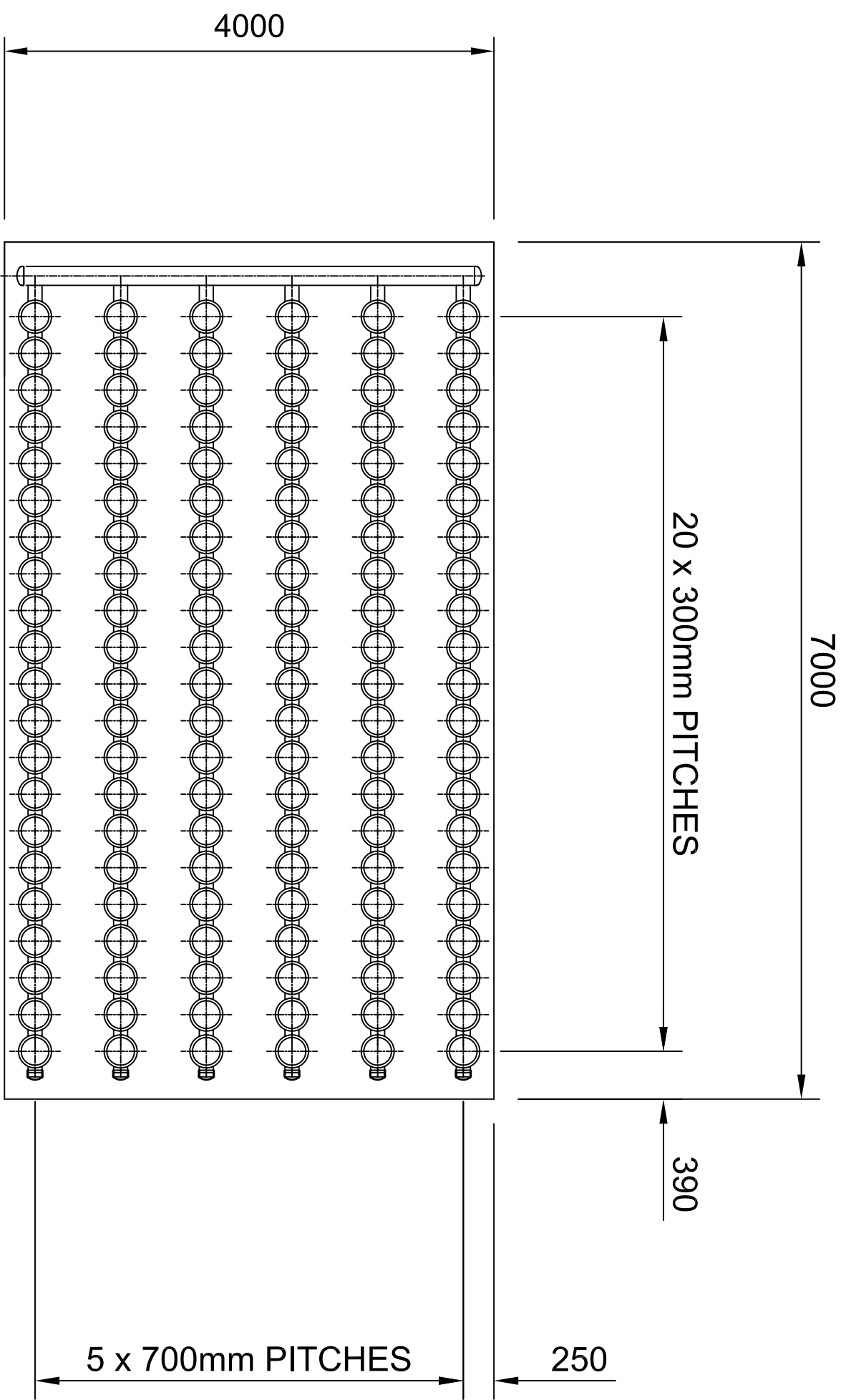
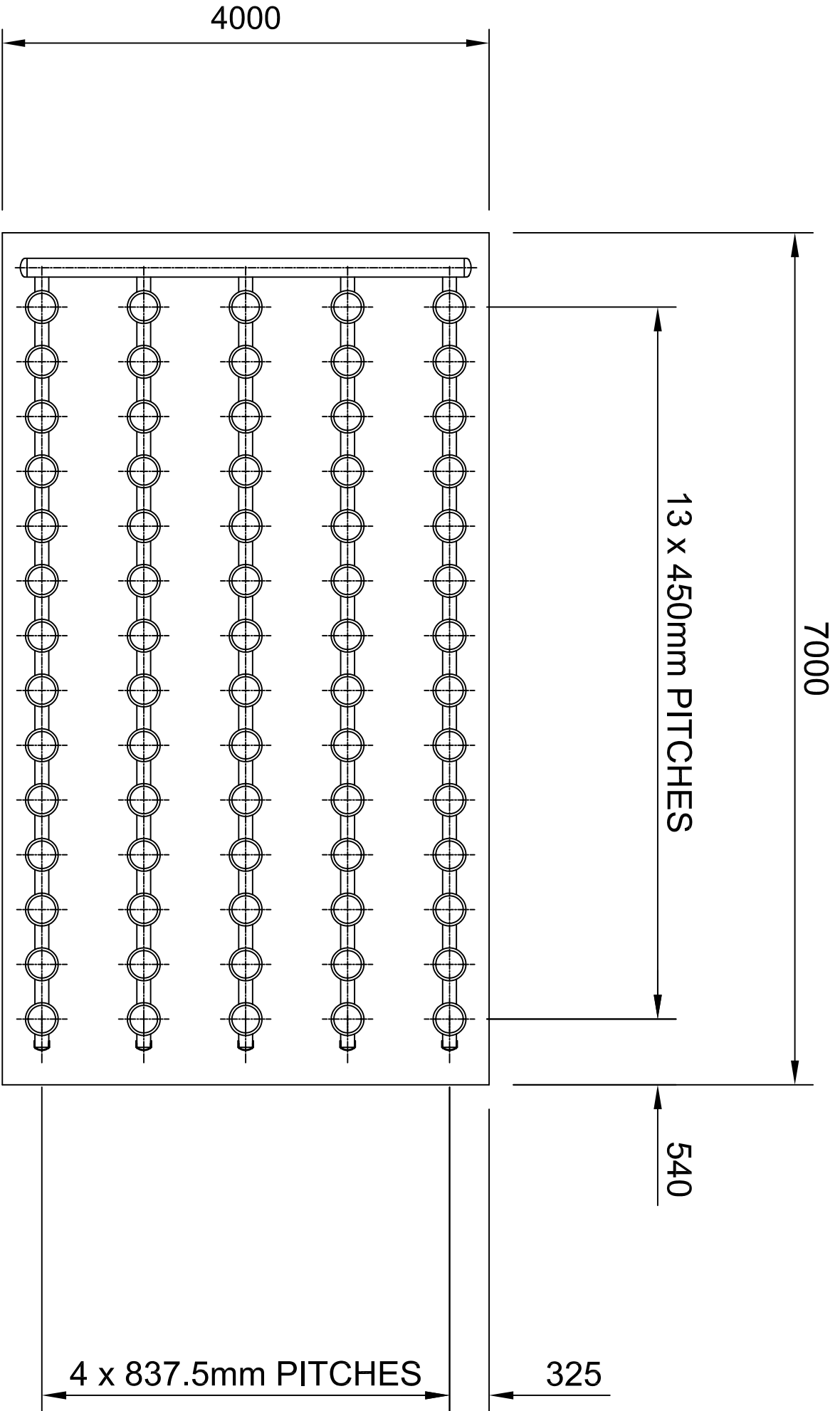


Fig. 1 SCHEMATIC OF TESTING TANK AND CONTROL DEVICES

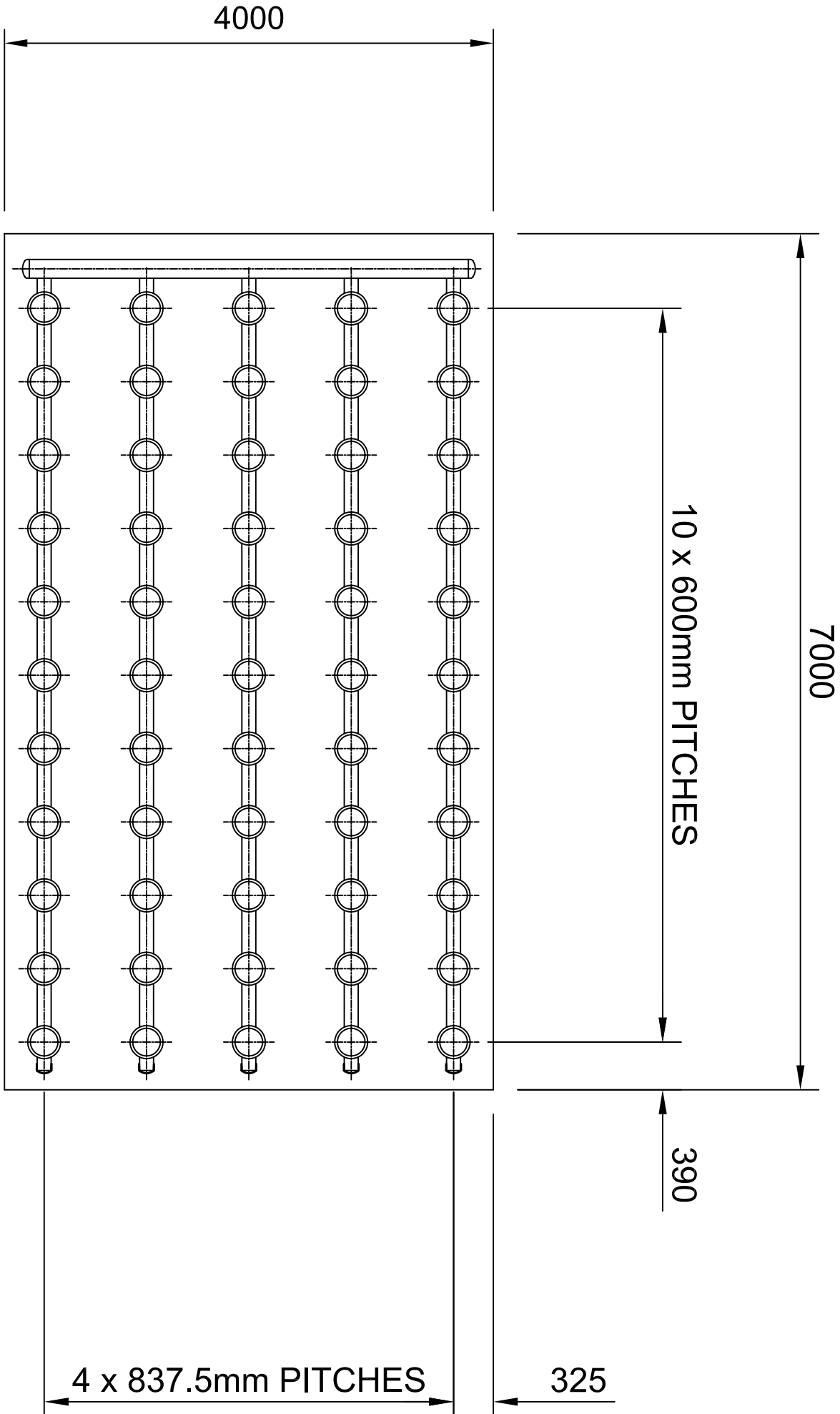
ZONE 1 - 126 DIFFUSERS



ZONE 2 - 70 DIFFUSERS



ZONE 3 - 55 DIFFUSERS



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 3000 μS .

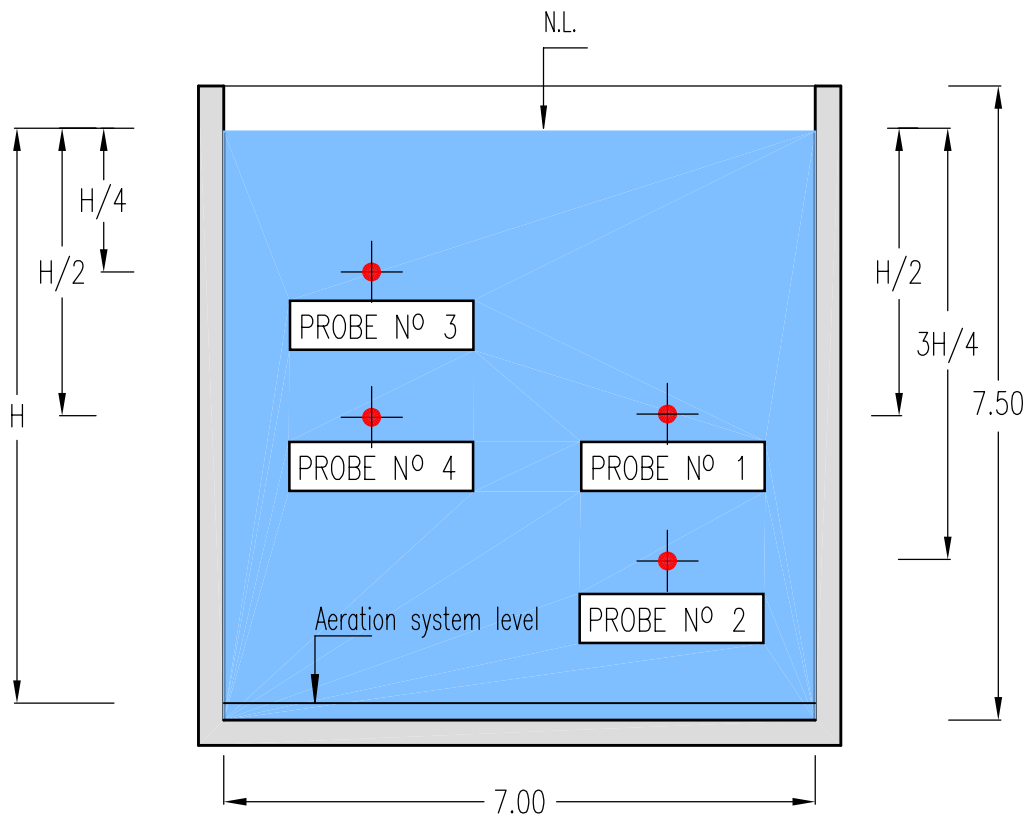
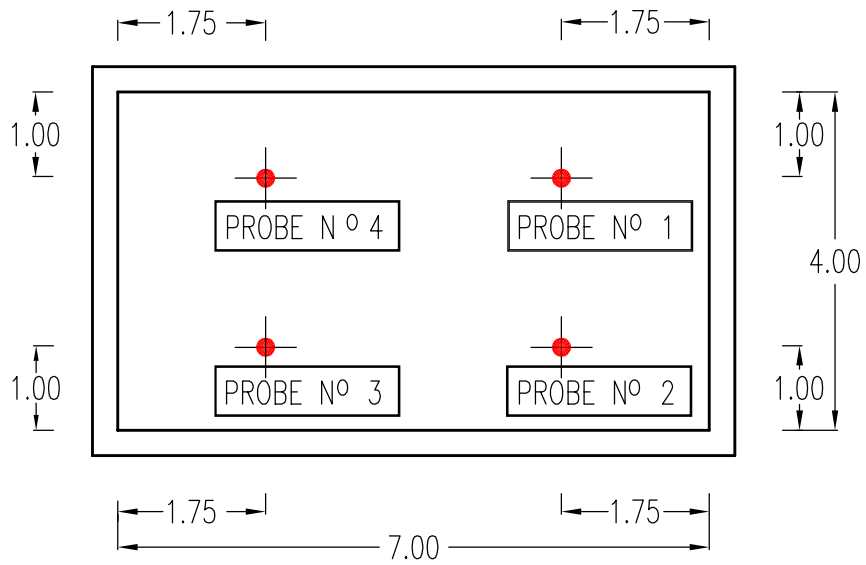
3.1. DEOXYGENATION

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 $\cdot 6\text{H}_2\text{O}$ 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 K_{La} 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. K_{La} 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 20°C, 1 atm) values are then 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 NORTH COAST STW aeration tests included a total of 9 test runs as listed in the following test programme:

Aeration Grid	# Tests	Operating Airflows	Total Airflow, Nm ³ /h	Diff.Submergence,m
ZONE 1	3	3 runs @ 2,68 Nm ³ /h-diff	337,7	5,70
ZONE 2	3	3 runs @ 2,04 Nm ³ /h-diff	142,8	5,70
ZONE3	3	3 runs @ 1,53 Nm ³ /h-diff	84,2	5,70

- Nm³/h is volumetric airflow expressed at 0°C and 1 atm absolute pressure.

5. TEST DATA AND RESULTS

The following tables include basic test conditions and results for the 9 test runs conducted and comparison of result with respect to performance guarantee values. Detailed listing of full test data and conditions, together with individual probe C* and K_{la} values, both in test and standard conditions, for each probe and test run are included in Annex 3.

TABLE A: TEST CONDITIONS AND RESULTS

ZONE	TEST	AIRFLOW,Nm ³ /hr	W. TEMP.,°C	SOTE,%
1	G1R1	340,1	11,3	37,49
1	G1R2	333,3	11,5	38,97
1	G1R3	332,0	11,7	40,61
2	G2R1	141,4	13,1	37,63
2	G2R2	143,3	13,3	38,48
2	G2R3	142,9	13,5	38,32
3	G3R1	84,7	12,6	37,63
3	G3R2	84,4	12,8	38,53
3	G3R3	84,3	12,9	38,27

TABLE B: COMPARISON OF RESULTS WITH PERFORMANCE GUARANTEES

ZONE	Avg. SOTE (%)	Avg. SOTE/m (%/m)	MEASURED Oxygen Transfer (grO2/Nm3·hr)	GUARANTEE Oxygen Transfer (grO2/Nm3·hr)	+/- (%)
1	39,02	6,85	20,48	18,0	+13,7
2	38,14	6,69	20,00	18,0	+11,1
3	38,43	6,74	20,15	16,0	+25,9

As may be observed, performance values observed for all zones show performance values above guarantee values (values between 11,1 and 25% in excess of guarantee performance values).

6. 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 Teflon 9" disc aeration systems representative of the systems to be supplied by Suprafilt Ltd for installation in Zones 1 through 3 of the NORTH COAST STW aeration lanes.

During the series of tests conducted, Standard Oxygen Transfer Efficiency (SOTE,%) has been measured on all three systems when running at the design maximum airflow per diffuser condition with a diffuser submergence of 5,70 metres.

All results obtained in the present series of tests have shown oxygen transfer performances above performances guaranteed by the equipment supplier with excess performances between 11,1 and 25,9% above guaranteed values.

Barcelona, March 19th 2006

The Engineer in Charge of the Testing



Ian Trillo

Asesoría Técnica y Control, S.A.

ANNEX 1

WATER QUALITY

ANNEX N°1: CLEAN WATER CHARACTERÍSTICS

SOURCE: Mina Pública de Terrassa

QUALITY PARAMETERS

<i>PARAMETER</i>	<i>VALUE</i>
pH	7,7
Total Dissolved Solids (mg/l)	750
Conductivity (uS/cm)	1.160
Alcalinity (mg/l)	246
Hardness (mg/l CaCO ₃)	424
Oxydability (mg O ₂ /l)	1,94
Salt Contents (mg/l):	
Fe	< 1
Mn	<1
Cu	<40
Zn	<40

ANNEX 2

TEST CONDITIONS

ZONE 1 TEST CONDITIONS

TEST REF.	G1R1	G1R2	G1R3
DATE	Mar15th	Mar15th	Mar15th
BAROMETER, mbar	993	993	993
WATER DEPTH, m	5,95	5,95	5,95
DIFF. SUBMERGENCE, m	5,70	5,70	5,70
WATER TEMPERATURE, °C	11,3	11,5	11,7
CONDUCTIVITY, µS	2000	2340	2710
VOLUME,m3	166,6		
TARGET AIRFLOW,Nm3/hr	337,7		
DIFF.PRESSURE, mbar	-	-	-
AIRFLOW (flowmeter), m3/hr	264,5	261,5	262,0
LINE TEMPERATURE, °C	64	67	69
LINE PRESSURE, bar	0,615	0,615	0,615
AIRFLOW, Nm3/hr	340,1	333,3	332,0

ZONE 2 TEST CONDITIONS

TEST REF.	G2R1	G2R2	G2R3
DATE	Mar13th	Mar13th	Mar13th
BAROMETER, mbar	999	999	999
WATER DEPTH, m	5,95	5,95	5,95
DIFF. SUBMERGENCE, m	5,70	5,70	5,70
WATER TEMPERATURE, °C	13,1	13,3	13,5
CONDUCTIVITY, µS	1950	2150	2400
VOLUME,m3	166,6		
TARGET AIRFLOW,Nm3/hr	142,8		
DIFF.PRESSURE, mbar	0,65	0,67	0,67
AIRFLOW (flowmeter), m3/hr	-	-	-
LINE TEMPERATURE, °C	57	58	60
LINE PRESSURE, bar	0,61	0,61	0,61
AIRFLOW, Nm3/hr	141,4	143,3	142,9

ZONE 3 TEST CONDITIONS

TEST REF.	G3R1	G3R2	G3R3
DATE	Mar17th	Mar 17th	Mar 17 th
BAROMETER, mbar	1001	1001	1001
WATER DEPTH, m	5,95	5,95	5,95
DIFF. SUBMERGENCE, m	5,70	5,70	5,70
WATER TEMPERATURE, °C	12,6	12,8	12,9
CONDUCTIVITY, µS	2150	2400	2680
VOLUME,m3	166,6		
TARGET AIRFLOW,Nm3/hr	84,2		
DIFF.PRESSURE, mbar	0,23	0,23	0,23
AIRFLOW (flowmeter), m3/hr	-	-	-
LINE TEMPERATURE, °C	51	53	54
LINE PRESSURE, bar	0,60	0,60	0,60
AIRFLOW, Nm3/hr	84,7	84,4	84,3

ANNEX 3

EXPERIMENTAL DATA, DATA ANALYSIS AND REGRESSION CURVES

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

- **NORTH COASTDATA.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 zone (Zone 1 through Zone 3) to which data correspond. Each spreadsheet includes three different data sets named after the corresponding test run (run1, run2, run3).
- **Files GxRy:** For each of the test runs considered, files GxRy include regression curves and fitting residuals for all DO probes, K_{La} 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 G2R1, corresponding to the first run conducted for the aeration grid corresponding to Zone 2.

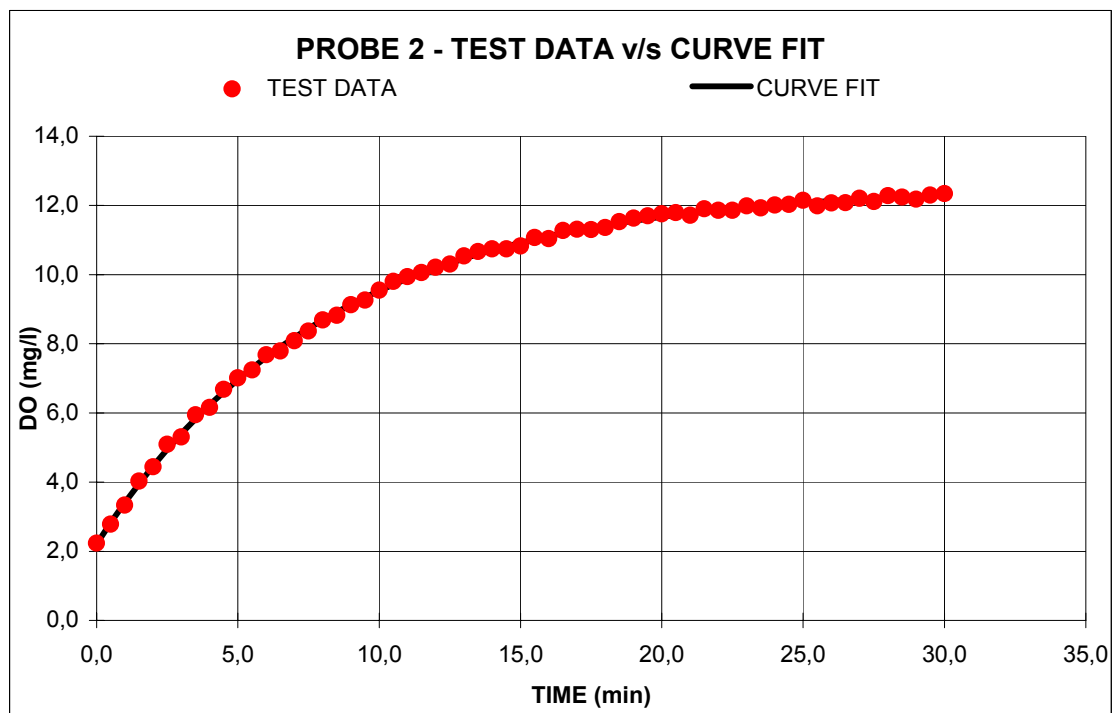
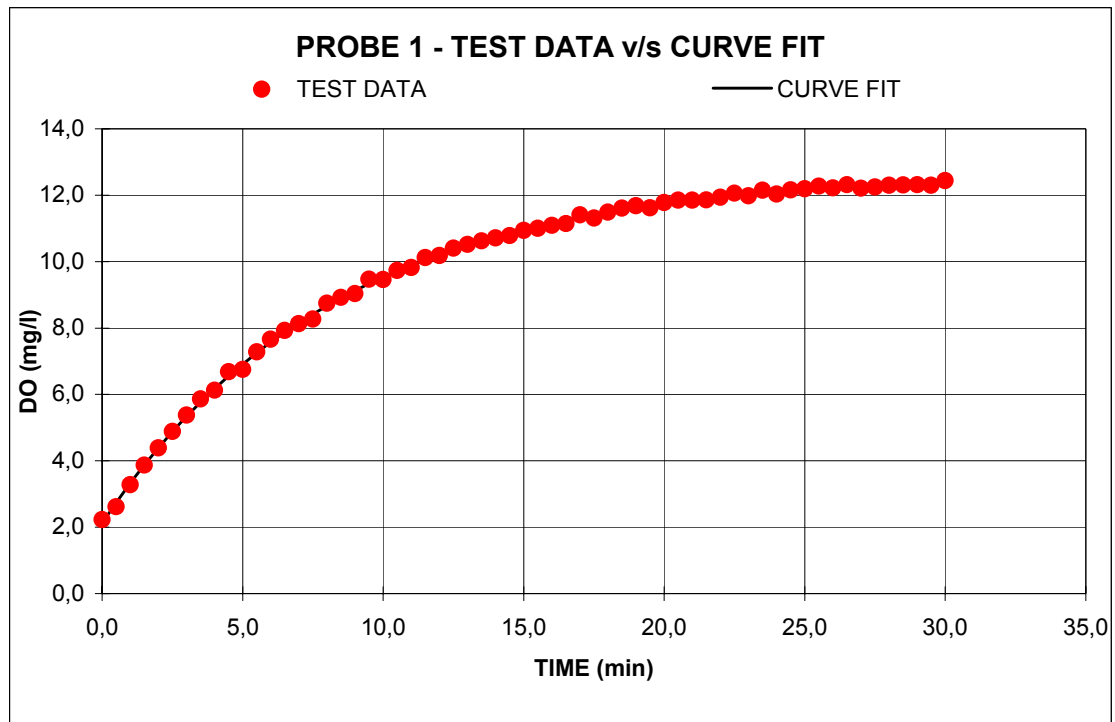
NORTH COAST STW
ZONE
2
RUN
1

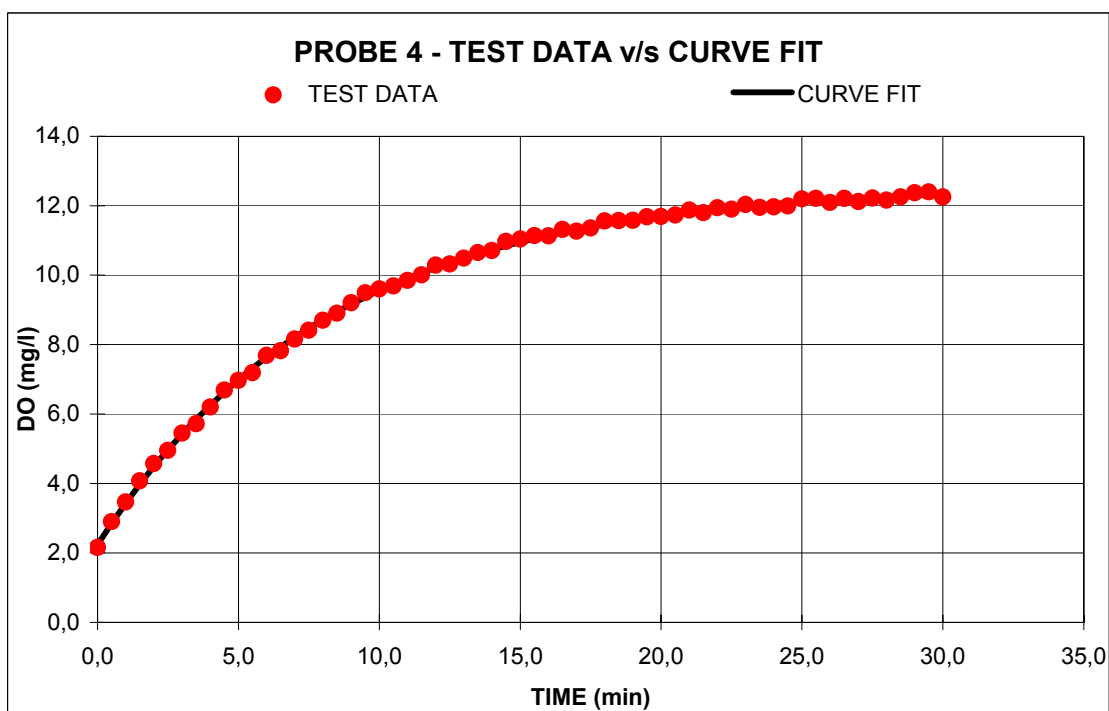
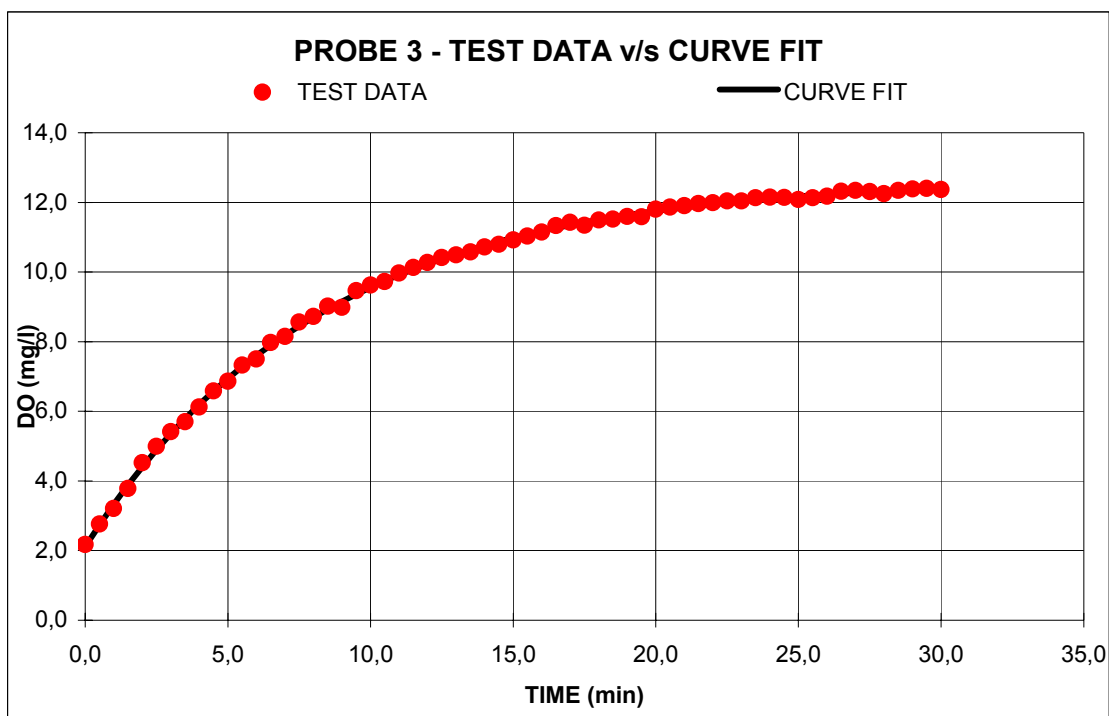
WATER DEPTH 5,95 m
 TANK VOLUME 166,60 m³
 WATER TEMPERATURE 13,1 C
 BAROMETER 999 mbar
 AIRFLOW 141,37 Nm³/h

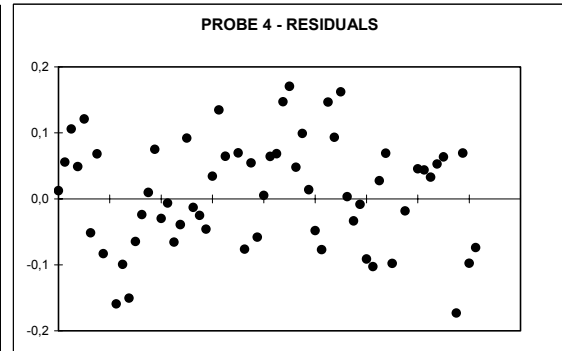
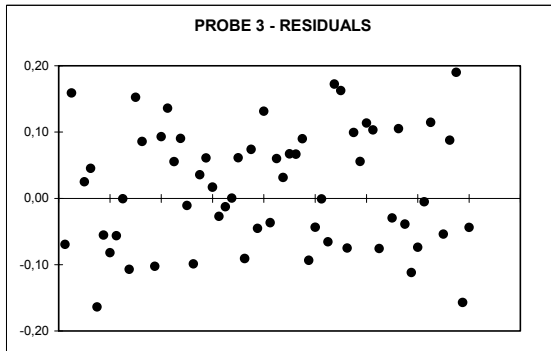
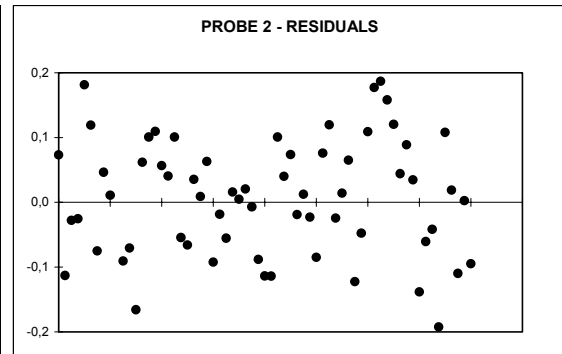
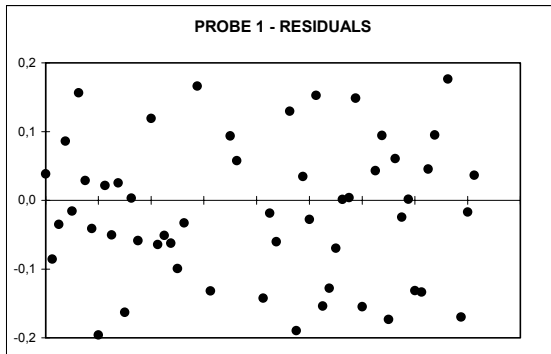
TEST CONDITIONS	KLA	C*	TRUNC.L
PROBE 1	7,27	12,67	16
PROBE 2	7,39	12,55	18
PROBE 3	7,33	12,67	16
PROBE 4	7,37	12,59	16
AVERAGE	7,340	12,620	

STANDARD CONDS.	KLA	C*	KLA·C*
PROBE 1	8,56	11,09	94,87
PROBE 2	8,70	10,98	95,60
PROBE 3	8,64	11,08	95,73
PROBE 4	8,68	11,02	95,65
AVERAGE	8,646	11,042	95,46

OXYGEN TRANSFER RATE
15,90 KGO₂/HR
SOTE
37,63 %







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 on the expression.

$$C = C_{\infty}^* - (C_{\infty}^* - C_0) \exp(-K_{La} \cdot t)$$

where:

C = DO concentration, mL^{-3}

C_{∞}^* = 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_{La} = rate of mass transfer per unit volume / $(C_{\infty}^* - C_0)$

$$m = \text{mass}, L = \text{length}, t = \text{time}, f = \text{force}$$

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_{La} and C_{∞}^* 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_{La} values, the corresponding adjusted determination point C_{∞}^* values, and the tank volume.

$$\text{SOTR (KgO}_2\text{/h)} = \Sigma K_{La_{20i}} \cdot C_{\infty^*_i} \cdot V_i$$

The SOTR value shall be determined by correcting the values of $K_L a$ and C^*_{∞} for each determination point to standard conditions by:

$$K_L a_{20} = K_L a \theta^{(20-T)}$$

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

where:

$K_L a$ = determination point value of apparent mass transfer coefficient

$K_L a_{20}$ = determination point value of $K_L a$ 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^*_{∞} = 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

$$= Q_s \cdot 0,299 \quad (Q_s = \text{airflow rate at normal conditions-0}^\circ\text{C, 1atm))$$

Example:

Following is a calculation example for test G3R3, where estimation of $K_L a$ and C^*_{∞} values in test conditions using non-linear regression of the field data yielded the following values:

PROBE	$K_L a$	C^*_{∞}
1	4,33	12,81
2	4,41	12,76
3	4,52	12,61
4	4,41	12,80

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

$$K_{La20} = K_L a \cdot 1.024^{(20-T)} = 1,183 \cdot K_L a \quad \text{for test temperature of } 12,9^\circ\text{C}$$

$$C^*_{\infty 20} = C^*_{\infty} \left(\frac{1}{\tau \Omega} \right), \quad \tau = \frac{10,561}{9,092} = 1,162$$

$$\Omega = \frac{P_b}{P_s} = \frac{1001}{1013} = 0,988$$

= 0,871 C^*_{∞} for a test water temperature of 12,9 and barometric pressure of 1001 mbar.

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

PROBE	$K_L a$	C^*_{∞}
1	5,12	11,16
2	5,22	11,11
3	5,35	10,98
4	5,22	11,15

and the calculated SOTR (KgO_2/h):

$$\text{SOTR (KgO}_2/\text{h)} = \sum K_L a_{20} \cdot C^*_{\infty 20} \cdot V_i$$

where $V_i = V/4$ for the selected probe location = 41,65 m³

$$\begin{aligned} \text{SOTR (KgO}_2/\text{h)} &= V/4 (5,12 \cdot 11,16 + 5,22 \cdot 11,11 + 5,35 \cdot 10,98 + 5,22 \cdot 11,15) \\ &= 41,65 \text{ m}^3 (232,08 \text{ gO}_2/\text{m}^3 \cdot \text{h}) = 9,67 \text{ kgO}_2/\text{h} \end{aligned}$$

Once SOTR is determined, and knowing the total airflow to the basin is of 84,27 Nm³/h, the calculated SOTE (%) would be:

$$\text{SOTE (\%)} = \frac{9,67 \text{ KgO}_2/\text{h}}{84,27 \text{ Nm}^3/\text{h} \cdot 0,299 \text{ KgO}_2/\text{Nm}^3/\text{h}} \cdot 100 = 38,38\%$$

Differences with respect to data presented in the body of the document (38,27%) 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..

$$Q = Q_{cal} \cdot \sqrt{\frac{T_{cal}}{P_{cal} \cdot \Delta p_{cal}}} \cdot \sqrt{\frac{P_{test} \cdot \Delta p_{test}}{T_{test}}}$$

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)

T_{line} = Line temperature during test (K)

P_{line} = 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:

$$Q (Sm^3/h) = 600 \cdot \sqrt{\frac{(273 + 70)}{1,7 \cdot 10}} \cdot \sqrt{\frac{P_{line} \cdot \Delta p_{line}}{T_{line}}}$$

EXAMPLE:

For test run G2R1, $\Delta p = 0,65$, $T_{line} = 57^\circ C$, $P_{atm} = 999$ and $P_{line} = 0,61$.
Therefore,

$$Q (Sm^3/h) = 600 \cdot \sqrt{\frac{(273 + 70)}{1,7 \cdot 10}} \cdot \sqrt{\frac{1,609 \cdot 0,65}{(273 + 57)}} = 151,72$$

$$\text{And therefore } Q (Nm^3/hr) = Q (Sm^3/hr) \cdot \frac{T_N}{T_S} = 151,72 \cdot \frac{273}{293} = 141,36 \text{ Nm}^3/hr$$