TD 296 OPERATING MANUAL
Oxygen Optode 4531
April 2018

Oxygen Optode 4531

AANDERAA
a xylem brand

1st edition	05 February	2012	PRELIMINARY
2nd edition	03 July	2014	
3rd edition	02 June	2015	Pin configuration in chapter 1.6 updated
4th edition	31 January	2016	New foil version included and general upgrade
5th edition	16 April	2018	New cable 5972 and general update

© Copyright: Aanderaa Data Instruments AS

Table of content

INTRODUCTION 5
CHAPTER 1 Short description and specifications 7
1.1 Description 7
1.2 Oxygen Optode 4531 dimensions 9
1.3 Cable options for Oxygen Sensor 4531 9
1.4 Cable 5440 with Amphenol plug 10
1.5 Pin configuration for cable 5440 10
1.6 Connector 5441 with Subconn 11
1.7 Pin configuration for Connector 5441 11
1.8 Cable 5442 with free end 12
1.9 Wiring diagram for Oxygen Optode 4531 with free end cable 12
1.10 Cable 5443 with Subconn 13
1.11 Pin configuration for cable 5443 13
1.12 Cable 5972 with 9pin D-Sub 14
1.13 Pin configuration for cable 5972 14
1.14 User accessible sensor properties 14
1.15 Specifications 18
1.16 Manufacturing and Quality Control 18
CHAPTER 2 Sensor measurements and output 19
2.1 Analog Output 19
2.2 Calculating engineering data from analog signals 20
2.3 Default sensor settings 21
2.4 Sensor parameters 21
2.5 Sensor integrated firmware 21
2.6 Salinity compensation of data 22
2.7 Depth compensation of data 23
CHAPTER 3 Connection to PC 24
3.1 Sensor connection to PC/laptop 24
CHAPTER 4 Sensor configuration and operation using Real-Time Collector 26
4.1 Establishing a new connection 26
4.2 Changing Values 28
4.3 Deployment Settings 30
4.4 System Configuration 32
4.4.1 Common settings 33
4.4.2 Terminal Protocol settings 33
4.4.3 Analog Converter 34
4.4.4 Output Settings 36
4.4.5 Calibration 37
4.4.6 System Control 37
4.5 User Maintenance settings 38

4.4.7 Mandatory ... 39
4.4.8 Site Info ... 39
4.4.9 Serial Port ... 40
4.4.10 Calculation Settings ... 40
4.4.11 Calibration ... 41
4.4.12 Sample Settings ... 42
CHAPTER 5 Smart Sensor Terminal operation ... 43
5.1 Smart Sensor Terminal communication setup ... 43
5.2 Sensor Startup in Analog Output mode ... 43
5.3 Sensor startup in Smart Sensor Terminal mode ... 44
5.4 Startup info in AADI Real-Time mode ... 44
5.5 Communication sleep ... 45
5.6 Smart Sensor Terminal protocol ... 46
5.7 Passkey for write protection ... 47
5.8 Save and Reset ... 47
5.9 Available commands for the oxygen optodes ... 48
5.9.1 The Get command ... 49
5.9.2 The Set command ... 49
5.9.3 Formatting the output string ... 50
5.9.4 XML commands ... 50
5.10 Scripting -sending a string of commands ... 50
5.11 Sensor configuration ... 51
CHAPTER 6 Maintenance ... 52
6.1 Changing the sensor foil ... 54
6.1.1 Procedure for changing foil ... 54
6.2 Function test ... 56
6.3 Calibration ... 56
6.3.1 Calibration procedure using a terminal program ... 57
CHAPTER 7 Theory of operation ... 59
Appendix 1 The optical design ... 62
Appendix 2 Electronic and mechanical design ... 64
Appendix 3 Primer – Oxygen calculations in the sensor ... 66
Appendix 4 Product change notification: FW3 ... 69
Appendix 5 Examples of scientific papers in which Aanderaa Optodes have been used and evaluated ... 71
Appendix 6 Frequently Asked Questions – FAQ ... 74
Appendix 7 Oxygen Dynamics in Water ... 90
Seawater and Gases ... 90
Tables ... 90

INTRODUCTION

Purpose and scope

This document is intended to give the reader knowledge of how to operate, calibrate and maintain the Aanderaa Aqua Oxygen Optode 4531. It also aims to give insight in how the Oxygen Optode works.

Commercially available Oxygen Optodes for oceanographic application were introduced by Aanderaa Instruments in 2002. The proven long-term stability (years) and reliability of these sensors has revolutionized oxygen measurements and several thousand are in use in applications ranging from streams to the deepest trenches on earth, from fish farms to waste water, from polar ice to hydrothermal vents.

Aqua Oxygen Optode 4531 is based on the same technology as the deep water version 4831. The main difference is the housing and therefore the maximum depth range. 100 meter for 4531 and up to maximum 8000 meter for 4831.

Examples of scientific papers in which Aanderaa Oxygen Optodes have been used and evaluated can be found in Appendix 6

Document overview

CHAPTER 1 gives a short description of the Sensor including dimensions, available cables and sensor properties.

CHAPTER 2 gives the sensor output and calculation of engineering data from analog signals.

CHAPTER 3 describes connection to PC.

CHAPTER 4 describes sensor configuration using AADI Real-Time Collector.

CHAPTER 5 describes sensor configuration in Smart Sensor Terminal mode.

CHAPTER 6 describes sensor maintenance

CHAPTER 7 presents theory of operation.

Appendix 1 Optical design

Appendix 2 Electronic and mechanical design

Appendix 3 Formulas and calculations in the sensor

Appendix 4 Product change notification

Appendix 5 Example of scientific papers

Appendix 6 Frequently asked questions

Appendix 7 Oxygen dynamics in water

Applicable documents

Form 838	Test & Specification Sheet, Oxygen Optode 4531
Form 710	Calibration certificate, Oxygen Optode 4531
Form 770	Calibration certificate, sensing foil
D404	Data sheet, Oxygen Optode 4531

Abbreviations

ADC	Analogue to Digital Converter
ASCII	American Standard Code for Information Interchange
DSP	Digital Signal Processor
EPROM	Erasable Programmable Read Only Memory
FAQ	Frequently asked questions document, in appendix
LED	Light Emitting Diode
MSB	Most significant bit
O_2	Oxygen molecule
RTC	Real Time Clock
UART	Universal Asynchronous Transmitter and Receiver
UNESCO	The United Nations Educational, Scientific and Cultural Organization
USB	Universal Serial Bus

CHAPTER 1 Short description and specifications

1.1 Description

Oxygen Opotde 4531 is equipped with both serial RS-232 and analog output. RS-232 are used for both configuration and real time data output. In addition the sensor may be set to 0-5V or 4–20mA. A special version 4531B is also available with 0-10V analog output. If the analog output is not used we recommend switching of the analog circuit to save power. Factory settings for each of the sensor versions are:

- 4531A output: RS-232, 0 – 5V
- 4531B output: RS-232, 0 – 10V
- 4531C output: RS-232, 4 – 20mA
- 4531D output: RS-232

Version 4531A, 4531C and 4531D can all be set to 0-5V, 4-20mA or analog output disabled by using a RS-232 cable and a terminal program such as Terra Term, Hyper Terminal or AADI Real-Time Collector. 4531B has a different electronic board and can in addition to RS-232 only be set as 0-10V or analog output disabled. Please note that for analog 0-10V the minimum supply voltage is 12V compared to 7V for 0-5V and 4-20mA. Minimum supply voltage for RS-232 is 5V.

The sensor operating depth is 0 to 100m.

These sensors belong to the Aanderaa series of smart sensors. Apart from high quality temperature measurement, which is always included for automatic compensation, other smart sensors can measure Currents, Conductivity, Wave/Tide and Pressure. Common features for these sensors are:

- Multitasking, several parameters measured/calculated/presented with the same sensor e.g. for oxygen O_2 in µM, O_2 in % saturation, Temperature and Raw data.
- Calibration coefficients and unique identification number included.
- Autonomous sampling, down to 2sec. interval.
- RS-232 serial communication which means that the sensors can be connected directly to computers or data loggers e.g. from other manufacturers, gliders, floats, buoys, landers, cable operated and autonomous vehicles.

The lifetime-based luminescence quenching principle, as used in Aanderaa 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.
- Less affected by pressure.
- Pressure behavior is predictable and fully reversible.

The optode can be logged directly by a PC (via the RS-232 protocol) and by most custom made dataloggers and systems.

The Aanderaa Oxygen Optode 4531 is 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. Characteristic features of these foils and sensors are exceptional stability and robustness. Hundreds of examples exist of field stability for periods of 1-6 years (see summary of scientific publications). In addition the ability to withstand high temperatures, to have low and fully reversible pressure effects and minimal dry out effects are particularities of the Aanderaa optodes.

The 4531 optode is fitted with standard foil. The slow responding foil is robust and recommended in most applications. A black optical isolation coating protects the sensing complex from direct incoming sunlight and fluorescent particles in the water. It is always recommended to store sensors dark and to put them in water at least 24 h hours prior to the deployment.

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 housing.

The foil is excited by modulated blue light, and the optode measures the phase of a returned red light, ref Appendix 1. By linearizing and temperature compensating with an incorporated temperature sensor located on top of the sensor, the absolute O_2- concentration is determined.

1.2 Oxygen Optode 4531 dimensions

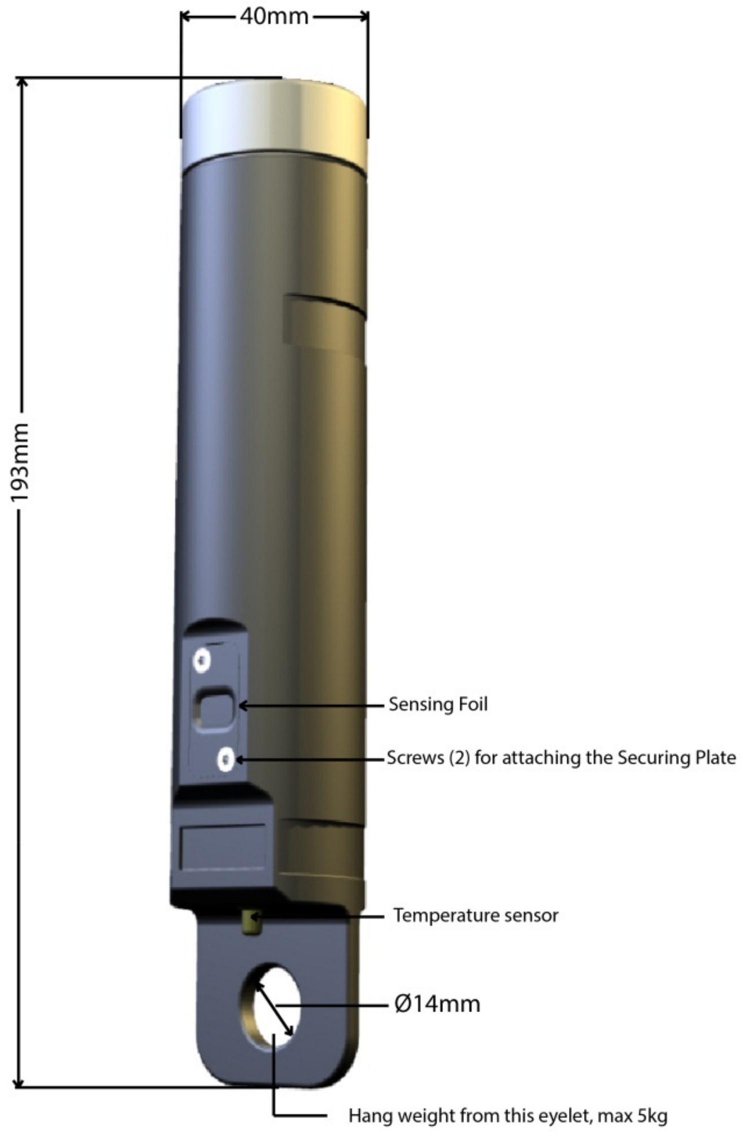


Figure 1-1 Illustration of Oxygen Optode 4531.

1.3 Cable options for Oxygen Sensor 4531

Four different cables are available for Oxygen Sensor 4531. Each cable is supplied with a Sensor end plug with nut for watertight connection to the sensor. See chapter 1.4 to 1.11 for illustration and pin configuration for each cable. The sensor can't operate without one of these cables.

1.4 Cable 5440 with Amphenol plug

Cable length is specified in the number, e.g. 5440A is a 20 meter long cable. Mates with Amphenol C16 female plug.

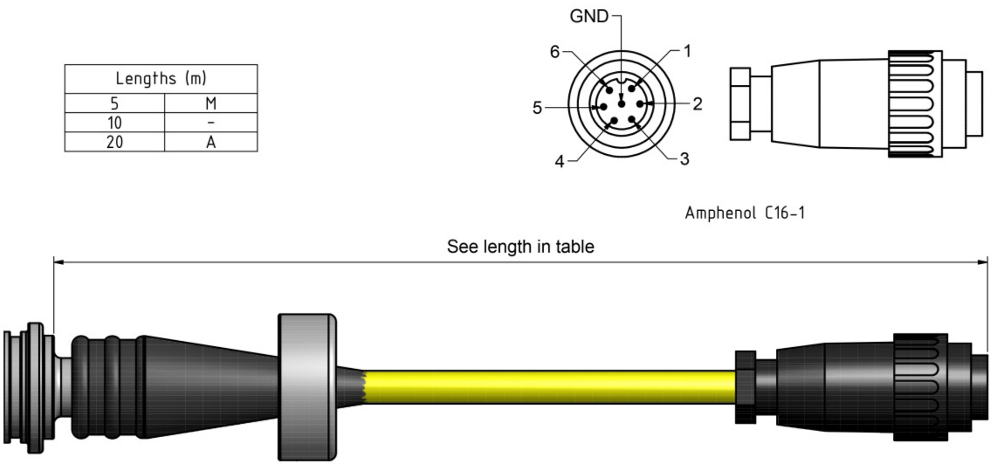


Figure 1-2 Cable 5440

1.5 Pin configuration for cable 5440

The cable 5440 including pin orientation is shown in Figure 1-2. Pin configuration and description is given in Table 1-1.

Table 1-1 Description of the Pin Configuration 5440

Pin	Description
1	Positive supply
2	Analog output 1 (Oxygen)
3	RS-232 TXD (Transmit line)
4	RS-232 RXD (Receive line)
5	Analog output 2 (Temperature)
6	Analog GND (Signal ground for Analog output)
GND	Signal ground

1.6 Connector 5441 with Subconn

Subconn connector MCBH8M connected directly to the sensor housing without any cable. This plug mates with e.g. Subconn MCBH8F/MCIL8F underwater mateable cable.

Figure 1-3 Connector 5441

1.7 Pin configuration for Connector 5441

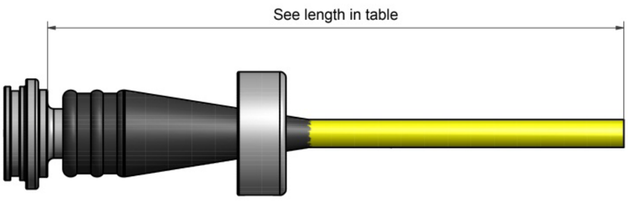
The connector 5441 pin orientation is given in Figure 1-3. Pin configuration and description is given in Table 1-2.

Table 1-2 Description of the Pin Configuration 5441

Pin	Description
1	Analog output 2 (Temperature)
2	RS-232 RXD
3	RS-232 TXD
4	Analog GND 2
5	Analog GND 1
6	Analog output 1 (Oxygen)
7	GND
8	Positive supply

1.8 Cable 5442 with free end

Cable length is specified in the number, e.g. 5442A is a 20 meter long cable.

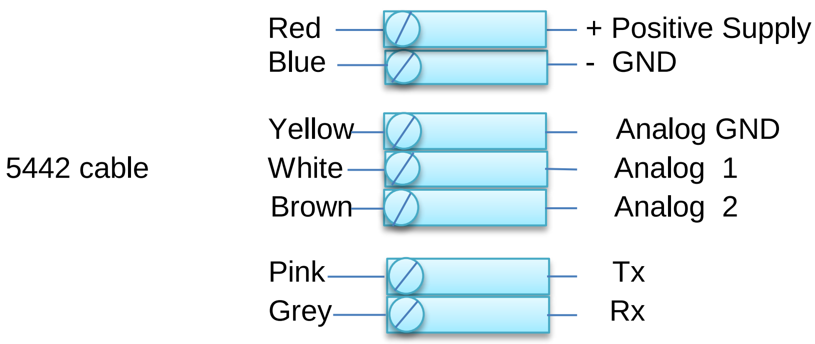


Lengths (m)	
5	M
10	-
20	A

Figure 1-4 Cable 5442

1.9 Wiring diagram for Oxygen Optode 4531 with free end cable

Cable 5442 is shown in Figure 1-4. Color code for each conductor with associated signal name is given in Figure 1-5.



Note! Do not connect green wire.

Figure 1-5 Wiring diagram for free end cable 5442.

1.10 Cable 5443 with Subconn

Subconn connector MCBH8M connected to the sensor housing with a 60 cm cable. This cable mates with e.g. Subconn MCBH8F/MCIL8F.

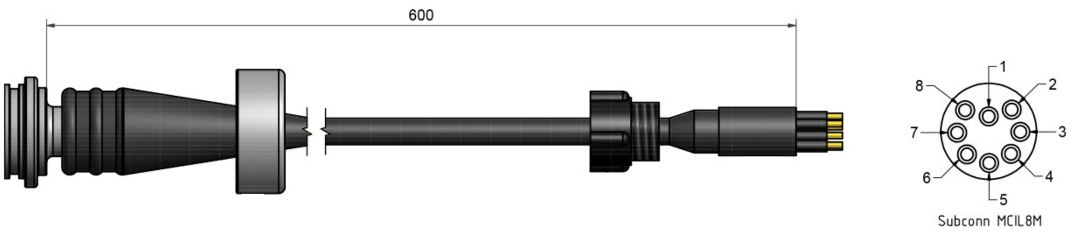


Figure 1-6 Cable 5443

1.11 Pin configuration for cable 5443

Pin orientation for 5443 is given in Figure 1-6. Pin configuration and description is given in Table 1-3.

Table 1-3 Description and Pin Configuration for 5443

Pin	Description
1	Analog output 2 (Temperature)
2	Analog output 1 (Oxygen)
3	Positive supply
4	Not Connected
5	RS-232 TXD (Transmit line)
6	Signal ground
7	Analog GND (Signal ground for Analog output)
8	RS-232 RXD (Receive line)

1.12 Cable 5972 with 9pin D-Sub

For configuration use and when sensor is used in RS-232 mode. The 9pin D-Sub plug mates with computer COM-ports. Cable length is specified in the number, e.g. 5440D is a 50 meter long cable. Note that with longer cables than 50 meter the sensor baud rate need to be reduced.

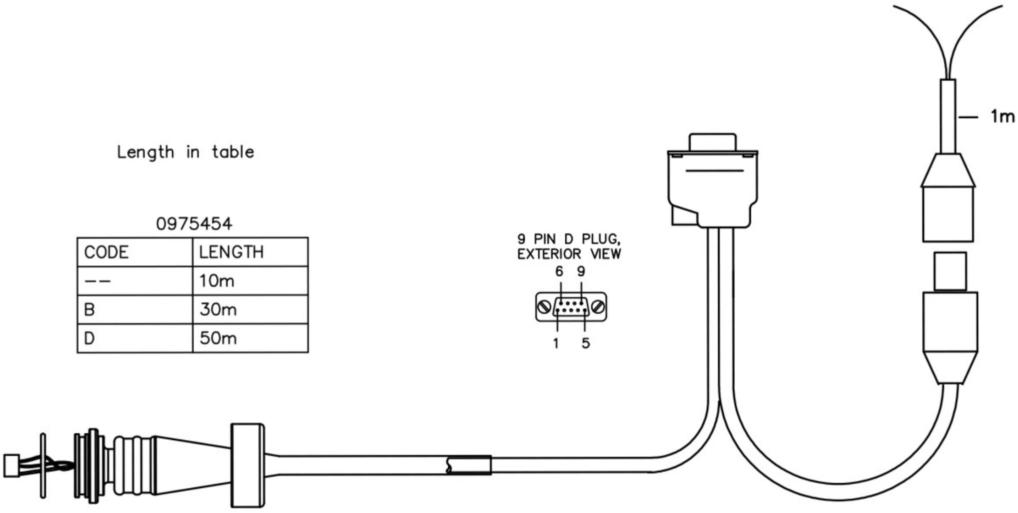


Figure 1-7 Cable 5972

1.13 Pin configuration for cable 5972

Pin orientation for 5972 is given in **Figure 1-7**. Pin configuration and description is given in **Table 1-4**.

Table 1-4 Description and Pin Configuration for 5972

9p D-Sub	USB	Description
2		TX-
3		RXD
5	4 (black)	GND
9	1 (red)	Positive Supply

1.14 User accessible sensor properties

All settings and configuration that determines the behavior 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 1-4 lists all user accessible properties for Oxygen Optode 4531.

Table 1-5 FC = Factory Configuration, UM = User Maintenance, SC = System Configuration, DS = Deployment setting. ENUM=Enumeration, INT =Integer, BOOL=Boolean ('yes'/'no')

Property	Type	No of elements	Use	Category	Access Protection RS-232
Product name	String	31	AADI Product name	FC	Read Only
Product Number	String	6	AADI Product number		
Serial Number	INT	1	Serial Number		
SW ID	String	11	Software Identifier		
SW Version	INT	3	Software version (Major, Minor, Built)		
HW ID X	String	19	Hardware Identifier, X=1..3		
HW Version X	String	9	Hardware Identifier, X=1..3		
System Control	INT	3	For internal use		
Production Date	String	31	AADI Production Date, format YYYY-MM-DD		
Last Service	String	31	Last service date, format YYYY-MM-DD, empty by default		
Last Calibration	String	31	Last calibration date, format YYYY-MM-DD		
Calibration Interval	INT	1	Recommended Calibration Interval in Days		
Interval	Float	1	Sampling Interval in seconds	DS	No
Location	String	31	User setting for location		
Geographic Position	String	31	User setting for geographic position, format: xx.xxxxxx,xx.xxxxx		
Vertical Position	Float	1	User setting for describing sensor position		
Reference	String	31	User setting for describing sensor reference		
Mode	Enum	1	Sets the sensor operation mode (Smart Sensor Terminal, AADI Real-Time, Smart Sensor Terminal FW2, Analog Output)	SC	Low
Enable Sleep	BOOL	1	Enable sleep mode		
Enable Polled Mode	BOOL	1	Enable Polled Mode (for RS-232), when set to 'no' the sensor will sample at the interval given by the *Interval* property, when set to 'yes' the sensor will wait for the Do Sample command.		
Enable Text	BOOL	1	Controls the insertion of descriptive text in Smart Sensor Terminal mode, i.e. parameter names and units, when set to 'no' the text is removed		

Enable Decimalformat	BOOL	1	Controls the use of decimal format in the output string in Smart Sensor Terminal mode. Default is scientific format (exponential format).	SC	Low
Analog TempLimit	Float	2	Lower and upper ranger limits for analog temperature output (Output 2), default -5 to 35°C		
Analog ConcLimit	Float	2	Lower and upper ranger limits for analog O2 concentration output (Output 1), default 0 to 800 µM		
Analog SatLimit	Float	2	Lower and upper ranger limits for analog Saturation output (Output 1), default 0 to 200%		
Analog PhaseLimit	Float	2	Lower and upper ranger limits for analog phase output (CalPhase,Output1), default 10 to 70°		
Analog Output	Enum	1	Controls which parameter is presented at analog Output; O2Concentration, AirSaturation, CalPhase, Fixed1, Fixed2		
Analog1 Volt Coef	Float	2	Coefficients (offset, slope) used for trimming the analog output1 in voltage operation		
Analog2 Volt Coef	Float	2	Coefficients (offset, slope) used for trimming the analog output2 in voltage operation		
Analog1 mA Coef	Float	2	Coefficients (offset, slope) used for trimming the analog output1 in current operation		
Analog2 mA Coef	Float	2	Coefficients (offset, slope) used for trimming the analog output2 in current operation		
Analog Type	BOOL	1	Selects voltage or current operation of the analog outputs, 0-5V(default) or 4-20mA		
Enable AirSaturation	BOOL	1	Controls inclusion of air saturation(%) in the output		
Enable Rawdata	BOOL	1	Controls inclusion of raw data in the output string		
Enable Temperature	BOOL	1	Controls inclusion of Temperature in the output		
Enable HumidityComp	BOOL	1	Enable compensation for vapor pressure, - disable only for use in dry air or external humidity compensation		
Enable SVUformula	BOOL	1	Used for foils with SVU coefficients		
Enable Burn-In Mode	BOOL	1	Enable burn-in mode, factory use only		
Node Description	String	31	User text for describing node, placement, number etc.	UM	High
Owner	String	31	User setting for owners name		
Baudrate	Enum	1	RS-232 baud rate: 300,1200,2400,4800,9600,57600,115200[1)]		
Flow Control	BOOL	1	RS-232 flow control: None or Xon/Xoff		
Enable Comm Indicator	BOOL	1	Enable the Communication Sleep (‘%’) and Communication Ready (‘!’) indicators		
Comm TimeOut	Enum	1	RS-232 communication activation timeout: Always On,10 s,20 s,30 s,1 min,2 min,5 min,10 min		

[1] Note! Baud rates lower than 9600 may limit the sampling frequency

Salinity	Float	1	Salinity (PSU) for use in salinity compensation of O_2 concentration, default 0	UM	High
TempCoef	Float	6	Curve fitting coefficients for the temp measurements.		
PTC0Coef	Float	4	Raw phase temperature compensation coefficients, normally not used (0,0,0,0)		
PTC1Coef	Float	4	Raw phase temperature compensation coefficients, normally not used (1,0,0,0)		
PhaseCoef	Float	4	Linearization coefficients for calculating compensated phase		
FoilID	String	9	Sensing Foil Identifier		
FoilCoefA	Float	14	Foil coefficients, general curve fit function, set A		
FoilCoefB	Float	14	Foil coefficients, general curve fit function, set B		
FoilPolyDegT	INT	28	Exponents for temperature, general curve fit function		
FoilPolyDegO	INT	28	Exponents for oxygen, general curve fit function		
SVUFoilCoef	Float	7	Foil coefficients for the 'Stern Volmer Uchida' formula		
ConcCoef	Float	2	Linear adjustments coefficients for final O_2 concentration calculation, nominal values 0 (offset) and 1 (slope).		
NomAirPress	Float	1	Nominal air pressure for use in O_2 concentration calculations		
NomAirMix	Float	1	Nominal O_2 percentage in air for use in O_2 concentration calculations		
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 10^{th} sample.		

1.15 Specifications

Refer Datasheet D404 for sensor specifications available on our web site http://www.aanderaa.com/ follow Products/Oxygen Optodes/Documents or contact aanderaa.info@xyleminc.com.

You will always 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. On our website http://www.aanderaa.com/ select Login and then Sign up. Please contact aanderaa.info@xyleminc.com for guidance.

1.16 Manufacturing and Quality Control

Aanderaa Data Instruments products have a record for proven reliability. With over 50 years' experience producing instruments for use in demanding environments around the globe you can count on our reputation of delivering the most reliable products available.

We are an ISO 9001, ISO 14001 and OHSAS 18001 Certified Manufacturer. As a company 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.

CHAPTER 2 Sensor measurements and output

All sensor models are equipped with serial RS-232 port. This interface can be used for both configuration and real time data output. The sensor can also be set to output 0-5V or 4-20mA. 4531B is a special version with 0-10V and RS-232 output. See list in CHAPTER 1 for all available versions. Analog output may be switched on/off or changed by using the RS-232 output.

RS-232 output parameters:

- O2-concentration in µM
- Air Saturation in %
- Temperature in °C
- Oxygen raw data
- Temperature raw data

2.1 Analog Output

Analog output parameters (0-5V, 0-10V or 4-20mA):

- Output 1 can be set to output either oxygen concentration, air saturation or raw data (CalPhase)
- Output 2 is designated to output temperature

Table 2-1 gives the calibrated range, the accuracy and resolution of the Oxygen Sensor 4531:

Table 2-1 Output specifications

Parameter	Output	Default range[2)]	Calibrated range	Accuracy	Resolution
Oxygen Concentration	0 - 5V	0 to 800µM	0 to 500µM	<8µM or 5% whichever is greater	< 1µM
	4 - 20mA	0 to 800µM	0 to 500µM	<9µM or 5.2% whichever is greater	< 1µM
Oxygen Saturation	0 - 5V	0 – 200%	0 - 120%	<5 %	<0.4%
	4 - 20mA	0 – 200%	0 - 120%	<5.2 %	<0.4%
Temperature	0 - 5V	-5 to + 35°C	0 - 36°C	±0.1°C	±0.01°C
	4 - 20mA	-5 to + 35°C	0 - 36°C	±0.15°C	±0.02°C

[2)] By default the range of the analog outputs are set wider than the calibrated range. The accuracy outside the calibrated range will be reduced.

2.2 Calculating engineering data from analog signals

Equations for calculating the engineering values from the raw data readings are given below. Please verify default range, not the calibrated range, refer Table 2-1.

From voltage (V_{out}) to temperature (°C): .... $T = \frac{V_{out} \cdot 40}{V_{max}} - 5$

From voltage (V_{out}) to Air Saturation (%): .... $AirSat = \frac{V_{out}}{V_{max}} \cdot 200$

From voltage (V_{out}) to Oxygen Concentration (µM): .... $Cons = \frac{V_{out}}{V_{max}} \cdot 800$

From current (I_{out}) to temperature (°C): .... $T = \frac{(I_{out} - 4) \cdot 40^{*}}{16} - 5$

From current (I_{out}) to Air Saturation (%): .... $AirSat = \frac{I_{out} - 4}{16} \cdot 200$

From current (I_{out}) to Oxygen Concentration (µM): .... $Cons = \frac{I_{out} - 4}{16} \cdot 800$

The range of the analog outputs can be changed by setting the lower and upper range limit. These limits are stored in the following properties:

Property	Default values		Default range	Parameter
	$Limit_0$	$Limit_1$		
Analog TempLimit	-5	35	Temperature	-5 to + 35°C
Analog ConcLimit	0	800	Oxygen Concentration	0 to 800µM
Analog SatLimit	0	200	Oxygen Saturation	0 – 200%
Analog PhaseLimit	10	70	Oxygen raw data	10 – 70°

When changing the analog output range the following equations must be used:

From voltage (V_{out}):

$$\boldsymbol{Enginering\ values = Limit_0 + \left(\frac{Limit_1 - Limit_0}{5}\right) \cdot V_{out}}$$

From current (I_{out}):

$$\boldsymbol{Enginering\ values = Limit_0 + \left(\frac{Limit_1 - Limit_0}{16}\right) \cdot (I_{out} - 4)}$$

Where $Limit_0$ and $Limit_1$ are the corresponding range limits for the parameter in use.

2.3 Default sensor settings

The default sensor setting is O_2 air saturation in %.

The default salinity value is 0. The setting can be changed according to the salinity conditions on site.

2.4 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 Oxygen content is presented in µM (1 Molar = 1 mole/liter). Conversion to other commonly used units is according to the following relationship: 1 ml/l = 44.66 µM, 1 mg/l = 31.25 µM. Please observe that to obtain absolute concentrations of oxygen these values needs to be salinity and pressure compensated, see chapter 2.6 and 2.7.
- The relative Air Saturation is presented in % relative to the nominal air pressure (1013.25 hPa). These values do not need to be salinity compensated.
- The ambient Temperature is presented in ºC.

The optode raw data 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. If raw data are not needed the user can select to turn off the delivery and logging of these.

2.5 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 RS-232 port, refer CHAPTER 4 and CHAPTER 5 for communication with the sensor using AADI Real-Time Collector or 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.

2.6 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 cannot 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.com and select Products/ Oxygen Optodes, then under Documents select Technical Notes and Oxygen Optode Calculations.

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 or PSU

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:

$$O_{2C} = [O_2] \cdot e^{(S - S_0)\left(B_0 + B_1 T_S + B_2 T_S^2 + B_3 T_S^3\right) + C_0 (S^2 - S_0{}^2)}$$

Where S_0 is the internal salinity setting.

2.7 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 1000 dbar – investigated in detail by Uchida et al., 2008, for full reference see publication list). This effect is the same for all Aanderaa oxygen optodes and 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 by a pressure sensor at the same level as the oxygen sensor is paced) – atmospheric pressure (measured by a barometer or set to nominal air pressure 1013).

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

$O_{2c}= 400\times1.000032= 400.012$ µM

Example 2: The measured O_2-concentration with the optode is 400 µM. The measurement was performed at 100m depth, which is 100dbar relative pressure.

$O_{2c}=400\times1.0032= 401.28$ µM

CHAPTER 3 Connection to PC

This chapter describes how to connect and communicate with the Oxygen Optode 4531, using the RS-232 protocol. Sensor configuration using AADI Real-Time Collector is described in CHAPTER 4 and sensor configuration using Terminal software like Tera Term or HyperTerminal is shown in CHAPTER 5.

3.1 Sensor connection to PC/laptop

Connect your sensor to one of the COM ports on your PC. If your PC comes without serial ports(COM ports) you may also use an USB to Serial Adapter. We then recommend the Tripp-lite Keyspan Model USA -19HS

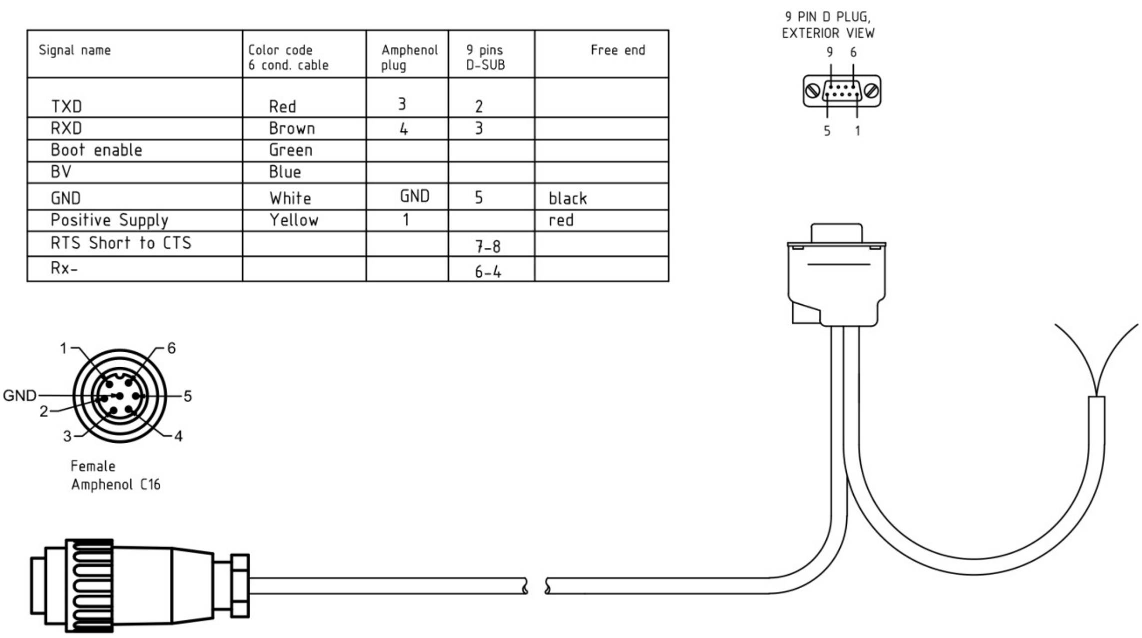
For sensors with cable 5440 an additional Sensor Cable 5427, refer Figure 3-1, is used for connection between the Amphenol plug and your PC.

For sensors with cable 5443 or connector 5441 an additional Sensor cable 5335, ref Figure 3-2, is used for connection between the Subconn plug and your PC.

For sensors with free end cable 5442 refer to chapter 1.8 and chapter 1.9 for connection between sensor and PC

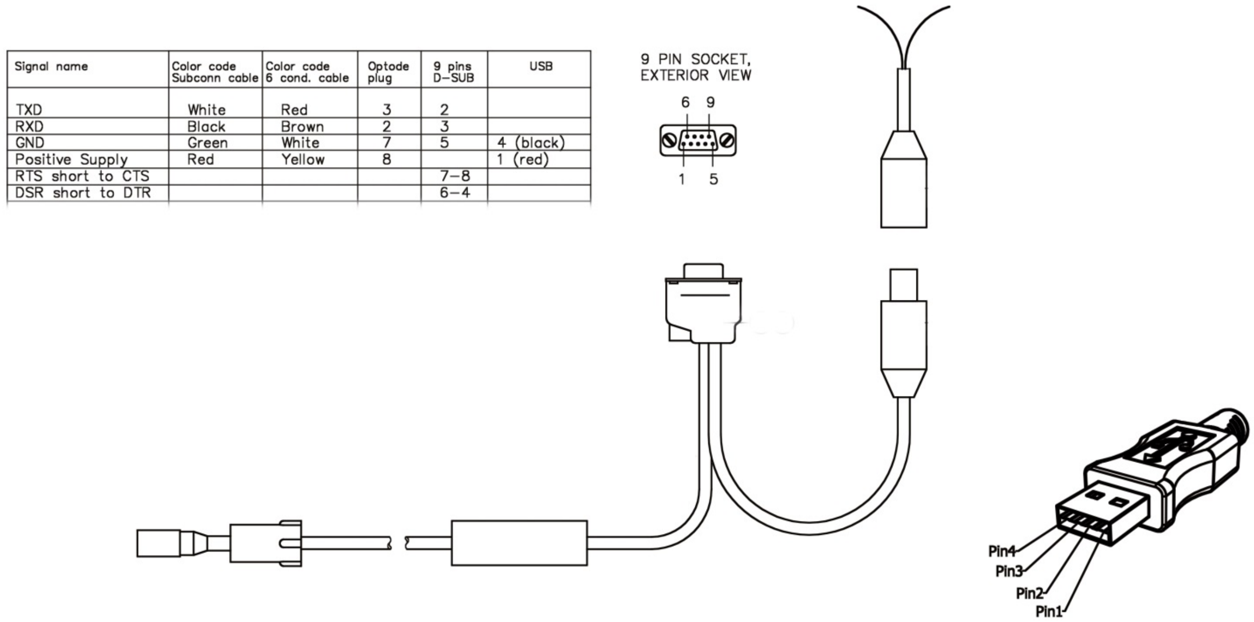
Note! If power cannot be obtained from an USB port a practical solution is to use a squared 9V alkaline battery (6LF22) to set the sensor up or log it in the laboratory.

Note! When Analog output is enabled most computers do not deliver enough power on USB to run the sensor. Then connect an external power source, 9V battery or laboratory supply to the power ports, Positive Supply and GND.



Signal name	Color code 6 cond. cable	Amphenol plug	9 pins D-SUB	Free end
TXD	Red	3	2	
RXD	Brown	4	3	
Boot enable	Green			
BV	Blue			
GND	White	GND	5	black
Positive Supply	Yellow	1		red
RTS Short to CTS			7-8	
Rx-			6-4	

Figure 3-1 PC connection cable 5427 with Amphenol



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

Figure 3-2 PC connection cable 5335 with Subconn

CHAPTER 4 Sensor configuration and operation using Real-Time Collector

This chapter describes the sensor configuration using AADI Real-Time Collector. Refer to CHAPTER 3 for description how to connect the sensor to a PC.

All sensors that are updated with Sensor Framework version 3 can be configured as stand-alone sensors using AADI Real-Time Collector. Multiple sensors may be connected to the same Collector. AADI Real-Time Collector is a configuration tool but may also be used for real-time presentation and storing data to log file if sensor is operating in AADI Real-Time mode.

Install and start the AADI Real-Time Collector software on your computer. For more information about the AADI Real-Time Collector, refer TD 268 AADI Real-Time Collector Operating Manual.

4.1 Establishing a new connection

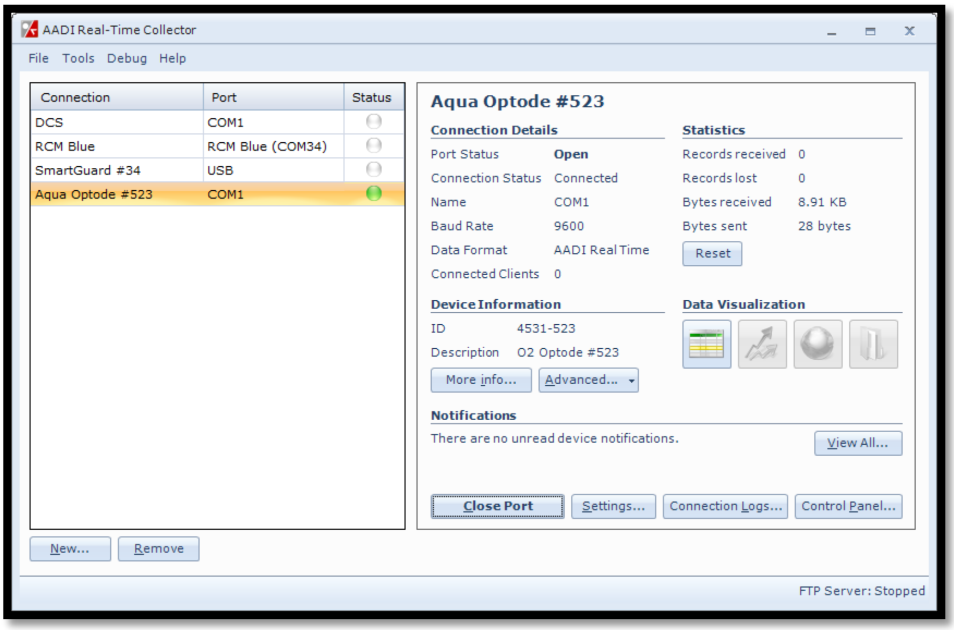


Figure 4-1: New connection

If the AADI Real-Time Collector program is being used for the first time, the connection list on the left side will be empty. Click on the ***New*** button in the lower left corner to create a new connection (refer Figure 4-1).

NOTE: This only needs to be done once. Next time you might select the connection name and press ***Open Port*** or even select ***Connect automatically on application startup*** in the ***Connection Settings*** menu.

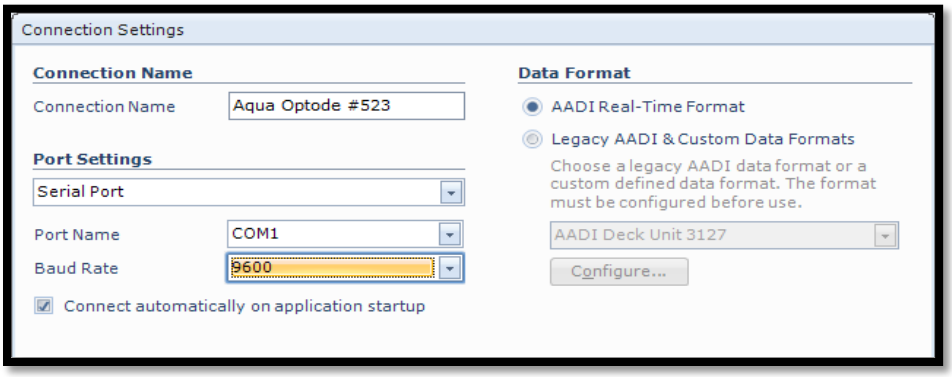


Figure 4-2: Connection Settings

After selecting ***New*** you will enter the ***Connection Settings*** menu. At any time you may go back to this menu by selecting ***Settings…*** in the main menu. Select ***Serial Port*** as Port setting and the ***COM*** port your sensor is connected to. ***9600*** is the default baud rate.

When the connection is established you can start and stop recordings or configure the device under the ***Control Panel*** located in the bottom right corner of the main menu.

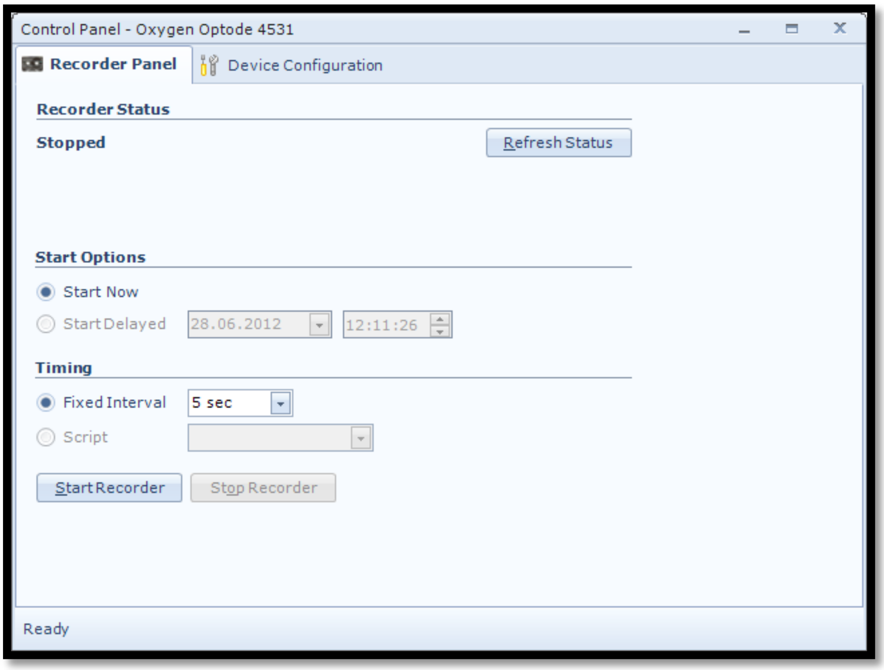


Figure 4-3: Recorder Panel

If the recorder is running you always need to stop it before you view or change settings and configurations, refer Figure 4-3. The recorder status is dependent on the sensor mode. To stop the recorder, select ***Recorder Panel*** and then ***Stop Recorder***.

Note! When operating in AADI Real-Time mode do not use 2 sec. intervals with baud-rate lower than 56700. Lower baud-rate will slow down the communication and the response time may exceed the default setting.

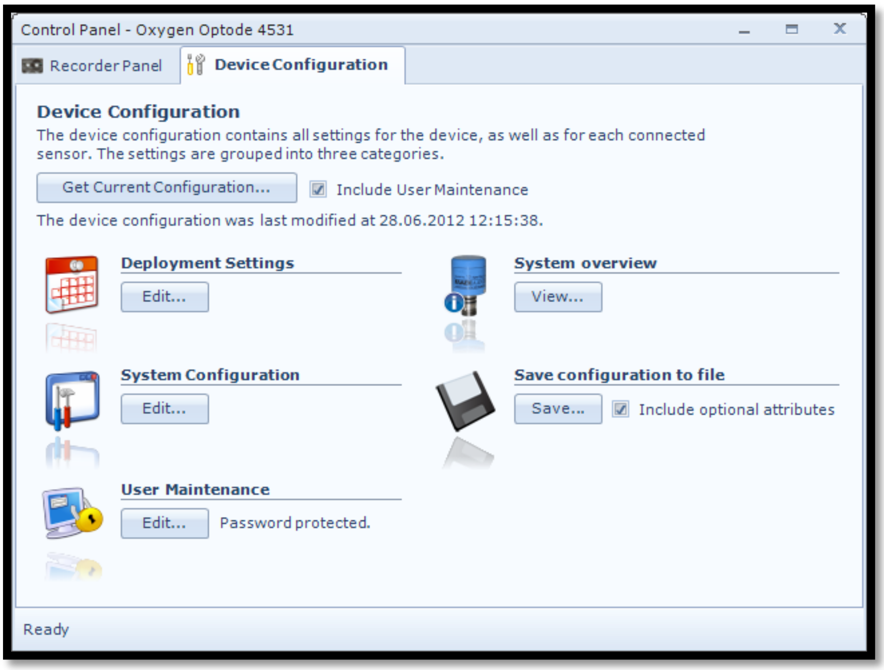


Figure 4-4: Device Configuration

Then select ***Device Configuration*** and press ***Get Current Configuration***. Check ***Include User Maintenance*** if you want to view/change maintenance settings. The password to access the ***User Maintenance*** menu is ***1000***.

Note! After changing some of the parameters you may go to recording panel and press Refresh Status to proceed.

Device Configuration is divided into five different groups.

- **Deployment Settings**
- **System Configuration**
- **User Maintenance**
- **System Overview**
- **Save Configuration to file**

User accessible sensor properties are found in ***Deployment Settings, System Configuration*** and ***User Maintenance***. ***Deployment Settings*** are described in chapter 4.3, ***System Configuration*** is described in chapter 4.4 and ***User Maintenance*** is described in chapter 4.5.

To edit the configuration, click in the value-field and enter new value. Press ***Next*** to update sensor flash and store changes. The new value is not stored before you get the confirmation from sensor. See chapter 4.2 for a full procedure.

4.2 Changing Values

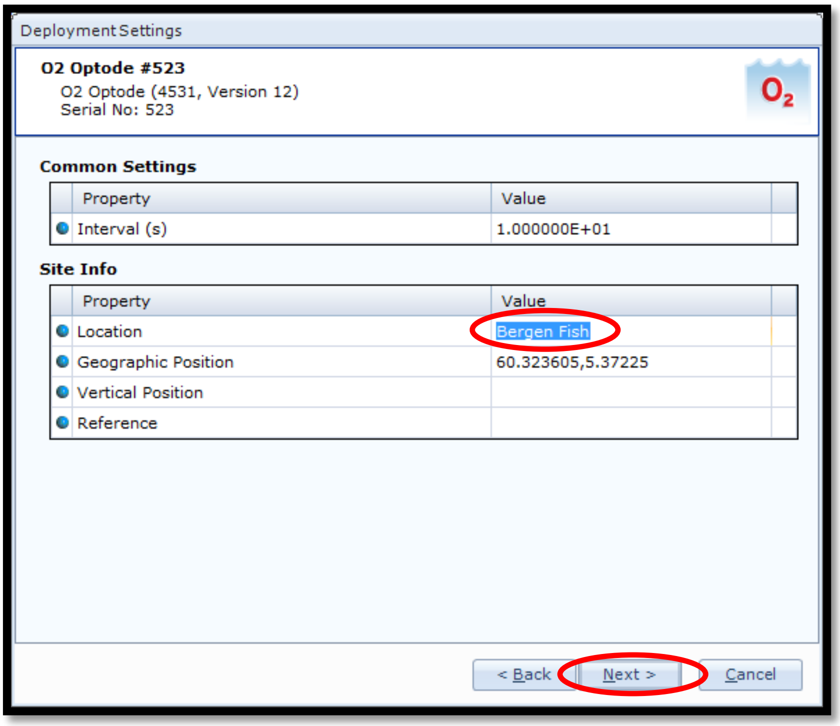
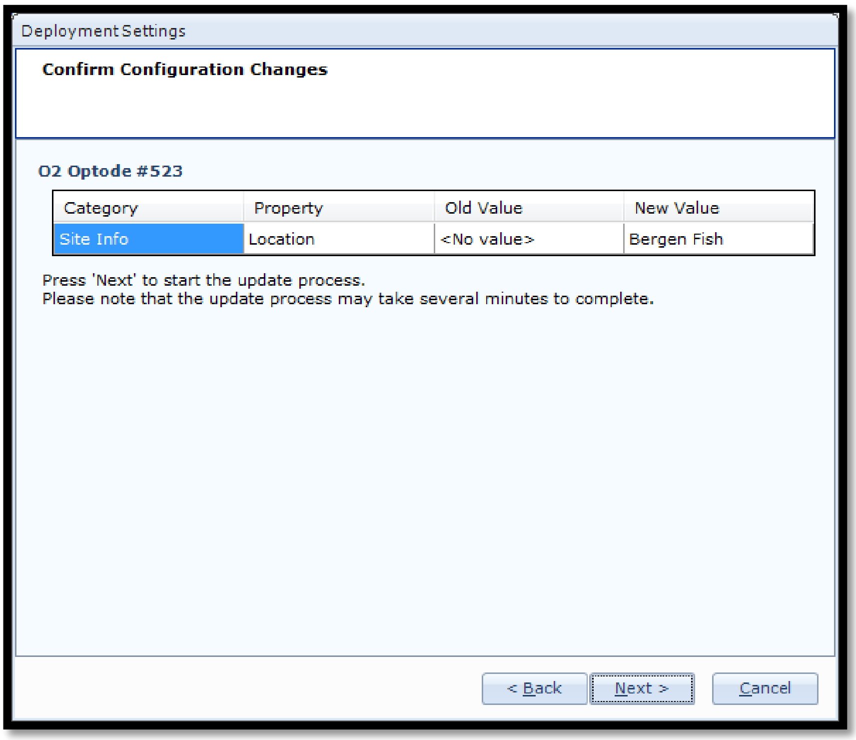


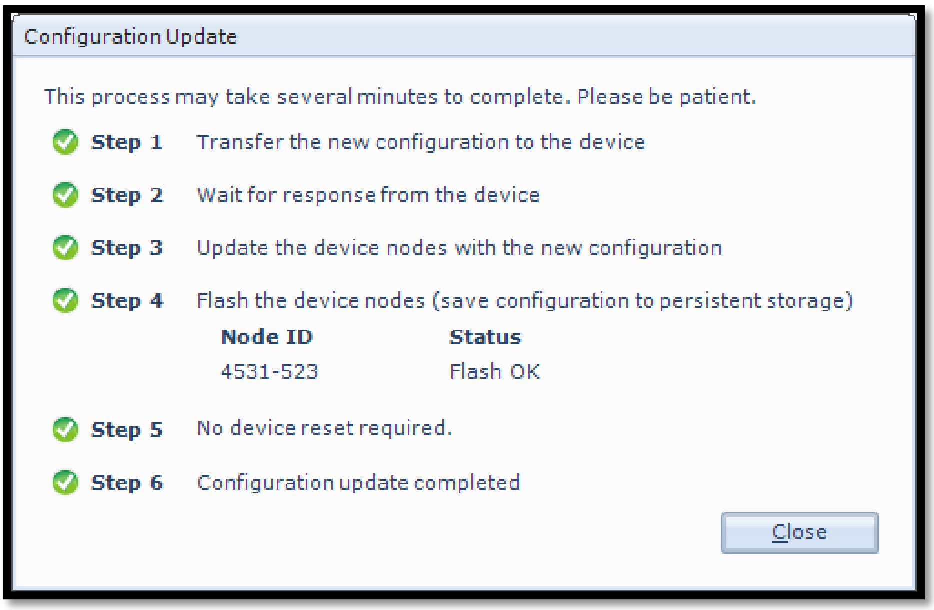
Figure 4-5 Change value

To change values enter the text or number in the value box and press ***Next.***



In next window you will find a list of changes. If the list of configuration changes is correct press ***Next*** to start the update process.

Figure 4-6 Confirm Configuration Changes



An automatic process will start with 6 steps transferring and storing the new information/settings in the sensor Flash. If necessary a reset will be executed. Do not switch off before the entire process is completed.

Figure 4-7 Configuration Update

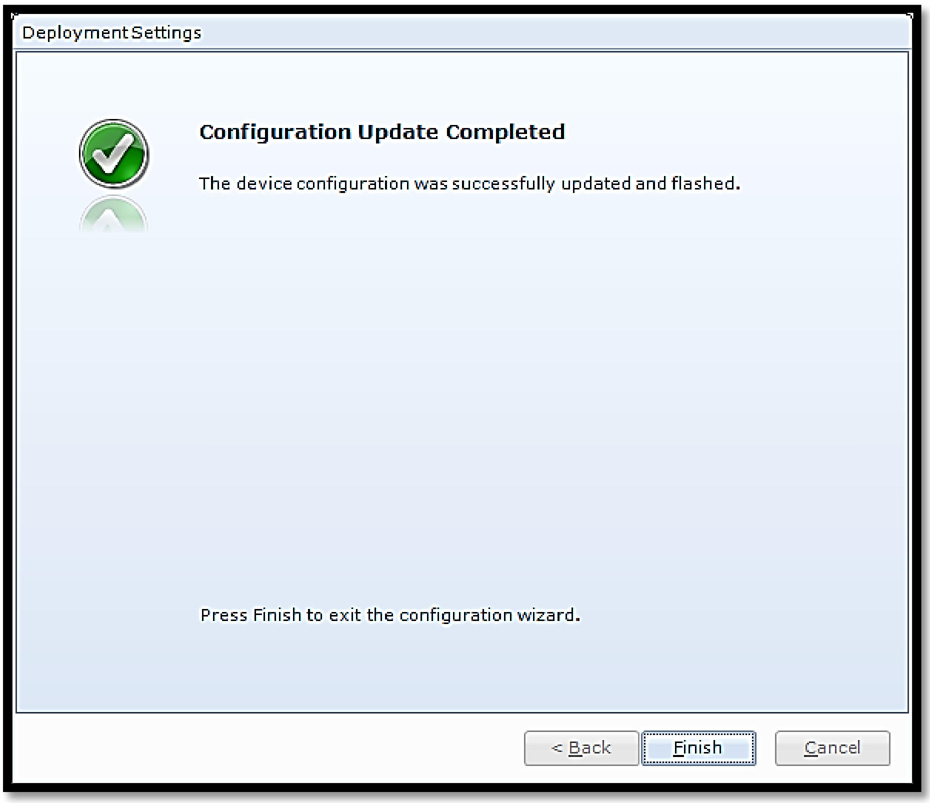


Figure 4-8 Configuration Update Completed

When the updating process is finished a confirmation will show up. Press Finish to continue.

Note! The screen shots might show minor discrepancies compared to screen shots taken from your sensor due to sensor updates. We recommend that you verify the system settings prior to starting a recording session.

4.3 Deployment Settings

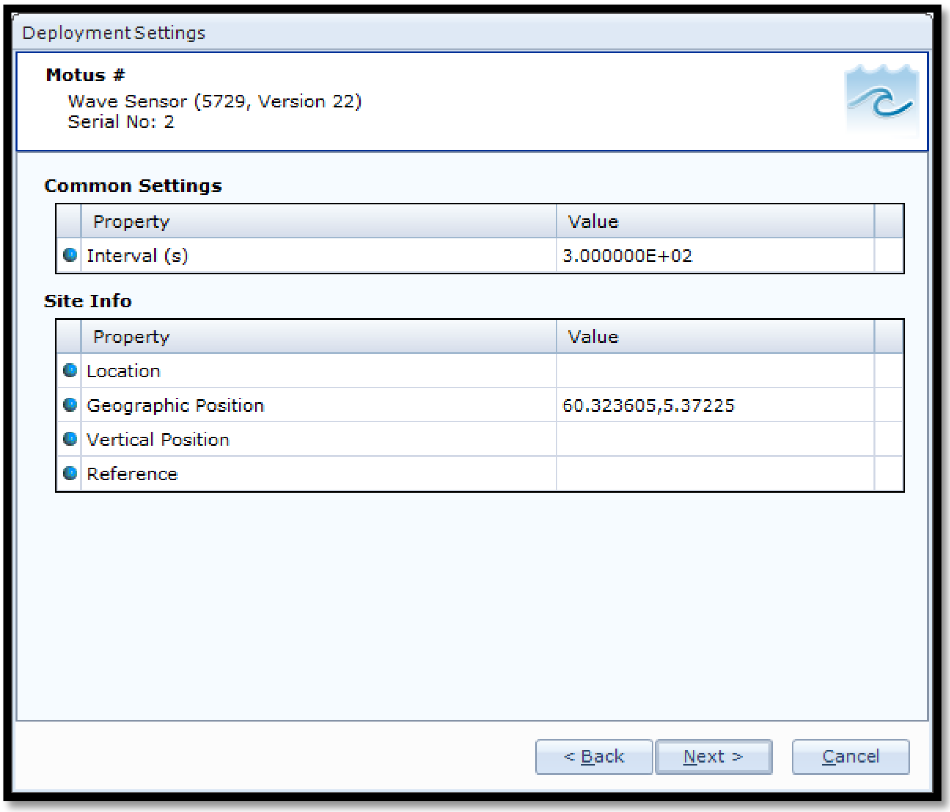


Figure 4-9: Deployment Settings

Select the ***Deployment Settings*** by pressing press "***Edit…***" in the Device Configuration menu, refer **Figure 4-1**.

This menu holds two different sections, ***Common Settings*** and ***Site Info.***

Under ***Common Settings*** you will find only one property, ***Interval (s).*** This setting is used to control the sensors recording interval, the number of seconds between each output.
This setting may also be set from ***Recorder Panel***. The last entered value will be the valid one if properly stored to flash.

Site Info is optional information to be entered to store information about the deployment. These setting are not used in internal calculations only stored as a part of the sensor Meta data. Geographical Position is however used to give the map coordinates to display software or post possessing software unless a GPS input is connected. The Properties under ***Site Info*** are:

- ***Location***
- ***Geographical Position***
- ***Vertical Position***
- ***Reference***

Location is typical the Site name or any name that can be used later to identify the location. ***Geographical Position*** is normally the GPS Coordinates for the deployment. This might also be in order to reproduce position in an electronic map. ***Vertical Position*** is used to set the deployment depth or position in a chain of sensors. ***Reference*** is a field where you might add information to be stored in the sensor metadata.

4.4 System Configuration

System Configurations holds six different sections that are controlling the output from the sensor. The sections are:

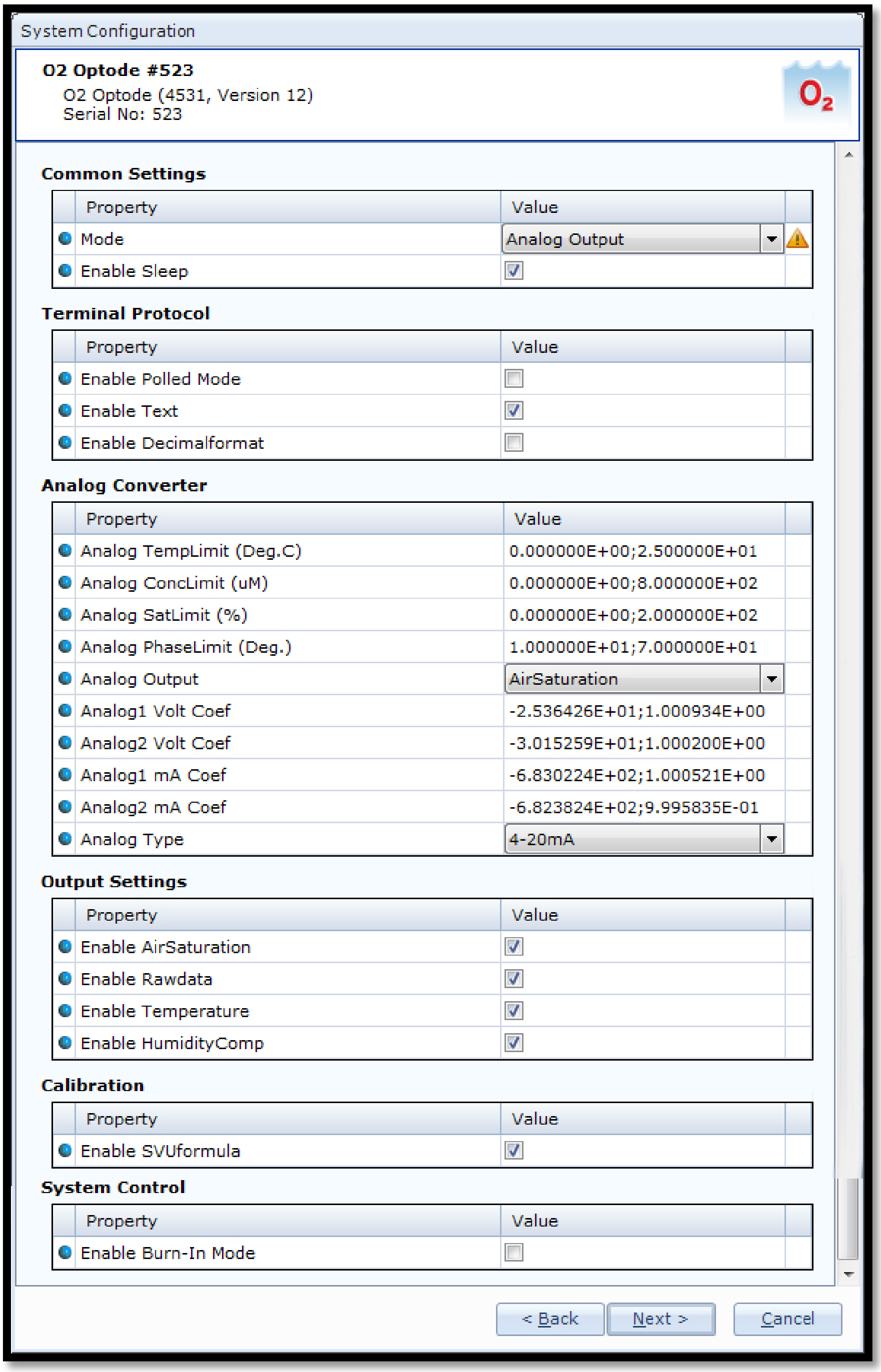


Figure 4-10: System Configuration

- ***Common Settings***
- ***Terminal Protocol***
- ***Analog Converter***
- ***Output Settings***
- ***Calibration***
- ***System Control***

See chapter 4.4.1 to chapter xx for a explanation of each parameter, Please note that some of the parameters are linked to specific modes and has no influence if the sensors is set to a different mode.

All parameters are also listed in Table 1-5

4.4.1 Common settings

Common Settings

Property	Value
Mode	AADI Real-Time
Enable Sleep	☑

Figure 4-11: Common Settings in System Configuration

The ***Common Settings*** are available as shown in Figure 4-11**.**
Mode: The communication protocol has to be defined under "***Mode".*** There are four different choices:

- ***AADI Real-Time*** is the correct mode (protocol) when used together with Real-Time Collector. This is an xml based protocol which includes more metadata in the data messages. If the sensor is connected via RS-232 to the PC it is possible to configure the sensor either if it is set to Analog Output, AADI Real-Time or Smart Sensor Terminal, but it is not possible to run and log data with Real-Time Collector unless the sensor is set to AADI Real-Time.
- The ***Smart Sensor Terminal*** protocol is a simplified ASCII protocol which is easier to use together with a PC terminal program. This protocol is described more detailed in CHAPTER 5. Notice that the sensor always has to be reset when the protocol/mode has been changed.
- ***Smart Sensor Terminal FW2*** is compatible with the older versions of Smart Sensor Terminal. This is normally only used if you need an output string similar to an older version of the sensor.
- ***Analog Output*** is used when you want an analog output in addition to the RS-232.

Enable Sleep: This setting gives lower power consumption in AADI Real-Time and Smart Sensor Terminal mode when the sensor is able to go to sleep between measurements.

4.4.2 Terminal Protocol settings

Terminal Protocol

Property	Value
Enable Polled Mode	☐
Enable Text	☑
Enable Decimalformat	☐

Figure 4-12: Terminal Protocol settings in System Configuration

The ***Terminal Protocol*** settings are available as shown in Figure 4-12 but are only used if the sensor is set to Smart Sensor Terminal protocol. See CHAPTER 5 for more details. If the ***Enable Polled Mode*** is enabled then the sensor outputs data when the user/system polls for data with a ***Do Sample ()*** command. ***Enable Text*** and ***Enable Decimalformat*** control the output string in Smart Sensor Terminal. With ***Enable Text*** enabled the sensor will put out a string with parameter name together with each reading, refer Figure 5-2 for an example where this command is toggled. ***Enable Decimalformat*** toggle between decimal format like 0.10 and Engineering format like 1.000E-01.

4.4.3 Analog Converter

Analog Converter

Property	Value
Analog TempLimit (Deg.C)	0.000000E+00;2.500000E+01
Analog ConcLimit (uM)	0.000000E+00;8.000000E+02
Analog SatLimit (%)	0.000000E+00;2.000000E+02
Analog PhaseLimit (Deg.)	1.000000E+01;7.000000E+01
Analog Output	AirSaturation
Analog1 Volt Coef	-2.536426E+01;1.000934E+00
Analog2 Volt Coef	-3.015259E+01;1.000200E+00
Analog1 mA Coef	-6.830224E+02;1.000521E+00
Analog2 mA Coef	-6.823824E+02;9.995835E-01
Analog Type	4-20mA

Figure 4-13: Analog Converter in System Configuration

Analog TempLimit(Deg.C) settings as shown in Figure 4-13 are settings used to set the range for the Temperature output. First value is the lower limit and second value is the higher limit. In Figure 4-13 the range is set from 0 Deg.C. to 25 Deg.C. Default Range is -5 Deg.C to 35 Deg.C. A more narrow range will increase the resolution.

Analog ConcLimit(uM) is used to set the range for Air Concentration in µM. The default range is from 0µM to 800µM. Please note that this exceeds the calibration range and that accuracy for readings above the calibrated range might be outside the specification. This setting is only valid if ***Analog Output*** is set to Air Concentration.

Analog SatLimit(%) is used to set the range for Air Saturation in %. The default range is from 0% to 200µM. Please note that this exceeds the calibration range and that accuracy for readings above the calibrated range might be outside the specification. This setting is only valid if ***Analog Output*** is set to Air Saturation.

Analog PhaseLimit(Deg.) is used to set the range for CalPhase/Oxygen raw data in Deg. The default range is from 10 Deg. to 70 Deg. This setting is only valid if ***Analog Output*** is set to CalPhase.

Analog Output. This setting selects what parameter to present on the Analog output channel 1. Temperature is always selected as Analog output channel 2. Available alternatives are:

- O2Concentration
- Air Saturation
- CalPhase
- Fixed1
- Fixed2.

Fixed1 and Fixed 2 are fixed values dependent on the Analog Type, see Table 4-1 for values. This setting is normally used to test the analog circuit with a fixed value from the sensor.

Property	Analog Output	Output 1	Output 2
0-5V	Fixed 1	4V	1V
	Fixed 2	1V	4V
4-20mA	Fixed 1	16.8mA	7.2mA
	Fixed 2	7.2mA	16.8mA
0-10V	Fixed 1	8V	2V
	Fixed 2	2V	8V

Table 4-1: Readings with Analog Output set to fixed

Analog1 Volt Coef, Analog2 Volt Coef, Analog1 mA Coef and ***Analog2 mA Coef*** are used during calibration to trim the analog output to match the sensor reading. If the analog value from the sensor differs from the reading due to cable length new coefficients might be calculated based on expected reading and actual reading. Expected analog output value are listed in the startup message when sensor is powered up, refer **Figure 5-1**. This adjustment might also be done in the PLC or similar if possible.

Analog1 Volt Coef is coefficients (offset, slope) used for trimming the analog output1 in voltage operation.

Analog2 Volt Coef is coefficients (offset, slope) used for trimming the analog output2 in voltage operation.

Analog1 mA Coef is coefficients (offset, slope) used for trimming the analog output1 in current operation.

Analog2 mA Coef is coefficients (offset, slope) used for trimming the analog output2 in current operation.

Analog Type is used to select the analog output signal. Available signal types are for version 4531A,4531C and 4531D:

- 4-20mA
- 0-5V

For version 4531B:

- 0-10V version 4531B)

Please note that 0-10V is only available with 4531B and this version cannot be set to any other output signals. Version 4531A is preset to ***Analog Type*** 0-5V but can easily be changed to 0-24mA by changing this property. 4531C is preset to 4-20mA but can easily be changed to 0-5V. 4531D is preset to analog output off. This might be changed by setting mode to ***Analog Output***, refer **Figure 4-11,** and then select the ***Analog Type***.

4.4.4 Output Settings

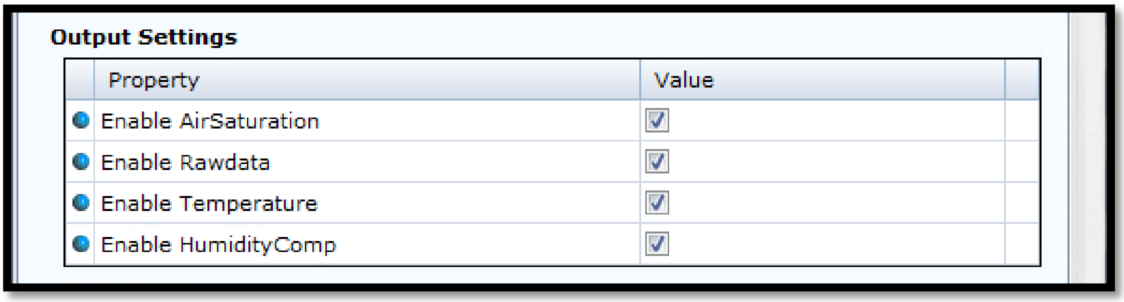


Figure 4-14: Output settings in System Configuration

The first three settings are used to control the serial output both for ASCII- and XML-output. The parameters will be included in the serial output string if setting is enabled. These settings do not influence the internal use of these parameters.

Enable AirSaturation. This setting is used to enable or disable the ***Air Saturation*** parameter from the output string.

Enable Rawdata. This setting toggles on and off a set of raw data readings from the serial output string. These rawdata readings are used internally in the calculation independently of this setting. The parameters are:

- ***CalPhase(Deg)***
- ***TCPhase(Deg)***
- ***C1RPh(Deg)***
- ***C2RPh(Deg)***
- ***C1Amp(mV)***
- ***C2Amp(mV)***
- ***RawTemp(mV)***

Enable Temperature. This setting is used to enable or disable the ***Temperature*** output. The temperature reading are used to compensate for internal temperature drift when oxygen level is calculated independently of this setting

Enable HumidityComp. This 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 (dry air) 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.

4.4.5 Calibration

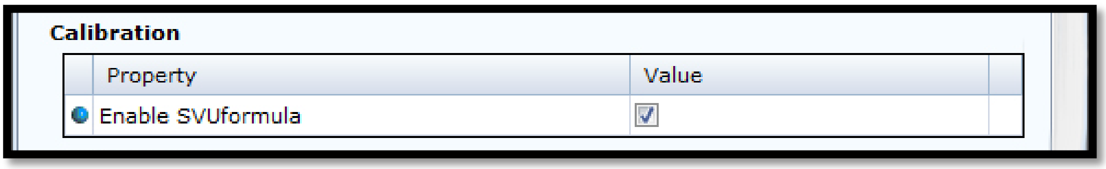


Figure 4-15: Calibration settings in System Configuration

Enable SVUformula. In order to use the “Stern-Volmer-Uchida” formula this property must be set to ‘yes’. The coefficients c_0 to c_6 are stored in the ***SVUFoilCoef*** property. Stern Volmer Uchida (SVU) formula is used for describing the relationship between phase shift/temperature and oxygen concentration.

4.4.6 System Control

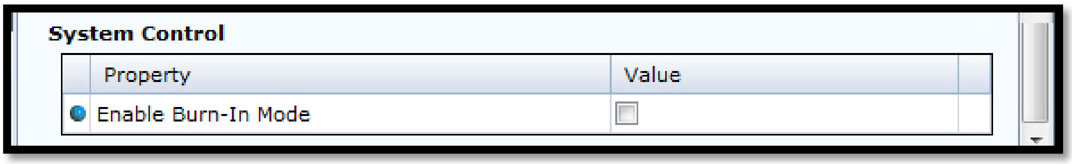


Figure 4-16: System Control settings in System Configuration

Enable Burn-in Mode are use internally at the factory to premature the foil before calibration. When enabled the sensor will blink at 1Hz. Don’t use this setting unintentional as it might influence the accuracy.

4.5 User Maintenance settings

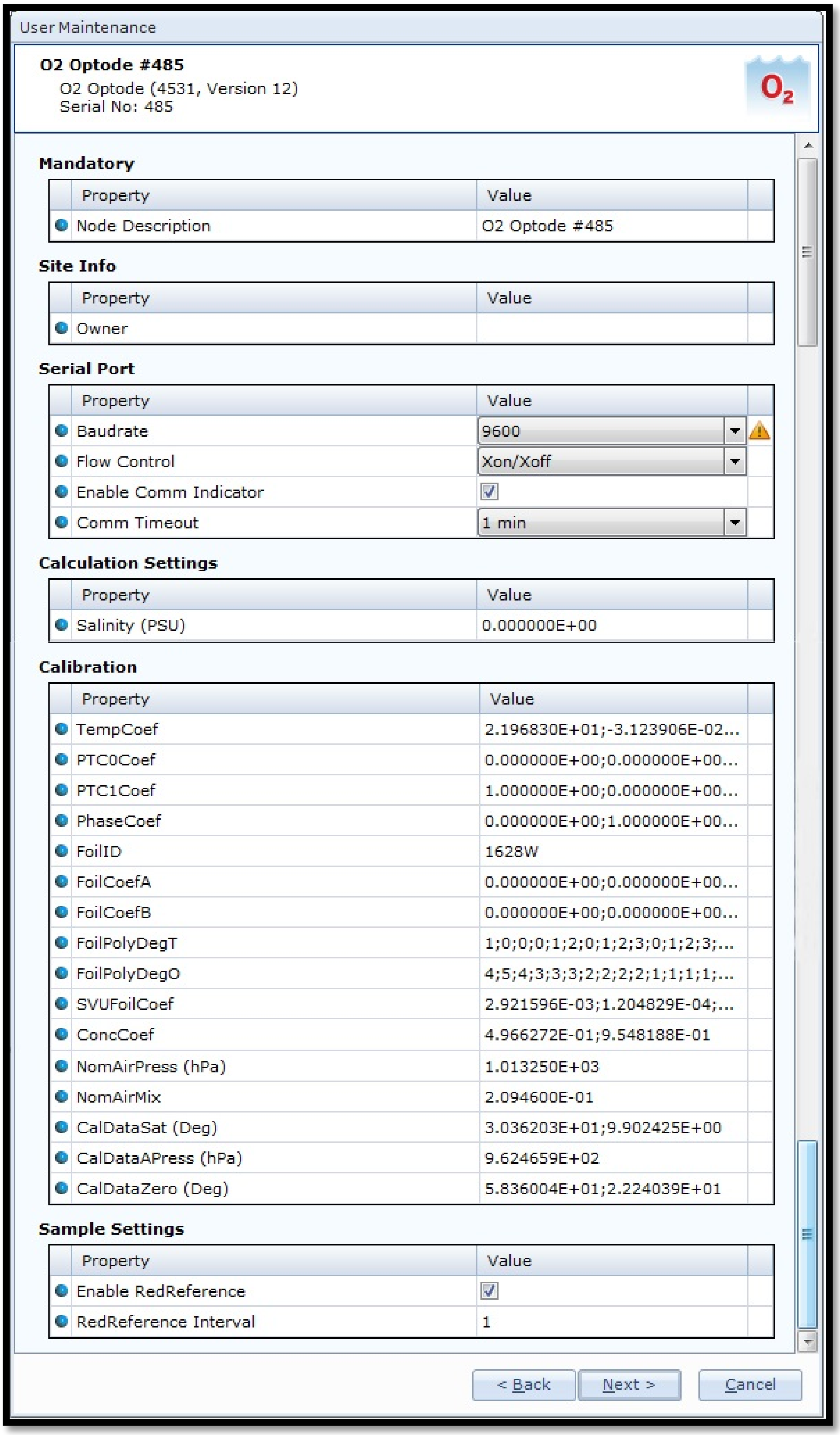


Figure 4-17: User Maintenance

Under ***User Maintenance***, you find properties that are password protected and are set or altered by a trained user. It is not recommended to change properties unless instructed. To access this menu, check the "***Include User Maintenance"*** box in the ***Device Configuration*** before clicking on the "***Get Current Configuration…***" button. The password is: **1000**. This menu consists of six sessions:

- **Mandatory**
- **Site Info**
- **Serial Port**
- **Calculation Settings**
- ***Calibration***
- ***Sample Settings***

For a full description of each property please refer to chapter 4.6.1 to 4.6.6.

4.4.7 Mandatory

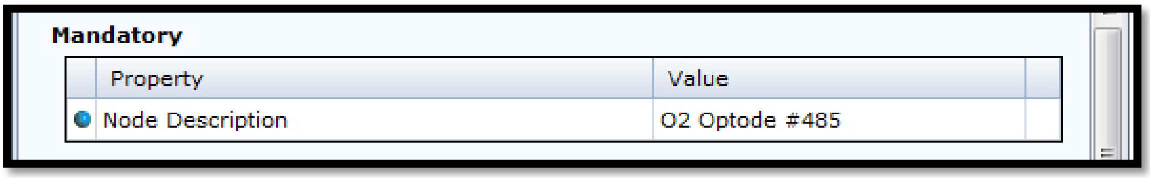


Figure 4-18: Mandatory in User Maintenance

In the ***Mandatory*** section you will find only one property, ***Node Description***. All sensors are given a ***Node Description*** text like O2 Optode #xxx (xxx is the serial number of the sensor) by default. The user can modify this ***Node Description*** text if required. Be aware that the ***Node Description*** changes to ****Corrupt Configuration*** if it has lost the configuration in flash. Contact the factory if this happens. The configuration is saved in two sectors in flash memory. A flash sector can be corrupted if the power is lost during the saving of new configuration. The double flash sector saving ensures that it does not lose the configuration. If one of the sectors is corrupted, the other sector is used and also saved to the corrupt sector.

4.4.8 Site Info

Figure 4-19; Site Info in User Maintenance

In the ***Site Info*** section you will find only one property. ***Owner*** is optional information to be entered to store information about the owner. This setting is not used in calculation. By default this setting is empty.

4.4.9 Serial Port

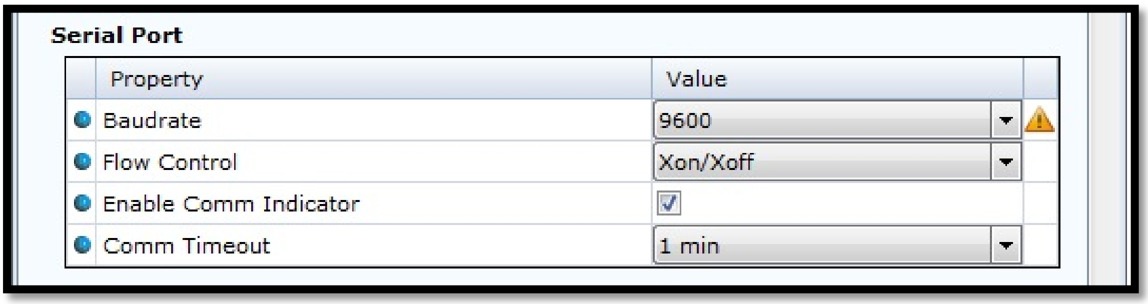


Figure 4-20: Serial Port settings in User Maintenance

The ***Serial Port*** group contains setting that deals with the RS-232 setup. When using RS-232 make sure that the sensor setting is the same as terminal software set-up. The default settings from factory for Baudrate are 9600 and ***Flow Control*** is set to Xon/Xoff. ***Enable Comm Indicator*** is enabling communication sleep ('%') and communication ready ('!') indicators, when set to ***Smart Sensor Terminal*** or ***Analog*** mode. '!' indicates that the sensor is ready to communicate after sleep and '%' indicates that the sensor is going to sleep due to inactivity longer than the value/time set in ***Comm Timeout***. The default settings are enable and 1 min.

4.4.10 Calculation Settings

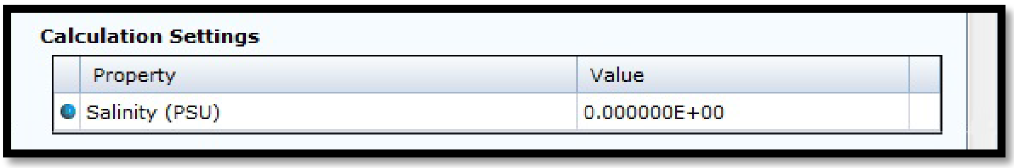
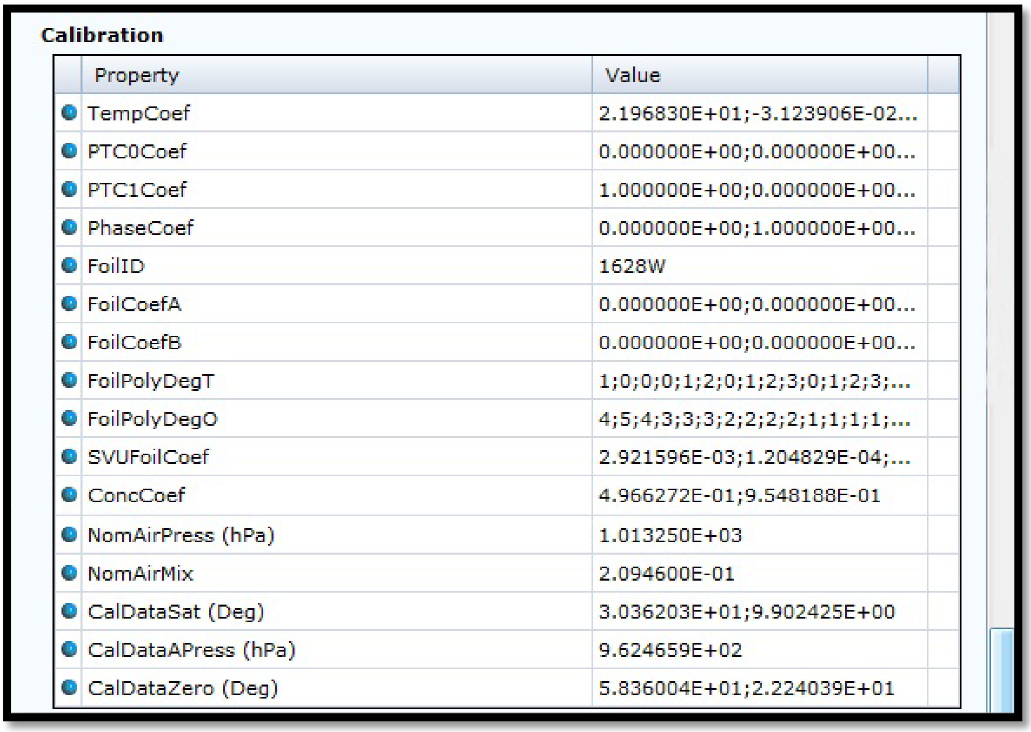


Figure 4-21: Calculation Settings in User Maintenance

Salinity (PSU) is used for salinity compensation of Oxygen concentration. 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. See chapter 2.6 for more info. If you are post compensating for the salinity, you should set the property value to 0. The default setting from factory is 0. When measuring Air Saturation in % the value does not need to be salinity compensated, this is only for O_2-concentration

4.4.11 Calibration



Calibration

Property	Value
TempCoef	2.196830E+01;-3.123906E-02...
PTC0Coef	0.000000E+00;0.000000E+00...
PTC1Coef	1.000000E+00;0.000000E+00...
PhaseCoef	0.000000E+00;1.000000E+00...
FoilID	1628W
FoilCoefA	0.000000E+00;0.000000E+00...
FoilCoefB	0.000000E+00;0.000000E+00...
FoilPolyDegT	1;0;0;0;1;2;0;1;2;3;0;1;2;3;...
FoilPolyDegO	4;5;4;3;3;3;2;2;2;2;1;1;1;1;...
SVUFoilCoef	2.921596E-03;1.204829E-04;...
ConcCoef	4.966272E-01;9.548188E-01
NomAirPress (hPa)	1.013250E+03
NomAirMix	2.094600E-01
CalDataSat (Deg)	3.036203E+01;9.902425E+00
CalDataAPress (hPa)	9.624659E+02
CalDataZero (Deg)	5.836004E+01;2.224039E+01

Figure 4-22: Calibration coefficients in User Maintenance

The ***Calibration*** section contains 16 sets of calibration coefficients and settings. Except from the ***FoilID***, foil coefficients and ***ConcCoef***, most of these coefficients are calculated during a calibration process at the factory and are not recommended to change for other than trained personal at Aanderaa certified calibration laboratories. For more information refer to Appendix 3.

TempCoef is a set of 6 coefficients used as curve fitting coefficient for temperature measurements. Together with ***RawTemp*** it is used to calculate the absolute temperature.

PTC0Coef and ***PTC1Coef*** are a possibility for temperature compensation of the phase measurement but are normally not used and set to respectively 0 and 1.

PhaseCoef are linearization coefficients for calculating compensated phase used to calculate ***CalPhase***. These coefficients are set at the factory before calibration and should not be changed. For older sensors the ***PhaseCoef*** are set to (0,1,0,0)

FoilID is the batch number for the foil used. If you change to another foil batch this setting together with foil coefficient or ***SVUFoilCoef*** need to be changed. See chapter 6.1.1 for a full procedure how to change the foil.

FoilCoefA and ***FoilCoefB*** are a total of 28 coefficients that's need to be entered if you change to another foil and not using the ***SVUFormula***. For newer sensors these coefficients are not used.

FoilPolyDegT are 28 temperature exponents and ***FoilPolyDegO*** are 28 phase exponents used together with ***FoilCoefA***, ***FoilCoefB, CalPhase*** and ***Temperature*** to calculate the partial pressure of O_2. These settings are not used when ***SVUFormula*** is enabled.

SVUFoilCoef are 6 coefficients used in the ***SVUFormula*** calculation. If foil is changed to another foil batch these coefficient must also be changed. To use this formula under ***System Configuration*** and ***Calibration*** select ***Enable SVUFormula***, refer chapter 4.4.5.

ConcCoef are used for linear correction of O_2 concentration. These coefficients are also adjusted during a two-point calibration. First coefficient is offset coefficient and second is slope coefficient. The slope coefficients may also be used to adjust the sensor output. If you want to adjust the sensor according to an accurate reference the adjusted value in percent may be added to the existing coefficient. Ec. If the sensor reads 98% and the reference read 100% you may add 0.02 to the second coefficient.

ConCoef before adjustment (4.966272E-01;9.548188E-01)

ConCoef after adjustment (4.966272E-01;9.568188E-01)

NomAirPress(hPa) is a property for the nominal air pressure, usually 1013.25hPa and used in the ***AirSaturation*** calculation.

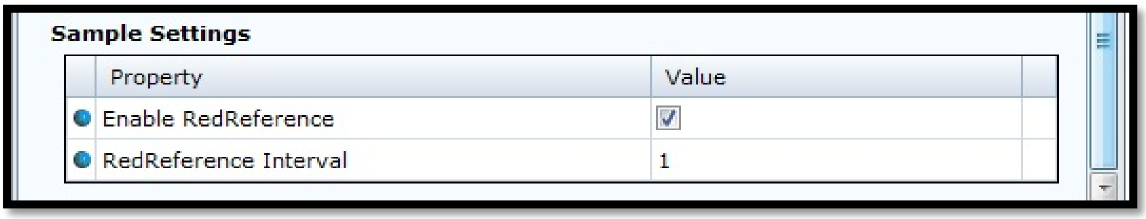
NomAirMix is the nominal O_2 content in air set to default 0.20946 and used in ***AirSaturation*** calculation.

CalDataSat(Deg) are a property that stores data obtained at the 100% calibration point during the two-point calibration procedure refer chapter 6.3.

CalDataAPress(hPa) is a property that holds the actual air pressure set by the user during the two-point calibration procedure refer chapter 6.3.

CalDataZero(Deg) are a property that stores data obtained at the 0% calibration point during the two-point calibration procedure refer chapter, 6.3.

4.4.12 Sample Settings


Sample Settings

Property	Value
Enable RedReference	☑
RedReference Interval	1

Figure 4-23: Sample Settings in User Maintenance

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.

RedReference Interval is used to set the interval for the RedRerenece LED. When value is 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 10th sample. Avoid setting RedReference Interval too long compared to temperature changes in the sensor, as the RedReference is used to compensate for temperature drift in the electronics.

CHAPTER 5 Smart Sensor Terminal operation

Refer to CHAPTER 3 for description how to connect the sensor to a PC.

5.1 Smart Sensor Terminal communication setup

Most third party terminal programs, e.g. Tera Terminal Pro or Hyper Terminal can be used for RS-232 communication with the sensor when connected to a PC.

For sensors with default configuration the following Smart Sensor Terminal setup should be used:

9600 Baud

8 Data bits

1 Stop bit

No Parity

Xon/Xoff Flow Control

Note! If using Tera Terminal Pro, after setting up the com port according to settings above please select "Terminal" in the "Set up" menu and click "Local echo" also select "CR+LF" for both "Receive" and "Transmit" under "New line".

Note! If using Hyper Terminal the options "Send line ends with line feeds" and "Echo line ends with line feeds" in the HyperTerminal ASCII setup must be selected.

5.2 Sensor Startup in Analog Output mode

Sensors in ***Analog Output*** mode and with default configuration will start by presenting a start-up message including the analog output settings, analog output level and scaling coefficients for both channels when powered up, see Figure 5-1. Then the sensor will perform a sample (depending on the configuration) and then enter a power down mode. After this first startup info the sensor will act like a sensor in ***Smart Sensor Terminal*** mode, see chapter 5.3.

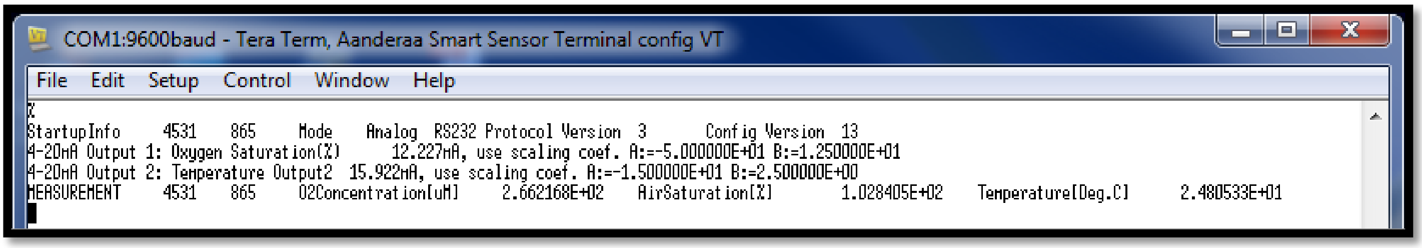


Figure 5-1 Startup info in analog mode

5.3 Sensor startup in Smart Sensor Terminal mode

When used in ***Smart Sensor Terminal*** mode the sensor will always start by doing a sample that will be presented within 2 seconds from powering the sensor, see **Figure 5-2**. This does not apply for Polled operations.

In order to minimize the current drain the sensor normally enters a power down mode after each sampling; the sensor can be awakened by any characters on the Smart Sensor Terminal input, and will stay awake for a time set by the ***Comm TimeOut*** property after receiving the last character.

Figure 5-2 Startup info in Smart Sensor Terminal

5.4 Startup info in AADI Real-Time mode

When used in ***AADI Real-Time*** mode the sensor will always start by sending a startup XML, first 14 lines in Figure 5-3 and then after first interval it will perform a measurement and display the xml message including sensor data and parameters.

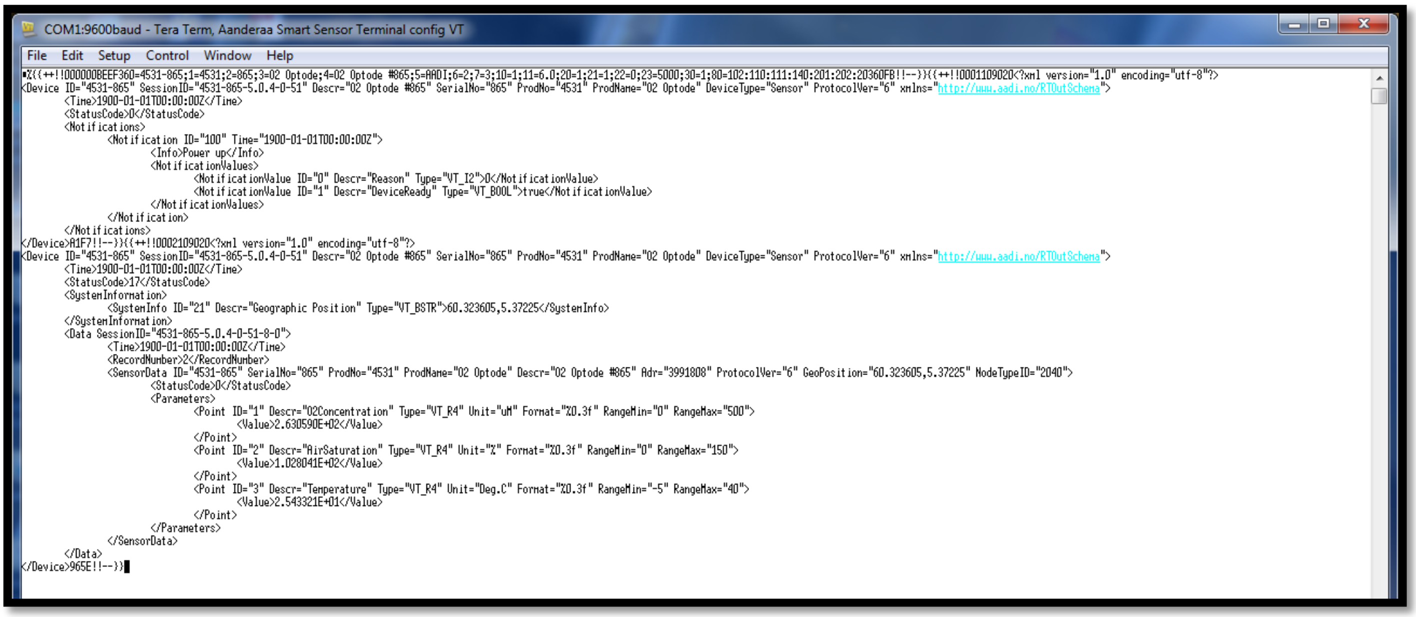


Figure 5-3: Startup info in AADI Real-Time mode

5.5 Communication sleep

If the property ***Comm TimeOut*** is set to other than 'Always On' the serial interface will not be activated after power-up (or the Reset command). Any character will activate the serial interface, but a Carriage Return (CR or CR+LF), '/' or ';' are often preferred since these character do not interfere with the command syntax. The serial interface will then be active until a period of input inactivity specified by the ***Comm TimeOut value*** (10 s, 20 s, 30 s, 1 min, 2 min, 5 min, 10 min). The Communication Sleep Indicator, '%', will be transmitted when the serial communication is deactivated, and the Communication Ready Indicator, '!' is outputted subsequent to activation. When ***Comm TimeOut*** is set to 'Always On' the communication (and microprocessor) will be kept active all time.

The Communication Sleep Indicator '%' and the Communication Ready Indicator '!' are not followed by Carriage Return and Line Feed.

The character '%' indicates that communication with the sensor is not possible (shut-down). In this mode the electronics requires up to 500ms 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.

When communicating with the sensor, you must start by pressing *Enter*. The sensor will respond in two ways (***Comm TimeOut*** is 1 minute by default in the following description):

- If the sensor is ready for communication, it will not send any response indicator. The sensor will stay awake and ready to receive commands for 1 minute (controlled by the ***Comm TimeOut)*** since the last command.
- If the sensor is in sleep mode and not ready for communication, the sensor will send a 'communication ready' indicator (!) when awakened (within 500ms). The sensor will then be ready for communication.

5.6 Smart Sensor Terminal protocol

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

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

All configurations of sensors in RS-232 operation are the same regardless of mode setting.

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 parentheses containing comma-separated values.
- The command string must be terminated by Carriage Return and Line Feed (ASCII code 13 and 10).
- 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 output string is terminated by Carriage Return and Line Feed (ASCII code 13 & 10).

5.7 Passkey for write protection

To avoid accidental change of the sensor configuration, most of the properties are write-protected. There are five levels of access protection, refer Table 5-1.

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 5-1. E.g.:

Set passkey(1000)

Table 5-1 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

After a period of inactivity at the serial input, the access level will revert to default. This period corresponds to the ***Comm TimeOut*** setting, or 1 minute if the ***Comm TimeOut*** is set to Always On.

5.8 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.

When changing the ***Mode*** and ***Baudrate*** property a reset is required for the change to take effect. This can be done by recycling power or entering the ***reset*** command. At start-up/reset the sensor normally presents a start-up information string as shown in Figure 5-1 to Figure 5-3.

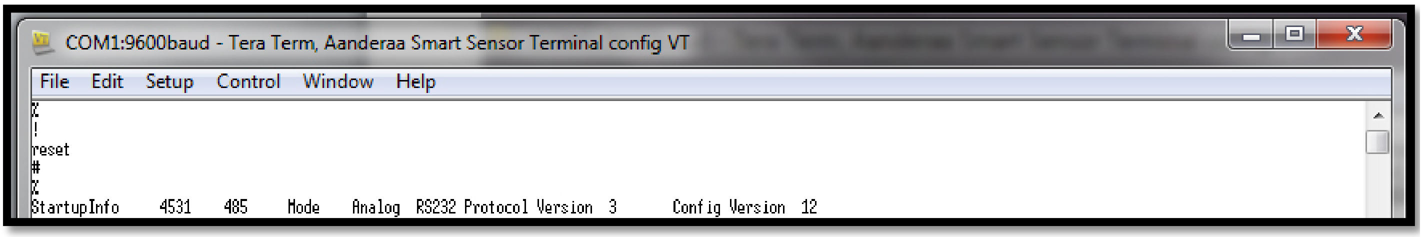


Figure 5-4 Sensor start-up/reset.

5.9 Available commands for the oxygen optodes

Available commands and properties for the Oxygen Optode are given in Table 5-2 and respectively.

Table 5-2 Main RS-232 commands available for the Oxygen Optode.

Command	Description
Do Sample	Execute an oxygen measurement and presents the result
Start	Start a measurement sequence according to current configuration
Stop	Stop a measurement sequence
Do CollectCalDataSat[3)]	Collect and save calibration data for 100% saturation
Do CollectCalDataZero[3)]	Collect and save calibration data for 0% saturation
Do Calibrate[3)]	Execute a two point internal calibration function
Do Test	Internal use
Do AdjustGain	Optimize internal amplification to foil type, only used when changing foil version
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
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[1)]	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

[3] Note that the Save procedure might require up to 20 seconds. Losing power during this period will cause loss of latest configuration change. Wait for acknowledge, '#', before powering down the sensor. The save procedure is also executed when running the Do CollectCalDataSat, Do CollectCalDataZero and Do Calibrate –commands.

5.9.1 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 5-5.

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 5-5.

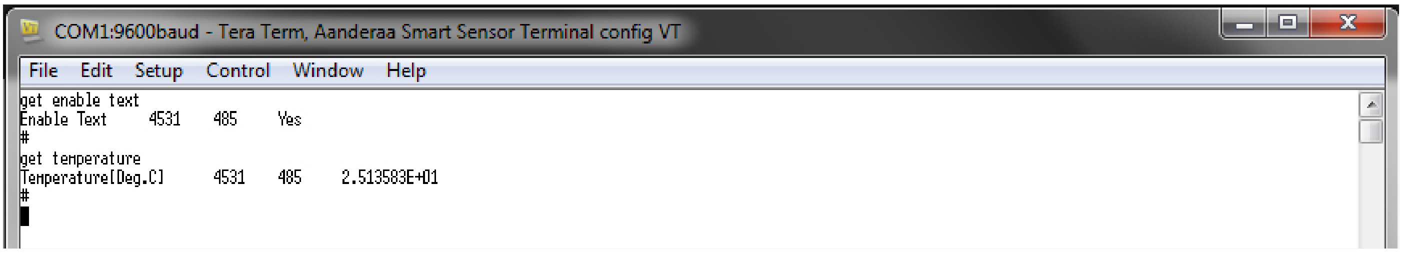


Figure 5-5 Examples of the Get command.

A special version, ***Get All***, reads out all available properties in the sensor according to the selected passkey level.

5.9.2 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 5-6.

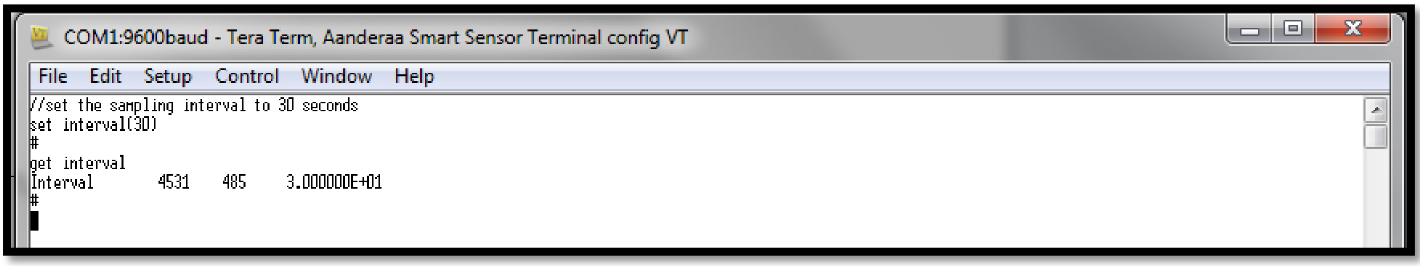


Figure 5-6 Example of the Set command.

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

5.9.3 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 5-7 for an example.

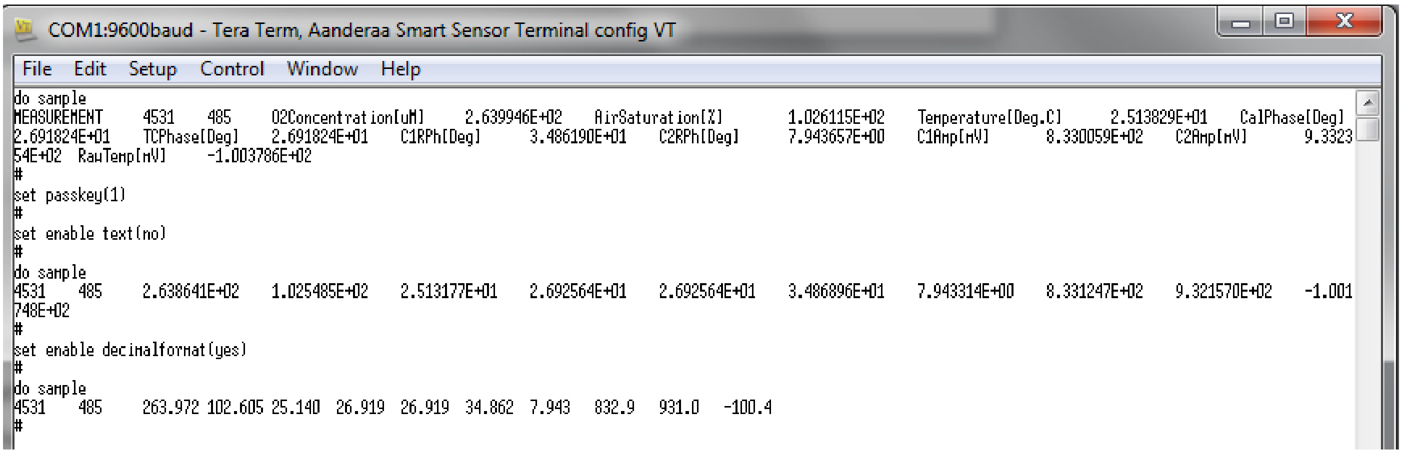


Figure 5-7 Example of output string: enable/disable text/decimal format

The property called ***Enable DecimalFormat*** controls the format of the output values, either as decimal numbers (***Yes***), or in exponential format (***No***). Refer Figure 5-7 for an example.

5.9.4 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.

5.10 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 HyperTerminal click *send text file* in the *Transfer* menu, and select the correct file. In Tera Terminal click “Send File” under “File” in main menu and select the file to be transferred.

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. Note that higher baud rates might require more lines of ‘/’ to provide sufficient delay. Communication wake up will normally require less than 100mS.

5.11 Sensor configuration

The sensor configuration consists of sensor settings and customized presentation of data. Refer Table 1-4 for a list of all sensor properties and the input format; refer chapter 4.1 for a description of the properties that are typically set by the user prior to a deployment (RS-232 application). Description of properties regarding the sensing foil and calibration are given in CHAPTER 6

CHAPTER 6 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 fouled. Therefore, the sensor should be cleaned at regular intervals depending on the fouling condition at the site.

Field experiences have demonstrated that Aanderaa Optodes typically are a factor of 2-4 more fouling resistant than electrochemical oxygen sensors from other manufacturers.

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) for at least 12 hour depending on the amount of fouling. Then remove the remaining fouling with a soft scrape. Only use a soft brush or cotton pin directly on the foil.

Figure 6-1 Example of fouling on an RCM 9 Mk II with an Oxygen Optode 3830 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 or 5551) and new foil coefficient must be entered unless the two foils are from same batch. If a different foil version is used then run ***Do AdjustGain*** and recalibrate if necessary.

The fluorescence life time measurement technology provides for very good long term stability. There is however a minor bleaching (break down) of the luminophore for every excitation of the foil. For the Aanderaa optodes this change is minimized by use of exceptional stable foil chemistry and careful excitation. Experience show that the foils have very good durability and generally become more stable over time. In Figure 6-2 typical drift versus the number of excitations (samples) is depicted.

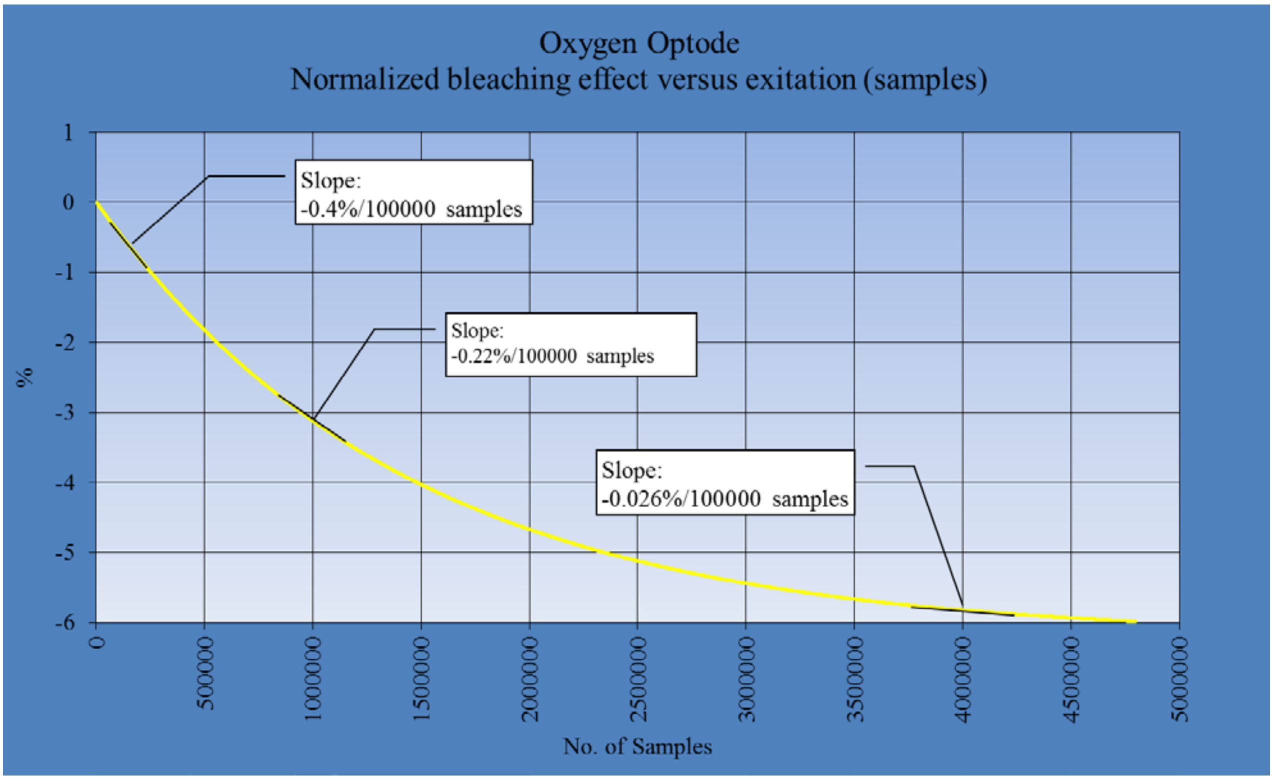


Figure 6-2 Normalized bleaching effect versus number of excitations

In order to maintain optimum accuracy it is recommended that the sampling frequency is not set higher than the application require. Annual recalibration is recommended (refer next section) although for many applications longer calibration interval can be adequate. In case where longer calibration intervals are expected use of a controlled reference can be adequate to QC the data.

The standard foil is equipped with a black optical isolation layer to protect it from ambient light.

For old foil version, foil kit 4733:

When saturated with moisture the polymer of the sensing foil will swell a little. This will cause a minor approximately 2% change in the response of the Optode. For optimum accuracy the foils should be wetted for 48 hours prior to use. We recommend keeping the foil wet and shielded from ambient light if possible.

For new foil version, foil kit 5551:

There is no wetting effect for these foils. We recommend keeping the foil shielded from ambient light if possible

NOTE! It is not recommended to change foils unless they have serious mechanical damages.

Aanderaa Service department can perform a cost-effective performance check and recalibration. Please contact Aanderaa Service Department, aanderaa.support@xyleminc.com or our local representative, refer Services page at www.aanderaa.com

6.1 Changing the sensor foil

If the sensor foil gets damaged it can easily be changed.

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

*NOTE! If you use a different foil version you need to run **Do AdjustGain**.*

NOTE! After changing the foil and entering new foil coefficients a new twopoint or multipoint calibration are recommended (see below)

Table 6-1 Contents of Sensor Foil Kit 4733/5551

Part no.	Pieces	Description	Foil Kit 4733[1)]	Foil Kit 5551[2)]
1206005C	1	Standard Sensing Foil PSt3	X	
1206019	1	Standard Sensing Foil FDO 701		X
1913032	1	Torx key no. T10	X	X
1642223	4	M3 x 6mm screw torx a4 Din 965a (not used for 4531)	X	X
1642222	2	M2.5 x 6mm screw torx a4 Din 965a	X	X
Form No. 770	Calibration Sheet for Sensing Foil (each batch of foils is calibrated)		X	X

[1)] Foil Kit 4733 is used for older versions of the sensor, may also be replaced with Foil Kit 5551
[2)] Foil Kit 5551 is used for newer version of the sensor, the foil ID number for this version is followed by a W, see foil calibration certificate for more info.

6.1.1 Procedure for changing foil

Using foil kit 4733/5551:

- The sensor foil is changed by unscrewing the 2 torx screws in the securing plate, refer Figure 6-3. 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 center the new foil to fit the optical window. It is important that the foil is mounted with the black side out.
- Remount the securing plate.
- Optical signal level of the new version foil and the old version foil is different. If changing from one type of foil to another the internal amplification should be optimized to the new foil. This is done by executing the command ***Do AdjustGain***, refer Figure 6-4. 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 (10-15 seconds)
- Control and if necessary update the sensing foil coefficients according to the foil certificate, refer chapter 6.3.
- Recalibrate the sensor if necessary, refer chapter 6.3.

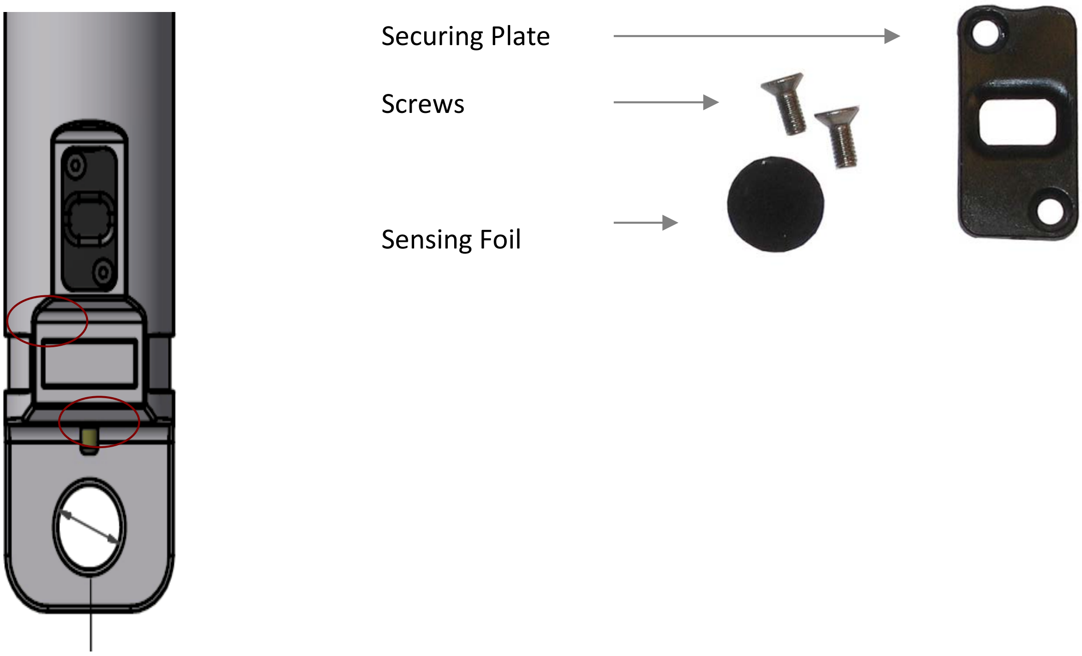
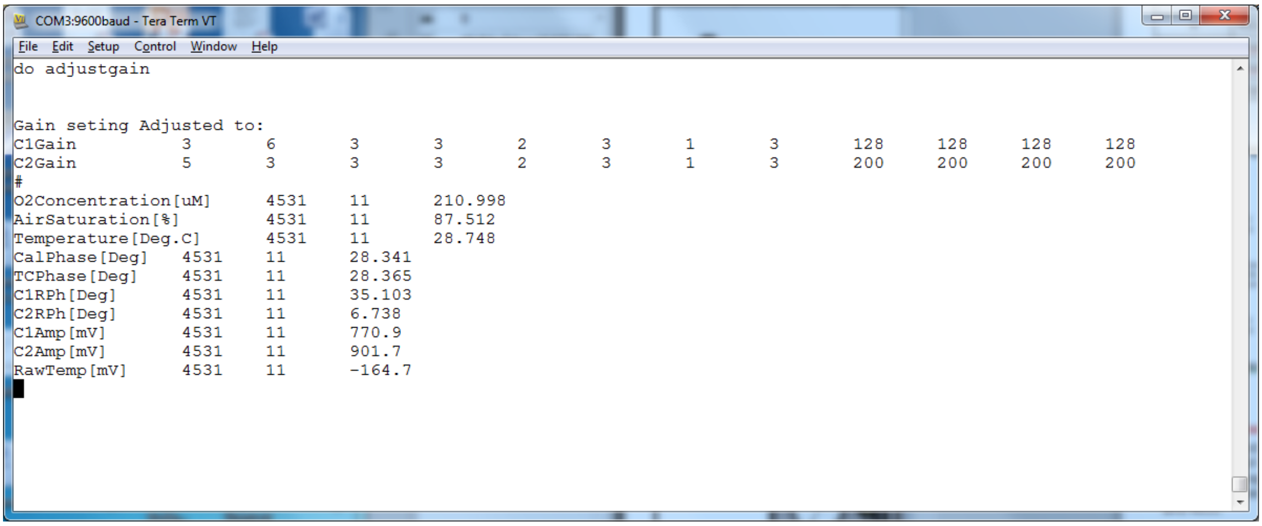


Figure 6-3 Removing the securing plate and change the sensing foil.



```
COM3:9600baud - Tera Term VT
do adjustgain


Gain seting Adjusted to:
C1Gain          3       6       3       3       2       3       1       3       128     128     128     128
C2Gain          5       3       3       3       2       3       1       3       200     200     200     200
#
O2Concentration[uM]     4531    11      210.998
AirSaturation[%]        4531    11      87.512
Temperature[Deg.C]      4531    11      28.748
CalPhase[Deg]   4531    11      28.341
TCPhase[Deg]    4531    11      28.365
C1RPh[Deg]      4531    11      35.103
C2RPh[Deg]      4531    11      6.738
C1Amp[mV]       4531    11      770.9
C2Amp[mV]       4531    11      901.7
RawTemp[mV]     4531    11      -164.7
```

Figure 6-4 Adjust Gain.

6.2 Function test

We recommend that you perform a function test of the sensor operating in air to verify the sensor readings.

At sea level the oxygen saturation should be approximately 100% in air (90-110 %, depending on air pressure, local oxygen production/consumption and if the temperature sensor measurements are representative to the temperature of the foil). The saturation will be significantly lower when you breathe near the sensing foil.

The measured temperature should be according to the ambient temperature.

6.3 Calibration

In order to ensure the optimum accuracy yearly calibration is recommended. However as long as the sensor foil has not been changed and the sampling frequency is moderate the Aanderaa Optode will normally provide stable data for years. Also it has been discovered that an after-curing appears in the foils during the first 1-3 months after manufacturing which typically leads to 1-4 % lower readings if the sensors are calibrated before the after-curing has stopped. As of today methods are in place to after-cure all foils before they are mounted on the Optodes and calibrated.

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

***FoilCoeffA**$_{0-13}$*
***FoilCoeffB**$_{0-13}$*

These coefficients are found in the Calibration Certificate for the Sensing Foil 4733/5551, refer enclosed documentation. Refer chapter 6.3.1 for changing foil coefficients.

In addition to the above mentioned coefficient update a one or two point calibration may 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 sulfite (Na_2SO_3) in 500ml water.

6.3.1 Calibration procedure using a terminal program

NOTE! To obtain the highest accuracy the sensor(s) to be calibrated should be submerged into water at least 24 hours prior to the calibration. If a sensor is allowed to dry out this could lead to a bias in the readings of up to 2 %. This effect disappears when the sensor is submerged into the water.

1. Prepare a suitable container with fresh water. Aerate (apply bubbling) to 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 (Na_2SO_3) in 500 ml of water. Other substances that remove oxygen can also be used.

NOTE! Stripping of the oxygen with e.g. N_2 gas is also possible, but not recommended, since it is uncertain when and if ever an absolute zero oxygen level is/can be reached using this method.

3. Connect the sensor to a PC by use of the PC connection cable 5427 or 5335, refer to CHAPTER 3
4. Start a terminal program, i.e. the HyperTerminal or Tera Terminal with the following set-up:

   9600 Baud

   8 Data bits

   1 Stop bit

   No Parity

   Xon/Xoff Flow Control

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 5 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.

5. 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(1000)

   Set Interval(30)

   Save

6. Store calibration values by typing:

   Set Passkey(1000)

   Do CollectCalDataSat

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

7. Set the CalDataAPress property to the actual air pressure in hPa at the site.

   Set Passkey(1000)

   Set CalDataAPress (..)

   Save

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

8. 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.

9. Enter the *Do* CollectCalDataZero command to store calibration values. The *save* command is automatically performed.

   Set Passkey(1000)

   Do CollectCalDataZero

10. Enter the *Do Calibrate* command to effectuate the new calibration and store the new coefficients in the sensor memory. The *save* command is automatically performed.

    Set Passkey(1000)

    Do Calibrate

11. 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.

CHAPTER 7 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

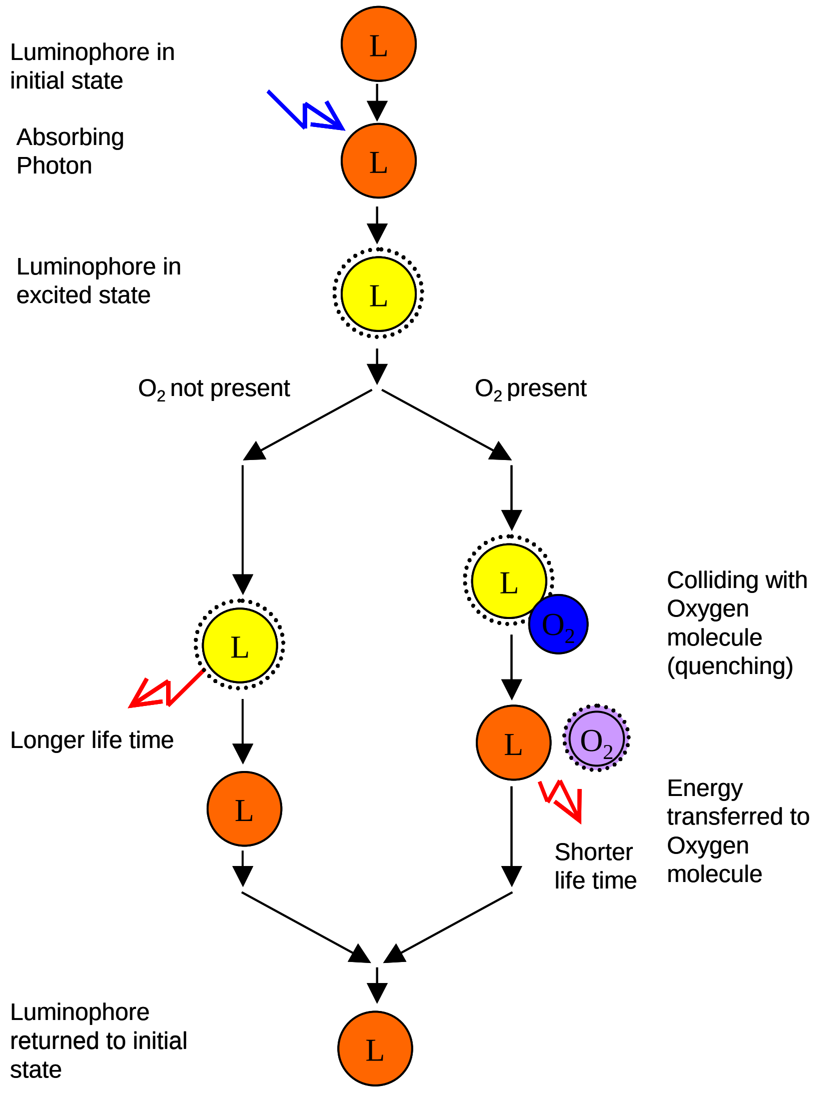


Figure 7-1 Dynamic luminescence quenching

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 normal monitoring foil is also equipped with a black gas permeable coating. The coating gives optical isolation between the indicator layer and the surroundings.

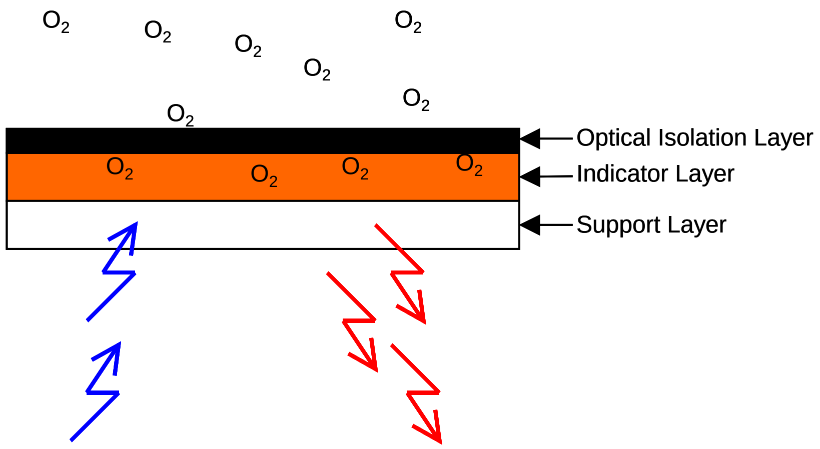


Figure 7-2 Sensing foil

Luminescence Decay TimeDue to its fluorescent behavior 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.

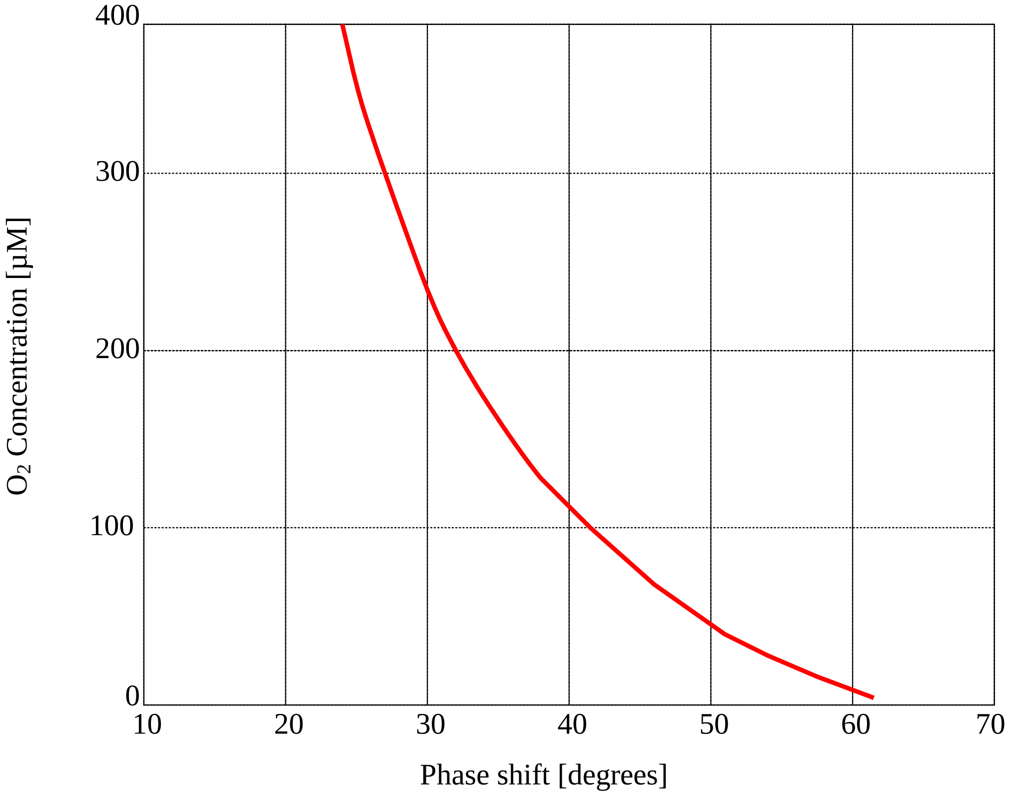


Figure 7-3 Typical phase/O2 response

Appendix 1 The optical design

An illustration of the optical design is given in Figure A 1.

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 though the sensing foil is highly fluorescent parts of the transmitted light will be directly reflected.

The photo diode is equipped with a color 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 2.

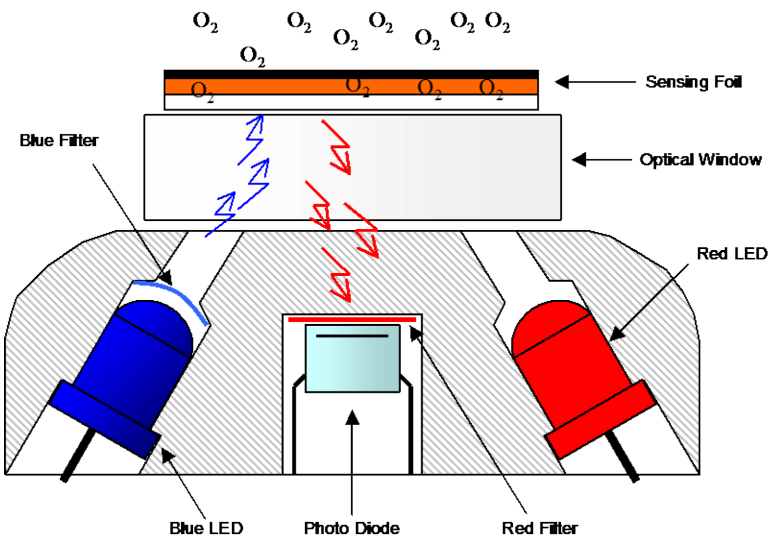


Figure A 1 The Optical Design

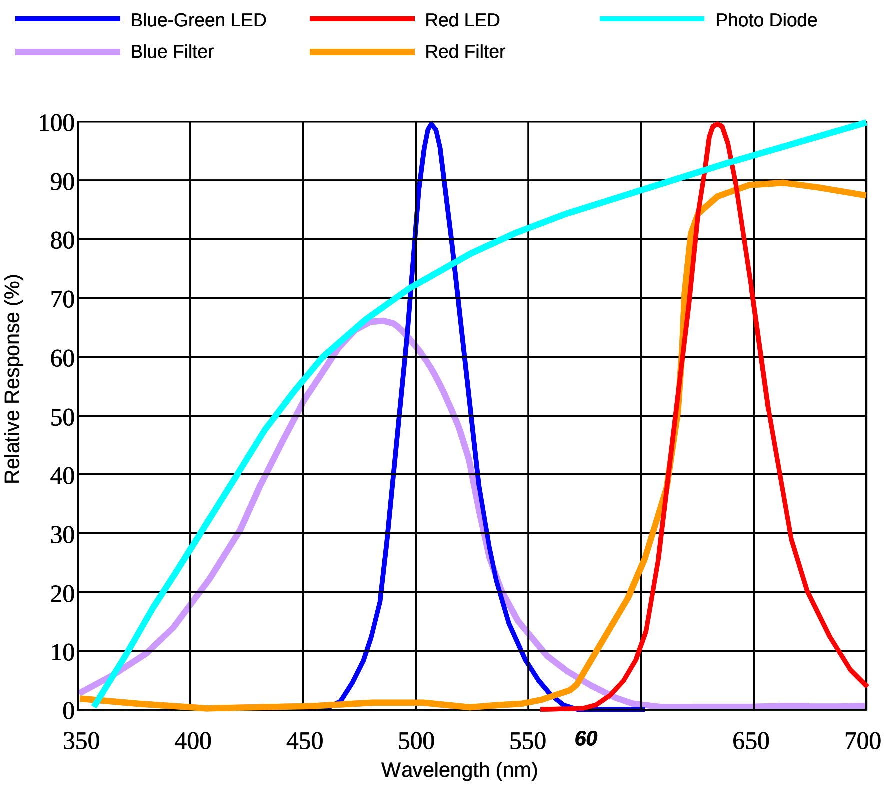


Figure A 2 An example of Spectral Response

Appendix 2 Electronic and mechanical design

A2.1 Electronic design

Figure A 3 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.

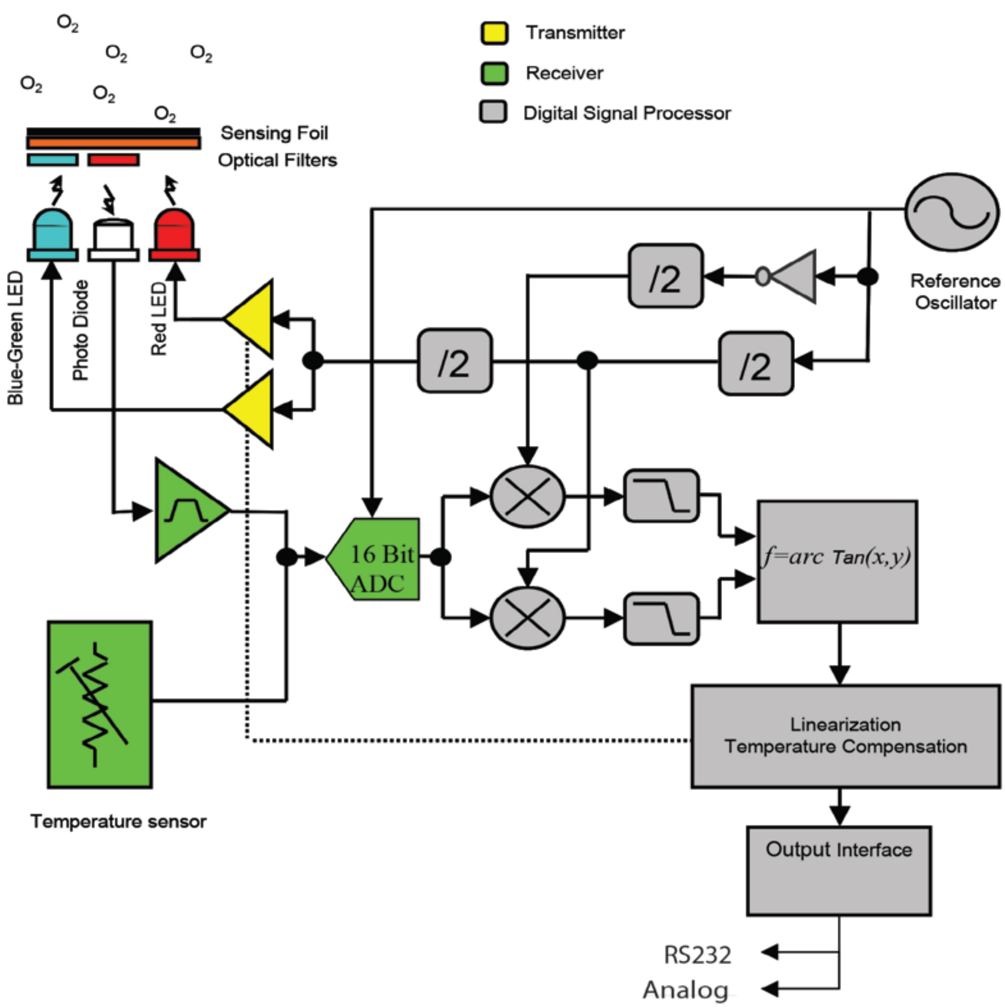


Figure A 3 Functional diagram

A2.2 Mechanical design of Oxygen Optode 4531

Refer Figure A 4 for illustration of the Oxygen Optode 4531. Rugged polymer housing shields the electronics from the surrounding water.

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.

Refer chapter 6.1 for instructions concerning changing the Sensing Foil.

Note! The sensor should not be opened! Opening the sensor housing can breach the warranty.

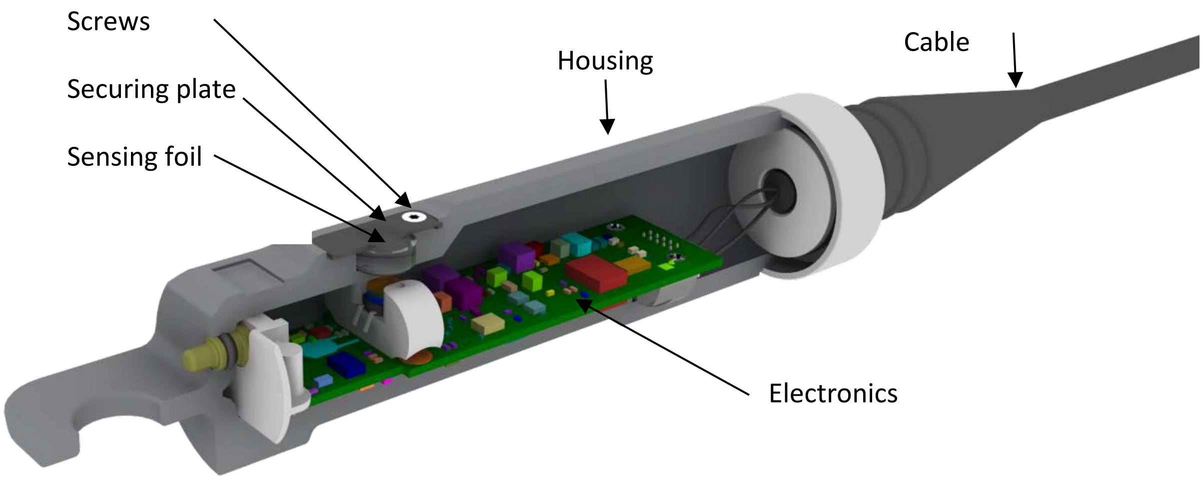


Figure A 4 Inside view of Oxygen Optode 4531.

Appendix 3 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 this option is not used and A(t)=0, B(t)=1. Coefficients for A and B are held in the properties called PTC0Coef and PTC1Coef respectively.

Subsequently the CalPhase is calculated as:

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

For newer optodes this function is normally not in use (i.e. *$PhaseCoef_0=0$, $PhaseCoef_1=0$, $PhaseCoef_2=0$, $PhaseCoef_3=0$*).

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

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:

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

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

By nature the relationship between the phase shift and oxygen concentration should follow Stern-Volmer relationship. The above formula is a general two dimensional polynomial with a flexible degree and was introduced since the basic Stern-Volmer did not provide satisfactory curve fit. In Uchida et al., 2008 a modified Stern-Volmer function was suggested:

$$[\boldsymbol{O_2}]' = \frac{\left(\frac{\boldsymbol{P_0}}{\boldsymbol{P_c}} - \boldsymbol{1}\right)}{\boldsymbol{K_{SV}}}$$

and:

$$K_{SV} = c_0 + c_1 t + \ c_1 t^2$$

$$P_0 = c_3 + c_4 t P_c = c_5 + c_6 P_r$$

where t is temperature (°C) and P_r is the raw phase shift reading (CalPhase)

Later it has been shown by Craig Neill (CSIRO) that this formula generally performs better with respect to interpolation between calibration points and extrapolation outside the calibration range. Based on this and recommendation from the Argo oxygen meeting in Brest 2011 the above formula has been implemented in the optode firmware.

In order to use the “Stern-Volmer-Uchida” formula the property called *Enable SVUformula* must be set to ‘yes’. The coefficients c_0 to c_6 are stored in the *SVUFoilCoef* property.

A possibility for linear correction of the O_2 concentration was also introduced:

$$\mathbf{O2Concentration[uM]} = \boldsymbol{ConcCoef_0} + \boldsymbol{ConcCoef_1}[\boldsymbol{O_2}]'$$

For new optodes the two-point calibration procedure (ref Calibration Procedure chapter 6.3.1) will adjust the *ConcCoef* coefficients.

$$[\boldsymbol{O_2}]' = \frac{\left(\frac{\boldsymbol{P_0}}{\boldsymbol{P_c}} - \boldsymbol{1}\right)}{\boldsymbol{K_{SV}}} K_{SV} = c_0 + c_1 t + \ c_1 t^2 P_0 = c_3 + c_4 t P_c = c_5 + c_6 P_r$$

Appendix 4 Product change notification: FW3

Copy of content in Product Change Notification Document ID: DA-50009-01 of date 09 December 2011:

Product(s) Affected:

Product Number	**Product Name**	**From Serial No.**
4050	Temperature Sensor	300
4060	Temperature Sensor	500
4017	Pressure Sensor	700
4117	Pressure Sensor	600
4319(A/B)	Conductivity Sensor	800
4330(F/A)	Oxygen Optode	1000
4420	ZPulse® Doppler Current Sensor	500
4520	ZPulse® Doppler Current Sensor	600
4646(R)	Pressure Sensor	600
4647(R)	Tide Sensor	600
4648(R)	Wave and Tide Sensor	600
4830	ZPulse® Doppler Current Sensor	100
4835	Oxygen Optode	300
4930	ZPulse® Doppler Current Sensor	100
4880(R)	Temperature Sensor	200
4930	ZPulse® Doppler Current Sensor	100

General Change Description:

Most of AADI's Smart Sensors utilized common communication protocols for use at the RS-232 and RS-422 interface. Two protocols are available; Smart Sensor Terminal protocol and the AADI Real Time protocol, where the Smart Sensor Terminal protocol is a simple ASCII command string based protocol and the AADI Real Time is an XML based protocol. To accommodate for higher security and future expansions both protocols will be updated when releasing Sensor Framework version 3 (common software for the above sensors). This notification aim to give an overview of the changes in the Smart Sensor Terminal protocol. Please refer to the specific Operating Manuals for further details and to Technical Description TD267a for updates in the AADI Real Time protocol.

Specific Changes:

1. Input command line termination is changed from line feed (LF) with optional carriage return to line feed and mandatory carriage return (LF+CR).
2. ‘Do Stop’ and ‘Do Start’ command changed to ‘Stop’ and ‘Start’
3. All units in output string changed from ‘(‘ and ‘)’ type parenthesis to ‘[‘ and ‘]’ type, example [hPa].
4. The Sleep indicator (‘%’) and the Wakeup indicator (‘#’) is replaced by a Communication Sleep (‘%’) indicator and a Communication Ready (‘!’) indicator. A property called ‘Enable Comm Indicator’ can be used for enabling/disabling of these characters.
5. Polled mode is no longer enabled by setting the interval to zero (Set Interval(0) is now illegal). A property called Enable Polled Mode is now used for controlling polled/non-polled mode.
6. The ‘Output’ property is substituted by a ‘Mode’ property for changing the operation mode, for example; ‘Set Mode(Smart Sensor Terminal)’. Specific properties control the formatting of the output string, for example ‘Set Enable Text(no)’.
7. The startup notification (at power up) is changed from ‘Mode <Mode name>’ to the following format: ‘StartupInfo <Product No.> <Serial no.> Mode <Protocol Name> Version <Version No.> Config Version <Version No.>’, for example; ‘StartupInfo 4330 83 Mode AADI Smart Sensor Terminal Protocol RS232 Protocol Version 3 Config Version 6’
8. The startup notification will be switched off when the ‘Enable Text’ property is set to ‘no’.
9. A ‘*’ will precede the parameter name if an error status related to the specific parameter occur. This applies for example to the tide parameter of the Wave an Tide Sensor before the sample base is complete : ‘*Tide Pressure[kPa] 0.000000E+00’

Appendix 5 Examples of scientific papers in which Aanderaa Optodes have been used and evaluated

(Last updated in January 2012)

Commercially available Oxygen Optodes for oceanographic application were introduced by Aanderaa in 2002. The long-term stability (years) and reliability of these sensors have revolutionized oxygen measurements and several thousand are in use in applications ranging from streams to the deepest ocean trenches (11 000 m), from fish farms to waste water, from polar ice to hydrothermal vents. This document gives examples of published scientific investigations in which Aanderaa Optodes have played a central role.

The basic technique of the Aanderaa Oxygen Optode, an evaluation of its functioning in aquatic environments and multivariate investigations on sensor cross-sensitivity were presented in Tengberg et al (2006). Other studies include use on autonomous Argo floats Joos et al (2003), Körtzinger et al (2004 and 2005), Johnson et al. (2010) and gliders (Nicholoson et al., 2008), long-term monitoring in coastal environments with high bio-fouling (Martini et al., 2007), on coastal buoys (Jannasch et al., 2008), on Ferry box systems (Hydes et al., 2009), on cabled CTD instruments for profiling down to 6000 m including suggestions for improved calibrations, pressure effect and compensation for slow response (Uchida et al., 2008) and in chemical sensor networks (Johnson et al., 2007). Drazen et al. (2005) presented a novel technique to measure respiration rates of deep sea fish and Sommer et al (2008) described an automatic system to regulate oxygen levels and to measure sediment-water fluxes during in-situ sediment incubation at vent sites. Also Pakhomova et al (2007) and Almroth et al. (2009) used the same type of optodes on autonomous landers to perform sediment-water incubations, with and without the introduction of sediment resuspension. In Wesslander at al (2011) the dynamics and coupling of carbon dioxide (CO_2) and oxygen was investigated in coastal Baltic Sea waters and McGillis et al (2011) described a novel method to assess the productivity of a coral reefs using boundary layer and enclosure methods. Champenois and Borges (2012) studied variations in community metabolism rates of a Posidonia oceanica seagrass meadow by continuous measurements of oxygen at three different levels during three years. Viktorson et al. (2012) used yearlong oxygen measurements at several Gulf of Finland locations to calibrate a 3D model for prediction of bottom water oxygen dynamics and the subsequent coupling of low oxygen conditions to release of sediment bound phosphorous. When this summary is written we know that several new papers are in the process of being published. Please look www.aanderaa.com for updates or contact us at aanderaa.info@xyleminc.com for the latest news.

Literature cited

Almroth E., A. Tengberg, H. Andersson, S. Pakhomova and P.O.J. Hall (2009) Effects of resuspension on benthic fluxes of oxygen, nutrients, dissolved inorganic carbon, iron and manganese in the Gulf of Finland, Baltic Sea. Continental Shelf Research, 29: 807-818.

Champenois W. and A. V. Borges (2012) Seasonal and interannual variations of community metabolism rates of a Posidonia oceanica seagrass meadow. Limnology and Oceanography, 57(1), 347–361.

Drazen J. C., L. E. Bird and J. P. Barry (2005) Development of a hyperbaric trap-respirometer for the capture and maintenance of live deep-sea organisms. Limnology and Oceanography Methods 3: 488-498.

Hydes D.J., M.C. Hartman, J. Kaiser and J.M. Campbell (2009) Measurement of dissolved oxygen using optodes in a FerryBox system. Estuarine, Coastal and Shelf Science, 83: 485-490.

Jannasch H.W., L. J. Coletti, K. S. Johnson, S. E. Fitzwater, J. A. Needoba and J. N. Plant (2008) The Land/Ocean Biogeochemical Observatory: A robust networked mooring system for continuously monitoring complex biogeochemical cycles in estuaries. Limnology and Oceanography Methods, 6: 263-273.

Johnson K. S., S. C. Riser and D. M. Karl (2010) Nitrate supply from deep to near-surface waters of the North Pacific subtropical gyre. Nature, Letters, Volume 465, 24 June 2010: 1062-1065.

Johnson K. S., J. A. Needoba, S. C. Riser and W. J. Showers (2007) Chemical Sensor Networks for the Aquatic Environment. Chemical Reviews, 107: 623-640.

Joos F., G.-K. Plattner, T. F. Stocker, A. Körtzinger and D.W.R. Wallace (2003) Trends in Marine Dissolved Oxygen: Implications for Ocean Circulation Changes and the Carbon Budget. EOS, 84, No. 21, 27, 197-201.

Körtzinger, A., J. Schimanski, and U. Send (2005) High-quality oxygen measurements from profiling floats: A promising new technique. J. Atmos. Ocean. Techn., 22: 302-308.

Körtzinger, A., J. Schimanski, U. Send, and D.W.R. Wallace (2004). The ocean takes a deep breath. Science, 306: 1337.

Martini M., B. Butman and M. Mickelson (2007) Long-Term Performance of Aanderaa Optodes and Sea-Bird SBE-43 Dissolved-Oxygen Sensors Bottom Mounted at 32 m in Massachusetts Bay. Journal of Atmospheric and Oceanic Technology, 24: 1924-1935.

McGillis W. R., C. Langdon, B. Loose, K. K. Yates and Jorge Corredor (2011) Productivity of a coral reef using boundary layer and enclosure methods. Geophysical Research Letters, Volume 38: L03611.

Nicholson D., S. Emerson and C. C. Eriksen (2008) Net community production in the deep euphotic zone of the subtropical North Pacific gyre from glider surveys. Limnology and Oceanography, 53: 2226–2236.

Pakhomova S., P.O.J. Hall, A. Tengberg, A. Rozanov and A. Vershinin (2007) Fluxes of Iron and Manganese across the sediment-water interface under various redox conditions. Marine Chemistry, 107: 319-331

Sommer S., M. Türk, S. Kriwanek and O. Pfannkuche (2008) Gas exchange system for extended in situ benthic chamber flux measurements under controlled oxygen conditions: First application—Sea bed methane emission measurements at Captain Arutyunov mud volcano. Limnology and Oceanography Methods 6: 23-33.

Tengberg A., J. Hovdenes, J. H. Andersson, O. Brocandel, R. Diaz, D. Hebert, T. Arnerich, C. Huber, A. Körtzinger, A. Khripounoff, F. Rey, C. Rönning, S. Sommer and A. Stangelmayer (2006).Evaluation of a life time based optode to measure oxygen in aquatic systems. Limnology and Oceanography, Methods, 4: 7-17.

Uchida H., T. Kawano, I. Kaneko and M. Fukasawa (2008) In-situ calibration of optode-based oxygen sensors. Journal of Atmospheric and Oceanic Technology, 25: 2271-2281.

Wesslander K., P. Hall, S. Hjalmarsson, D. Lefevre, A. Omstedt, A. Rutgersson, E. Sahlée and A. Tengberg (2011) Observed carbon dioxide and oxygen dynamics in a Baltic Sea coastal region. Journal of Marine Systems 86: 1–9.

Viktorsson L., E. Almroth-Rosell, A. Tengberg, R. Vankevich, I. Neelov, A. Isaev, V. Kravtsov, P.O.J. Hall (2012) Benthic phosphorus dynamics in the Gulf of Finland, Baltic Sea. Aquatic Geochemistry, in press.

Appendix 6 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 Aanderaa Oxygen Optodes; all features described in the FAQ 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 AADI Real-Time Collector software or with a terminal communication program like Hyperterminal or Tera Terminal.
The coefficients are:

1. The internal temperature sensor has its own calibration constants that 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$_{0\text{-}13}$,FoilCoefB$_{0\text{-}13}$, 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. SVU(Stern Volmer Uchida) formula is used for describing the relationship between phase shift/temperature and oxygen concentration. (Enable SVUformula set to 'yes'). The coefficients in this formula are stored in the SVUFoilCoef property$_{0..6}$.
4. In order to adjust for sensor to sensor variation linear correction of the O_2 concentration is used. This offset and slope coefficients are stored in ConcCoef$_0$ and ConcCoef$_1$ respectively. When performing a two point calibration these coefficients will be updated automatically and stored in the sensor. When changing or removing the foil a new calibration may be performed to obtain better accuracy.
   The most efficient way to do this calibration is to use a terminal program like Hyperterminal or Tera Terminal.
5. Converting the analog output signal will normally require use of scaling coefficients. These coefficients are dependent on for which parameter and range the outputs are configured. When the optode is configured to analog output mode these coefficients will be presented at the RS-232 interface at power up or reset.

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: On the paper the specifications of the Aanderaa optodes appears to be conservative compared to specifications given for other sensors on the market, 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 performance in the field not the best specifications you can obtain in the laboratory.

CCAP4

Q: How often do I need to re-calibrate the sensor?

A: If the foil is not mechanically damaged or moved no recalibrations are normally needed.
In our documentation we recommend a recalibration once a year but ample field experiences have demonstrated that these optodes are stable over much longer time periods than this. The longest field deployments without sensor drift have lasted 6 years.

It has however been concluded that when sensor foils are new they go through a maturation process that can last for approximately 1 month. The maturation will lead to lower readings and explain why some of the delivered sensors read some % lower than when they were calibrated.
When you receive the sensor from the factory no calibrations are needed but of course you should check that it is working properly

CCAP5

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.

CCAP6

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. If a calibrated optode reads a constant low value (e.g. from -1 to 1 µM) when the oxygen level in reality is 0 it most likely reflects an inaccuracy in the zero point calibration or in the temperature compensation.

CCAP7

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 same 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.

Another way of removing gas/air/oxygen from water is to boil it for at least 15 minutes and let it cool off in a gas tight vial (e.g. of glass). Be careful when opening the vial, exposure to the air will lead to immediate air contamination.

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 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 mean 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 (e.g. in a ferry box system).

CCAP 12
Q. Is there a difference in the sensor response if the foil is wet or dry?
A. The sensor is and should be calibrated in a wet environment.

For sensors using the old version foil 4733:
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 48 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.

For sensors using new version foil 5551, the foil ID number for this version is followed by a W:
There is no stabilization time for this version.

Please be aware of that the wetting effect is foil chemistry dependent. There are sensors from other manufacturers which can have wetting effects of up to 15 %.

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: Depending on the given accuracy of the sensor differences (within specifications) between sensors should be expected. There have also been cases when the user had not mixed the water well and consequently the oxygen concentrations were different at different locations in the water bath.

MR 3

Q: What physical factors will affect the sensor?

A: Temperature (which is already internally compensated), salinity and pressure.
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. There are examples in which Aanderaa optodes have been deployed for almost 2 years in H_2S rich environments without any detectable damage or drift.

MR 6

Q: What is the pressure behavior of the sensor?

A: The pressure effect is that the sensor reads 3.2% lower readings/1000 meters of water depth which means that at 1000 meters you will have to multiply your readings with 1.032 to get the correct absolute values and at 2000 meters with 1.064 etc.
This effect is the same for every sensor, it is linear and fully instantaneously reversible, when the pressure is released. The pressure effects were investigated in detail by Uchida et al. (2008). Please note that the pressure effect is foil dependent. Oxygen sensors from some other manufacturers will most likely not have the same behavior.

MR 7

Q: What about hysteresis?

A: As opposed to electrochemical sensors and optodes from some other manufacturers the AADI optodes does not suffer from hysteresis (irreversible pressure effects).

The pressure effect on the sensor described above immediately disappears when the pressure is released.

MR 8

Q: Can I log data of oxygen concentration, oxygen saturation and temperature simultaneously on the old AADI SR10 output (e.g. on a RCM9/RCM11/Buoy with 3660 datalogger 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 for 3830 and 3835 optodes 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.

Newer optodes e.g. 4330, 4831 and 4835 do not have SR10 output. When connected to dataloggers (using AiCaP/CAN and/or RS-232 format) all data coming from the sensor can be presented and logged including: O_2 concentration, O_2 saturation, Temperature and Raw data.

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 RS-232 or AiCaP/CAN bus there are no upper limits for the measurements range. However the user should be aware of that the sensors and the foils are normally only calibrated to 500µM beyond these limits a lower accuracy and precision should be expected.

AADI has however made several special deliveries of multipoint calibrated optodes that can measure with maintained accuracy up to 500 % air saturation. To calibrate such sensors demands special efforts and consequently are more costly.

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.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. Field experiences from parallel deployments have also demonstrated that the optodes typically can measure without effects of fouling for twice as long as the AADI conductivity 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 10 days in warm and highly productive waters.
Customers have adapted different strategies to improve the fouling resistance including cupper lining and wipers.

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 on the slow responding foils.

The situation is radically different for the transparent fast responding foils (can be used on the 4330 and 4831 sensors)These foils bleach if exposed to sunlight. This will lead to lower readings.

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 (1000 m), the These are pressure rated to 600 bar (6000 m). Please look in the Operating Manual or contact Aanderaa for more information.

The 4831 optode is delivered with a underwater matable Subcon connector which is pressure rated to 600 bar

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 of 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 sensing foil does not need to be replaced.

The relative oxygen computed by the optode is referred to standard atmospheric air pressure (1013.25 hPa).
The lower reading of 94.1 can be caused by that the saturation calibration of the optode was done in a vial in which there was over saturation (e.g. because of the pump or because of non stable temperature see also CCAP9) Another reason can be that your measurement is taken in an environment where the air pressure is lower than standard air pressure or that the oxygen concentration is lower.
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 24 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. One possible 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.

Another explination is that you use plastic chambers (Polycarbonate, Plexiglas) which act as efficient traps of air and oxygen (some plastic material can dissolve about 20 times more air than water).
To avoid this ventilate/equilibrate your chamber for several hours before closing the lid. **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. If exposed to the atmosphere 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.

If placing the sensor in a closed incubator the oscillations should not be detectable.

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 AiCap/RS-232 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 suggested by Garcia and Gordon (1992).

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= 1.04 = 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.

In the optode manual calculation formulas and tables of oxygen solubility at different temperatures and salinities are presented. Please also ask us for our interactive Technical Documents in Excel format TD257 and TD280 which enables you to convert phase measurements to oxygen readings, to compensate for salinity and pressure changes, to calculate saturation levels and to convert between different oxygen units.

MR 26

Q: What is influencing the O_2 concentration in water?

A: In the laboratory 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.

If a glass of sterile 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. In reality it is difficult to reach equilibrium since temperature and air pressure do not stay constant.

When measuring in natural surface waters which are in contact with the atmosphere the following factors can influence the dissolved oxygen concentrations: 1. Temperature: when water is cooling off it becomes under-saturated and can take up more oxygen from the atmosphere, when it heats up it becomes oversaturated and releases oxygen. Efficient exchange between water and air takes place when there are waves. 2. Salinity: water with higher salinity can dissolve less oxygen. 3. Primary production: when e.g. phytoplankton and sea grass grow in the photic zone (where there is light) oxygen will be produced, this can lead to oversaturation. 4. Consumption/respiration: when there is no light phytoplankton consume oxygen and so do animals (e.g. zooplankton and fish) living in the water also when organic material is degraded by bacteria oxygen is consumed. 5. Waves: if waves are breaking they will entrain bubbles to deeper levels which dissolve and create higher oxygen concentrations.

When moving deeper, out of the zone were there is light and waves, oxygen can only be consumed and no oversaturation should be expected. In deeper waters oxygen changes are mainly related to water movements where water coming from below in most cases contains less oxygen. At the bottom, where organic material accumulates, oxygen consumption is the highest leading to sharper oxygen gradients when approaching the bottom.

MR 27

Q: Does the sensor react to changes in salinity?

A: No, The sensor is measureing partial pressure and 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 am 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 (how this is done is described in the operating manual) 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.

MR 30

Q: I measured dissolved oxygen in open water on a mooring with an optode mounted on a Seaguard current meter. It seems that at low currents (below 10 cm/s) oxygen readings have a tendency to drop to *lower readings (negative excursions). Is this indicating that these sensors have difficulties measuring in low dynamic environments?*

A: No, oxygen optodes do not consume oxygen and are consequently not stirring sensitive. Metal structures immerged in water (of e.g. Stainless Steel, Aluminium, Bronze) are normally corrosion protected by sacrificial anodes. As the anode disintegrates oxygen is consumed at all “naked” metal parts which the anode is in electrical contact with. The oxygen consumption can be significant e.g. during its lifetime, normally 1-2 years, a 130 g Zn anode mounted on a Seaguard/RDCP/RCM pressure case can consume all oxygen in about 700 l of water. Water parcels with lower oxygen concentrations will form and can arrive in front of the oxygen sensors and lead to artificial dips in the oxygen readings. These effects are detectable in environments in which oxygen is stable (e.g. less than 2 % variations over time periods of days-weeks) and when currents are low (e.g. below 10 cm/s). In a vast majority of applications these effects are of low/no significance.

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 (applies to slower responding foils) 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, use cotton covered Q-tips (normally for cleaning of ears) to gently wipe of the remains after it has been softened by soaking in vinegar/HCl. Optode can be submerged in vinegar/HCl over night, or longer.

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. Caution should however be taken for transparent (fast response foils) and foils with a damaged black layer to keep them out of sunlight that could bleach the sensing layer.

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 around 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. The 4330 and 4831 optodes can be fitted with faster responding transparent foils that have approximately a factor 4 faster response.

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 approximately 100% (96-104 %) 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 low readings when you bubble the water with a different gas than air or oxygen (e.g. N_2 or Argon). When you add for example Sodium sulfite to your water solution the sensor should read 0 oxygen.
Please note that it can take a long 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: Communication can be done with all optodes using a standard Terminal program such as Hyperterminal (available in most Windows versions) or Tera Terminal. Please refer to optode manual for details. For earlier optode versions (e.g. 3830 and 3835) the OxyView software can be used. 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. **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. 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 sensors?
A: The minimum supply is 5V the maximum is 14V.

SSC 6
Q: What is the peek current consumption for the sensors?
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 RS-232 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 AiCap/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 water column profiling 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 in several peer reviewed scientific papers. For more information please look at 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 or 4831 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 7 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/Default.aspx?ID=1109

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/Admin/Public/DWSDownload.aspx?File=%2fFiles%2fFiler%2fTables%2fgas_tables.pdf

Copies of Unisense AS tables for *solubility of oxygen in seawater* are given in Figure A 8, Figure A 9, and Figure A 10.

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

Unisense

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

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 6 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 7 Copy of Data Table 8 by Niels Ramsing and Jens Gundersen: 100% Oxygen Solubility @1013 mbar pressure

Aanderaa Data Instruments AS
P.O.Box 103 Midtun, Sanddalsringen 5b, N-5843 Bergen, Norway
Tel: +47 55 60 48 00 Fax: +47 55 60 48 01
email: aanderaa.info@xyleminc.com www.aanderaa.com

Aanderaa Data Instruments AS is a trademark of Xylem Inc. or one of its subsidiaries.

© 2018 Xylem, Inc. April 2018

xylem
Let's Solve Water