TD 269 OPERATING MANUAL
OXYGEN OPTODE 4330, 4835

AADI AANDERAA
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NOTE! The latest version of the FAQ for the Oxygen Optodes is available on our web site.

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INTRODUCTION

Purpose and Scope

This document is intended to give the reader knowledge of how to operate, calibrate and maintain the Aanderaa Oxygen Optode 4330 and 4835. It also aims to give insight in how the Oxygen Optode works.

Since oxygen is involved in most biological and chemical processes in aquatic environments, it is the single most important parameter needing to be measured. Oxygen can also be used as a tracer in oceanographic studies.

Document Overview

The document starts by giving a short description of the Oxygen Optode 4330 and 4835.

Subsequently, operating instructions, communication with the sensor, and maintenance issues are presented.

The Appendix includes the principle behind the Oxygen Optodes, electronic and mechanical design, calibration procedures, illustrations, and finally a chapter on Frequently Asked Questions.

Applicable Documents

- Form 712 Test & Specification Sheet, Oxygen Optode
- Form 770 Calibration Certificate, O2 Sensing Foil 3853
- Form 710 Calibration Certificate, Oxygen Optode 4330
- Data sheet D378, Oxygen Optode 4330
- Data sheet D385, Oxygen Optode 4835

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Abbreviations

O_2	Oxygen molecule
LED	Light Emitting Diode
ADC	Analogue to Digital Converter
DSP	Digital Signal Processor
EPROM	Erasable Programmable Read Only Memory
ASCII	American Standard Code for Information Interchange
MSB	Most significant bit
UART	Universal Asynchronous Transmitter and Receiver
RTC	Real Time Clock

CHAPTER 1 Short Description and Specifications

The optode is an optical oxygen sensor that does not consume oxygen. The measurement principle is based on fluorescence quenching, while traditional oxygen consuming sensors, often called Clark sensors, are based on electrochemical principles.

Oxygen Optode 4330 is depth rated to 6000m; Oxygen Optode 4835 is depth rated to 300m. Both optodes are digital sensors intended for mounting on AADI SEAGUARD® Instruments. The optodes can also be used as a stand alone sensors e.g. on a glider or a float where the optodes can be connected to a custom data logger via cable.

Oxygen Optode 4330 and 4835 interconnects with both RS232 and CANbus (AiCaP). The optode fits directly onto the top-end plate of the AADI SEAGUARD® instrument, where the optode is automatically detected and recognized.

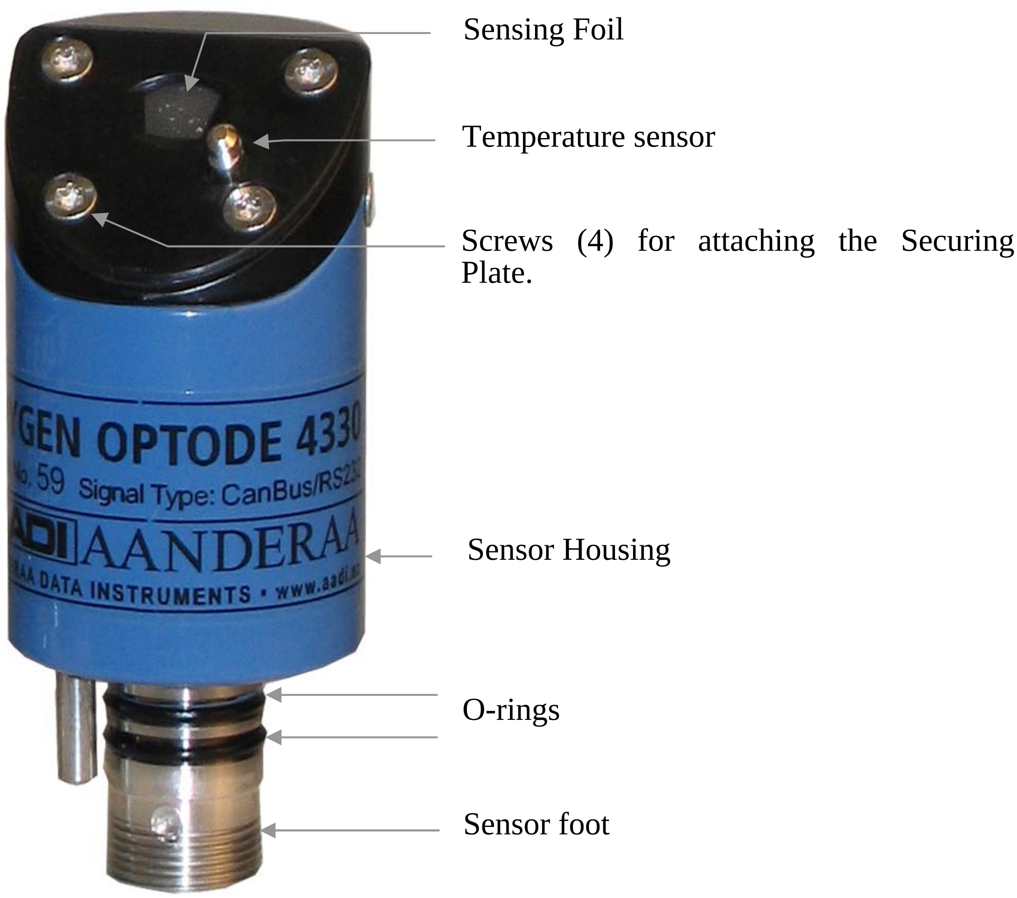


Figure 1-1 Illustration of the Oxygen Optode 4330.

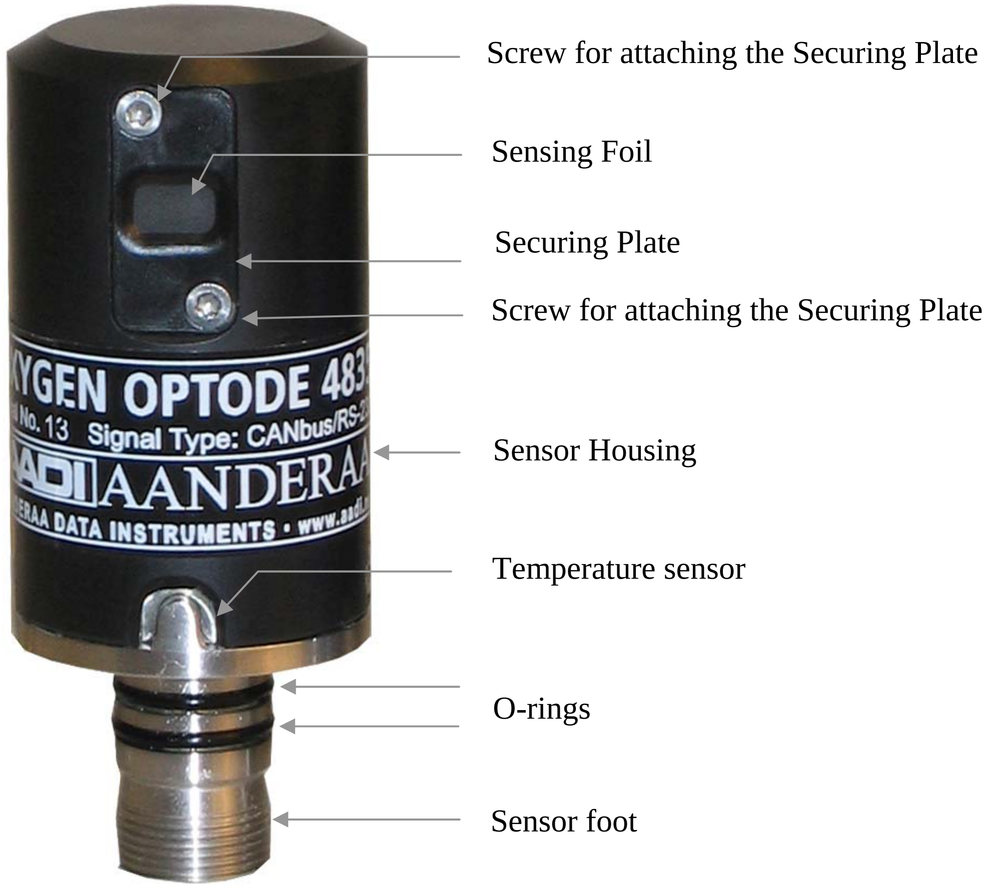


Figure 1-2 Illustration of the Oxygen Optode 4835.

1.1 Pin Configuration

The Oxygen Optode 4330 and 4835 pin configuration is given in Figure 1-3. A description of the receptacle notation is given in Table 1-1.

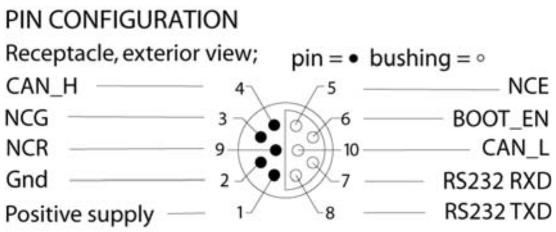


Figure 1-3 Oxygen Optode 4330 and 4835 Pin Configuration.

Table 1-1 Description of the Pin Configuration

Receptacle	Description
CAN_H	CANbus line (dominant high)
NCG	Node Communication Ground
NCR	Node Communication Request
Gnd	Ground
Positive supply	5-14V positive supply
NCE	Node Communication Enable
BOOT_EN	Boot Load Enable (do not connect)
CAN_L	CANbus line (dominant low)
RS232 RXD	RS232 Receive line
RS232 TXD	RS232 Transmit line

1.2 User Accessible Sensor Properties

All settings and configuration that determines the behaviour of the sensor are called properties and are stored in a persistent memory block (flash). One property can contain several data elements of equal type (Boolean, character, integer etc.). The different properties also have different access levels. Table 1-2 lists all user accessible properties for Oxygen Optode 4330 and 4835.

Table 1-2 FA = Factory Configuration, UM = User Maintenance, SC = System Configuration, H = Hidden, DS = Deployment setting.

Property	Type	No of elements	Use	AiCaP Category	Access Protection RS232 applications
Product name	String	31	AADI Product name	FA	Read Only
Product Number	String	6	AADI Product number		
Serial Number	Int	1	Serial Number		
Software Version	Int	3	Software version (Major, Minor, Built)		
Node Description	String	31	User text for describing node, placement etc	SC	No
TempCoef	Float	6	Curve fitting coefficients for the temp measurements.	UM	High
PTC0Coef	Float	4	Raw phase temperature compensation coefficients		
PTC1Coef	Float	4	Raw phase temperature compensation coefficients		

PhaseCoef	Float		Linearization coefficients for calculating compensated phase		
FoilID	String	9	Sensing Foil Identifier		
FoilCoefA	Float	14	Sensing Foil coefficients, set A		
FoilCoefB	Float	14	Sensing Foil coefficients, set B		
FoilPolyDegT	Int	28	Exponents for temperature		
FoilPolyDegO	Int	28	Exponents for oxygen		
NomAirPress	Float	1	Nominal air pressure for use in O2 concentration calculations		
NomAirMix	Float	1	Nominal O2 percentage in air for use in O2 concentration calculations		
Salinity	Float	1	Salinity (PSU) for use in salinity compensation of O2 concentration		
CalDataSat	Float	2	Two point calibration data, raw phase and temperature @ 100% air saturation		
CalDataAPress	Float	1	Two point calibration data, air pressure (hPa)		
CalDataZero	Float	2	Two point calibration data, raw phase and temperature @ 0% air saturation		
Enable RedReference	Bool	1	Controls the use of the red reference LED		
RedReference Interval	Int	1	Sample interval divisor for use of red reference. Examples: Value 1 for using red reference for each sample. Value 10 for using red reference for each 10th sample.		No
Wipe	Int		Reserved for future use	H	High
Interval	Int	1	Sampling Interval in seconds		No
Enable HumidityComp	Bool	1	Enable compensation for vapour pressure, -disable only for use in dry air or external humidity compensation	SC	Low
Enable AirSaturation	Bool	1	Controls inclusion of air saturation(%) in the output		
Enable Temperature	Bool	1	Controls inclusion of Temperature in the output		
Enable Rawdata	Bool	1	Controls inclusion of raw data in the output string		
Enable Text	Bool	1	Controls the insertion of descriptive text, i.e. parameter names	H	
Enable Decimalformat	Bool	1	Controls the use of decimal format in the output string		
Enable Sleep	Bool	1	Enable sleep mode		
SR10 TempLimit	Float	2	Reserved for future use		
Analog Coef	Float	2	Reserved for future use		
Output	Char	1	Selects RS232 or CANbus operation		

			-value 200 enables CANbus -all other values enables RS232		

1.3 Specifications

Refer Datasheet D378 available on our web site www.aanderaa.com or contact info@aadi.no.

You will find the latest versions of our documents on the web.

Customers can register to get a username and password necessary to gain access to e.g. manuals, technical notes and software. Please contact info@aadi.no for guidance.

1.4 Manufacturing and Quality Control

Aanderaa Data Instruments have proven reliability. With over 40 years of producing instruments for the scientific community around the world, you can count on our reputation for designing some of the most reliable products available.

We are guided by three underlying principles: quality, service, and commitment. We take these principles seriously, as they form the foundation upon which we provide lasting value to our customers.

Our quality is based on a relentless program of continuous monitoring to maintain the highest standards of reliability.

CHAPTER 2 Measurement Principles and Parameters

The AADI Oxygen Optode 4330 and 4835 are based on the ability of selected substances to act as dynamic fluorescence quenchers.

The fluorescent indicator is a special platinum porphyrin complex embedded in a gas permeable foil that is exposed to the surrounding water. A black optical isolation coating protects the complex from direct incoming sunlight and fluorescent particles in the water.

The sensing foil is fixed against a sapphire window by a screw mounted securing plate, providing optical access to the measuring system from inside a watertight titanium housing.

The foil is excited by modulated blue light, and the optode measures the phase of a returned red light, ref Appendix 2. By linearizing and temperature compensating, with an incorporated temperature sensor located next to the sensing foil, the absolute O_2- concentration can be determined.

The lifetime-based luminescence quenching principle, as used in AADI Oxygen Optodes, offers the following advantages over electrochemical sensors:

- Not stirring sensitive (it consumes no oxygen).
- Measures absolute oxygen concentrations without repeated calibrations.
- Better long-term stability (stable for at least one year).
- Less affected by pressure.
- Pressure behaviour is predictable and fully reversible.

The optode can be logged directly by a PC (via the RS232 protocol) and by most custom made dataloggers and systems.

The current drain is independent of the battery voltage (due to use of a linear regulator).

2.1 Sensor Integrated Firmware

The sensor integrated firmware's main tasks are to control the transmitter, sample the returned signal, extract the phase of this signal, and convert it into oxygen concentration and/or Air Saturation.

All properties that can be changed for each individual sensor, i.e. calibration coefficients, are called sensor properties. The properties can be displayed and changed using the RS232 port, refer CHAPTER 4 for communication with the sensor using a terminal communication program.

The Oxygen Optode will perform a measurement sample and present the result within the first 1.5 seconds after the optode has been powered up.

2.2 Sensor Parameters

Engineering data are calculated by firmware in the sensor (Sensor Firmware) based on measured raw data and sets of calibration coefficients stored in the sensor:

- The absolute Oxygen content is presented in µM (1 Molar = 1 mole/litre).
- The relative Air Saturation is presented in % relative to the nominal air pressure (1013.25 hPa).
- The ambient Temperature is presented in ºC.

The optode rawdata are the phase and amplitude of the returned signal after the luminophore quenching:

CalPhase(deg):	Calibrated phase
TCPhase(deg):	Temperature compensated phase
C1RPh(deg):	Phase measurement with blue excitation light
C2RPh(deg):	Phase measurement with red excitation light
C1Amp(mV):	Amplitude measurement with blue excitation light
C2Amp(mV):	Amplitude measurement with red excitation light
RawTemp(mV):	Voltage from thermistor bridge.

Calibration coefficients are stored in the sensors flash and are updated when recalibrated.

2.3 Salinity Compensation of Data

The O_2-concentration sensed by the optode is the partial pressure of the dissolved oxygen.

Since the foil is only permeable to gas and not water, the optode can not sense the effect of salt dissolved in the water, hence the optode always measures as if immersed in fresh water.

If the salinity variation on site is minor (less than ±1ppt), the O_2-concentration can be corrected inside the sensor by setting the internal property *Salinity* to the average salinity at the measuring site.

If the salinity varies significantly, you should measure the salinity externally and perform a more accurate correction by a post compensation of the data. An Excel spreadsheet containing the equations for post compensation of the measurements is available for download at the document download site at the Aanderaa Global Library, refer www.aanderaa.no.

If the *Salinity* property in the sensor is set to zero, the compensated O_2-concentration, O_{2c} in μM, is calculated from the following equation:

$$O_{2C} = [O_2] \cdot e^{S\left(B_0 + B_1 T_S + B_2 T_S^2 + B_3 T_S^3\right) + C_0 S^2}$$

where:

O_2 is the measured O_2-concentration

S = measured salinity in ppt

T_s = scaled temperature $= \ln\left[\frac{298.15-t}{273.15+t}\right]$

t = temperature, °C

B_0 = -6.24097e-3 C_0 = -3.11680e-7

B_1 = -6.93498e-3

B_2 = -6.90358e-3

B_3 = -4.29155e-3

If the *Salinity* property in the optode is set to other than zero (zero is the default value), the equation becomes:

$$O_{2C} = [O_2] \cdot e^{(S-S_0)\left(B_0+B_1T_S+B_2T_S^2+B_3T_S^3\right)+C_0(S^2-S_0{}^2)}$$

Where S_0 is the internal salinity setting.

2.4 Depth Compensation of Data

The response of the sensing foil decreases to some extent with the ambient water pressure (3.2% lower response per 1000 m of water depth or dbar –see reference 15 on page 7). This effect is totally and instantly reversible and easy to compensate for.

The depth compensated O_2-concentration, O_{2c}, is calculated from the following equation:

$$O_{2c} = O_2 \cdot \left(1 + \frac{0.032 \cdot d}{1000}\right)$$

where:

d is depth in meters or pressure in dbar.

O_2 is the measured O_2-concentration in either µM or %.

The unit of the compensated O_2 concentration, O_{2c}, depends on the unit of the O_2 input.

NOTE! Depth compensation is not performed within the optode.

Examples of depth compensation:

At normal atmospheric pressure (1013 mbar) the measured O_2 concentration should not be pressure compensated. As the sensor is submerged you must perform pressure compensation of 0.0032% per dbar or for every meter increase of the relative pressure.

The relative pressure = absolute pressure (measured with the optode) – atmospheric pressure (normally set to 1013 mbar).

Example 1: The measured O_2-concentration with the optode is 400 µM. The measurement was performed at 1m depth, which is 1dbar relative pressure.

$O_{2c} = 400 \times 1.000032 = 400.012\ \mu M$

Example 2: The measured O_2-concentration with the optode is 400 µM. The measurement was performed at 1000m depth, which is 1000dbar relative pressure.

$O_{2c} = 400 \times 1.032 = 412.8\ \mu M$

CHAPTER 3 SEAGUARD® Applications

The optode is equipped with a CANbus interface supporting AADI AiCaP (Automated idle line CANbus Protocol). This standard ensures easy plug and play connection to all AADI SEAGUARD® data loggers. Refer chapter 3.1 for installation of the optode on your SEAGUARD® Instrument.

When connected to a CANbus network the optode will report its capabilities and specifications to the data logger at power up. The data logger assembles the information and provides the user with the possibility to configure the instrument based on the present node. The solution provides for great flexibility on both use and design of the different elements within the system.

Note! This chapter describes the System Configuration of the Oxygen Optode 4330 and 4835. Refer TD262a for a thorough description of configuring the SEAGUARD® Instrument, and to perform Node Identification, Deployment settings, and Recorder settings.

3.1 Installation on SEAGUARD® Platform

The Oxygen Optode 4330 and 4835 can easily be installed on AADI SEAGUARD® data loggers. We recommend that you install the Oxygen Optode in sensor position 3, 4 or 6, refer Figure 3-1. If mounted in position 6 use patch cable to connect the optode onto the HUB, refer TD262a SEAGUARD® Platform Operating Manual.

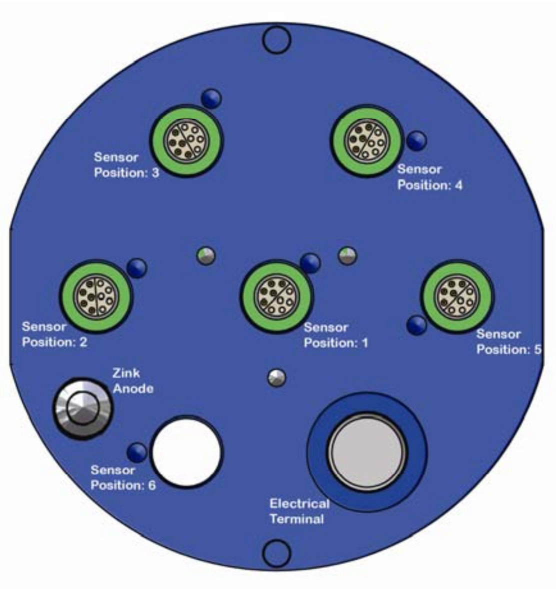


Figure 3-1 Illustration of the SEAGUARD® Top-end plate.

Important!

Refer SEAGUARD® Quick Start, TN 301 or the SEAGUARD® Platform Operating Manual, TD 262a, for an illustrated sensor installation guide.

TN 309 holds an extract of sensor connection/disconnection given in the SEAGUARD® Operating Manual.

Note!

Always replace O-rings when connecting to a sensor or a sealing plug.

Apply Tectyl 506 (included in Maintenance Kit) in the slit between the Sensor and the Top-end plate to prevent crevice corrosion of the Top-end plate.

3.2 Sensor Configuration

Open the *System Configuration* from the *Menu* button. Select the *Oxygen Optode* from the list of sensors, and tap *Configure* in the lower part of the window.

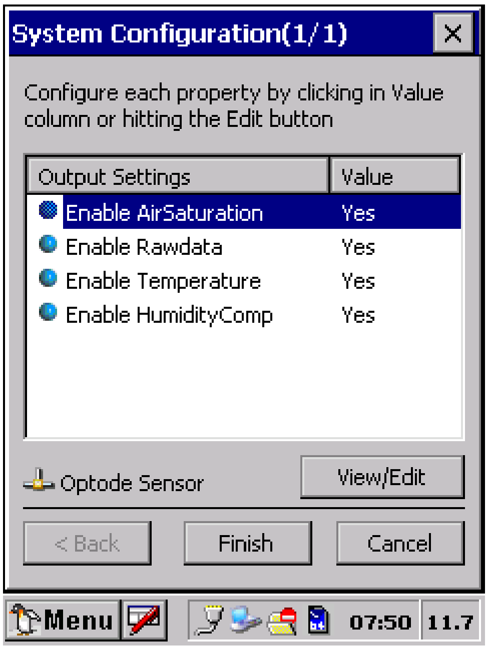


Figure 3-2 System Configuration; Output settings.

The *System Configuration* holds a list of output parameters which can be enabled/disabled by the user, refer Figure 3-2. Enabled properties (*Yes*) are stored in the datalogger:

- Air Saturation in engineering units.
- Raw data, refer chapter 2.2 .
- Temperature in engineering units.

The *Enable HumidityComp* property describes compensation of vapour pressure in the calculations of the output parameters. Enable HumidityComp can be set to *No* if measurements are performed in complete dry conditions or if you like to perform the humidity compensation as a post-processing operation. Measurements in dry conditions are more accurate when the Enable HumidityComp is set to *No*

The absolute oxygen level, µM, is a default parameter and can not be disabled, refer TD262a.

To enable/disable a parameter:

Select the output parameter from the list, press *View/Edit* in the lower part of the window, and change the setting.

We recommend that you enable all parameters in case of later use. The storage capacity is not an issue. Raw data can be used e.g. to control calibration coefficients.

3.3 RedReference, Calibration Coefficients and Salinity Compensation

Special property settings and calibration coefficients are found in user maintenance.

Open the *User Maintenance* from the *Menu* button. Select the *Oxygen Optode* from the list of sensors, and tap *Configure* in the lower part of the window. The user maintenance holds three submenus:

The first contains the Node Description. The second contains the Salinity setting. The third contains the individual *Calibration Coefficients*, and the last submenu holds the *Enable RedReference* property.

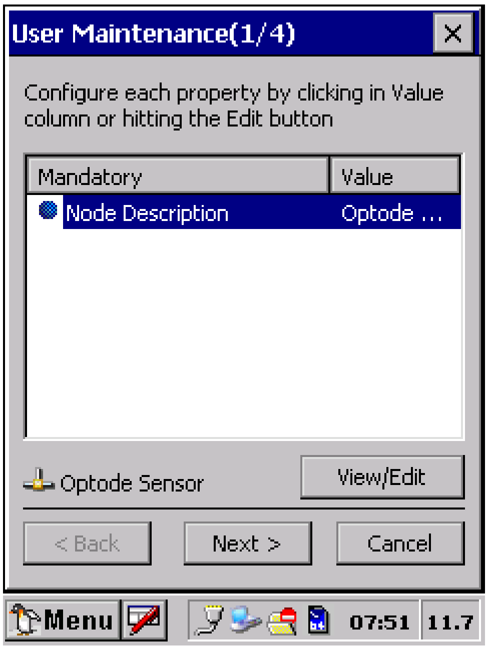


Figure 3-3 Set the Salinity

Select the *Node Description* property, press *View/Edit* in the lower part of the window, and change the setting. Press *Save* to store the setting when completed.

Node Description is a user text describing the sensor, placement etc. The text is by default set to the product name followed by product- and serial number, e.g. *Optode Sensor 4330#52*.

Press *Next* to continue with the next submenu.

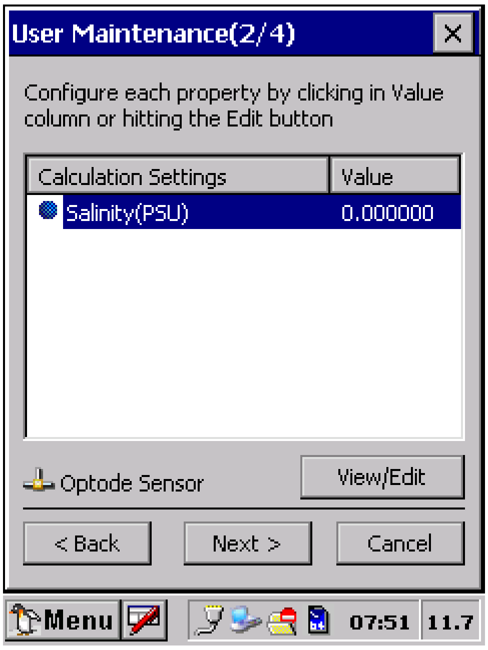


Figure 3-4 Set the Salinity

The second submenu in the Oxygen Optode user maintenance holds a setting for the Salinity:

Select the *Salinity* property, tap *View/Edit* and type the salinity value. Press *Save* to store the setting.

Note! If you are post compensating for the salinity, you should set the property value to 0.

Press *Next* to continue with the next submenu.

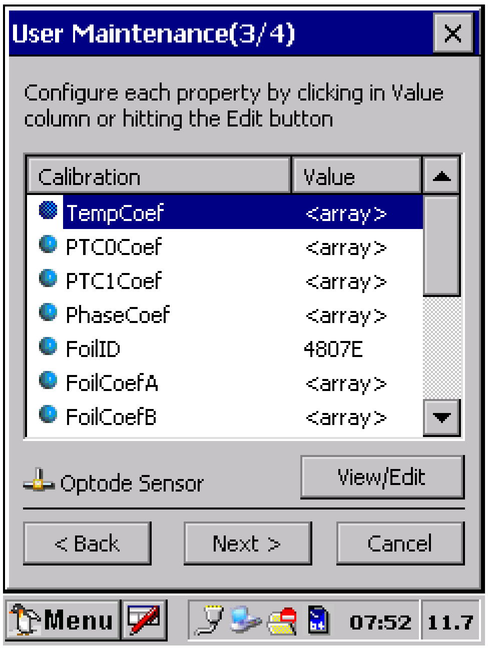


Figure 3-5 Calibration Coefficients

For each calibration property to be set, you must first select the property then press *View/Edit* and type the correct value. Press *Save* to store the settings.

The foil coefficients must be updated when changing the sensing foil.

Press *Next* to continue with the next submenu.

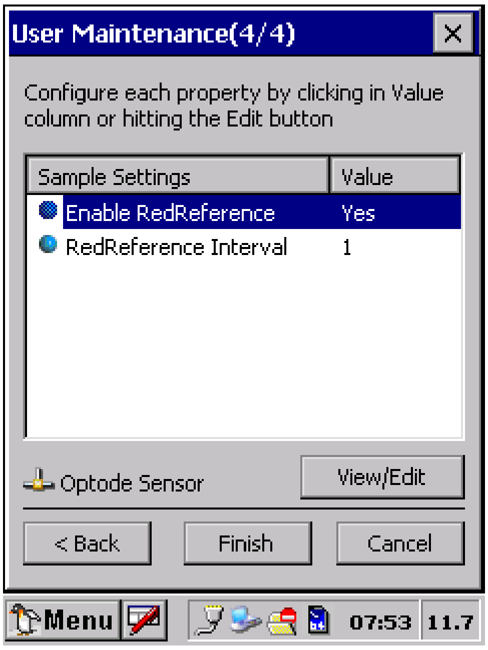


Figure 3-6 Enable RedReference

The last submenu in the Oxygen Optode user maintenance holds settings for:

- Enable RedReference; should normally be enabled (Yes). The phase measurements are then performed with a zero-point set at the red reference (no fluorescence). The property can be set to *No* in special measurement situations; contact AADI service department.

- RedReference Interval; this is a sample interval divisor for use of red reference. When the value is set to 1 (default) the red reference measurement is performed during each sample. The value can be increased to reduce power drain or to set a fast sampling interval, less than 2 sec. When the value is set to e.g. 10, the red reference measurement is only performed for each 10^{th} sample. Avoid setting the RedReference Interval too long compared to temperature changes in the sensor, as the RedReference is used to compensate for temperature drift in the electronics.

Procedure to change the property:

Select the output parameter from the list, press *View/Edit* in the lower part of the window, and change the setting. Press *Save* to store the setting when completed.

Press *Finish* to complete the Oxygen Optode User Maintenance.

CHAPTER 4 Connection to PC

This chapter describes how to connect and communicate with the Oxygen Optode 4330 and 4835 using the RS232 protocol. Sensor configuration is described in chapter 4.9

An optional Sensor Cable 3855 (1.5m), refer Figure 4-1 and Figure 4-2, is used for connection between the optode and the PC in the office/lab.

Either connect the additional USB plug in a USB port for providing power to the sensor (the USB port normally gives 5V power), or connect the USB plug to an included extension of the USB and connect to external power (5-14V), refer Figure 4-1.

A 10m version of this cable, 3855A, is also available. The cable has a stainless steel plug, and can be used in applications that require a directly connection to a PC in RS232 operations.

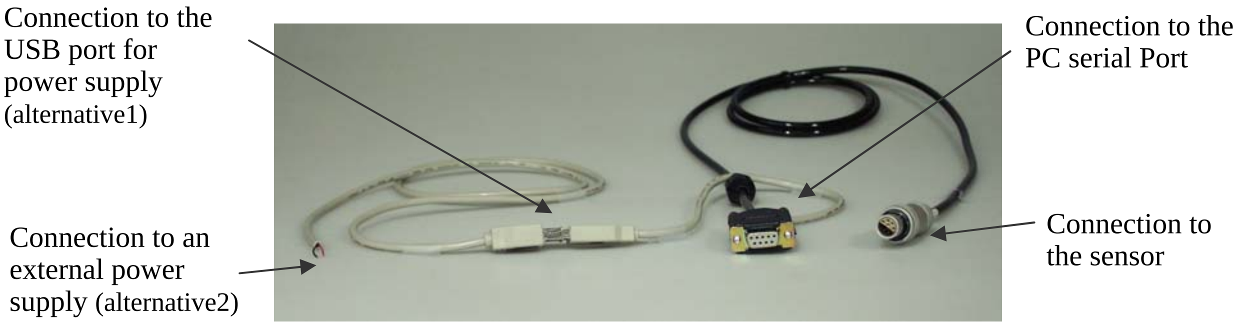
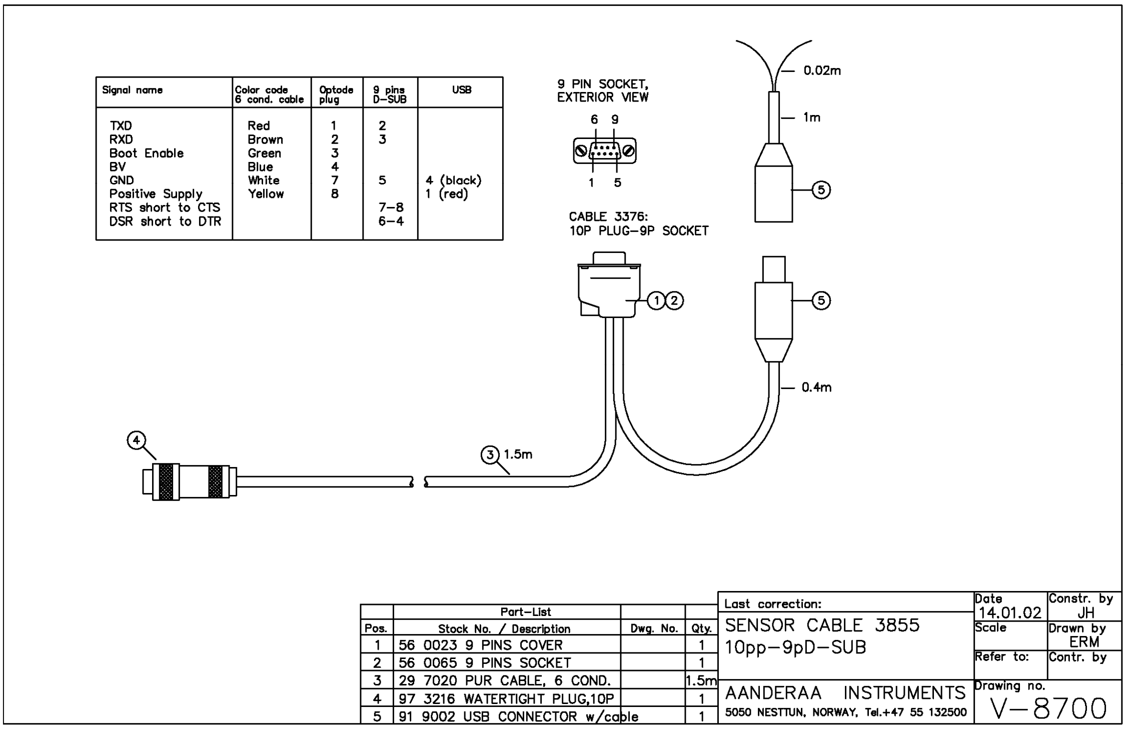


Figure 4-1 Sensor Cable 3855.



Signal name	Color code 6 cond. cable	Optode plug	9 pins D-SUB	USB
TXD	Red	1	2	
RXD	Brown	2	3	
Boot Enable	Green	3		
BV	Blue	4		
GND	White	7	5	4 (black)
Positive Supply	Yellow	8		1 (red)
RTS short to CTS			7-8	
DSR short to DTR			6-4	

Pos.	Part-List Stock No. / Description	Dwg. No.	Qty.
1	56 0023 9 PINS COVER		1
2	56 0065 9 PINS SOCKET		1
3	29 7020 PUR CABLE, 6 COND.		1.5m
4	97 3216 WATERTIGHT PLUG,10P		1
5	91 9002 USB CONNECTOR w/cable		1

Figure 4-2 Drawing of Sensor Cable 3855.

4.1 RS232 Communication Setup

Most terminal programs can be used for RS232 communication with the sensor when connected to a PC, e.g. HyperTerminal*) by Hilgraeve Inc (included in Microsoft's operating systems).

The following RS232 setup should be used:

9600 Baud

8 Data bits

1 Stop bit

No Parity

Xon/Xoff Flow Control

**) Note! The options "Send line ends with line feeds" and "Echo line ends with line feeds" in the HyperTerminal ASCII setup must be selected.*

When connected, you will get measurement data according to the measurement interval, refer chapter 4.9 If the measurement interval is set to zero, you can type the command *Do Sample* to generate a single sample of measurement data, or type *Reset* to get the operation mode and a single set of measurement data.

4.2 RS232 Operation

When used in RS232 mode the sensor will always start by doing a sample. If the output is enabled this data will be presented within 2 seconds from powering the sensor.

In order to minimize the current consumption the sensor normally enters a power down mode after each sampling; the sensor can be awakened by any characters on the RS232 input, and will stay awake for approximately 1 minute after receiving the last character.

4.3 RS232 Protocol

All inputs to the sensor are given as commands with the following format:

- *MainCmd SubCmd* or *MainCmd Property(Value.., Value)*

Description of ASCII coded communication rules:

- The main command, *MainCmd*, is followed by an optional subcommand (*SubCmd*) or sensor property (*Property*).
- The *MainCmd* and the *SubCmd*/*Property* must be separated with the space ' ' character.
- When entering new settings the *Property* is followed by a parentheses containing comma-separated values.

- The command string must be terminated by a Line Feed character (ASCII code 10). Termination with Carriage Return followed by Line Feed is also allowed.
- The command string is not case sensitive (UPPER/lower-case).
- A valid command string is acknowledged with the character '#' while character '*' indicates an error. Both are followed by Carriage Return/ Line Feed (CRLF).
- For most errors a short error message is also given subsequent to the error indicator.
- There are also special commands with short names and dedicated tasks, as *save*, *reset*, and *help*.
- All names and numbers are separated by tabulator spacing (ASCII code 9).
- The string is terminated by Carriage Return and Line Feed (ASCII code 13 & 10).

NOTE!

Losing power during the flashing process can cause corruption of vital settings, such as coefficients, serial number, model number etc. If losing power, contact AADI Service department for new setting file for the specific optode with further instructions.

4.4 Passkey for Write Protection

To avoid accidental change, most of the properties are write-protected. There are five levels of access protection, refer Table 4-1.

A special property called *Passkey* must be set according to the protection level before changing the value of properties that are write-protected, refer Table 1-2.

The *Passkey* property always returns to zero after power up or execution of the *Load* or *Save* command.

Table 4-1 Access protection levels

Output	Passkey	Description
No		No Passkey needed for changing property
Low	1	The Passkey must be set to 1 prior to changing property
High	1000	The Passkey must be set to 1000 prior to changing property This Passkey value also give read access to factory properties that usually are hidden
Read Only		The user have only read access, no passkey needed
Factory Write	XXXX	Sensor specific code for factory level access

4.5 Save and Reset

When the required properties are set, you must send a *Save* command to make sure that the new configuration are saved internally in the flash memory. The Oxygen Optode always reads the configuration from the internal flash memory after reset and power up.

You should normally send a *Reset* command when a new configuration has been saved (or switch the power OFF and then back ON). This forces the optode to start up with the new configuration input. If the *Enable Sleep* property is set to *Yes*, the sensor enters sleep mode after reset.

At start up/reset the sensor always presents the operation mode and a set of measurement data, refer Figure 4-3.

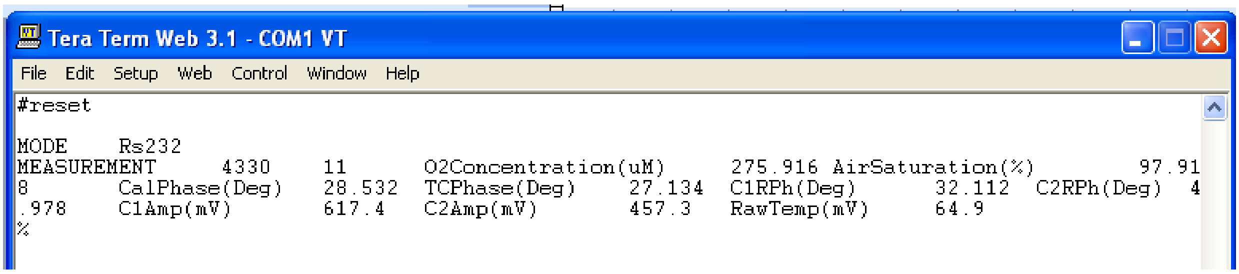


Figure 4-3 Sensor start up/reset.

If the *Save* command is executed the new setting will be stored in the internal Flash memory.

4.6 Sleep Mode

After approximately 60 second without any RS232 input the Oxygen Optode will enter a sleep mode. The character '%' indicates sleep mode, refer last line in the screen dump presented in Figure 4-3.

In this mode the electronics requires approximately 30 ms start up time.

Any character will cause the electronics to return to normal operation; when the sensor has responded with the character '#', new commands may be entered.

The sleep indicator '%' and the wake up indicator '#' are not followed by Carriage Return and Line Feed.

4.7 Available Commands for the Oxygen Optode

Available commands and properties for the Oxygen Optode are given in Table 4-2 and Table 1-2 respectively.

Table 4-2 Main RS232 commands available for the Oxygen Optode.

Command	Description
Do Sample	Execute an oxygen measurement and presents the result
Do Start	Start a measurement sequence according to current configuration
Do Stop	Stop a measurement sequence
Do CollectCalDataSat	Collect and save calibration data for 100% saturation
Do CollectCalDataZero	Collect and save calibration data for 0% saturation
Do Calibrate	Execute a two point internal calibration function
Do ReportPower	Reports power requirements. Io=Quiescent current consumption(mA) Im=average current consumption when sampling at 1 Hz(mA) Umin=minimum supply voltage(mV) Ip=peek current drain(mA)
Do Test	Internal use
Do AdjustGain	Optimize internal amplification to foil type, only used when changing between standard foil and fast response foil. Refer chapter 5.1 .
Get *ConfigXML*	Outputs info on available properties on XML format
Get *DataXML*	Outputs info on available(enabled) parameters on XML format
Get *Property*	Output Property value (refer Table 1-2)
Get All	Output all property values
Set *Property(Value,.. Value)*	Set Property to Value,… Value
Set *Passkey(Value)*	Set passkey to change access level
Save	Store current settings
Load	Reloads previous stored settings
Reset	Resets the sensor with new configuration
Help	Print help information
;	Comment string, following characters are ignored
//	Comment string, following characters are ignored

4.7.1 The Get Command

The *Get* command is used for reading the value/values of a property and for reading the latest value of a parameter.

The command name *Get* followed by a *Property* returns a string on following format:

Property ProductNo SerialNo Value, ..Value

The string starts with the name of the property, the product number and serial number of the sensor, and finally the value of the property, refer example in Figure 4-4.

The command name *Get* followed by a parameter returns the name and unit of the parameter, the product and serial number of the sensor, and finally the latest parameter reading, refer example in Figure 4-4.

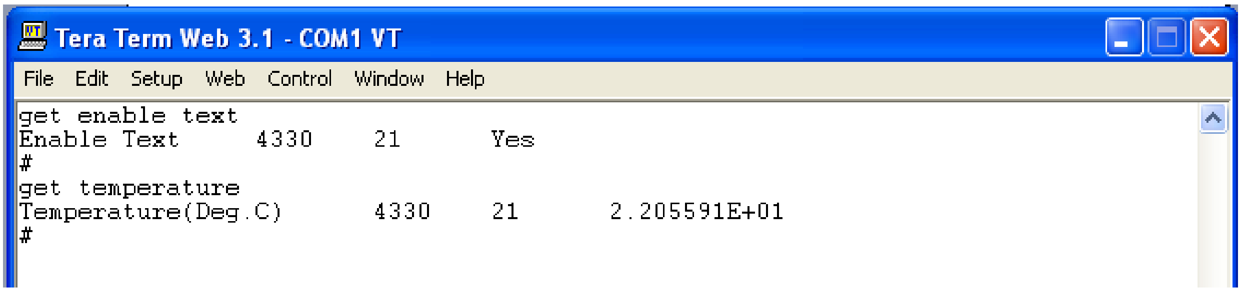


Figure 4-4 Examples of the Get command.

A special version, *Get All*, reads out all available properties in the sensor.

4.7.2 The Set Command

The *Set* command is used for changing a property. Type the corresponding *Get* command to verify the new setting, refer example in Figure 4-5.

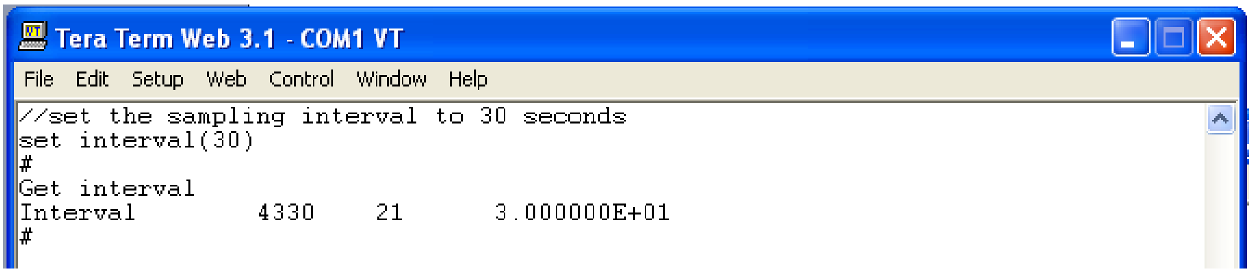


Figure 4-5 Example of the Set command.

Use the *Save* command to permanently store the new property value. Some properties will require a *Reset* before the change is executed.

4.7.3 Formatting the Output String

The property called *Enable Text* controls the presentation of measured data. When the property is set to *Yes* the output string includes the descriptive parameter name. When the property is set to *No*, the output parameters are presented without descriptive parameter names; the parameter order is the same, refer Figure 4-6 for an example.

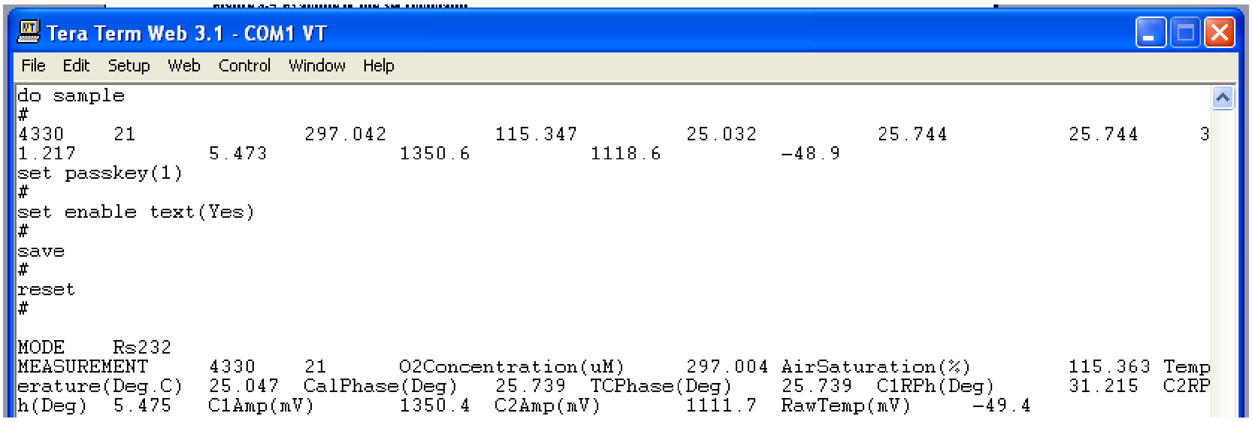


Figure 4-6 Example of output string: enable/disable text.

The *Enable Text* setting requires that the *Save* and *Reset* commands are executed before the sensor will start using the new setting.

The property called *Enable DecimalFormat* controls the format of the output values, either as decimal numbers (*Yes*), or in exponential format (*No*). Refer Figure 4-7 for an example.

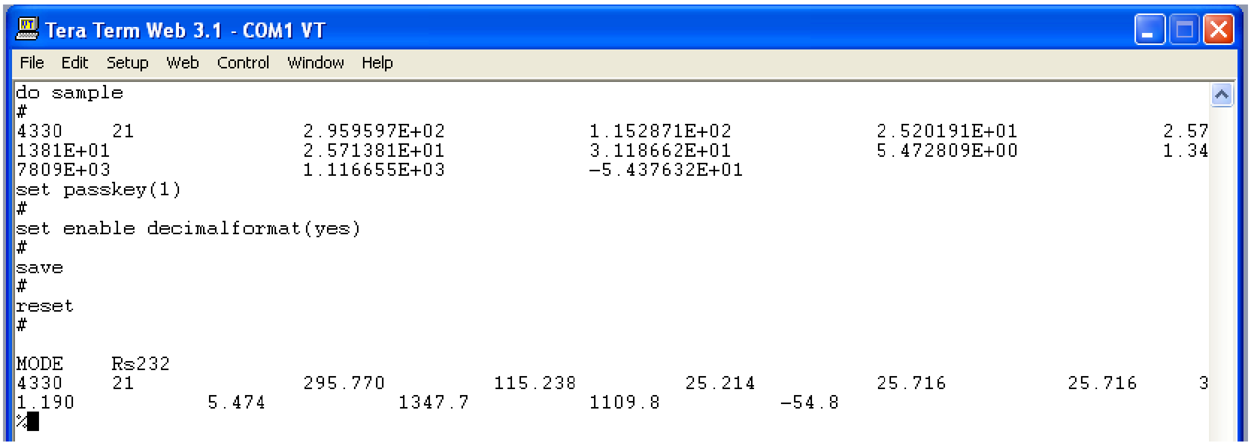


Figure 4-7 Example of output string: decimal/exponential format.

The *Enable DecimalFormat* setting requires that the *Save* and *Reset* commands are executed before the sensor will start using the new setting. The property setting affects the presentation of measured values in the output string, not in the sensors response to the *Get* command (which is always in exponential format).

4.7.4 XML Commands

Get *ConfigXML* presents the configuration of all the sensor properties in XML format.

Get *DataXML* presents all of the enabled parameters in XML format.

4.8 Scripting -sending a string of commands

Often it may be usefully to collect more than one command in a text file. For example the instructions below can be written in an ordinary text editor and saved as a text file, which can be sent to the sensor. In the HyperTerminal click *send text file* in the *Transfer* menu, and select the correct file.

Example of text file:

// Set sampling interval to 30 seconds

Set Passkey(1)

Set Interval(30)

Save

Get All

NOTE! The last line, Get All, reads out available properties for the sensor.

The first line is a comment line that is disregarded by the sensor. Strings starting with either '//' or ';' are ignored by the software, and do not produce errors or acknowledgements.

When sending text file the sensor can be awakened from sleep mode by sending a string of comment leads characters:

//

//

// Wake up test

Get All

This will provide time for the optode to wake up and be ready before the next string appears.

4.9 Sensor Configuration

The sensor configuration consists of sensor settings and customized presentation of data. Refer Table 1-2 for a list of all sensor properties and the input format; below follows a description of the properties that are typically set by the user prior to a deployment (RS232 application). Description of properties regarding the sensing foil and calibration are given in CHAPTER 5 .

The *Output* property is used to select between CANbus and RS232 operation. Set the output property to 200 to enable CANbus operation. Any other value enables RS232 operation.

Set the *Enable AirSaturation*, *Enable Temperature*, and *Enable Rawdata* to *Yes* to include these parameters in the output string.

Set the *Enable Text* to *Yes* for the optode to output a detailed text string with the measurements, or *No* to output the measured values without the descriptive text.

Set the *Enable Decimalformat* to *Yes* to output the measured values in decimal format. Set the property to *No* to output the values in exponential format (higher resolution in the output parameter value).

The *Interval* property describes the measurement interval in seconds; the optode provides a set of measured data for every measurement interval.

The *Salinity* property is set to 0 at the factory and the measurements must be post processed to compensate for the salinity variations at the measurement site. If the salinity is known at the site, you can set the Salinity property according to the known value and the measurements will be salinity compensated inside the sensor before presentation (useful for Real-Time measurements).

The *Enable HumidityComp* property describes compensation of vapour pressure in the calculations of the output parameters. Enable HumidityComp can be set to *No* if measurements are performed in complete dry conditions or if you like to perform the humidity compensation as a post-processing operation. Measurements in dry conditions are more accurate when the Enable HumidityComp is set to *No*. The property is set to *Yes* at the factory.

When *Enable Redreference* is set to *Yes*, the phase measurements are performed with a zero-point set at the red reference (no fluorescence). The property can be set to *No* in special measurement situations; contact AADI service department. Enable Redreference is set to *Yes* at the factory before calibration; if the property is set to *No* the optode must be recalibrated.

Set the *Enable Sleep* to *Yes* for the optode to go to sleep between recordings, or *No* for the optode to stay continuously switched *on* between recordings (drains more power).

The properties *Wipe*, *SR10 TempLimit*, *Analog Coef* are reserved for future use, and will be described when utilized in the sensor.

CHAPTER 5 Maintenance

The Oxygen Optode requires very little maintenance.

When the membranes on traditional oxygen consuming sensors (based on electrochemical principles), often called Clark sensors, are fouled the water mixing in front of the sensor membrane becomes poorer, which influences the measurement directly.

Since the optode consumes no oxygen, the ability to diffuse gas has no influence on the measurement accuracy.

However, if the fouling is in the form of algae that produce or consume oxygen, the measurement might not reflect the oxygen concentration in the surrounding water correctly.

Also the response time of the measurements might increase if the sensing foil is heavily fouled.

Therefore, the sensor should be cleaned at regular intervals from 1 month to a year depending on the required accuracy and the fouling condition at the site.

The optode housing can be cleaned using a brush and clean water. Carefully, use a wet cloth to clean the sensing foil.

Fouling consisting of calcareous organisms (e.g. barnacles), can be dissolved by dipping the sensor/instrument in a weak acid solution (e.g. 7% Vinegar).

Figure 5-1 Example of fouling on an RCM 9 Mk II with an Oxygen Optode 3830 (optode version with SR-10 output) mounted to it: The optode was still giving correct readings.

If the sensing foil is scratched or if the protective black layer on the foil is removed the sensor will still work as long as there is enough Fluorophore on the foil.

If severely damaged (so that the sensor gives unrealistic readings) the sensing foil must be replaced (Sensing Foil Kit 4733/4794) and the sensor recalibrated.

NOTE! Enter new calibration coefficients when changing the sensor foil.

Due to the measurement technology, the optodes do not drift over time (within the given specifications).

It is recommended that the sensor is recalibrated annually (refer next section), although feedback tells us that the sensors are stable over a longer time period.

AADI Service department can perform a cost-effective performance check and recalibration. Please fill out our Service Order Form, form no. 135, for this purpose (refer Services page at www.aadi.no).

5.1 Changing the Sensor Foil

If the sensor foil gets damaged it can easily be changed. For the 4330 model it is possible to change between the standard foil and fast response foil. The *Sensor Foil Kit 4733* for optode 4330 and 4835 contains 2 standard foils while *Sensor Foil Kit 4794* for optode 4330 contains 2 fast response foils.

The content of Kit 4733/4794 is given in Table 5-1, and a procedure for changing the foil is given below the table.

NOTE! If you use a foil from a different batch, new foil coefficients must be entered.

Table 5-1 Contents of Sensor Foil Kit 4733/4794

Part no.	Pieces	Description	Foil Kit 4733	Foil Kit 4794
1206005C	2	Standard Sensing Foil packed in aluminium foil	X	
1206006	2	Fast Response Sensing Foil packed in aluminium foil		X
1913032	1	Torx key no. T10	X	X
1642223	2	M3 x 6mm screw torx a4 Din 965a (4330)	X	X
1642222	2	M2.5 x 6mm screw torx a4 Din 965a (4835)	X	X
Form No. 721	Calibration Sheet for Sensing Foil (each batch of foils is calibrated)		X	X

5.1.1 Procedure for Oxygen Optode 4330

Procedure for changing the sensor foil using kit 4733 or 4794:

- The sensor foil is changed by unscrewing the 4 torx screws in the securing plate, refer Figure 5-2. Remove the securing plate and the old foil.
  - o If the removed foil will be used in the future it should be packed in a light tight package marked with the foil type and batch number.

Figure 5-2 Removing the securing plate and change the sensing foil.

- Clean the window and centre the new foil to fit the optical window. It is important that the standard foil is mounted with the black side out, and the fast response foil with the *non-glossy* side out.
- Remount the securing plate.
- The optical signal levels of the fast response foil are quite different from the standard foil. If changing from a standard foil to a fast response foil or vice versa, the internal amplification should be optimized to the new foil. This is done by executing the command *Do AdjustGain* (refer Figure 5-3). This should be done at room-temperature in air or saturated water. Ensure that the sensor is connected until the new amplification settings are stored.
- Control and if necessary update the sensing foil coefficients according to the foil certificate, refer chapter 5.3 .
- Recalibrate the sensor, refer chapter 5.3.

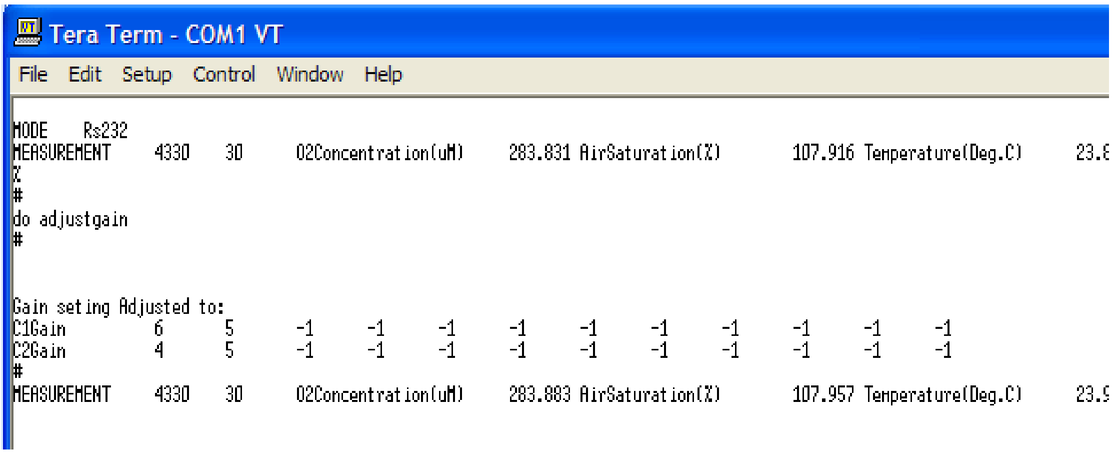


Figure 5-3 Adjust Gain.

5.1.2 Procedure for Oxygen Optode 4835

Procedure for changing the sensor foil using kit 4733:

- The sensor foil is changed by unscrewing the 2 torx screws in the securing plate, refer Figure 5-2. Remove the securing plate and the old foil.
  - o If the removed foil will be used in the future it should be packed in a light tight package marked with the foil type and batch number.
- Clean the window and centre the new foil to fit the optical window. It is important that the standard foil is mounted with the black side out.
- Remount the securing plate.
- Control and if necessary update the sensing foil coefficients according to the foil certificate, refer chapter 5.3 .
- Recalibrate the sensor, refer chapter 5.3.

Figure 5-4 Removing the securing plate and change the sensing foil.

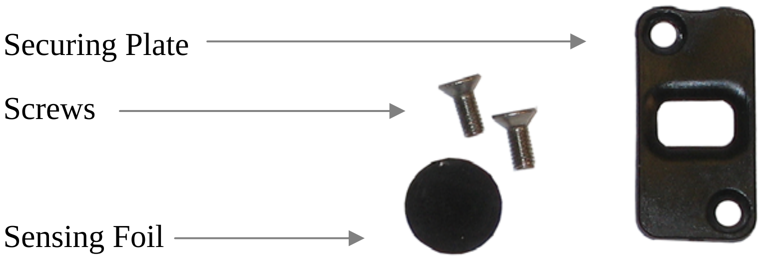


Figure 5-5 Illustration of parts, Optode 4835

5.2 Function Test

We recommend that you perform a function test of the sensor operating in air to verify the sensor readings. Refer chapter 5.2.1 and chapter 5.2.2 for a description of the function test procedure.

The oxygen saturation is approximately 100% in air (@1013 hPa the reading depends on the ambient pressure.

The saturation will be significantly lower when you breathe near the sensing foil.

The measured temperature should be according to the ambient temperature.

5.2.1 SEAGUARD® Applications

Leave the Oxygen Optode 4330/4835 mounted onto the SEAGUARD® Platform. Power the instrument; refer TD262a and TD262b for operating instructions.

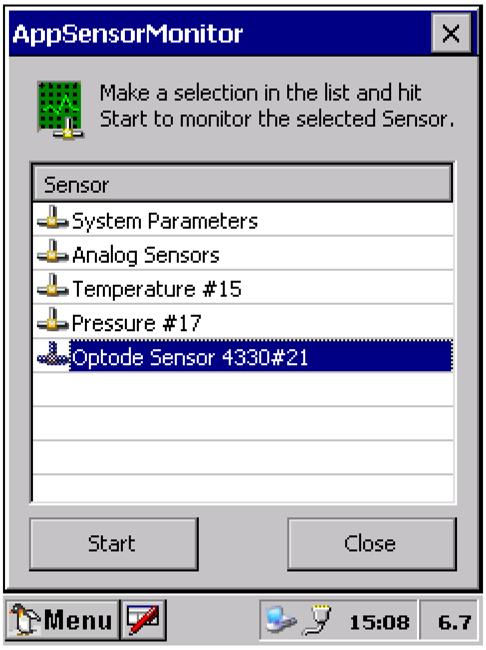


Figure 5-6 Select sensors to monitor

Open *Administrative Tools-> Sensor Monitor.*

Sensor Monitor can be used as a direct reading of the sensor; the function is mainly used for test purposes.

Select the optode from the list and press *Start*, refer Figure 5-6.

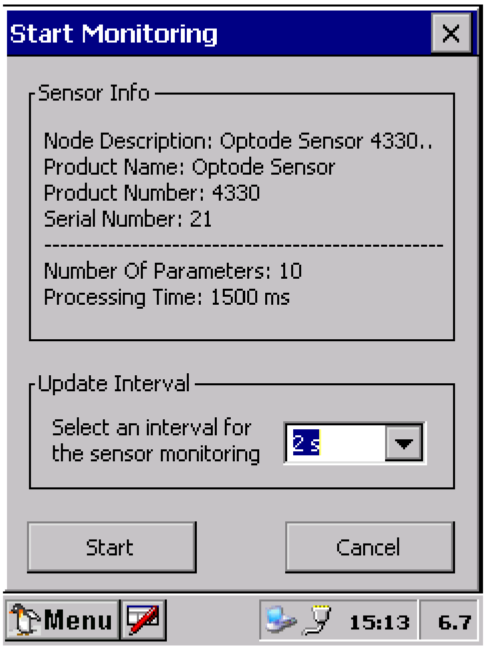


Figure 5-7 Set the Update Interval

The next window shows sensor information like the Node Description, Product name and number, and Serial number, refer Figure 5-7.

The number of sensor parameters and the processing time can be viewed in the window.

Select an *Update Interval* for the sensor monitoring. Press *Start* to start monitoring the sensor readings.

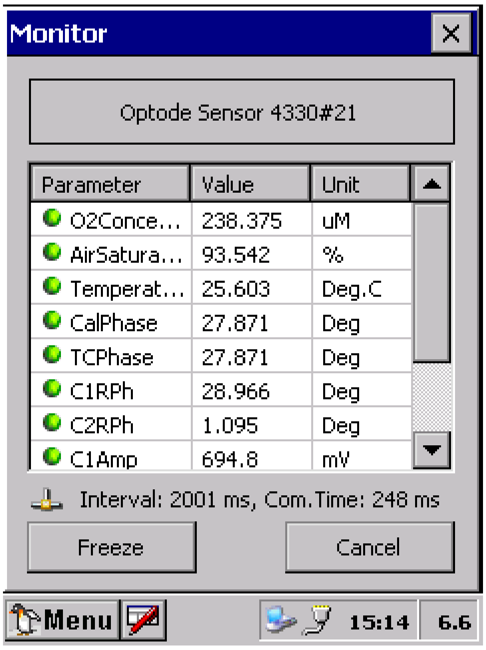


Figure 5-8 Monitor Sensor Readings

The parameter reading in engineering units is shown as illustrated in Figure 5-8. The reading updates according to the update interval.

Press *Freeze* to temporarily stop the update; press *Start* to restart monitoring (Start is the same button as Freeze).

Press *Cancel* to stop monitoring.

The sensor readings should be according to the description in chapter 5.2 .

5.2.2 RS232 Applications

Connect the Oxygen Optode to your PC using e.g. sensor cable 3855 (refer Figure 4-1). Set the sensor in RS232 mode (Set the output property to 200). Refer CHAPTER 4 for RS232 communication with the sensor.

Test procedure:

1. Connect power to the sensor.
2. Wake up the sensor by typing any character. The sensor outputs a '#' when waken up, refer last line in Figure 5-9.
3. type: *do sample*. The sensor presents its output for a function test, refer Figure 5-9.

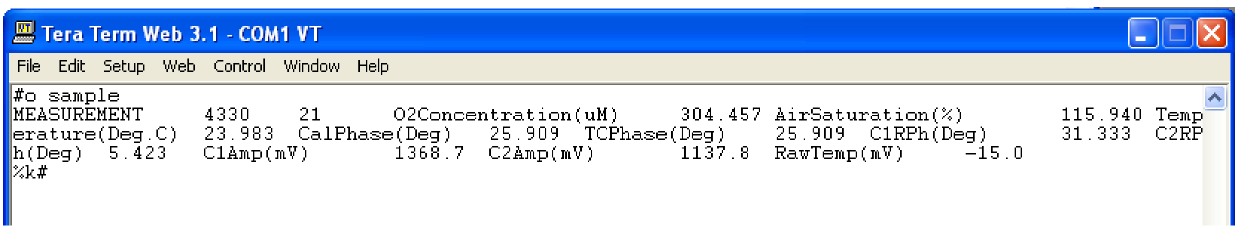


Figure 5-9 Function test of the Oxygen Optode 4330.

The output parameters are presented in one line terminated with CR+LF (the line is broken by the terminal program in the above example).

The sensor readings should be according to the description in page 33.

5.3 Calibration

If the sensor foil has not been removed or changed recalibration is normally not necessary. Feedback from our users shows that the sensors (and foils) are stable for one to several years.

Each batch of sensing foils is delivered with calibration data describing the behaviour with respect to oxygen concentration and temperature. When changing the sensing foil the following 28 coefficients must be updated:

$FoilCoeffA_{0\text{-}13}$

$FoilCoeffB_{0\text{-}13}$

These coefficients are found in the Calibration Certificate for the Sensing Foil 3733/4793, refer enclosed documentation. Refer chapter 5.3.1 for changing foil coefficients.

In addition to the above mentioned coefficient update a two point calibration must be done. This calibration compensates for individual sensor and foil variations.

Two controlled oxygen concentrations are relatively easy to obtain, one in air saturated water, and one in a zero-oxygen solution.

An air-saturated solution is obtained by inserting freshwater in a glass and bubble it with a standard aquarium pump. For a more efficient bubbling it is recommended to use a bubble dispenser. The water should be allowed to achieve temperature stability for at least 1 hour. We recommend the zero oxygen solution to be obtained by preparing another glass of the same water (as for air saturation) and dissolving 5g of sodium sulphite (Na_2SO_3) in 500ml water.

NOTE!

Losing power during the flashing process can cause corruption of vital settings, such as coefficients, serial number, model number etc. If losing power, contact Aanderaa Data Instruments for new setting file for the specific optode with further instructions.

Flashing is carried out when running the Do CollectCalDataSat, Do CollectCalDataZero, Do Calibrate and save commands.

5.3.1 Calibration Procedure using a Terminal Program

1. Prepare a suitable container with fresh water. Aerate (apply bubbling) the water using an ordinary aquarium pump together with an airstone, and let the temperature stabilize (might take hours).

2. Prepare a zero oxygen solution by dissolving 5 grams of sodium sulfite (Na2SO3) in 500 ml of water. Other substances that remove oxygen can also be used.

NOTE! Stripping of the oxygen with e.g. N2 gas is also possible, but not recommended, since it is uncertain when an absolute zero oxygen level is reached using this method.

3. Connect the sensor to a PC by use of the Sensor Cable 3855 (**Error! Reference source not found.**).

   Start a terminal program, i.e. the HyperTerminal by Hilgraeve Inc (included in Microsoft operating systems), with the following set-up:

   9600 Baud

   8 Data bits

   1 Stop bit

   No Parity

   Xon/Xoff Flow Control

NOTE! Select one of the options 'Sent line ends with line feeds' or 'Echo line ends with line feeds' in the Hyper Terminal.

Control, and if necessary update, the *FoilID*, *FoilCoefA*, *FoilCoefB*, *FoilPolyDegT*, *FoilPolyDegO* properties accordingly to the Calibration Certificate for the sensing foil in use (refer CHAPTER 4 for communication with the sensor).

Example of changing foil coefficients:

Set Passkey(1000)

Set FoilID(1707)

Set FoilCoefA(1.71404376E-04,3.04290906E-04,-6.39414910E-02,5.14270106E+00,-2.84638794E-02,3.88090809E-05,-1.92200149E+02,1.66135018E+00,-5.18448297E-03,1.22642972E-05,2.89178945E+03,-3.48247963E+01,2.03067907E-01,-1.72740886E-03)

Set FoilCoefB(1.23230336E-05,0,0,0,0,0,0,0,0,0,0,0,0,0)

Set FoilPolyDegT(1,0,0,0,1,2,0,1,2,3,0,1,2,3,4,0,0,0,0,0,0,0,0,0,0,0,0,0)

Set FoilPolyDegO(3,4,3,2,2,2,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0)

Save

Type *Get All* to verify the new coefficients.

Script files for entering the foil coefficients via text terminal programs will be available from the factory.

4. Submerge the optode into the aerated water. Set the *Interval* property to e.g. 30 seconds. Enter the *save* command and wait until both the temperature and the phase measurements have stabilized:

   Set Passkey(1)

   Set Interval(30)

   Save

5. Store calibration values by typing:

   Set Passkey(1)

   Do CollectCalDataSat

   The *save* command is automatically performed when you type *Do CalAir*.

6. Set the *CalAirPressure* property to the actual air pressure in hPa at the site.

   Set Passkey(1)

   Set CalDataAPress (..)

   Save

NOTE! For maximum accuracy do not compensate the air pressure for height above sea level.

7. Submerge the optode in the zero solution. Make sure that the sensing foil is free from air bubbles. Wait until both the temperature and the phase measurements have stabilized.

8. Enter the *Do CalZero* command to store calibration values. The *save* command is automatically performed.

   Set Passkey(1)

   Do CollectCalDataZero

9. Enter the *Do Calibrate* command to effectuate the new calibration. The *save* command is automatically performed.

   Set Passkey(1)

   Do Calibrate

10. Check that the sensor is working properly by taking it up into the air and rinse off. In dry air, the sensor should show close to 100% oxygen saturation at sea level. Put the sensor back into the anoxic water; the reading should drop to zero.

Appendix 1 Theory of Operation

The Oxygen Optode is based on a principle called dynamic luminescence quenching.

This phenomenon is the ability of certain molecules to influence the fluorescence of other molecules. Fluorescence is the ability of a molecule to absorb light of certain energy and later emit light with lower energy (longer wave length). Such a molecule, called a luminophore, will after absorbing a photon with high enough energy, enter an exited state.

After a while the luminophore will emit a photon of lower energy and return to its initial state. Some types of luminophores might also return to the initial state when colliding with certain other molecules.

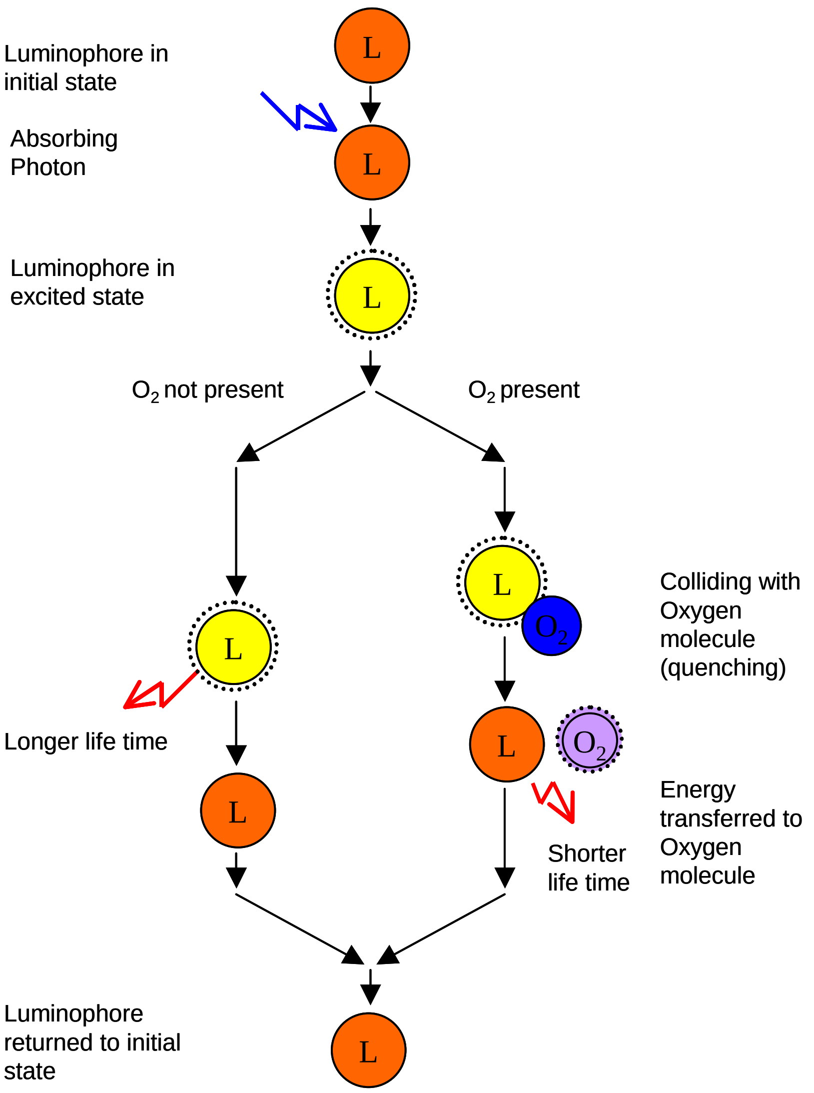


Figure A 1 Dynamic Luminescence Quenching

The luminophore will then transfer parts of its excitation energy to the colliding molecule, with the result that less photons (giving a shorter life time) are emitted from the luminophore. This effect is called dynamic luminescence quenching, and in the Oxygen Optode the colliding molecules are O_2.

The luminophore used in the Oxygen Optode is a special molecule called platinum porphyrine. These luminophores are embedded in a polymer layer, called the indicator layer (coated on a thin film of polyester support).

To avoid potential influence from fluorescent material surrounding the sensor or direct incoming sunlight when measuring in the photic zone, the foil is also equipped with gas permeable coating.

The coating gives optical isolation between the indicator layer and the surroundings.

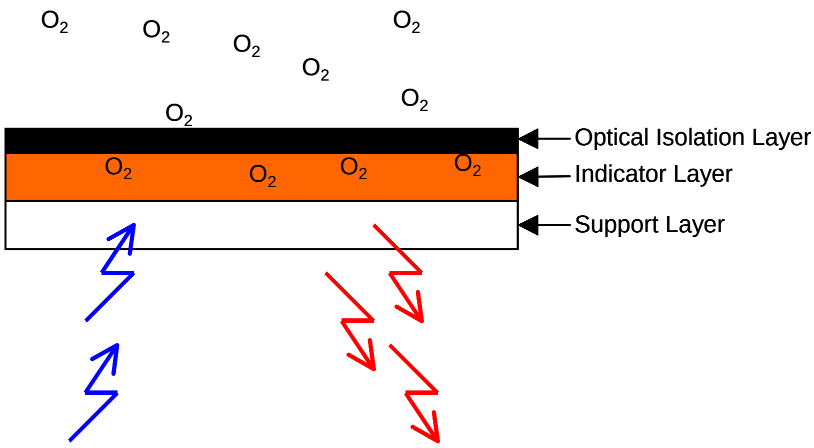


Figure A 2 Sensing Foil

Luminescence Decay Time

Due to its fluorescent behaviour the sensing foil will return a red light when it is excited with a blue-green light (505 nm). If there is O_2 present this fluorescent effect will be quenched.

The amount of returned light will therefore depend on the O_2-concentration in the foil.

The intensity of the returned light is however not the optimal property to measure since it depends on many other factors as i.e. optical coupling or bleaching of the foil.

Since the returned light is delayed with respect to the excitation light, the presence of O_2 will also influence the delay.

This property is called luminescence decay time (or lifetime) and it will decrease with increasing O_2-concentrations.

The relationship between the O_2-concentration and the luminescence decay time can be described by the Stern-Volmer equation:

$$[O_2] = \frac{1}{K_{SV}}\left\{\frac{\tau_0}{\tau} - 1\right\}$$

where:

τ = decay time

τ_0 = decay time in the absence of O_2

K_{SV} = Stern-Volmer constant (the quenching efficiency)

In order to measure this luminescence decay time, the sensing foil is excited with a blue-green light modulated at 5 kHz.

The decay time is a function of the phase of the received signal.

In the Oxygen Optode the relationship between the phase and the O_2-concentration is used directly, without calculating the decay time.

Figure A 3 shows a typical relationship between the phase measurement and O_2-concentration.

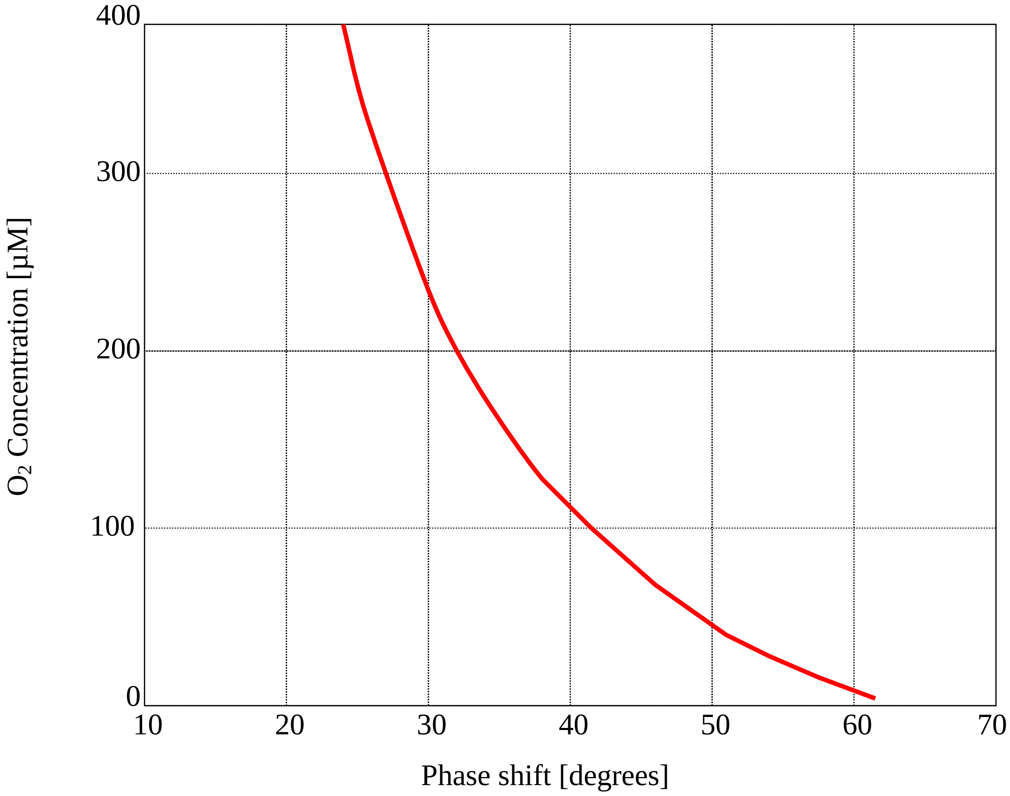


Figure A 3 Typical Phase/O_2 response

Appendix 2 The Optical Design

An illustration of the optical design is given in Figure A 4.

The sensing foil is mounted outside the optical window and is exposed to the surrounding water. The foil is held in place by a screw fixed plastic plate.

Two light emitting diodes (LEDs) and one photodiode are placed on the inside of the window. A blue-green LED is used for excitation of the foil. The photodiode is used for sensing the fluorescent light.

Even thought the sensing foil is highly fluorescent part of the light will be directly reflected.

The photo diode is equipped with a colour filter that stops light with short wavelengths to minimize the influence of the reflected light. Further, the blue-green LED is equipped with a filter that stops light with long wavelengths.

In addition, a red ‘reference’ LED is included to compensate for potential drift in the electronics of the transmitter and receiver circuit.

The spectral response of the LEDs and the filter are illustrated in Figure A 5.

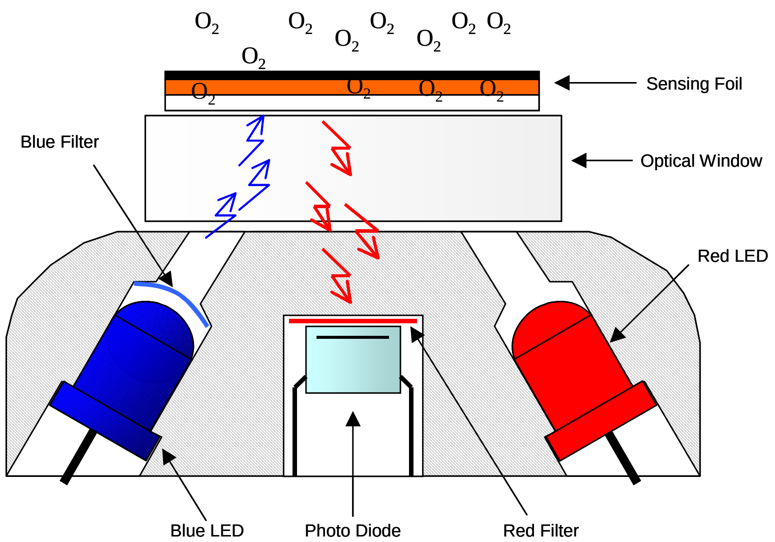


Figure A 4 The Optical Design

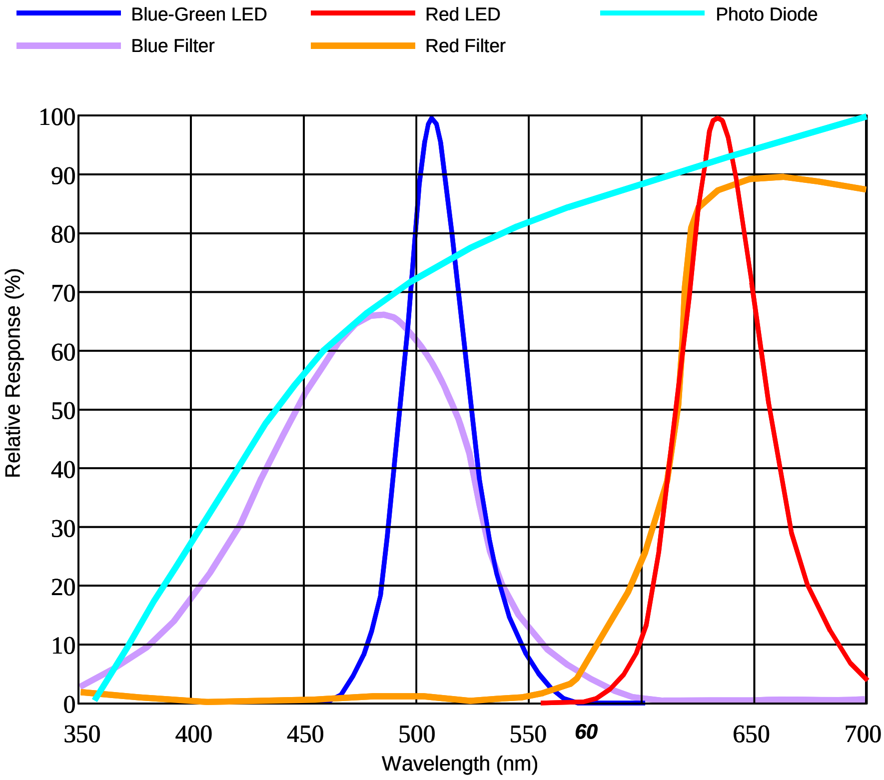


Figure A 5 An example of Spectral Response

Appendix 3 Electronic Design

Figure A 6 illustrates the main functions of the electronics.

To obtain good oxygen measurements the electronic circuit must be able to measure the phase between the excitation signal and the received signal accurately and with good resolution.

The received signal is sampled with a frequency of four times the excitation frequency. Two signal components with a phase difference of 90 degrees are extracted from these samples and are used for calculations of the phase of the received signal.

The O_2-concentration is calculated after linearizing and temperature compensating the phase measurements.

A thermistor thermally connected to the sensor body, provides temperature measurements.

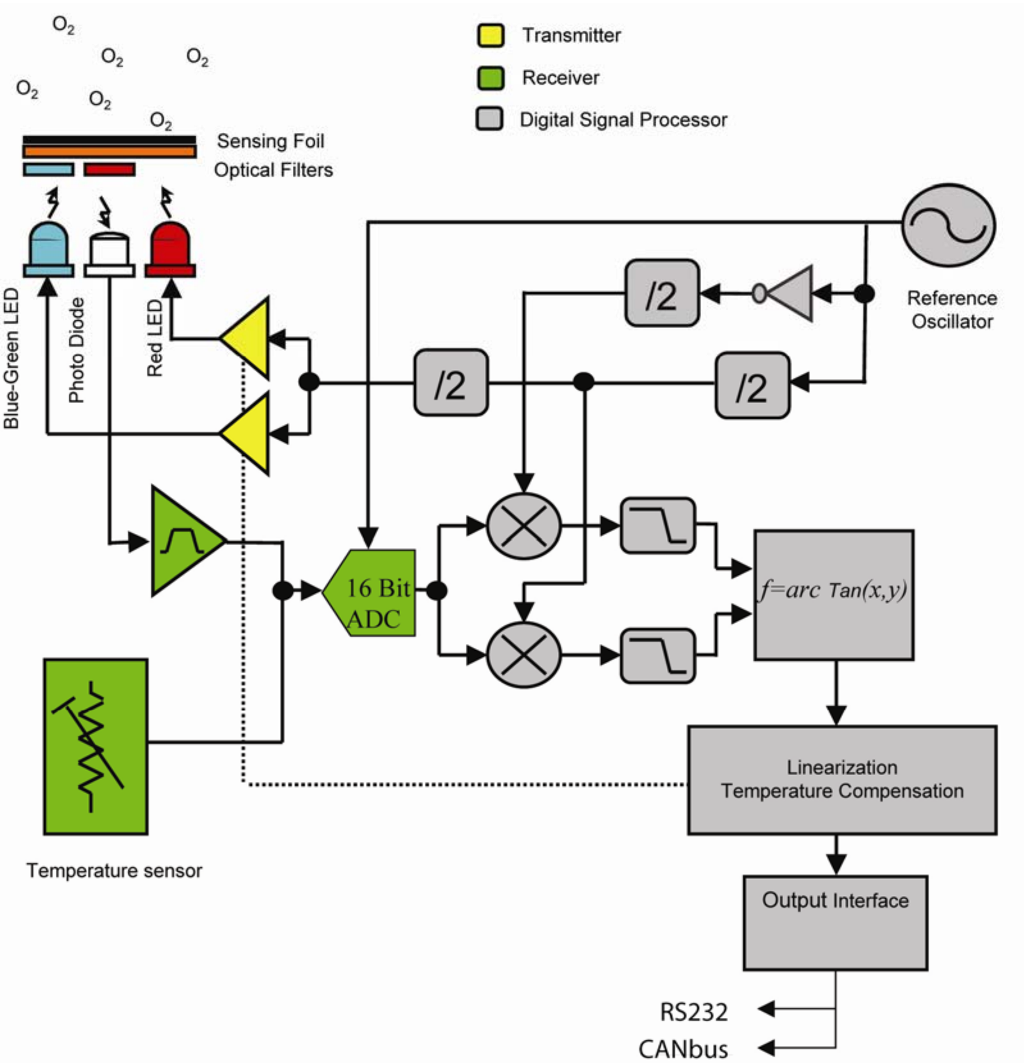


Figure A 6 Functional Diagram

Appendix 4 Mechanical Design of Optode 4330

Refer Figure 1-1 and Figure A 7 for illustration of the Oxygen Optode 4330.

A cylindrical stainless steel housing shields the electronics from the surrounding water and high pressure.

A 4mm thick sapphire window provides the optical connection between the optics inside the optode and the sensing foil on the outside.

The foil is fixed to the window by a POM securing plate and is easily replaceable.

A 10-pin receptacle in the sensor foot provides all electrical connection to the sensor.

To prevent potential leakage from the sensor to the rest of the measurement system, the receptacle is moulded inside a receptacle housing.

Refer CHAPTER 5 for instructions concerning changing the Sensing Foil.

Note! The sensor should not be opened! Opening the sensor housing can breach the warranty (ref. CHAPTER 5 , page 31 for instructions on how to change the Sensing Foil).

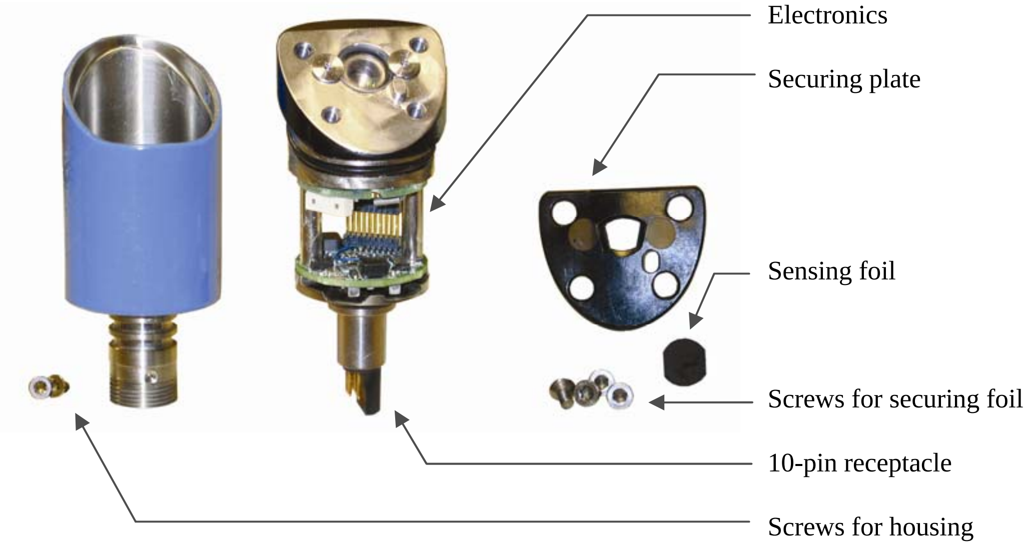


Figure A 7 Oxygen Optode 4330 components.

Appendix 5 Mechanical Design of Optode 4835

Refer Figure 1-2 and Figure A 8 for illustration of the Oxygen Optode 4835. A cylindrical polymer housing shields the electronics from the surrounding water and high pressure.

A 4mm thick sapphire window provides the optical connection between the optics inside the optode and the sensing foil on the outside. The foil is fixed to the window by a POM securing plate and is easily replaceable.

A 10-pin receptacle in the sensor foot provides all electrical connection to the sensor. To prevent potential leakage from the sensor to the rest of the measurement system, the receptacle is moulded inside a receptacle housing.

Refer CHAPTER 5 for instructions concerning changing the Sensing Foil.

Note! The sensor should not be opened! Opening the sensor housing can breach the warranty (ref. CHAPTER 5 , page 31 for instructions on how to change the Sensing Foil).

Figure A 8 Oxygen Optode 4835 components.

Appendix 6 Primer –Oxygen Calculations in the Sensor

The optode normally excites the foil with both blue and red light. Since the red light does not produce any fluorescence in the sensing foil the phase obtained in this measurement is used as a reference in the system. After collecting the raw data the difference between the phase obtained with blue (C1Phase) and red light (C2Phase) excitation is calculated as:

$$TPhase = A(t) + (C1Phase - C2Phase) \cdot B(t)$$

The A(t) and B(t) are 3rd order temperature dependent polynomials that provides for a possibility for temperature compensation of the phase measurement. Normally however, this option is not used and A(t)=0, B(t)=1.

Subsequently the calibrated phase, CalPhase, is calculated by use of another 3rd order polynomial:

$$CalPhase = PhaseCoef_0 + PhaseCoef_1 \cdot TPhase + PhaseCoef_2 \cdot TPhase^2 + PhaseCoef_3 \cdot TPhase^3$$

Note! When using the built in calibration procedure (2-point calibration), only the first two (1st order) coefficients are used.

The temperature in °C, is calculated from raw data (RawTemp) by use of a similar polynomial with coefficients called *TempCoef*.

Based on the calibrated phase (CalPhase) and temperature (Temperature) the partial pressure of O_2 is calculated by use of a two dimensional polynomial:

$$\Delta p = C_0 \cdot t^{m_0} \cdot ph^{n_0} + C_1 \cdot t^{m_1} \cdot ph^{n_1} + C_2 \cdot t^{m_2} \cdot ph^{n_2} + ... + C_{27} \cdot t^{m_{27}} \cdot ph^{n_{27}}$$

where the polynomial coefficients C_0 to C_{13} are stored in the property *FoilCoefA* and C_{14} to C_{27} are stored in *FoilCoefB*. The temperature exponents, $m_{0..27}$, are stored as *FoilPolyDegT* and phase exponents, $n_{0..27}$, are stored as *FoilPolyDegO*.

From the partial pressure the air saturation is then calculated as:

$$AirSaturation(\%) = \frac{\Delta p \cdot 100}{[NomAirPress - p_{vapour}(t)] \cdot NomAirMix}$$

where *NomAirPress* is a property for the nominal air pressure, usually 1013.25 hPa, and *NomAirMix* is the nominal O2 content in air, by default 0.20946.

The $p_{vapour}(t)$ is the vapour pressure calculated from temperature by the following equation:

$$p_{vapour}(t) = e^{\left(52.57 - \frac{6690.9}{t+273.15} - 4.681 * \ln(t+273.15)\right)}$$

If the property *Enable HumidityComp* is set ‘No’ the $p_{vapour}(t)$ will be set to zero.

The oxygen concentration is finally calculated as:

$$O2Concentration(\mu M) = \frac{C^{*} \cdot 44.614 \cdot AirSaturation}{100}$$

where C^{*} is the oxygen solubility (cm^3/dm^3) calculated from the Garcia and Gordon equation of 1992:

$$\begin{aligned}
&\ln(C^{*}) = \\
&A_0 + A_1 T_S + A_2 T_S^2 + A_3 T_S^3 + A_4 T_S^4 + A_5 T_S^5 \\
&+ S\left(B_0 + B_1 T_S + B_2 T_S^2 + B_3 T_S^3\right) + C_0 S^2
\end{aligned}$$

where:

T_s = scaled temperature

$$= \ln\left[\frac{298.15 - t}{273.15 + t}\right]$$

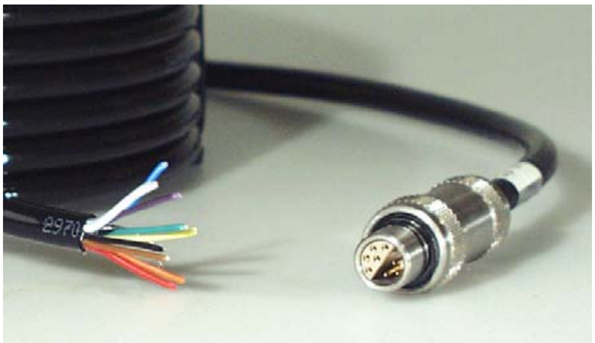
t = Temperature, °*C*

S = *Salinity* (configurable property, default set to zero)

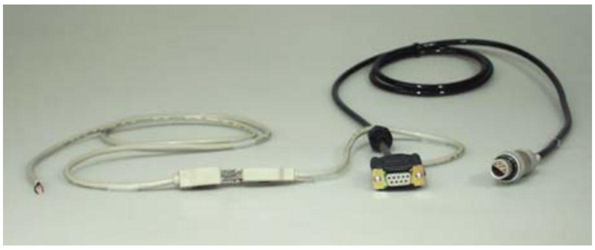
A_0 = 2.00856	B_0 = -6.24097e-3
A_1 = 3.22400	B_1 = -6.93498e-3
A_2 = 3.99063	B_2 = -6.90358e-3
A_3 = 4.80299	B_3 = -4.29155e-3
A_4 = 9.78188e-1	C_0 = -3.11680e-7
A_5 = 1.71069	

Appendix 7 Illustrations

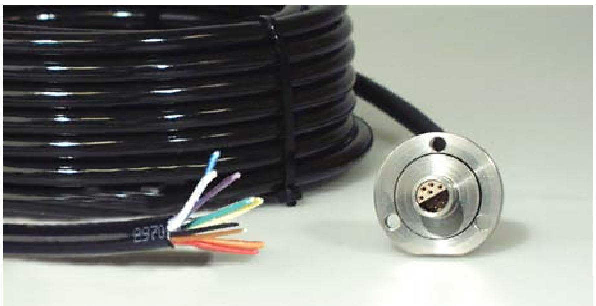
Figure no.	Description
Figure A 9	Illustration of some cables.
Figure A 10	Drawing Cable 3855.
Figure A 11	Assembly drawing of cable connection for deepwater version (1000-6000 m).
Figure A 12	Drawing Cable 3485 (0-1000 m).
Figure A 13	Drawing Cable 3976 (1000-6000 m).
Figure A 14	Drawing Cable 3980 (1000-6000 m).



3485. Connecting cable 10 pin to free end (1000m depth capability).



3855. Connecting cable for PC. *NOTE! The connector is made in aluminium and is not recommended for long term use in salt water.*



3976[1]. Flange connecting cable 10 pin to free end (6000m depth capability).

3980[1] Flange connecting cable 10 pin to 10 pin (1000m depth capability).

Figure A 9 Illustration of some cables.

[1] Used with coupling 3979 for 36mm sensors and coupling 3977 for 40mm sensors.

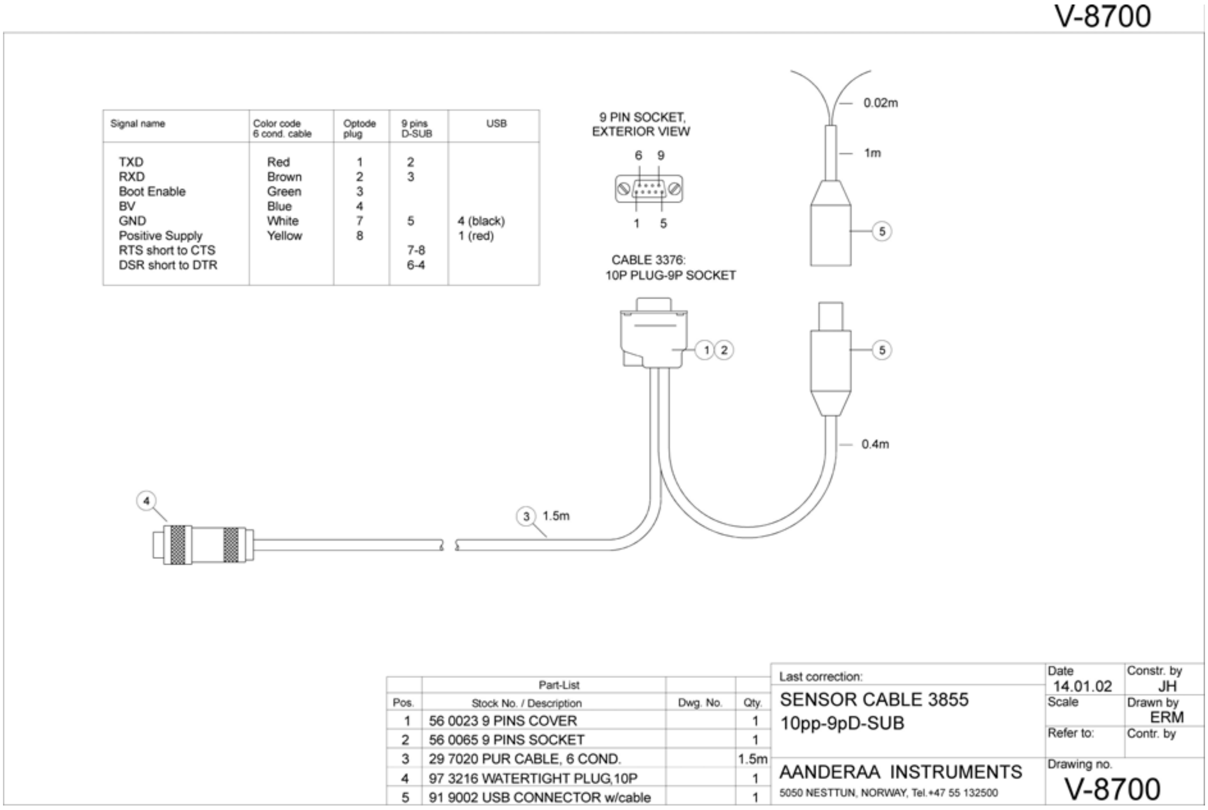


Figure A 10 Drawing Cable 3855.

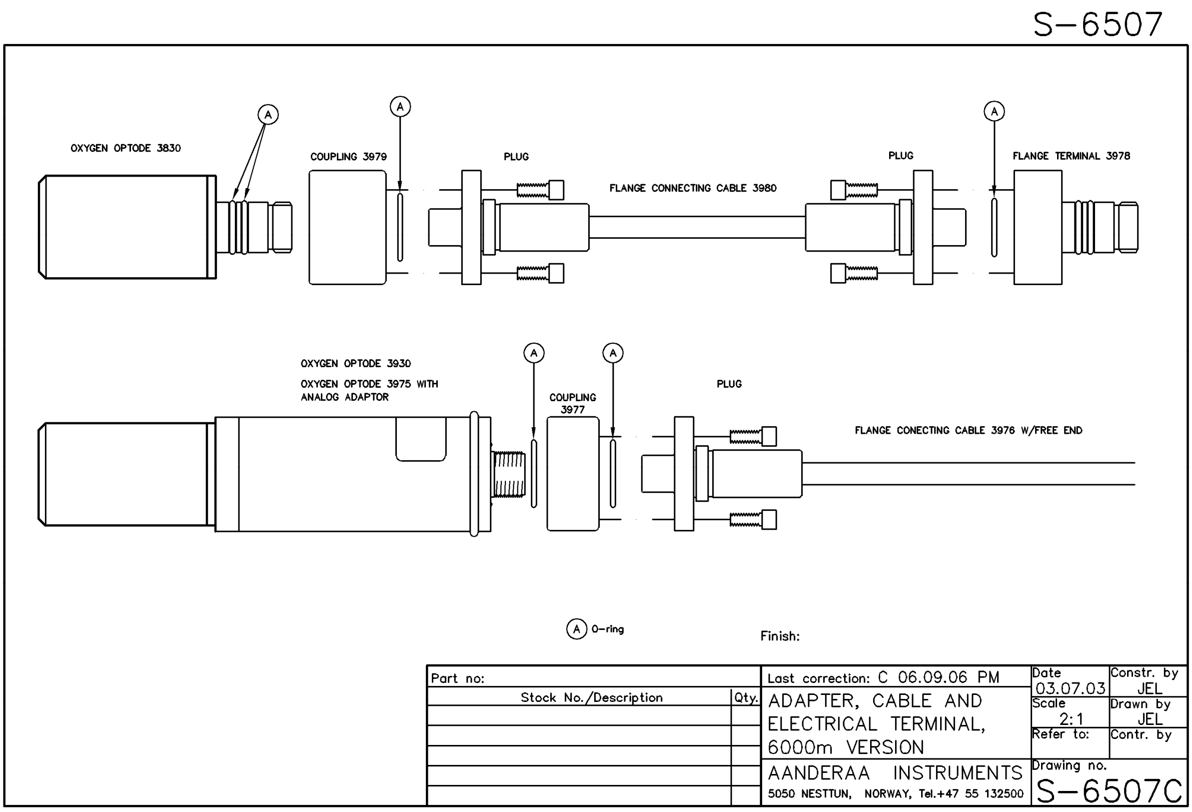


Figure A 11 Assembly drawing of cable connection for deepwater version (1000-6000 m).

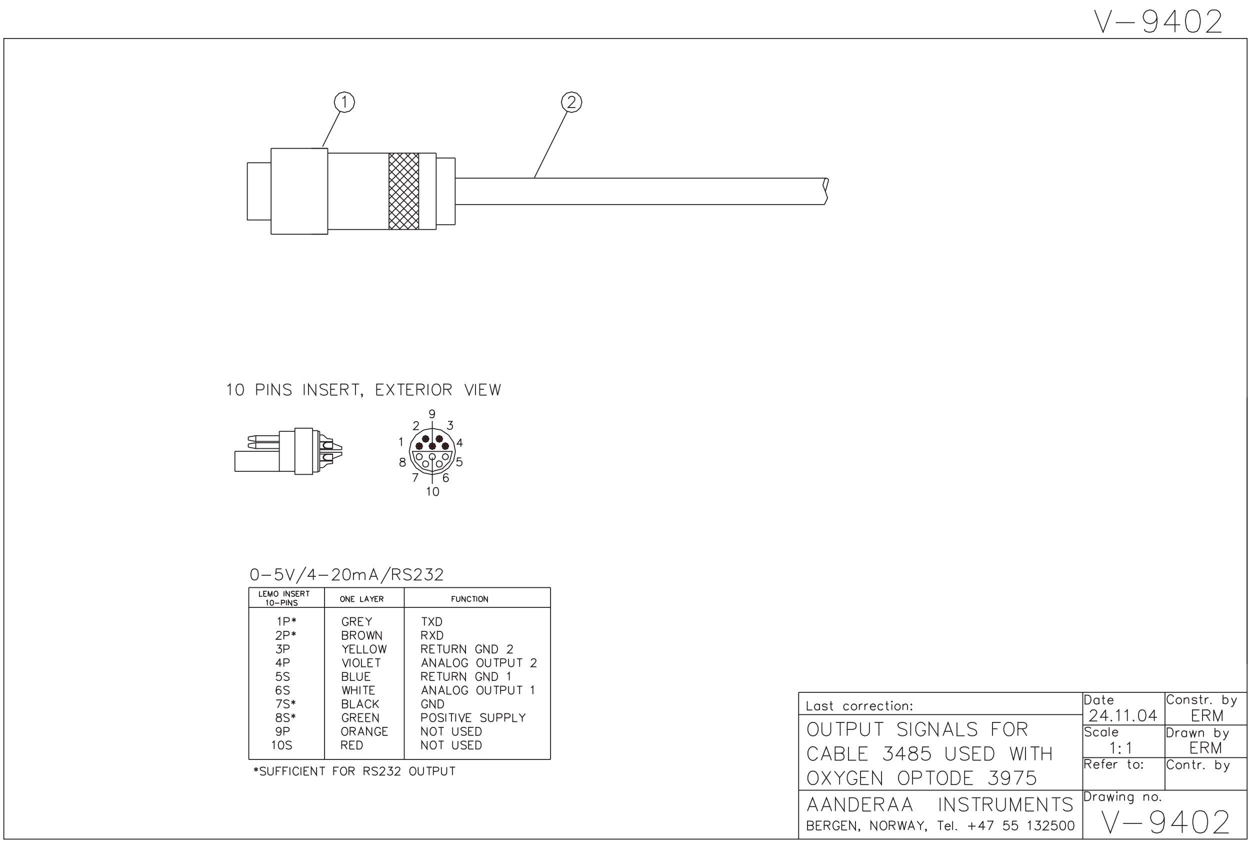


Figure A 12 Drawing Cable 3485 (0-1000 m).

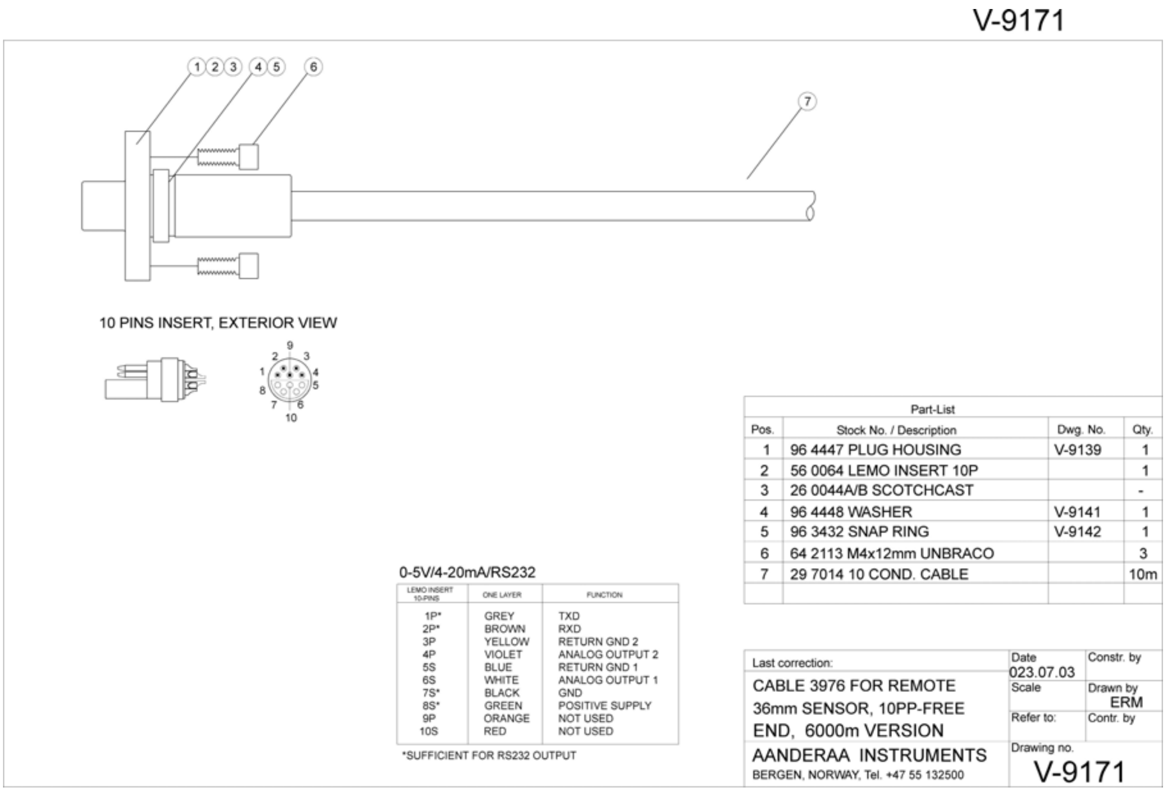
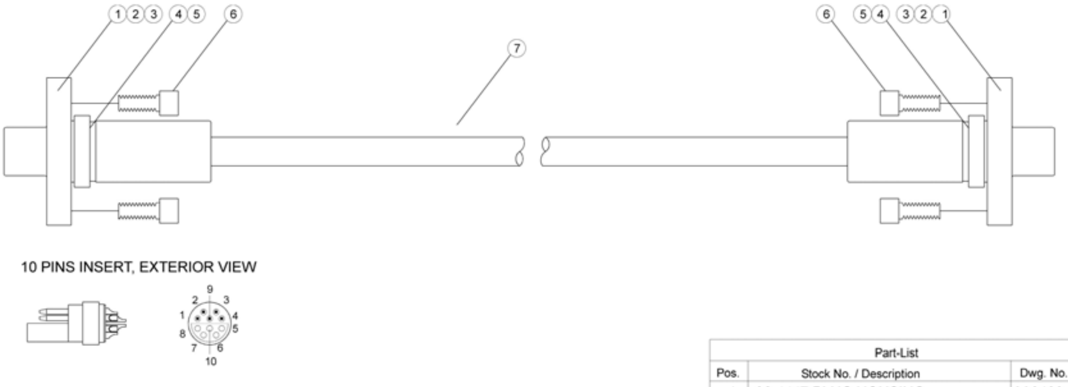


Figure A 13 Drawing Cable 3976 (1000-6000 m).

V-9151



Part-List			
Pos.	Stock No. / Description	Dwg. No.	Qty.
1	96 4447 PLUG HOUSING	V-9139	2
2	56 0064 LEMO INSERT 10P		2
3	26 0044A/B SCOTCHCAST		-
4	96 4448 WASHER	V-9141	2
5	96 3432 SNAP RING	V-9142	2
6	64 2113 M4x12mm UNBRACO		6
7	29 7014 10 COND. CABLE		10m

SR-10

LEMO INSERT 10-PINS	ONE LAYER	FUNCTION
1P	GREY	NOT USED
2P	BROWN	NOT USED
3P	YELLOW	(BOOT ENABLE)
4P	VIOLET	BV
5S	BLUE	(SR10-CH.5)
6S	WHITE	-9V
7S	BLACK	NOT USED
8S	GREEN	POSITIVE SUPPLY
9P	ORANGE	SR10-CH.2
10S	RED	CONTROL VOLTAGE

0-5V/4-20mA/RS232

LEMO INSERT 10-PINS	ONE LAYER	FUNCTION
1P*	GREY	TXD
2P*	BROWN	RXD
3P	YELLOW	RETURN GND 2
4P	VIOLET	ANALOG OUTPUT 2
5S	BLUE	RETURN GND 1
6S	WHITE	ANALOG OUTPUT 1
7S*	BLACK	GND
8S*	GREEN	POSITIVE SUPPLY
9P	ORANGE	NOT USED
10S	RED	NOT USED

*SUFFICIENT FOR RS232 OUTPUT

Last correction: D 11.09.03 ERM	Date 023.07.03	Constr. by
CABLE 3980 FOR REMOTE 36mm SENSOR, 10PP-10PP 6000m VERSION	Scale	Drawn by ERM
	Refer to:	Contr. by
AANDERAA INSTRUMENTS BERGEN, NORWAY, Tel. +47 55 132500	Drawing no. V-9151D	

Figure A 14 Drawing Cable 3980 (1000-6000 m).

Appendix 8 Frequently Asked Questions –FAQ

In this chapter we present a copy of our FAQ for the optodes. The latest version is on our web site, refer www.aanderaa.com

IMPORTANT! This FAQ is general for all versions of AADI Oxygen Optodes; all features described in the FAQ are not are not available for all optode versions.

Calibration, Calibration Coefficients, Accuracy and Precision

CCAP1
Q: What calibration coefficients are used in the sensor, how can I make sure that I use the correct ones?
A: The sensor has several sets of calibration constants stored in its memory.
These can be verified from your PC via the OxyView software or with a terminal communication program.
The coefficients are:

1. The internal temperature sensor has its own calibration constants that can not and do not need to be changed by the user.

2. The sensing foil has a set of 28 constants C_0 to C_4 (FoilCoefA_{0-13},FoilCoefB_{0-13} for Optode 4330 and 4835), which are specific to that batch of foils (normally produced in batches of 100). If you change the foil with a foil from a different batch you must update the foil constants stored in the sensor with a set of new constants by entering them manually into the sensor.
   These constants are delivered on a calibration certificate together with the new foil.

3. The sensor and the foil has a set of calibration constants (called phase coefficients) that are obtained and automatically stored in the sensor when a two point calibration is performed, using a 100% air saturated solution and 0% oxygen solution.
   When changing or removing the foil a new calibration must be performed to obtain accuracy and precision.
   The most efficient way to do this calibration is to use the OxyView software.

4. When data from the sensor is registered on an Aanderaa data-logger (e.g. on a RCM 9, a buoy etc.) the Aanderaa specific SR10 format is used.
   These readings then need to be post-processed (converted to the desired engineering units) by multiplying with a constant.
   This constant is obtained by dividing the range by the 10-bit resolution of the SR10 format.
   If you have selected to output oxygen concentration in µM in the SR10 format you will have to multiply the obtained data by 0.488281.
   If you select to output % saturation you will have to multiply with 0.146484.

CCAP2
Q: If I change the foil and forget to update the internal constants but I made a new calibration can I back-calculate to get the correct data?
A. If the foil is from the same batch it will have the same constants and the data should be ok.
If the foil is not from the same batch it will not be possible to post-compensate the obtained data.

It is imperative to use the correct foil constants and to do a new two-point calibration if the foil has been changed or moved.

CCAP3
Q: It appears as if the specifications for accuracy and precision of the sensor are conservative compared to its actual performance, why?
A: After calibration the sensors normally perform better than the given specifications.
Aanderaa has a tradition to be conservative when giving sensor specifications so that these reflect the "worst situation" performance in the field.

CCAP4
Q: Can the accuracy of the sensor be further improved?
A: Yes, if the individual sensor was calibrated in more calibration points (e.g. 30 point calibration), both with respect to oxygen concentration and temperature compensation of the foil, the accuracy would be improved by approximately a factor of 4.
However, this means an increase in the production cost and requires the sensor to be sent back to the factory for recalibration if the foil is changed after delivery.
Some customers that need particularly high accuracy have established their own calibration procedures.

CCAP5
Q: How often do I need to re-calibrate the sensor?
A: If the foil is not mechanically damaged or moved no recalibrations are needed within the time of one year.
We recommend a recalibration once a year but from field experiences we see that the sensor is stable over much longer time periods than this.
For investigators that have experience with electrochemical sensors it might be tempting to make frequent foil changes and recalibrations but this is not needed.
When you receive the sensor from the factory no calibrations are needed but of course you should check that it is working properly.

CCAP6
Q. The brochure says accuracy of 8µM or 5% (whichever is greater).
Does this mean that at very low levels the accuracy is 5% of the measurement?
A: No, this means that the accuracy is 8µM for readings below 160µM and 5% for readings above 160µM.

CCAP7
Q: Is there a minimum measuring point or will the sensor go all the way down to zero?
A: It will go all the way to 0. There is no minimal measuring point.

CCAP8
Q: When calibrating, which substance should I use to remove the oxygen in the water?
A: At Aanderaa we use Sodium sulfite for this purpose.
Sodium sulfite rapidly removes the oxygen and as long as crystals of the compound can be seen the oxygen level in the water will stay at 0. Sodium sulfite also has the advantage of being inexpensive and the level of toxicity is low.
There are many other chemical substances that could be used for the purpose.
Some investigators use Sodiumdithionit, which is also effective but more expensive and more toxic.
Bubbling with gases (e.g. N2, Argon etc) will also "strip off" the oxygen from the water but this takes longer time and sometimes, especially if the water volume is large, it can be difficult to

know when a true zero oxygen level has been reached.

CCAP9

Q: When calibrating at saturation, which type of device should I use to get 100% saturation?

A: It is advisable to use standard aquarium equipment, which is normally inexpensive.

An aquarium pump connected to a tube which has been fitted with porous stone (bubble dispenser) at the end is suitable.

This will create small air bubbles that are efficient in equilibrating the water rapidly.

Be careful with using compressed air or compressor/vacuum type pumps since these are likely to compress the air/oxygen which will give errors when calibrating.

Normally the sensor will under-read after such a calibration.

A similar situation will occur if the sensor is calibrated in a “deeper” water tank.

If the air bubbling and the sensor are placed at for example at 1 m water depth the over pressure will be approximately 10%.

CCAP10

Q: When calibrating which type of vials/containers should be used?

A: It is preferable to use clean glass vials, instead of plastic, for calibrations and any types of experiments.

There have been examples in which oxygen has either been consumed by substances bound into the plastic container walls or oxygen has diffused through the walls from the outside.

Glass is preferable for basically all applications that are dealing with dissolved gases.

CCAP11

Q: When sampling the sensors at high frequencies (1-10 s intervals) there appears to be some self heating of the sensor.

What can be done to minimize the effects of the self heating and how big is the effect of it?

A: The sensor has linear power regulators which means that if you supply it with higher voltage (e.g. 8-14V) it will still consume the same amount of Amperes as at 5V.

The additional energy at higher voltages will be lost as heating which will contribute to the self heating.

Therefore it is better to supply the sensor with 5V in high sampling frequency applications.

Laboratory testing at 5V has revealed that self heating of the sensor can introduce a 1µM (giving lower readings than correct) when sampled at a 1 second sample-interval.

This error drops to 0.2 µM for a 5 second interval. The error of the internal temperature sensor at a 5 s sampling interval is approximately 0.03ºC. At a 1 s sampling interval it is approximately 0.1ºC. Care should be taken when using the sensor in on-line system applications.

The internal temperature sensor is placed in the “foot” of the sensor. If mounting the sensor in the wall of an on-line system that has high thermal conductivity (e.g. metal walls) with the outside this might give significant effects on the optode temperature sensor, which also will lead to errors in the oxygen readings since these temperature readings are used for the necessary temperature compensation.

CCAP 12

Q: I am measuring in the laboratory and the sensors are oscillating regularly with an amplitude of a couple of µM.

The oscillations decrease when I immerge the sensors into air saturated water but they are still detectable.

What is the reason for these oscillations?

A. The response of the sensors are directly affected by changes in air pressure.

If you are working in a laboratory which is equipped with an automatic climate control system the ventilation will most likely be turned on and off at regular intervals.

The operation of the ventilation will create air pressure changes in the room which are sensed by

the optodes.
It is important to think about this especially if you are calibrating sensors.
You have to take into account the local air pressure and if this is not the same inside your laboratory as at the air pressure you enter during calibration it will introduce errors.

CCAP 13
Q. Is there a difference in the sensor response if the foil is wet or dry?
A. Yes the sensor is and should be calibrated in a wet environment and it takes hours for the foil to become completely wet or dry.
Taking a sensor which has been sitting in a dry environment for several hours and introducing it into water to make a spot measurement can lead to an error of maximum 2%.
Keeping the sensor in a humid environment for at least 12 h will eliminate this error.
If you would like to do spot measurements, where the sensor is out of the water most of the time, we recommend you to keep the sensor in a wet environment (such as a plastic bag with water) in-between measurements.

Measurement Related

MR 1
Q: Can I measure oxygen in air with the sensor?
A: Yes, but in dry air you should expect slightly higher readings since there is no water vapor present.
The space normally taken by vapor in humid air is here replaced by more air and consequently the sensor should give slightly higher readings.
Please be aware that there is a high risk of having a different temperature at the foil compared to the temperature of the incorporated temperature sensor in air.
This might lead to errors in the temperature compensation and to readings that are not correct.

MR 2
Q: What is the reason that several sensors plunged into the same water do not give exactly the same values?
A: From experience we know that at occasions when this question was raised the user had not mixed the water well and consequently the oxygen concentrations were different at different locations in the water bath.
Due to the simple two point calibration (see above) differences (within specifications) between sensors should be expected.
It has happened that customers that want a higher accuracy have developed their own calibration procedures.
This can improve the accuracy significantly (see above).

MR 3
Q: What physical factors will affect the sensor?
A: Temperature (which is already internally compensated), salinity (see below or Operating Manual) and pressure (see below or Operating Manual).
The two latter parameters are easily compensated for by simple formulas which are common for all sensors.

MR 4

Q: What chemical factors/elements will affect the sensor?
A: There exists no cross sensitivity for carbon dioxide (CO_2), hydrogen sulfide (H_2S), ammonia (NH_3), pH, any ionic species like sulfide (S_2^-), sulfate (SO_4^{2-}) or chloride (Cl^-).
The sensors can also be used in methanol- and ethanol -water mixtures as well as in pure methanol and ethanol.
It should not be used in other organic solvents, such as acetone, chloroform or methylene chloride, which may swell the foil matrix and destroy it.
Interferences (cross-sensitivity) are found for gaseous sulfur dioxide (SO_2) and gaseous chlorine (Cl_2).

MR 5
Q: Is the sensor sensitive to H_2S?
A: No, it is not. It will not be damaged by H_2S and it is not cross-sensitive to it.
If H_2S is present the oxygen concentration should be zero or very close to zero since O_2 and H_2S rarely coexists, especially over longer time periods.

MR 6
Q: What is the pressure behavior of the sensor?
A: The pressure effect is that the sensor reads 4% lower readings/1000 meters of water depth which means that at 1000 meters you will have to multiply your readings with 1.04 to get the correct absolute values and at 2000 meters with 1.08 etc.
This effect is the same for every sensor, it is linear and fully instantaneously reversible, when the pressure is released.

MR 7
Q: What about hysteresis?
A: As opposed to electrochemical sensors this optode does not suffer from hysteresis.
The pressure effect on the sensor described above immediately disappears when the pressure is released.
A recent publication in which the optode was compared with an electrochemical sensor is found at our web site.

MR 8
Q: Can I log data of oxygen concentration, oxygen saturation and temperature simultaneously on the SR10 output (e.g. on a RCM9/RCM11/Buoy etc.).
A: No, the Optode only has one SR-10 output channel.
You can either select to log oxygen concentration or oxygen saturation on your instrument.
To see how this set-up is done see the Operating Manual or the OxyView software.
If you also would like to log the Optode's internal temperature sensor you will have to order the Oxygen Optode model 3930 which can output the temperature in parallel in VR22 format.
Note this is normally not necessary as our recording instruments include a separate temperature sensor.

MR 9
Q: Why is the sensor limited to a range of 0-120% and 0-500 µM?
A: These limitations are only present when logging the sensor in SR10 or analog formats.
If logging the sensor in RS232 or CAN bus there are no upper limits for the measurements range.
However the user should be aware of the sensors and the foils are only calibrated to 500µM beyond these limits a lower accuracy and precision should be expected.
The 120% saturation limit is given for extreme conditions, which will rarely occur in reality.
At 0ºC at a salinity of 0 ppt the 100% saturation reading of water is 457µM.
It is unlikely that in such waters there would be supersaturation since there is normally no or low primary production in water that is freezing.

Sea water (35 ppt) at 0ºC contains 358µM at 100% saturation so here there is margin of up to 140% before the sensor reaches the SR10 measuring limit of 500µM.
To conclude the limitation when logging the sensor in SR10 or analog format is 500µM = 16mg /l the corresponding saturation limitations in % can be calculated when the temperatures and salinities are known.

MR 10
Q: How fouling sensitive is the sensor?
A: The sensor does not consume any oxygen and it is not stirring sensitive therefore it is less sensitive to fouling than electrochemical sensors.
The fouling sensitivity varies from case to case.
In the marine environment with high fouling conditions an unprotected Optode will give accurate readings as long as the fouling is not changing the local oxygen conditions around the sensing foil.
Some user experiences have shown that this, in the worst cases, can start to occur already after one week in warm and highly productive waters.
Previously a copper plate was used to mount the sensing foil with.
This solution offered improvements only in areas with important water circulation around the sensor.
In other applications it resulted in faulty readings and this solution has been discarded.

MR 11
Q: For how long time can you run the sensor before it will not work anymore?
A: The most critical limitation for the operational time (foil life) is foil bleaching.
When excited for a long time with strong blue light the foil will bleach and eventually reach a stage where the amplitude of the returning signal (even if it is lifetime based) will be too weak to be registered.
Laboratory tests at 2-second intervals have shown that the sensor can measure more than a year with this interval setting.
This means that the sensors can for example be operated for 5 years at a 10-second interval without any amplitude effects.
Exposure to direct sunlight will also excite/bleach the foil over time however this effect is minimal with the protection provided by the opaque/optical isolation layer.

MR 12
Q: Can the 3830 sensor be used down to full ocean depth just by connecting it to a standard titanium connector from Aanderaa?
A: No, for high pressures, beyond 100 bar, the Cable Adapter 3979 and Flange Connecting Cable 3976 should be used.
These are pressure rated to 600 bar. Please look in the Operating Manual or contact Aanderaa for more information.

MR 13
Q: Can I use the sensor for long-term measurements, in for example an on-line system, just by connecting it to a PC with the PC communication cable (model # 3855) that was delivered with the sensor?
A: Yes and No. It is not a problem to connect and log the sensor like this but you should be aware that the connector on the cable is made out of anodized Aluminium that will start to corrode when it is used for to long times in salt water.
The sensor is of Titanium and will not corrode. For long-term applications you should use a Titanium connector. Please ask Aanderaa for more information.

MR 14

Q: The Aanderaa Optode and/or software appear to be programmed to only report percent saturation relative to sea level.
How is it intended to take into account the barometric pressure, i.e., elevation, in reporting percent saturation?
A: External calculation and post-processing must be used for calculating "real" saturation with respect to barometric/water pressure.
The Optode's internal software has not been prepared for measurements at high altitudes.

MR 15
Q: How high operation and storage temperature can the sensor stand?
A: Operating 0 to 40°C; Transport -40°C to 70°C, for storage we recommend room temperature or lower.

MR 16
Q: After calibration the maximum reading we can get in air at room temperature is 94.1 instead of 100. Do we need to replace the oxygen sensing foil?
A: The relative oxygen computed by the optode is referred to standard atmospheric air pressure (1013.25 hPa).
The lower reading of 94.1 most likely means that your measurement is taken in an environment where the air pressure is lower than standard air pressure.
See also question MR1.
You can find more about this topic in the operating manual.

MR 17
Q: Is there a difference in the sensor response if the foil is wet or dry?
A. Yes the sensor is and should be calibrated in a wet environment and it takes hours for the foil to become completely wet or dry.
Taking a sensor which has been sitting in a dry environment for several hours and introducing it into water to make a spot measurement measurements can lead to an error of maximum 2%.
Keeping the sensor in a humid environment for at least 12 hours will eliminate this error.
If you would like to do spot measurements, where the sensor is out of the water most of the time, we recommend you to keep the sensor in a wet environment (such as a plastic bag with water) in-between measurements.

MR 18
Q. I have mounted my sensors in chambers.
When I immerge them into the water the response increases dramatically and already at 10m water depth I am measuring about twice the concentrations compared to what I am measuring at the surface.
What is happening?
A. The most likely explanation is that you have trapped air inside your chambers and that the sensors are measuring in this air.
At 10m water depth the partial pressure of oxygen is two times higher and this is what you are measuring.

MR 19
Q. I have mounted my sensors in chambers to make sediment-water incubations at the bottom.
The oxygen readings looks normal until the chambers are inserted into the sediment and the lids are closed.
Then it looks like, from the response of the optodes, as if the oxygen concentrations increase.
What can the explanation be to this?
A. The most likely explanation is that you have trapped air inside your chambers and when you close the lid it dissolves and change concentration in the now sealed chamber.

The effect becomes particularly visible if you are working in environments with low ambient oxygen concentrations.
To avoid this ventilate your chamber for several hours before closing the lid. Then the air bubbles will dissolve.

MR 20
Q: I am measuring in the laboratory and the sensors are oscillating regularly with an amplitude of a couple of µM.
The oscillations decrease when I immerge the sensors into air saturated water but they are still detectable.
What is the reason for these oscillations?
A. The response of the sensors are directly affected by changes in air pressure.
If you are working in a laboratory which is equipped with an automatic climate control system the ventilation will most likely be turned on and off at regular intervals.
The operation of the ventilation will create air pressure changes in the room which are sensed by the optodes.
It is important to think about this especially if you are calibrating sensors.
You have to take into account the local air pressure and if this is not the same inside your laboratory as at the air pressure you enter during calibration it will introduce errors.

MR 21
Q: How do I convert oxygen data logged by the optode to other units?
A: The optode measures and presents data in micromole dissolved oxygen per liter (µmol/l). This unit is often also called micromolar (µM). Depending on the background and tradition of the user converting into other units might be useful.
To convert into mg/l the obtained values have to be divided by 31.25. To obtain ml/l the obtained values have to be divided by 44.66. To obtain µm/kg the density of the water has to be calculated from temperature, salinity and pressure values that are measured in parallel with the oxygen.
For more specific information about this subject please look in: Methods of Seawater Analysis, 3rd Edition (1999). Klaus Grasshoff (Editor), Klaus Kremling (Editor), Manfred Ehrhardt (Editor). ISBN: 3-527-29589-5. Wiley.

MR 22
Q: What is the use of the phase, amp and rawTemp data in the long RS232 data format when using the Optode in stand alone mode?
Is there any diagnostic value in these data that would suggest foil aging, thermistor failure or otherwise indicate Optode service is required?
A: The initial reason for including these data as an option was mainly to have the possibility to quality check the internal calculations. For most users these data have no value and could be “turned off”.
The comprehensive string of raw data can be limited to oxygen concentration, oxygen saturation and temperature by setting the output to 0 (zero). This can be done either by using the OxyView software or by transferring a three line command string using any terminal program (please refer to the manual). However, for investigators that are using the optode on a fast profiling CTD it is recommended to use the CTD’s fast responding temperature sensor to temperature compensate the oxygen readings.
To do this the DPhase values have to be registered. For more specific information about how this is done please look at SSC13 in this FAQ and in the manual.

MR 23
Q: Why is salinity compensation needed?
A: As other oxygen sensors the Aanderaa optodes are measuring the level of oxygen saturation (partial pressure) in the water and not the absolute concentrations. To get the absolute

concentrations, the salinity has to be measured in parallel/known and compensated for. This can be done either internally by setting the salinity to a fixed value or externally by applying the formulas of Garcia and Gordon.

As a default value the internal salinity is set to 0 when optodes are delivered from the factory. This setting can be changed by using the OxyView software or a standard terminal program (please see the operation manual for more information). The formulas from Garcia and Gordon (1992) that can be used to post compensate the measured values are also given in the optode operation manual.

MR 24
Q: How does the air pressure influence the O_2 concentration?
A: If the air pressure is high (good weather or created by a ventilation system which gives over pressure) more oxygen can dissolve. For example if the air pressure is 1030 mbar compared to 990 mbar the saturation level will be 1030/990=4% higher.

MR 25
Q: How does the salinity and temperature influence the O_2 concentration?
A: If the salinity and temperature are high, less oxygen can dissolve compared to if the salinity and temperature are low. For example: at 1000 mbar air pressure, a temperature of 20ºC and a salinity of 35 ppt (typical for sea water) the water will reach an equilibrium concentration of 231 µM. At the same air pressure and temperature but at a salinity of 0 ppt (e.g. tap water) the saturation concentration will be 284µM.

Because the dissolution of a real gas does not follow the common gas law exactly, these concentrations are calculated with empirical formulas. Formulas that are frequently used (also by Aanderaa) are presented in: Garcia and Gordon (1992) Oxygen solubility in seawater: Better fitting equations. Limnol. Oceanogr. 37:1307-1312.

A link to Unisense AS tables for solubility of oxygen in seawater is given here.

MR 26
Q: What is influencing the O_2 concentration in water?
A: If a glass of water is left in a room with constant temperature and constant air-pressure, oxygen in the air will dissolve in the water according to the common gas law. After some time a saturation equilibrium will be reached where no more oxygen can be dissolved in the water. If the water is stirred it will reach saturation faster.

How much oxygen that can be dissolved in the water is dependent on the salinity and temperature of the water and on the air pressure in the room.

A link to Unisense AS tables for solubility of oxygen in seawater is given here.

MR 27
Q: Does the sensor react to changes in salinity?
A: No, The sensor does not react to changes in salinity.
This can be verified by having two glasses of air-bubbled water, at the same temperature, next to each other.
One filled with freshwater (0 ppt) and the other with saltwater (e.g. 35 ppt).
When moving the sensor from one glass to the other it should read the same absolute oxygen concentration, in µm, even though the absolute oxygen solubility in the salt water is lower.

MR 28
Q: Does the % saturation level change with the salinity compensation?

A: No, the % saturation level should be the same.

MR 29

Q: I'm going to have a deployment in ocean water with constant salinity (35 ppt). Is it possible to preset the internal setting in the sensor, to avoid post calibration?

A: Yes, this can be done. The default internal salinity is set to zero. If changing the internal salinity setting in the sensor (preferably using the OxyView software) to the correct value the sensor should give the correct absolute saturation concentration in the salt water.

This means that when working in waters with a constant and known salinity this value can be entered into the sensor prior to deployment.

Mechanical and Maintenance

MM 1

Q: How do I clean the foil after a deployment if it has been fouled?

A: In all cases the cleaning procedure should be done with caution so that the protective foil coating is not removed.

If the fouling is calcareous it can normally be dissolved with household vinegar (essig in German, eddik in Norwegian).

Another substance that can be used is commercially called muriatic acid, which is a 5% HCl solution (dilute solution by 50% should be tested to see how well it dissolves growth before using a stronger concentration).

If needed, the remains use Q-tips to gently wipe it off after it has been softened by soaking in vinegar/HCl. Optode can be submerged in vinegar/HCl over night, or longer.

If the marine growth

After cleaning the sensor it should be rinsed well in clean tap water before storing or reuse.

Do not use any organic solvents such as: Acetone, Chloroform and Toluene since these and others will damage the foil.

MM 2

Q: My foil has been damaged so that I can see scratches in the black protective layer and some blue light is coming out when measuring.

Do I need to change the foil?

A: No, normally not.

Even if quite heavily damaged the foil continues to work, in most cases.

As long as enough of the fluorophore remains on the foil the sensor will measure correctly.

If heavily damaged it is however recommended to recalibrate the sensor (with a standard two point calibration, see Operating Manual or OxyView software).

If the sensor behaves normally when placed in an air-bubbled water solution (showing 100 % saturation) the foil should be ok.

If the foil is not ok the sensor will return values that are illogical to what should be expected.

Then the foil needs to be exchanged, new calibration constants entered and a new two point calibration performed.

Remember that the Optode sensors can also be operated with transparent foils so the black protective layer is not essential.

If using a transparent foil it should then be noted that blue light will be spread out into the water.

This might induce primary production if measuring at a frequent time interval without moving the sensor.

MM 3
Q: I have an old RCM7/RCM8, can I mount the Optode and log it with this instrument?
A: No, the sensor does not fit physically on the top plate.
Neither will the RCM 7/8 be able to read the standard SR10 signal.

Response Time and Performance Checks

RTPC 1
Q: Why is the response time of the sensor slow?
A: It is slow because of two reasons.
First, the foil is covered with an opaque optical isolation layer to make it more rugged.
The optical isolation slows down the time it takes for oxygen to equilibrate within the foil.
Second, the response time of the temperature sensor, needed to compensate the optical readings, is also a limiting factor. In most long term applications the response time (t_{63} < 25 s) is sufficient but when doing fast profiling (e.g. with a CTD or on a towed vehicle) the response time can be a limiting factor.

RTPC 2
Q: What is the maximum sampling rate of the sensor?
A: 1 sample/second (1Hz).
If sampling at rates faster than 1 sample/5seconds please be aware of potential self heating errors (maximal error due to self heating 1-2µM).
When sampling at high rates it is better to power the sensor with 5 V (instead of higher tensions) to reduce the self heating (see above).

RTPC 3
Q: Can I check that the sensor is giving correct readings without doing any Winkler titration's?
A: Yes, if you have a glass of water that is open to the air and bubbled with an air pump (normally used in aquariums, compressor type pumps should be avoided) the water will rapidly become 100% saturated and it stays saturated if you continue the bubbling.
The bubbling also ensures mixing in the glass so that oxygen gradients do not form in the water.
The absolute concentration (in µM or mg/l) in this water, at saturation, is dependent on three parameters: the salinity, the temperature and the air pressure.
For example if the salinity is 0 ppt and the temperature is 20°C the oxygen concentration should be around 284µM but this value is given for an air-pressure of 1013 mbar.
The saturation values can be obtained from tables and/or mathematical formulas given in the Operating Manual.
If the air pressure is higher, for example 1030, you should expect higher readings of about (1030-1013) / 1013 = 27 / 1013 = 2.7% and if it is lower the readings should be lower.
If you would like to go further with your tests you can vary the temperature in the glass either by adding ice or by heating the water.
The saturation should then stay close to 100% at all the times but the absolute concentration will increase when the temperature goes down and decrease when it increases.
Of course the sensor should drop to 0 when you bubble the water with a different gas than air or oxygen (e.g. N_2 or Argon) or when you add for example Sodium sulfite to your water solution.

Please note that it can take quite some time before the water reaches a zero oxygen level when bubbling with gas.

Software, Settings, Communication and connection to various dataloggers (including CTD's)

SSC 1
Q: How do I most easily communicate and use the sensor from my PC? How do I calibrate it and set it up?
A: We recommend to use the OxyView software, which is available for a nominal license fee. This software is more or less self-explanatory and provides utilities, graphic & tabular display for set-up, calibration, logging etc. These functions are easily accessed without deeper knowledge about the sensor. As an alternative you can also communicate with any standard Terminal program (such as HyperTerminal included in Windows or Terra Terminal) but then you will have to read the Operating Manual carefully and every command has to be typed in separately.

SSC 2
Q: Many new PC's do not have a serial port. How can I communicate with the sensor without this?
A: The only way to communicate with the sensor is through the serial port. There are adaptors available that convert from USB to serial port. Experience has shown that these do not always function out of the box and may not be fully compatible with Windows or with your computer's specific software. It is recommended that you download the latest drivers from the Internet site of the manufacturer of the USB/serial adaptor. It has turned out that the drivers delivered with the adaptor are not always up to date.

SSC 3
Q: Which COM port is normally used when I use an USB/serial adaptor.
A: This varies from PC to PC and it has to be found out in the operative system.

SSC 4
Q: Is OxyView required to change the sampling interval? If not, how is it done?
A: No. However, it makes this process simpler. Communication and setting of sample intervals can all be done from a standard terminal program (like HyperTerminal). All this is explained in detail in the Operating Manual.

SSC 5
Q: What is the minimum supply voltage for the sensor?
A: The minimum supply is 5V the maximum is 14V.

SSC 6
Q: What is the peek current consumption for the sensor?
A: Less than 100mA (for 0.5 second).

SSC 7
Q: Is it possible to drive the Rx, Tx signals from the Optode directly by the 0-5V without a transceiver?
A: No, you must use RS-232 levels.

SSC 8
Q: When logging the sensor in RS232 format what is the minimum of signal lines we have to

connect?
A: The minimum is four; TX, RX, Positive Supply and GND. For more information refer the Operating Manual.

SSC 9
Q: If you switch ON / switch OFF the power supply between the data acquisition, do you have to keep a delay time before acquiring some data or after a new switch ON?
A: Yes, the sensor will always do a sample after power up. The data output is after approximately 2 seconds. Approximately 2 seconds power off is needed to assure a new reset of the Optode. So in total it is recommended to supply power to the sensor for a minimum of 5 seconds during each sampling period.

SSC 10
Q: If I have internally set the sensors sample interval to 2 seconds and then decide to mount it on e.g. an RCM9 current meter, logging at a 1 hour sample interval, will there be a conflict between the sensor's internal interval and the one used by the RCM9?
A: No, there will not be any conflict. When the Optode is used with an Aanderaa data logger the power is only applied when the data-logger scans the connected sensors (Control Voltage is active). Every time the sensor is powered up, regardless of the internal interval settings, it will output one data reading (requires that the SR10 output is enabled, see Operating Manual for more information). The same happens for the RS-232 output. Even if the sensor is set up for long measurement intervals it will output new data every time power is connected. If power is connected continuously the sensor will measure at the programmed time interval (anything from 1 second and upwards).

SSC 11
Q: I have connected the Optode to my Aanderaa current meter but no data is delivered from the sensor, why?
A: The Optode output has to be set to -1 or -2 to present data on the SR10 output channel. Please refer to the Operating Manual or the OxyView software for more information on how this is done.

SSC 12
Q: What should I think about if I want to use the optode mounted on a CTD or a towed vehicle?
A: In spite of the relatively slow response time with respect to these applications many customers have chosen to use the sensor mounted on a CTD, a profiling vehicle or a towed vehicle. Users have selected the optode mainly because of the long-term stability and the absence of pressure hysteresis. Mainly pressure hysteresis makes electrochemical sensors unreliable when profiling at depths beyond 500-1000 meters. Weather the slow response time of the optode will be an impediment to getting good data or not depends of course on how strong the gradients are and at what speed you are profiling/towing. Data from some successful profiling applications are presented on the Aanderaa Internet pages.

SSC 13
Q: How should I connect and mount the sensor on for example a CTD or a towed vehicle?
A: If the CTD is equipped with a fast responding temperature sensor it is better to do the temperature compensation externally. This will improve the accuracy when subjected to fast temperature changes (when going through a gradient). The Optode must then be configured to output differential phase shift information (DPhase). Based on this data and the temperature data from the CTD, the oxygen concentration can be calculated with formulas (see the Operating Manual for details). If the CTD is not able to receive the RS-232 output, the Oxygen Optode 3975 with analog output can be used. The two channel "intelligent" digital to analog converter supplied with this sensor is able to output two channels of your selection (including DPhase).

The optode has normally been mounted on the lower part of the CTD and with the window (where the foil is) close to a horizontal frame tube of the CTD. The hydrodynamic effect of the tube will then force water towards the foil and assures a good circulation both when going up and down. The optode of course has to be connected to the CTD with a cable.

SSC 14
Q: When powered on does the Optode expect a "XON" command before it starts or does it just start sending data?
A: The Optode does not wait for an "XON" before it starts.

Appendix 9 Oxygen Dynamics in Water

Seawater and Gases

Refer Unisense AS for tabulated physical parameters of interest to those working with micro sensors in marine systems:

http://www.unisense.com/support/support.html

Tables

Refer Unisense AS for Gas tables with diffusion coefficients, solubility of oxygen in seawater, density of water versus temperature and salinity, and much more:

http://www.unisense.com/support/pdf/gas_tables.pdf

Copies of Unisense AS tables for *solubility of oxygen in seawater* are given in Figure A 15, Figure A 16, and Figure A 17.

NOTE! Refer Unisens AS for more information about the tables.

Oxygen solubility at different temperatures and salinities of seawater

Units:µmol/l

Salinity	Temperature (°C)																				
(‰)	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0
0.0	456.6	444.0	431.9	420.4	409.4	398.9	388.8	379.2	369.9	361.1	352.6	344.4	336.6	329.1	321.9	314.9	308.3	301.8	295.6	289.7	283.9
1.0	453.5	441.0	429.0	417.6	406.7	396.3	386.3	376.7	367.6	358.8	350.4	342.3	334.5	327.1	319.9	313.0	306.4	300.0	293.9	287.9	282.2
2.0	450.4	438.0	426.1	414.8	404.0	393.6	383.7	374.3	365.2	356.5	348.1	340.1	332.4	325.0	317.9	311.1	304.5	298.2	292.1	286.2	280.6
3.0	447.3	435.0	423.2	412.0	401.3	391.0	381.2	371.8	362.8	354.2	345.9	338.0	330.4	323.0	316.0	309.2	302.7	296.4	290.4	284.5	278.9
4.0	444.2	432.0	420.4	409.2	398.6	388.5	378.7	369.4	360.5	351.9	343.7	335.9	328.3	321.0	314.0	307.3	300.9	294.6	288.6	282.9	277.3
5.0	441.1	429.1	417.5	406.5	396.0	385.9	376.3	367.0	358.2	349.7	341.6	333.7	326.2	319.0	312.1	305.5	299.0	292.9	286.9	281.2	275.7
6.0	438.1	426.1	414.7	403.8	393.3	383.3	373.8	364.6	355.9	347.5	339.4	331.6	324.2	317.1	310.2	303.6	297.2	291.1	285.2	279.5	274.0
7.0	435.1	423.2	411.9	401.1	390.7	380.8	371.3	362.3	353.6	345.2	337.2	329.6	322.2	315.1	308.3	301.7	295.4	289.4	283.5	277.9	272.4
8.0	432.1	420.3	409.1	398.4	388.1	378.3	368.9	359.9	351.3	343.0	335.1	327.5	320.2	313.1	306.4	299.9	293.6	287.6	281.8	276.2	270.8
9.0	429.1	417.5	406.3	395.7	385.5	375.8	366.5	357.6	349.0	340.8	333.0	325.4	318.2	311.2	304.5	298.1	291.9	285.9	280.1	274.6	269.2
10.0	426.1	414.6	403.6	393.0	383.0	373.3	364.1	355.2	346.8	338.6	330.8	323.4	316.2	309.3	302.6	296.2	290.1	284.2	278.5	273.0	267.6
11.0	423.2	411.8	400.8	390.4	380.4	370.8	361.7	352.9	344.5	336.5	328.7	321.3	314.2	307.3	300.8	294.4	288.3	282.5	276.8	271.3	266.1
12.0	420.3	409.0	398.1	387.8	377.9	368.4	359.3	350.6	342.3	334.3	326.7	319.3	312.2	305.4	298.9	292.6	286.6	280.8	275.1	269.7	264.5
13.0	417.4	406.2	395.4	385.2	375.3	366.0	357.0	348.3	340.1	332.2	324.6	317.3	310.3	303.5	297.1	290.8	284.8	279.1	273.5	268.1	262.9
14.0	414.5	403.4	392.7	382.6	372.8	363.5	354.6	346.1	337.9	330.0	322.5	315.3	308.3	301.7	295.2	289.1	283.1	277.4	271.9	266.5	261.4
15.0	411.7	400.6	390.1	380.0	370.4	361.1	352.3	343.8	335.7	327.9	320.5	313.3	306.4	299.8	293.4	287.3	281.4	275.7	270.2	265.0	259.9
16.0	408.8	397.9	387.4	377.4	367.9	358.7	350.0	341.6	333.5	325.8	318.4	311.3	304.5	297.9	291.6	285.5	279.7	274.0	268.6	263.4	258.3
17.0	406.0	395.2	384.8	374.9	365.4	356.4	347.7	339.4	331.4	323.7	316.4	309.4	302.6	296.1	289.8	283.8	278.0	272.4	267.0	261.8	256.8
18.0	403.2	392.5	382.2	372.4	363.0	354.0	345.4	337.2	329.2	321.7	314.4	307.4	300.7	294.2	288.0	282.1	276.3	270.8	265.4	260.3	255.3
19.0	400.4	389.8	379.6	369.9	360.6	351.7	343.1	335.0	327.1	319.6	312.4	305.5	298.8	292.4	286.3	280.3	274.6	269.1	263.8	258.7	253.8
20.0	397.7	387.1	377.0	367.4	358.2	349.3	340.9	332.8	325.0	317.6	310.4	303.5	296.9	290.6	284.5	278.6	273.0	267.5	262.3	257.2	252.3
21.0	394.9	384.5	374.5	364.9	355.8	347.0	338.6	330.6	322.9	315.5	308.4	301.6	295.1	288.8	282.7	276.9	271.3	265.9	260.7	255.7	250.8
22.0	392.2	381.8	371.9	362.4	353.4	344.7	336.4	328.5	320.8	313.5	306.5	299.7	293.2	287.0	281.0	275.2	269.7	264.3	259.1	254.1	249.3
23.0	389.5	379.2	369.4	360.0	351.0	342.4	334.2	326.3	318.7	311.5	304.5	297.8	291.4	285.2	279.3	273.5	268.0	262.7	257.6	252.6	247.9
24.0	386.8	376.6	366.9	357.6	348.7	340.2	332.0	324.2	316.7	309.5	302.6	295.9	289.6	283.4	277.5	271.9	266.4	261.1	256.0	251.1	246.4
25.0	384.1	374.0	364.4	355.2	346.4	337.9	329.8	322.1	314.6	307.5	300.7	294.1	287.8	281.7	275.8	270.2	264.8	259.5	254.5	249.6	244.9
26.0	381.5	371.5	361.9	352.8	344.0	335.7	327.7	320.0	312.6	305.5	298.7	292.2	285.9	279.9	274.1	268.5	263.2	258.0	253.0	248.2	243.5
27.0	378.8	368.9	359.5	350.4	341.7	333.4	325.5	317.9	310.6	303.6	296.8	290.4	284.2	278.2	272.4	266.9	261.6	256.4	251.5	246.7	242.1
28.0	376.2	366.4	357.0	348.0	339.5	331.2	323.4	315.8	308.6	301.6	294.9	288.5	282.4	276.5	270.7	265.3	260.0	254.9	250.0	245.2	240.6
29.0	373.6	363.9	354.6	345.7	337.2	329.0	321.2	313.8	306.6	299.7	293.1	286.7	280.6	274.7	269.1	263.6	258.4	253.3	248.5	243.8	239.2
30.0	371.0	361.4	352.2	343.4	334.9	326.9	319.1	311.7	304.6	297.8	291.2	284.9	278.8	273.0	267.4	262.0	256.8	251.8	247.0	242.3	237.8
31.0	368.5	358.9	349.8	341.1	332.7	324.7	317.0	309.7	302.6	295.9	289.3	283.1	277.1	271.3	265.8	260.4	255.3	250.3	245.5	240.9	236.4
32.0	365.9	356.5	347.4	338.8	330.5	322.5	314.9	307.7	300.7	294.0	287.5	281.3	275.4	269.6	264.1	258.8	253.7	248.8	244.0	239.4	235.0
33.0	363.4	354.0	345.1	336.5	328.3	320.4	312.9	305.6	298.7	292.1	285.7	279.5	273.6	268.0	262.5	257.2	252.2	247.3	242.6	238.0	233.6
34.0	360.9	351.6	342.7	334.2	326.1	318.3	310.8	303.7	296.8	290.2	283.9	277.8	271.9	266.3	260.9	255.7	250.6	245.8	241.1	236.6	232.2
35.0	358.4	349.2	340.4	332.0	323.9	316.2	308.8	301.7	294.9	288.3	282.0	276.0	270.2	264.6	259.3	254.1	249.1	244.3	239.7	235.2	230.9
36.0	355.9	346.8	338.1	329.7	321.7	314.1	306.7	299.7	293.0	286.5	280.3	274.3	268.5	263.0	257.7	252.5	247.6	242.8	238.2	233.8	229.5
37.0	353.5	344.4	335.8	327.5	319.6	312.0	304.7	297.7	291.1	284.6	278.5	272.5	266.8	261.4	256.1	251.0	246.1	241.4	236.8	232.4	228.2
38.0	351.0	342.0	333.5	325.3	317.4	309.9	302.7	295.8	289.2	282.8	276.7	270.8	265.2	259.7	254.5	249.5	244.6	239.9	235.4	231.0	226.8
39.0	348.6	339.7	331.2	323.1	315.3	307.9	300.7	293.9	287.3	281.0	274.9	269.1	263.5	258.1	252.9	247.9	243.1	238.5	234.0	229.7	225.5
40.0	346.2	337.4	329.0	320.9	313.2	305.8	298.7	292.0	285.4	279.2	273.2	267.4	261.8	256.5	251.4	246.4	241.6	237.0	232.6	228.3	224.1

Figure A 15 Copy of Data Table 6 by Niels Ramsing and Jens Gundersen: 100% Oxygen Solubility @ 1013 mbar pressure

Unisense

Oxygen solubility at different temperatures and salinities of seawater
Units:µmol/l

Salinity	Temperature (°C)																				
(‰)	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0	30.0	31.0	32.0	33.0	34.0	35.0	36.0	37.0	38.0	39.0	40.0
0.0	283.9	278.3	273.0	267.8	262.8	257.9	253.2	248.7	244.3	240.0	235.9	231.9	228.0	224.2	220.5	217.0	213.5	210.1	206.7	203.5	200.4
1.0	282.2	276.7	271.4	266.3	261.3	256.5	251.8	247.3	243.0	238.7	234.6	230.6	226.8	223.0	219.4	215.8	212.3	209.0	205.7	202.5	199.3
2.0	280.6	275.1	269.8	264.7	259.8	255.0	250.4	245.9	241.6	237.4	233.3	229.4	225.6	221.8	218.2	214.7	211.2	207.9	204.6	201.4	198.3
3.0	278.9	273.5	268.3	263.2	258.3	253.6	249.0	244.6	240.3	236.1	232.1	228.1	224.3	220.6	217.0	213.5	210.1	206.8	203.6	200.4	197.3
4.0	277.3	271.9	266.7	261.7	256.8	252.1	247.6	243.2	238.9	234.8	230.8	226.9	223.1	219.5	215.9	212.4	209.0	205.7	202.5	199.4	196.3
5.0	275.7	270.3	265.2	260.2	255.4	250.7	246.2	241.8	237.6	233.5	229.5	225.7	221.9	218.3	214.7	211.3	207.9	204.6	201.4	198.3	195.3
6.0	274.0	268.7	263.6	258.7	253.9	249.3	244.8	240.5	236.3	232.2	228.3	224.4	220.7	217.1	213.6	210.2	206.8	203.6	200.4	197.3	194.3
7.0	272.4	267.2	262.1	257.2	252.5	247.9	243.4	239.1	235.0	230.9	227.0	223.2	219.5	215.9	212.4	209.0	205.7	202.5	199.4	196.3	193.3
8.0	270.8	265.6	260.6	255.7	251.0	246.5	242.1	237.8	233.7	229.7	225.8	222.0	218.3	214.8	211.3	207.9	204.7	201.5	198.3	195.3	192.3
9.0	269.2	264.1	259.1	254.2	249.6	245.1	240.7	236.5	232.4	228.4	224.5	220.8	217.2	213.6	210.2	206.8	203.6	200.4	197.3	194.3	191.3
10.0	267.6	262.5	257.6	252.8	248.2	243.7	239.4	235.2	231.1	227.1	223.3	219.6	216.0	212.5	209.1	205.7	202.5	199.4	196.3	193.3	190.3
11.0	266.1	261.0	256.1	251.3	246.7	242.3	238.0	233.8	229.8	225.9	222.1	218.4	214.8	211.3	208.0	204.7	201.4	198.3	195.3	192.3	189.4
12.0	264.5	259.5	254.6	249.9	245.3	240.9	236.7	232.5	228.5	224.6	220.9	217.2	213.7	210.2	206.8	203.6	200.4	197.3	194.2	191.3	188.4
13.0	262.9	257.9	253.1	248.4	243.9	239.6	235.3	231.2	227.3	223.4	219.7	216.0	212.5	209.1	205.7	202.5	199.3	196.2	193.2	190.3	187.4
14.0	261.4	256.4	251.6	247.0	242.5	238.2	234.0	229.9	226.0	222.2	218.5	214.9	211.4	208.0	204.6	201.4	198.3	195.2	192.2	189.3	186.5
15.0	259.9	254.9	250.2	245.6	241.1	236.8	232.7	228.6	224.7	220.9	217.3	213.7	210.2	206.8	203.6	200.4	197.2	194.2	191.2	188.3	185.5
16.0	258.3	253.4	248.7	244.2	239.8	235.5	231.4	227.4	223.5	219.7	216.1	212.5	209.1	205.7	202.5	199.3	196.2	193.2	190.2	187.4	184.6
17.0	256.8	252.0	247.3	242.8	238.4	234.2	230.1	226.1	222.2	218.5	214.9	211.4	208.0	204.6	201.4	198.2	195.2	192.2	189.3	186.4	183.6
18.0	255.3	250.5	245.9	241.4	237.0	232.8	228.8	224.8	221.0	217.3	213.7	210.2	206.8	203.5	200.3	197.2	194.1	191.2	188.3	185.4	182.7
19.0	253.8	249.0	244.4	240.0	235.7	231.5	227.5	223.6	219.8	216.1	212.5	209.1	205.7	202.4	199.2	196.1	193.1	190.2	187.3	184.5	181.7
20.0	252.3	247.6	243.0	238.6	234.3	230.2	226.2	222.3	218.6	214.9	211.4	207.9	204.6	201.3	198.2	195.1	192.1	189.2	186.3	183.5	180.8
21.0	250.8	246.1	241.6	237.2	233.0	228.9	224.9	221.1	217.3	213.7	210.2	206.8	203.5	200.3	197.1	194.1	191.1	188.2	185.4	182.6	179.9
22.0	249.3	244.7	240.2	235.8	231.7	227.6	223.6	219.8	216.1	212.5	209.1	205.7	202.4	199.2	196.1	193.0	190.1	187.2	184.4	181.6	179.0
23.0	247.9	243.2	238.8	234.5	230.3	226.3	222.4	218.6	214.9	211.4	207.9	204.6	201.3	198.1	195.0	192.0	189.1	186.2	183.4	180.7	178.0
24.0	246.4	241.8	237.4	233.1	229.0	225.0	221.1	217.4	213.7	210.2	206.8	203.4	200.2	197.1	194.0	191.0	188.1	185.2	182.5	179.8	177.1
25.0	244.9	240.4	236.0	231.8	227.7	223.7	219.9	216.2	212.5	209.0	205.6	202.3	199.1	196.0	193.0	190.0	187.1	184.3	181.5	178.8	176.2
26.0	243.5	239.0	234.7	230.5	226.4	222.5	218.6	214.9	211.4	207.9	204.5	201.2	198.0	194.9	191.9	189.0	186.1	183.3	180.6	177.9	175.3
27.0	242.1	237.6	233.3	229.1	225.1	221.2	217.4	213.7	210.2	206.7	203.4	200.1	197.0	193.9	190.9	188.0	185.1	182.4	179.6	177.0	174.4
28.0	240.6	236.2	231.9	227.8	223.8	219.9	216.2	212.5	209.0	205.6	202.3	199.0	195.9	192.9	189.9	187.0	184.2	181.4	178.7	176.1	173.5
29.0	239.2	234.8	230.6	226.5	222.5	218.7	215.0	211.4	207.9	204.5	201.2	198.0	194.8	191.8	188.9	186.0	183.2	180.5	177.8	175.2	172.6
30.0	237.8	233.5	229.3	225.2	221.3	217.4	213.7	210.2	206.7	203.3	200.1	196.9	193.8	190.8	187.9	185.0	182.2	179.5	176.9	174.3	171.7
31.0	236.4	232.1	227.9	223.9	220.0	216.2	212.5	209.0	205.5	202.2	199.0	195.8	192.7	189.8	186.9	184.0	181.3	178.6	175.9	173.4	170.9
32.0	235.0	230.7	226.6	222.6	218.7	215.0	211.3	207.8	204.4	201.1	197.9	194.7	191.7	188.7	185.9	183.0	180.3	177.6	175.0	172.5	170.0
33.0	233.6	229.4	225.3	221.3	217.5	213.8	210.1	206.7	203.3	200.0	196.8	193.7	190.7	187.7	184.9	182.1	179.4	176.7	174.1	171.6	169.1
34.0	232.2	228.0	224.0	220.0	216.2	212.5	209.0	205.5	202.1	198.9	195.7	192.6	189.6	186.7	183.9	181.1	178.4	175.8	173.2	170.7	168.2
35.0	230.9	226.7	222.7	218.8	215.0	211.3	207.8	204.3	201.0	197.8	194.6	191.6	188.6	185.7	182.9	180.1	177.5	174.9	172.3	169.8	167.4
36.0	229.5	225.4	221.4	217.5	213.8	210.1	206.6	203.2	199.9	196.7	193.6	190.5	187.6	184.7	181.9	179.2	176.5	173.9	171.4	168.9	166.5
37.0	228.2	224.1	220.1	216.2	212.5	208.9	205.4	202.1	198.8	195.6	192.5	189.5	186.6	183.7	180.9	178.2	175.6	173.0	170.5	168.1	165.7
38.0	226.8	222.7	218.8	215.0	211.3	207.7	204.3	200.9	197.7	194.5	191.4	188.5	185.6	182.7	180.0	177.3	174.7	172.1	169.6	167.2	164.8
39.0	225.5	221.4	217.5	213.8	210.1	206.6	203.1	199.8	196.6	193.4	190.4	187.4	184.5	181.7	179.0	176.3	173.8	171.2	168.7	166.3	164.0
40.0	224.1	220.1	216.3	212.5	208.9	205.4	202.0	198.7	195.5	192.4	189.3	186.4	183.5	180.8	178.1	175.4	172.8	170.3	167.9	165.5	163.1

Figure A 16 Copy of Data Table 7 by Niels Ramsing and Jens Gundersen: 100% Oxygen Solubility @1013 mbar pressure

Unisense

Oxygen solubility at different temperatures and salinities of seawater

Units:µmol/l

Salinity (‰)	Temperature (°C) 0.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0	95.0	100.0
0.0	456.6	398.9	352.6	314.9	283.9	257.9	235.9	217.0	200.4	185.6	172.2	159.9	148.3	137.2	126.5	115.9	105.5	95.1	84.7	74.5	64.3
5.0	441.1	385.9	341.6	305.5	275.7	250.7	229.5	211.3	195.3	181.0	168.1	156.2	145.0	134.2	123.8	113.6	103.4	93.3	83.2	73.2	63.3
10.0	426.1	373.3	330.8	296.2	267.6	243.7	223.3	205.7	190.3	176.6	164.1	152.6	141.7	131.3	121.2	111.3	101.4	91.6	81.7	71.9	62.2
15.0	411.7	361.1	320.5	287.3	259.9	236.8	217.3	200.4	185.5	172.3	160.2	149.1	138.6	128.5	118.7	109.0	99.4	89.8	80.2	70.7	61.2
20.0	397.7	349.3	310.4	278.6	252.3	230.2	211.4	195.1	180.8	168.0	156.4	145.6	135.5	125.7	116.2	106.8	97.5	88.1	78.8	69.4	60.2
25.0	384.1	337.9	300.7	270.2	244.9	223.7	205.6	190.0	176.2	163.9	152.7	142.3	132.4	123.0	113.7	104.6	95.5	86.4	77.3	68.2	59.2
30.0	371.0	326.9	291.2	262.0	237.8	217.4	200.1	185.0	171.7	159.9	149.0	139.0	129.4	120.3	111.3	102.5	93.6	84.8	75.9	67.0	58.2
35.0	358.4	316.2	282.0	254.1	230.9	211.3	194.6	180.1	167.4	155.9	145.5	135.7	126.5	117.7	109.0	100.4	91.8	83.2	74.5	65.8	57.2
40.0	346.2	305.8	273.2	246.4	224.1	205.4	189.3	175.4	163.1	152.1	142.0	132.6	123.7	115.1	106.7	98.3	90.0	81.6	73.1	64.7	56.3
45.0	334.4	295.8	264.6	238.9	217.6	199.6	184.2	170.8	159.0	148.3	138.6	129.5	120.9	112.6	104.4	96.3	88.2	80.0	71.8	63.5	55.3
50.0	323.0	286.1	256.3	231.7	211.3	194.0	179.2	166.3	154.9	144.7	135.3	126.5	118.2	110.1	102.2	94.3	86.4	78.5	70.5	62.4	54.4
55.0	311.9	276.7	248.2	224.7	205.1	188.5	174.3	161.9	151.0	141.1	132.1	123.6	115.5	107.7	100.0	92.4	84.7	77.0	69.2	61.3	53.5
60.0	301.3	267.7	240.4	217.9	199.1	183.2	169.6	157.7	147.1	137.6	128.9	120.7	112.9	105.4	97.9	90.5	83.0	75.5	67.9	60.2	52.6
65.0	291.0	258.9	232.8	211.3	193.3	178.1	165.0	153.5	143.4	134.2	125.8	117.9	110.4	103.1	95.8	88.6	81.4	74.1	66.6	59.2	51.7
70.0	281.0	250.4	225.5	204.9	187.7	173.0	160.5	149.5	139.8	130.9	122.8	115.2	107.9	100.8	93.8	86.8	79.8	72.6	65.4	58.1	50.8
75.0	271.4	242.2	218.4	198.7	182.2	168.2	156.1	145.6	136.2	127.7	119.9	112.5	105.5	98.6	91.8	85.0	78.2	71.2	64.2	57.1	50.0
80.0	262.2	234.2	211.5	192.6	176.8	163.4	151.9	141.7	132.7	124.6	117.0	109.9	103.1	96.4	89.9	83.3	76.6	69.9	63.0	56.1	49.1
85.0	253.2	226.6	204.8	186.8	171.7	158.8	147.7	138.0	129.3	121.5	114.2	107.3	100.8	94.3	88.0	81.6	75.1	68.5	61.8	55.1	48.3
90.0	244.5	219.1	198.3	181.1	166.7	154.3	143.7	134.4	126.0	118.5	111.5	104.9	98.5	92.3	86.1	79.9	73.6	67.2	60.7	54.1	47.5
95.0	236.2	211.9	192.1	175.6	161.8	150.0	139.8	130.8	122.8	115.6	108.8	102.4	96.3	90.2	84.3	78.2	72.1	65.9	59.6	53.1	46.6
100.0	228.1	205.0	186.0	170.3	157.1	145.8	136.0	127.4	119.7	112.7	106.2	100.0	94.1	88.3	82.5	76.6	70.7	64.6	58.4	52.2	45.8
105.0	220.3	198.2	180.2	165.1	152.5	141.7	132.3	124.0	116.7	109.9	103.6	97.7	92.0	86.3	80.7	75.0	69.3	63.4	57.4	51.2	45.1
110.0	212.7	191.7	174.5	160.1	148.0	137.7	128.7	120.8	113.7	107.2	101.2	95.4	89.9	84.4	79.0	73.5	67.9	62.1	56.3	50.3	44.3
115.0	205.4	185.4	169.0	155.2	143.7	133.8	125.2	117.6	110.8	104.5	98.7	93.2	87.9	82.6	77.3	72.0	66.5	60.9	55.2	49.4	43.5
120.0	198.4	179.3	163.6	150.5	139.5	130.0	121.8	114.5	108.0	102.0	96.4	91.0	85.9	80.8	75.7	70.5	65.2	59.8	54.2	48.5	42.8
125.0	191.6	173.4	158.5	146.0	135.4	126.3	118.4	111.5	105.2	99.4	94.1	88.9	83.9	79.0	74.0	69.0	63.9	58.6	53.2	47.7	42.1
130.0	185.0	167.7	153.4	141.5	131.4	122.8	115.2	108.5	102.5	97.0	91.8	86.9	82.0	77.3	72.5	67.6	62.6	57.5	52.2	46.8	41.3
135.0	178.7	162.2	148.6	137.2	127.6	119.3	112.1	105.7	99.9	94.6	89.6	84.8	80.2	75.6	70.9	66.2	61.3	56.4	51.2	46.0	40.6
140.0	172.6	156.9	143.9	133.1	123.8	115.9	109.0	102.9	97.3	92.2	87.4	82.9	78.4	73.9	69.4	64.8	60.1	55.3	50.3	45.1	39.9
145.0	166.6	151.7	139.4	129.0	120.2	112.7	106.0	100.2	94.9	90.0	85.4	80.9	76.6	72.3	67.9	63.5	58.9	54.2	49.3	44.3	39.2
150.0	160.9	146.7	134.9	125.1	116.7	109.5	103.2	97.5	92.4	87.7	83.3	79.0	74.9	70.7	66.5	62.2	57.7	53.1	48.4	43.5	38.6
155.0	155.4	141.9	130.7	121.3	113.3	106.4	100.3	95.0	90.1	85.6	81.3	77.2	73.2	69.1	65.1	60.9	56.6	52.1	47.5	42.7	37.9
160.0	150.1	137.2	126.5	117.6	110.0	103.4	97.6	92.5	87.8	83.4	79.3	75.4	71.5	67.6	63.7	59.6	55.4	51.1	46.6	42.0	37.2
165.0	144.9	132.7	122.5	114.0	106.7	100.5	94.9	90.0	85.5	81.4	77.4	73.6	69.9	66.1	62.3	58.4	54.3	50.1	45.7	41.2	36.6
170.0	139.9	128.3	118.7	110.5	103.6	97.6	92.3	87.6	83.4	79.4	75.6	71.9	68.3	64.7	61.0	57.2	53.2	49.1	44.9	40.5	36.0
175.0	135.1	124.1	114.9	107.2	100.6	94.9	89.8	85.3	81.2	77.4	73.8	70.2	66.8	63.3	59.7	56.0	52.1	48.2	44.0	39.7	35.3
180.0	130.5	120.0	111.3	103.9	97.6	92.2	87.4	83.1	79.1	75.5	72.0	68.6	65.2	61.9	58.4	54.8	51.1	47.2	43.2	39.0	34.7
185.0	126.0	116.0	107.8	100.8	94.8	89.6	85.0	80.9	77.1	73.6	70.3	67.0	63.8	60.5	57.1	53.7	50.1	46.3	42.4	38.3	34.1
190.0	121.7	112.2	104.3	97.7	92.0	87.0	82.7	78.7	75.2	71.8	68.6	65.4	62.3	59.2	55.9	52.6	49.1	45.4	41.6	37.6	33.5
195.0	117.5	108.5	101.0	94.7	89.3	84.6	80.4	76.7	73.2	70.0	66.9	63.9	60.9	57.9	54.7	51.5	48.1	44.5	40.8	36.9	32.9
200.0	113.5	104.9	97.8	91.8	86.7	82.2	78.2	74.6	71.4	68.3	65.3	62.4	59.5	56.6	53.6	50.4	47.1	43.6	40.0	36.3	32.4

Figure A 17 Copy of Data Table 8 by Niels Ramsing and Jens Gundersen: 100% Oxygen Solubility @1013 mbar pressure