TD 296 OPERATING MANUAL
Oxygen Sensor 4531
May 2024

Oxygen Optode 4531

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.
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6th edition	03 May	2024	mg/l added as output alternative. WTW foil as standard. From version:

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INTRODUCTION

Purpose and scope

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

All sensor variants are covered in one single manual since the operation and configuration is identical. The main difference is selected mode and cable connection.

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 wastewater, from polar ice to hydrothermal vents.

Aqua Oxygen Optode 4531 is based on the same technology as the deep-water version 4330 and 4831. The main difference is the housing and therefore the maximum depth range. 100 meter for 4531 and up to maximum 8000 meter for 4330 and 4831.

Examples of scientific papers in which Aanderaa Oxygen Optodes have been used and evaluated can be found in Appendix 5

All new sensors are individually multipoint calibrated in 40 points (at 5 temperatures and 8 oxygen concentrations) to an enhanced accuracy.

Aanderaa Smart Sensors utilize communication protocols at the RS232 interface where the Smart Sensor Terminal protocol is a simple ASCII command string-based protocol and the AADI Real Time is an XML based protocol.

The 4531 Aqua Optode can either be used with a RS-232 output or with Analog output.

Each Chapter in this manual is independent and we recommend jumping directly to the chapter covering your setup or read the start of each chapter to decide which setup fits your needs.

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 parameters including analog output configuration.

CHAPTER 3 describes connection to PC via RS-232.

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

CHAPTER 5 describes sensor configuration using terminal software such as Tera Term.

CHAPTER 6 describes sensor maintenance, procedure for changing foil, calibration and functional test for the sensors.

CHAPTER 7 presents maintenance and calibration.

CHAPTER 8 gives you theory of operation and design.

CHAPTER 9 describes the Oxygen calculation in the sensor.

CHAPTER 10 describes the Multipoint calibration.

CHAPTER 11 gives Example of Test and spec Sheet and Calibration Certificate

CHAPTER 12 Example of scientific papers.

CHAPTER 13 Frequently asked questions.

CHAPTER 14 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
AiCaP	Automated idle line CANbus Protocol; A modified communication protocol developed by Aanderaa for a distributed network of smart sensors when connected to SeaGuard, SeaGuardII or SmartGuard loggers.
ASCII	American Standard Code for Information Interchange
COM port	Communication port used for Serial communication RS232/RS422
DSP	Digital Signal Processor
EPROM	Erasable Programmable Read Only Memory
FAQ	Frequently Asked Questions; documented in appendix of this OM
GND	Ground
LED	Light Emitting Diode
mA	Milliampere measuring electrical current
mg/l	Milligrams pr. liter
µM or µmol	micromolar
MSB	Most significant bit
O_2	Oxygen molecule
RS-232	Recommended Standard 232 refers to a standard for serial communication of data
RTC	Real Time Clock
RXD	Serial communication Received data
SVU	‘Stern Volmer Uchida’ formula
TXD	Serial communication Transmitted data
UART	Universal Asynchronous Receiver/Transmitter
UNESCO	The United Nations Educational, Scientific and Cultural Organization
USB	Universal Serial Bus
V	Voltage, difference in electrical potential between two points.

CHAPTER 1 **Short description and specifications**

1.1 Description

Oxygen Optode 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 either 0-5V or 4–20mA. 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
- 4531C output: RS-232, 4 – 20mA
- 4531D output: RS-232

All versions may 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. With analog output enabled the minimum supply voltage is 7V. 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, Turbidity, 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 or mg/l, O_2 in % saturation, Temperature in °C and Raw data.
- Multipoint Calibration with increased accuracy.
- 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 Optode can be connected to a PLS with either RS-232 or Analog input.

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.

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.

If you want to measure O2 Concentration you also need to compensate for Salinity. This can either be done by setting the ***Salinity*** parameter to an average level or you may compensate for Salinity postprocessing.

1.2 Oxygen Optode 4531 dimensions

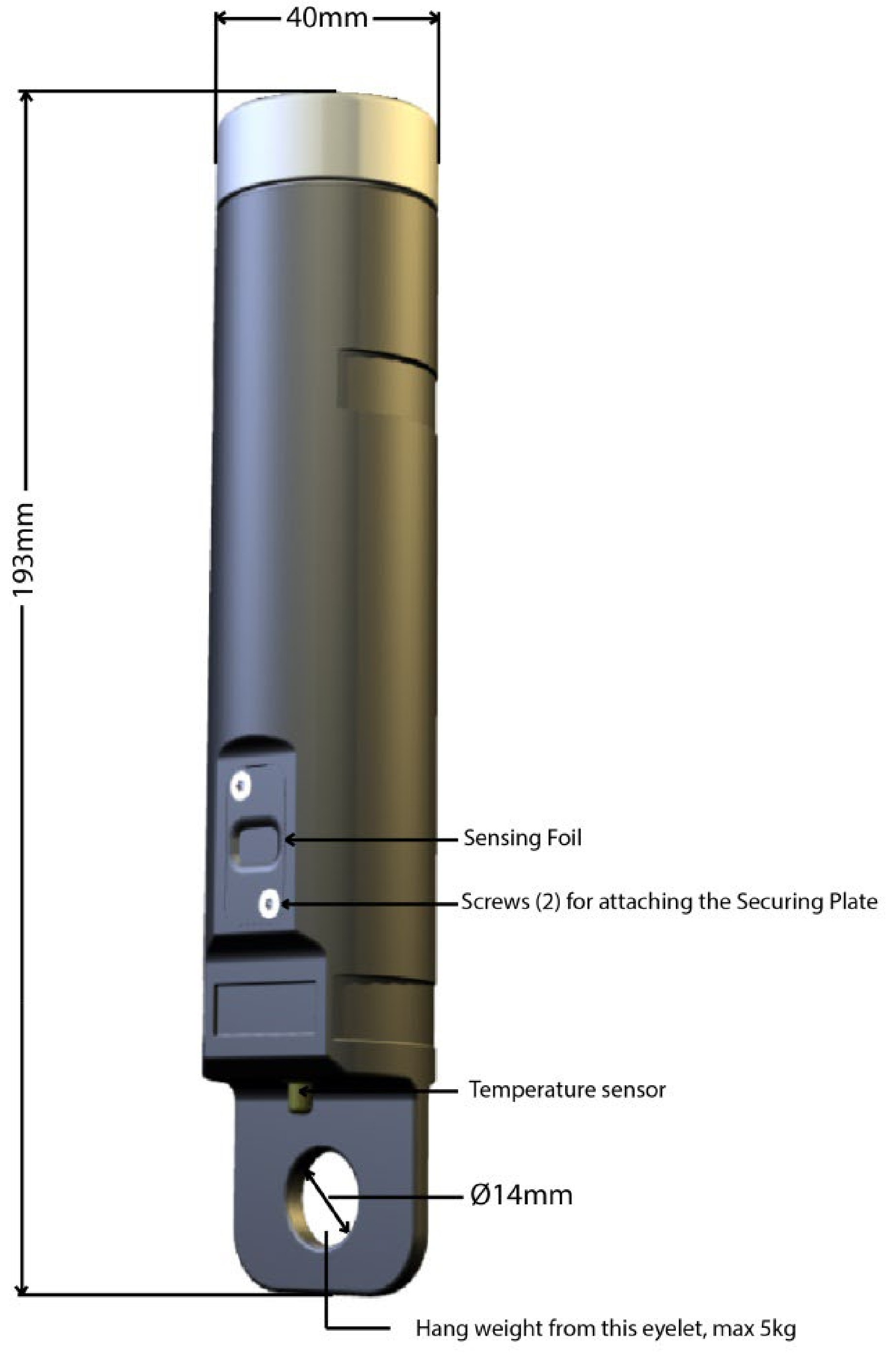


Figure 1-1: Illustration of Oxygen Optode 4531

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 ***1.7*** 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.

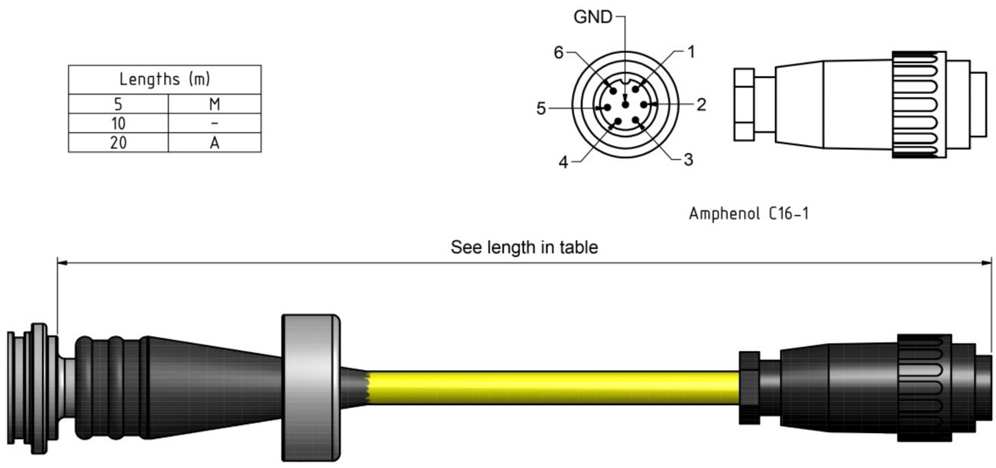


Figure 1-2: Cable 5440

1.4.1 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. (5-14V)
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.

1.5 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.

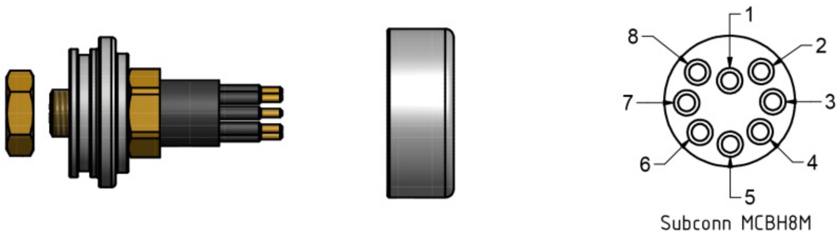


Figure 1-3: Connector 5441

1.5.1 Pin configuration for Connector 5441

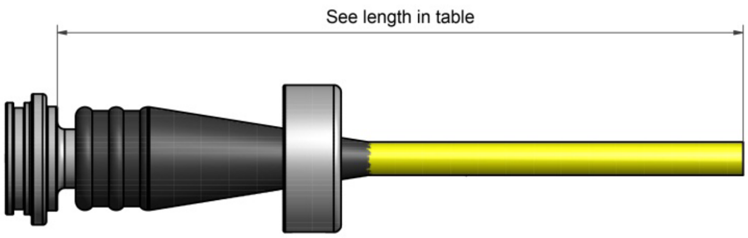
The connector 5441 pin orientation is given in ***Figure 1-3.*** Pin configuration and description is given in ***Table 1-2***.

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(5-14V)

1.6 Cable 5442 with free end

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

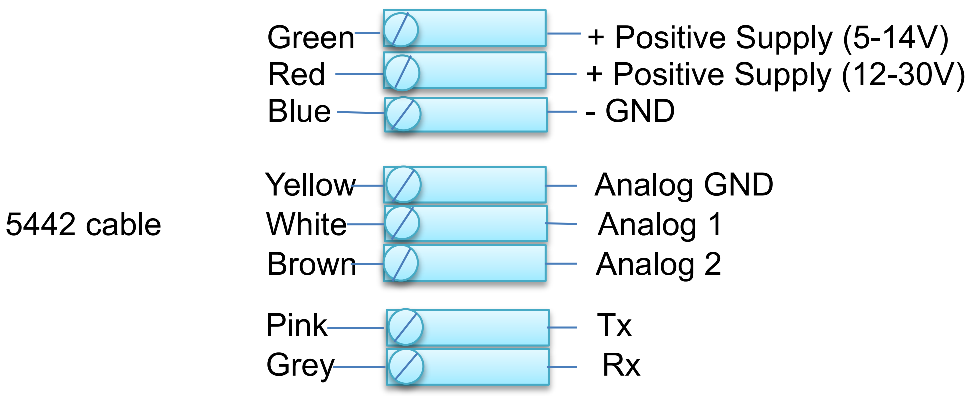


Lengths (m)	
5	M
10	-
20	A

Figure 1-4 Cable 5442

1.6.1 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! Green not connected in cables produced before 2024.

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

1.7 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.

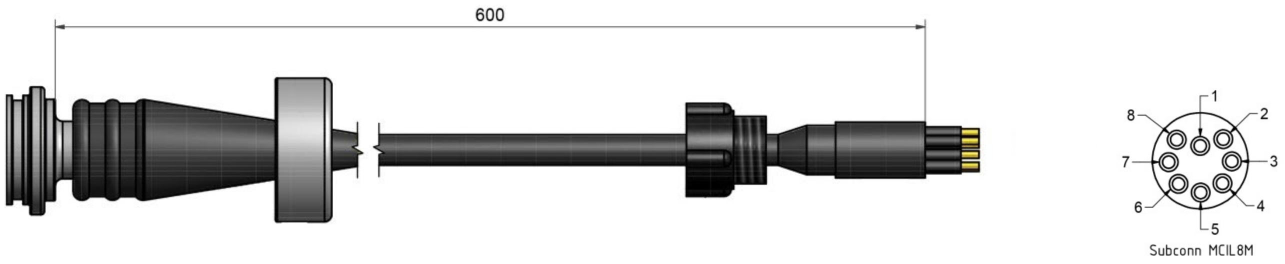


Figure 1-6 Cable 5443

1.7.1 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(5-14V)
4	Not Connected
5	RS-232 TXD (Transmit line)
6	Signal ground (12-30V)
7	Analog GND (Signal ground for Analog output)
8	RS-232 RXD (Receive line)

1.8 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 needs to be reduced.

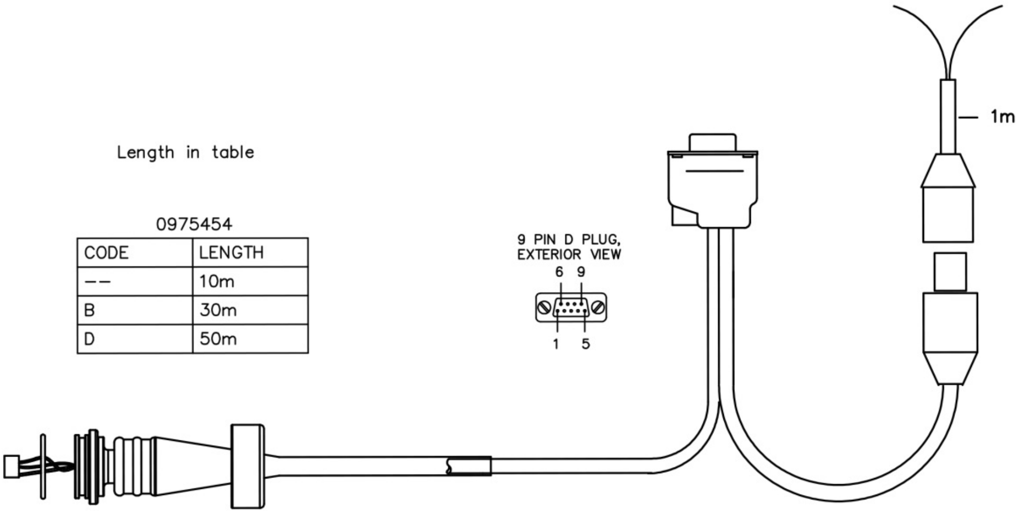


Figure 1-7 Cable 5972

1.8.1 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		RS-232 TXD
3		RS-232 RXD
5	4 (black)	GND
9	1 (red)	Positive Supply (5-14V)

1.9 Sensor Connection

Aanderaa offers a wide range of cables for different use of the sensors, both standard cables for use with loggers using RS-232 or free-end cables for use with analog or RS-232 signal output, but also special customer specified cables for use in project. See ***chapter 1.3*** through ***1.8*** for an overview of standard cables or contact ***aanderaa.sales@xylem.com*** for more info. To configure the sensor it need to be connected via RS-232 to a PC with Real-Time Collector or any terminal software.

1.10 Configure a sensor in Analog mode.

A sensor set to Analog mode also output RS-232. This means that you may connect a sensor configuration cable to your cable/ sensor plug or you may use a separate RS-232 configuration cable 5972 as shown in ***chapter 1.8.***

1.11 Using PC without COM-port.

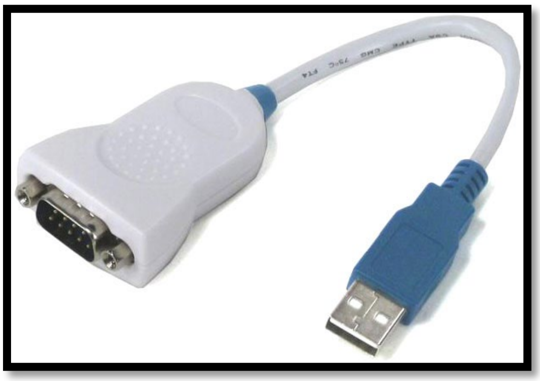


Figure 1-8: Serial to USB converter.

When connecting to PC using RS-232.

If your PC comes without a COM-port we recommend using a USB to serial converter.

Figure 1-8 shows one alternative, FTDI Serial to USB, recommended for use with Win10 and newer.

Connect the USB plug to your PC USB-port and then your sensor to the 9pin D-Sub.

Your computer will then set up a virtual COM-port and the number you will find under Device Manager>Ports (COM & LPT).

1.12 User accessible sensor properties

All configuration settings that determine 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.

To read the value of a certain properties you need to send ASCII string starting with the command ***get*** and then followed by the property name to the sensor, see example below.

To change the content of a property an ASCII string starting with ***set*** and then followed by the property name and new value in brackets need to be sent to the sensor.

Get Interval	//When sending this string to the sensor, it will then return the value stored in this property.
Interval 4531 17 1min	//Returned from sensor, where 4531 is the product number, 17 is the serial number of the sensor and 1min is the value stored as interval.
	To change the value you might send the following command:
Set Interval(10min)	//This will change the value for this property to 10 minutes.
Save	//Always end with save to store setting in flash.

The interval will now be changed to 10 minutes.

1.13 Passkey for write protection.

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

A special property called ***Passkey*** must be set according to the protection level before changing the value of properties that are write-protected, refer ***Table 1-5.*** 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 minutes it the ***Comm TimeOut*** is set to ***Always On.***

Table 1-5: Passkey protection

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 gives read access to factory properties that usually are hidden
Read Only	Factory	The user have only read access.

1.14 Sensor Properties

When using AADI Real-Time Collector you don't need to think about the command string sent to the sensor since this is fully controlled by the software, see ***CHAPTER 4*** for more information.

All sensor properties are listed in ***chapters 1.14.1*** through ***1.14.4.***

1.14.1 Factory Configuration

All properties in this section are Read Only, not possible to overwrite for the user. Only certified Aanderaa service personal can alter these settings. The access level for reading the status of this properties is however different for each property, see table ***Table 1-5*** for more details. In this group we find information about Software and hardware settings, Production, Service and Calibration dates.

Table 1-6 Factory Maintenance for Aqua Oxygen Sensor 4531. ENUM=Enumeration, INT =Integer, BOOL=Boolean ('yes'/'no')

Property	Type	No of elements	Use	Category	Access Protection Read/Write
Product name	String	31	AADI Product name	FC	No / 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		High / Read Only
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		

1.14.2 Deployment Settings

Deployment Settings contains settings for interval but also instruments metadata like position and owner which are not used in any calculations,

Table 1-7: Deployment Settings for Aqua Oxygen Sensor 4531. ENUM=Enumeration, INT =Integer, BOOL=Boolean ('yes'/'no')

Property	Type	No of elements	Use	Category	Access Protection Write/Read
Interval	Float	1	Sampling Interval in seconds	DS	No / 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		

1.14.3 System Configuration

This group is used to control the sensor via properties for sensor setup and parameter enabling and controlling the output from sensor. Some of the properties are only visible depending on the mode selected or if the function is enabled or not. These properties will either be grey or not visible at all.

Table 1-8: System Configuration for Aqua Oxygen Sensor 4531. ENUM=Enumeration, INT =Integer, BOOL=Boolean ('yes'/'no')

Property	Type	No of elements	Use	Category	Access Protection Read/Write
Mode	Enum	1	Sets the sensor operation mode (Smart Sensor Terminal, AADI Real-Time, Smart Sensor Terminal FW2, Analog Output)	SC	No / 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).		
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 Output1 and 2; O2Concentration, AirSaturation, CalPhase, SatO2Combo, Fixed1, Fixed2		

<table>
<tr><td>Analog1 Volt Coef</td><td>Float</td><td>2</td><td>Coefficients (offset, slope) used for trimming the analog output1 in voltage operation</td><td rowspan="12">SC</td><td rowspan="10">No / Low</td></tr>
<tr><td>Analog2 Volt Coef</td><td>Float</td><td>2</td><td>Coefficients (offset, slope) used for trimming the analog output2 in voltage operation</td></tr>
<tr><td>Analog1 mA Coef</td><td>Float</td><td>2</td><td>Coefficients (offset, slope) used for trimming the analog output1 in current operation</td></tr>
<tr><td>Analog2 mA Coef</td><td>Float</td><td>2</td><td>Coefficients (offset, slope) used for trimming the analog output2 in current operation</td></tr>
<tr><td>Analog Type</td><td>BOOL</td><td>1</td><td>Selects voltage or current operation of the analog outputs, 0-5V(default) or 4-20mA</td></tr>
<tr><td>Enable AirSaturation</td><td>BOOL</td><td>1</td><td>Controls inclusion of air saturation(%) in the output</td></tr>
<tr><td>Enable O2Content(On)</td><td>BOOL</td><td></td><td>Controls inclusion of mg/l as an addition to µM for concentration</td></tr>
<tr><td>Enable Rawdata</td><td>BOOL</td><td>1</td><td>Controls inclusion of raw data in the output string</td></tr>
<tr><td>Enable Temperature</td><td>BOOL</td><td>1</td><td>Controls inclusion of Temperature in the output</td></tr>
<tr><td>Enable HumidityComp</td><td>BOOL</td><td>1</td><td>Enable compensation for vapor pressure, - disable only for use in dry air or external humidity compensation</td></tr>
<tr><td>Enable SVUformula</td><td>BOOL</td><td>1</td><td>Used for foils with SVU coefficients</td><td>No / High</td></tr>
<tr><td>Enable Burn-In Mode</td><td>BOOL</td><td>1</td><td>Enable burn-in mode, factory use only</td><td>High /High</td></tr>
</table>

1.14.4 User Maintenance

This group contains sensor settings that normally are not altered by the user. To access most of these properties you need to send ***passkey(1000)*** or with Real-Time Collector use password: 1000. These properties are used to configure serial port settings, communication to and from sensor, temperature and foil coefficients and properties used during calibration.

Table 1-9 User Maintenance for Aqua Oxygen Sensor 4531. ENUM=Enumeration, INT =Integer, BOOL=Boolean ('yes'/'no')

<table>
<tr><th>Property</th><th>Type</th><th>No of elements</th><th>Use</th><th>Category</th><th>Access Protection Read/Write</th></tr>
<tr><td>Owner</td><td>String</td><td>31</td><td>User setting for owner's name or ID</td><td rowspan="10">UM</td><td>No / High</td></tr>
<tr><td>Baudrate</td><td>Enum</td><td>1</td><td>RS-232 baud rate: 300,1200,2400,4800,9600,57600,115200[1)]</td><td rowspan="4">High / High</td></tr>
<tr><td>Flow Control</td><td>BOOL</td><td>1</td><td>RS-232 flow control: None or Xon/Xoff</td></tr>
<tr><td>Enable Comm Indicator</td><td>BOOL</td><td>1</td><td>Enable the Communication Sleep ('%') and Communication Ready ('!') indicators</td></tr>
<tr><td>Comm TimeOut</td><td>Enum</td><td>1</td><td>RS-232 communication activation timeout: Always On,10 s,20 s,30 s,1 min,2 min,5 min,10 min</td></tr>
<tr><td>Salinity</td><td>Float</td><td>1</td><td>Salinity (PSU) for use in salinity compensation of O_2 concentration, default 0</td><td>No / High</td></tr>
<tr><td>TempCoef</td><td>Float</td><td>6</td><td>Curve fitting coefficients for the temp measurements.</td><td rowspan="3">High / High</td></tr>
<tr><td>PTC0Coef</td><td>Float</td><td>4</td><td>Raw phase temperature compensation coefficients, normally not used (0,0,0,0)</td></tr>
<tr><td>PTC1Coef</td><td>Float</td><td>4</td><td>Raw phase temperature compensation coefficients, normally not used (1,0,0,0)</td></tr>
<tr><td>PhaseCoef</td><td>Float</td><td>4</td><td>Linearization coefficients for calculating compensated phase</td><td rowspan="2">No / High</td></tr>
<tr><td>FoilID</td><td>String</td><td>9</td><td>Sensing Foil Identifier batch-number and version.</td></tr>
</table>

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

FoilCoefA	Float	14	Foil coefficients, general curve fit function, used with older sensors without SVU coefficients.		
FoilCoefB	Float	14	Foil coefficients, general curve fit function, used with older sensors without SVU coefficients.		
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).		No / High
NomAirPress	Float	1	Nominal air pressure for use in O_2 concentration calculations	UM	
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.		Low / High

1.14.5 Specifications

Refer Datasheet D404 for sensor specifications. This is available on memory stick following all new sensors or on our web site http://www.aanderaa.com/ follow Products/Oxygen Optodes/Document.

On our web site you will also find the latest version of product manuals, technical notes and software. Please contact aanderaa.info@xylem.com for guidance.

1.15 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. Analog output may be switched on/off or changed by using the RS-232 output.

2.1 RS-232 Output

Regardless of mode the sensor will always output RS-232 but the type of output is dependent on the mode setting. To fully use the RS-232 output you need to connect in both sensor and receiver end:

- ***Positive Supply***
- ***GND***
- ***Tx***
- ***Rx***

RS-232 output parameters:

- ***O2-concentration in µM***
- ***O2-concentration in mg/l***
- ***Air Saturation in %***
- ***Temperature in °C***
- ***Oxygen raw data***
- ***Temperature raw data***

Except from ***O2-concentration in µM*** the number of and which parameters to output are configurable.

2.2 Analog Output

When sensor is set to ***Analog Output*** mode an analog signal is presented for each of the two analog output channels. What parameters presented and scaling coefficient depend on the sensor configuration. Scaling coefficients for each channel are presented as a start-up message if connected via RS-232. This means that you may either get the scaling coefficient by connecting the sensor to PC or you may use the formula in ***chapter 2.4*** to calculate using current configuration.

You may select one or two analog output channels. It's possible to connect the sensor to both analog and serial in parallel and this is used for example when you calibrate an analog sensor.

In addition to sensor set to ***Analog Output*** mode the following signals needs to be connected to get analog output:

- ***Positive Supply***
- ***GND***
- ***Analog GND***
- ***Analog 1***
- ***Analog 2***

GND and ***Analog GND*** are internally in the sensor connected but to avoid noise on the output we recommend using separate Power GND and Analog GND in the cable.

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

- Output 1 can be set to output either:
  - ***Oxygen Concentration in µM***
  - ***Air Saturation in %***
  - ***Raw data (CalPhase)***

- Output 2 can be set to output either:
  - ***Temperature in °C***
  - ***Oxygen Concentration in mg/l***.

The ***Analog Output 1*** and ***2*** are dependent on the ***Analog Output*** and ***Analog Type*** Settings. If ***Analog Output*** is set to ***SatO2Combo*** then ***Output 1*** are ***Air Saturation in %*** and ***Output 2*** are ***O2Concentration in mg/l***. If ***Analog Output*** is set to any output except ***SatO2Combo*** the selected parameter will be presented as ***Analog Output 1*** and ***Temperature in °C*** as ***Analog Output 2***.

Analog Type may be set to either 4-20mA or 0-5V.

If sensor is used in Analog mode it might be interesting to keep the RS-232 signal available in the cable to make the calibration easier. These wires will then potentially pick up some noise from the surroundings. We therefore recommend setting ***Flow Control*** to ***None*** and use an interval equal or longer than 5 minutes.

2.3 Analog Output Specifications

Table 2-1 gives the default range, calibrated range, the accuracy and resolution of the Oxygen Sensor 4531 with ***Analog Output***:

Table 2-1 Output specifications

Parameter	Output	Default range[2]	Calibrated range	Accuracy	Resolution
Oxygen Concentration	0 - 5V	0 to 800µM / 0 to 25.6 mg/l	0 to 500µM / 0 to 16 mg/l	<8µM / 0.256mg/l or 5% whichever is greater	< 1µM / 0.032mg/l
	4 - 20mA	0 to 800µM / 0 to 25.6 mg/l	0 to 500µM / 0 to 16 mg/l	<9µM / 0.288mg/l or 5.2% whichever is greater	< 1µM / 0.032mg/l
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

This table is based on default values. If you change one or more of the limits this will influence both accuracy and resolution

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.

2.4 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 voltage (V_{out}) to Oxygen Concentration (mg/l): .... $Cons = \frac{V_{out}}{V_{max}} \cdot 800 / 31.25$

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): .... $Cons = \frac{I_{out} - 4}{16} \cdot 800$

From current (I_{out}) to Oxygen Concentration (mg/l): .... $Cons = \frac{I_{out} - 4}{16} \cdot 800 / 31.25$

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:

Table 2-2: Default analog limits

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}):

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

From current (I_{out}):

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

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

2.5 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.

2.6 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 Concentration*** is presented in ***µM*** (1 Molar = 1 mole/liter) and ***mg/l***. 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 2.8*** and ***2.9***.
- 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.

2.7 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 6*** 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.

2.8 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***, or ***O_{2c}*** in ***mg/l*** is calculated from the following equation:

$$\boldsymbol{O_{2C} = [O_2] \cdot e^{S(B_0+B_1T_S+B_2T_S^2+B_3T_S^3)+C_0S^2}}$$

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:

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

Where S_0 is the internal salinity setting.

2.9 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, $\boldsymbol{O_{2c}}$, is calculated from the following equation:

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

Where:

d is depth in meters or pressure in dbar.

O_2 is the measured O_2-concentration in either µM or mg/l.

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.

2.9.1 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.

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

$O_{2c} = 400 \times 1.0032 = 401.28$ 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 6***.

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 older versions of Windows and FTDI Serial to USB for use with Win10 and newer.

Your computer will then set up a virtual COM-port and the number you will find under Device Manager>Ports (COM & LPT).

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.

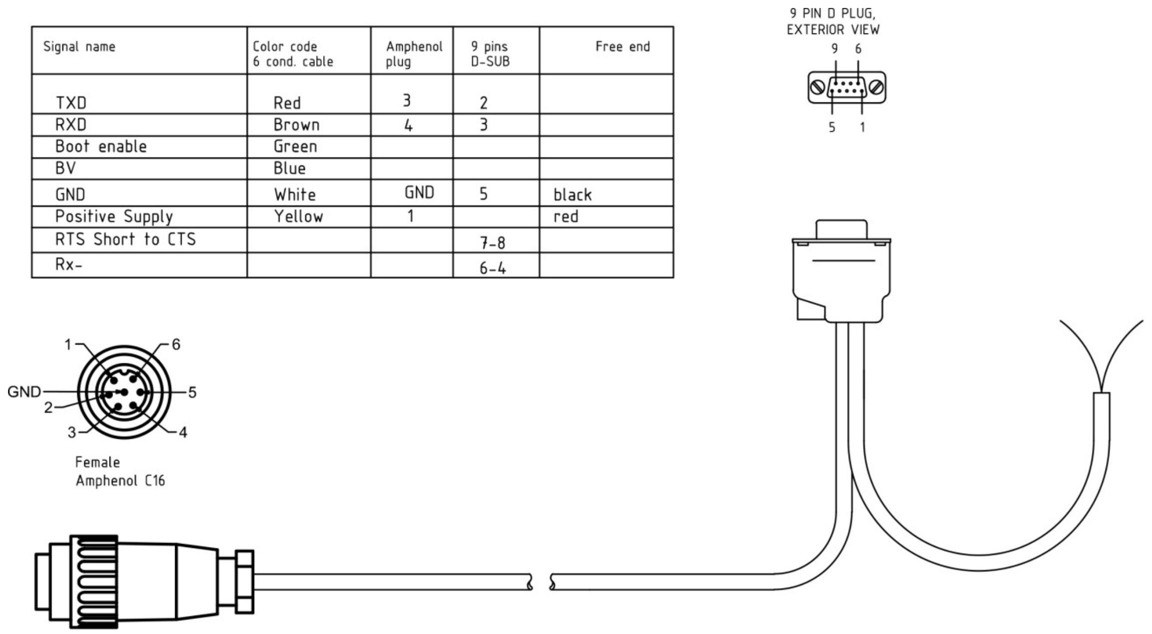
For sensors with cable 5443 or connector 5441 an additional Sensor cable 5335, ref ***Figure 3-2***, is used for connection between the Subconn plug and your PC.

For sensors with free end cable 5442 refer to ***chapter 1.6*** 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.

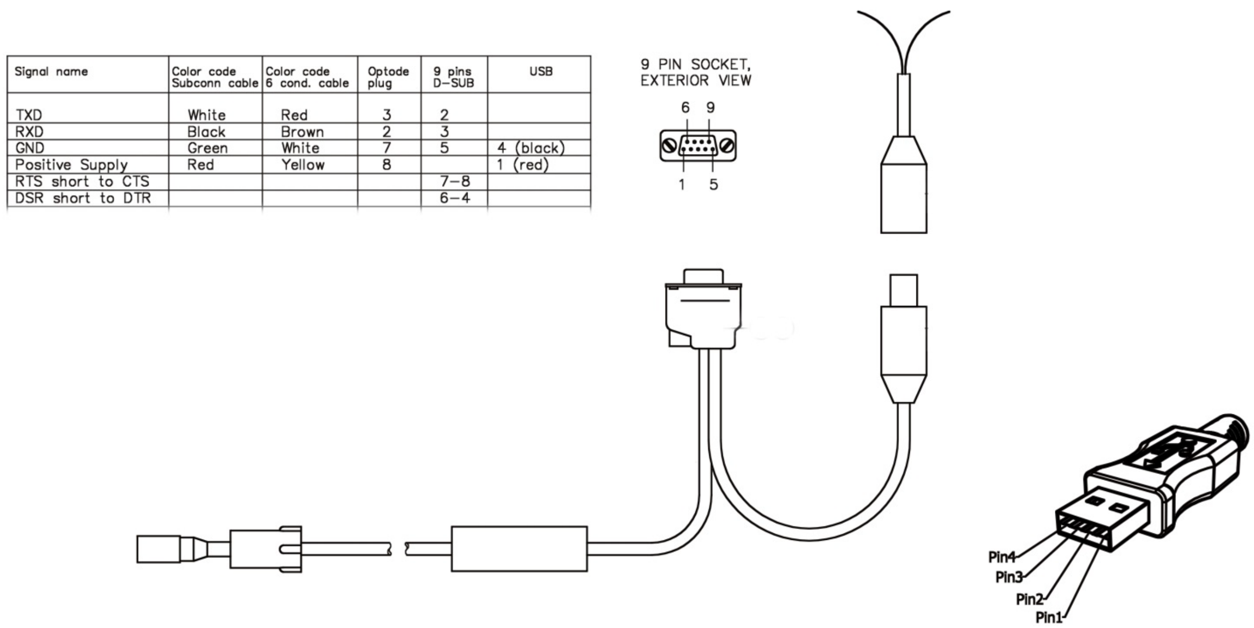
Note! When Analog output is enabled most computers do not deliver enough power on USB to run the sensor. Then connect an external power source, 9V battery or laboratory supply to the power ports, Positive Supply and GND.

Note! If Positive Supply(12-30Volt) is used then most computers do not deliver enough power on USB to run the sensor. Then change to Positive Supply(5-14Volt) if available or connect an external power source.



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

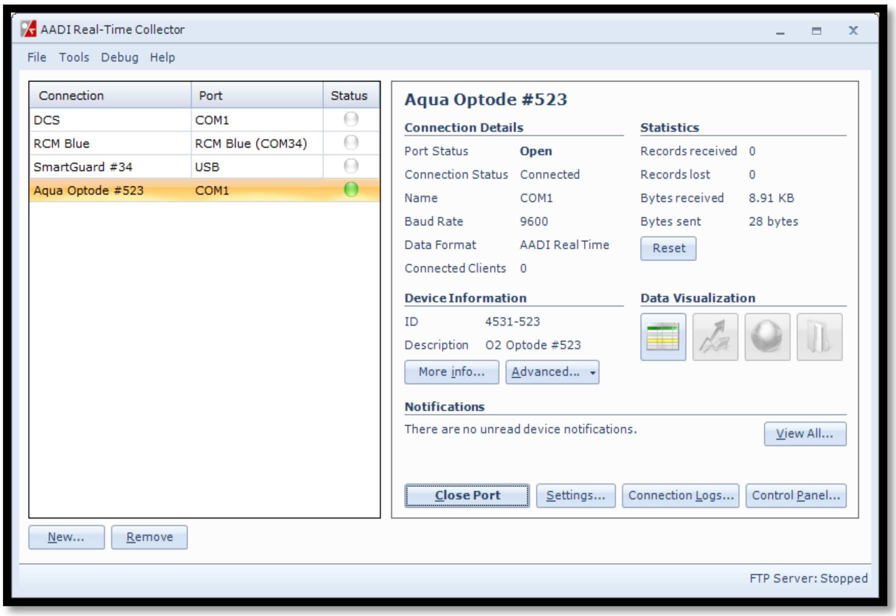


Figure 4-1: New connection

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.

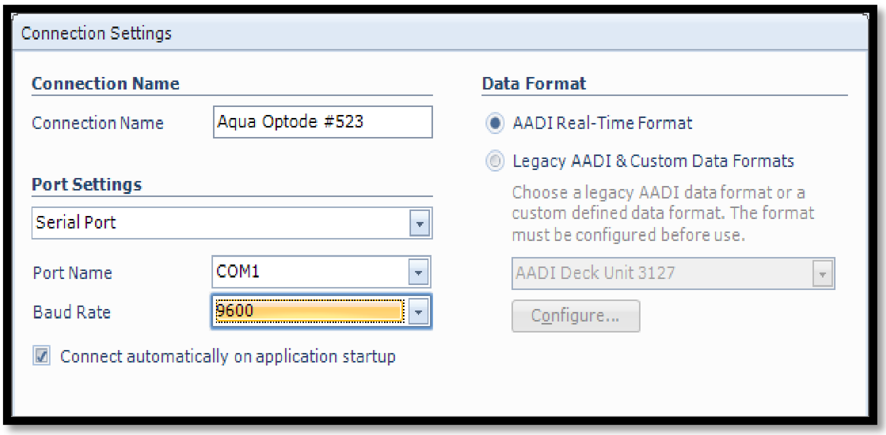


Figure 4-2: Connection Settings

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. Check Device Manager/Ports(COM&LPT) on your PC. ***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.

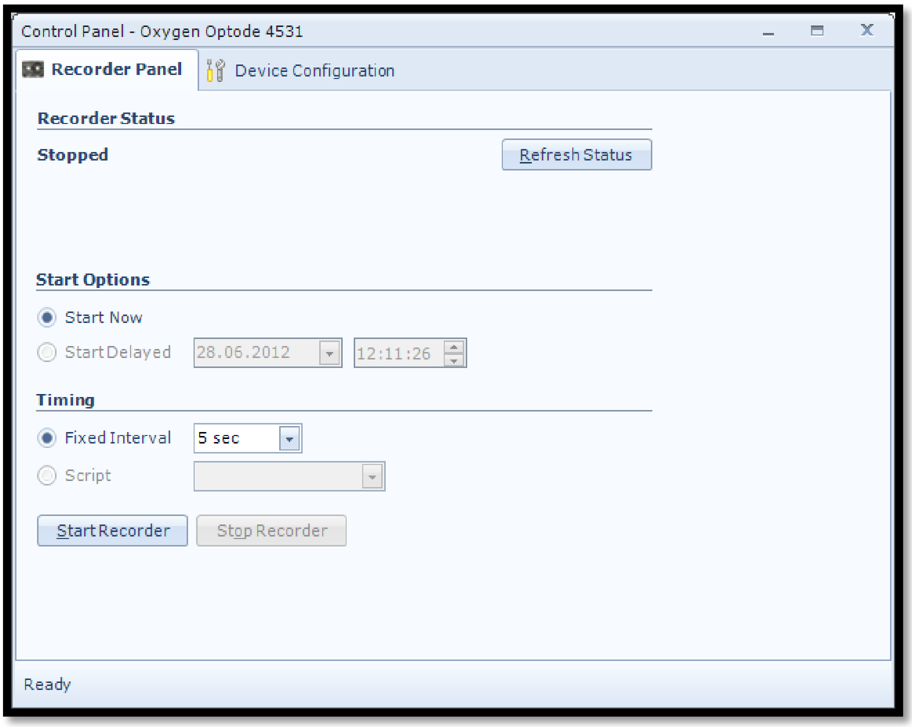


Figure 4-3: Recorder Panel

If the recorder is running you always need to stop it before you view or change settings and configurations.

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.

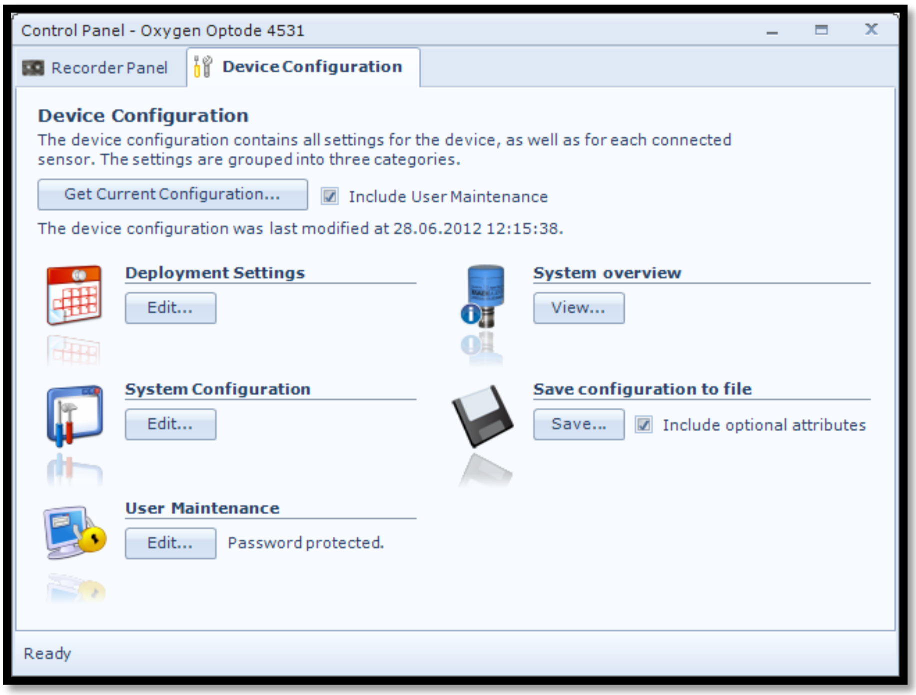


Figure 4-4: Device Configuration

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

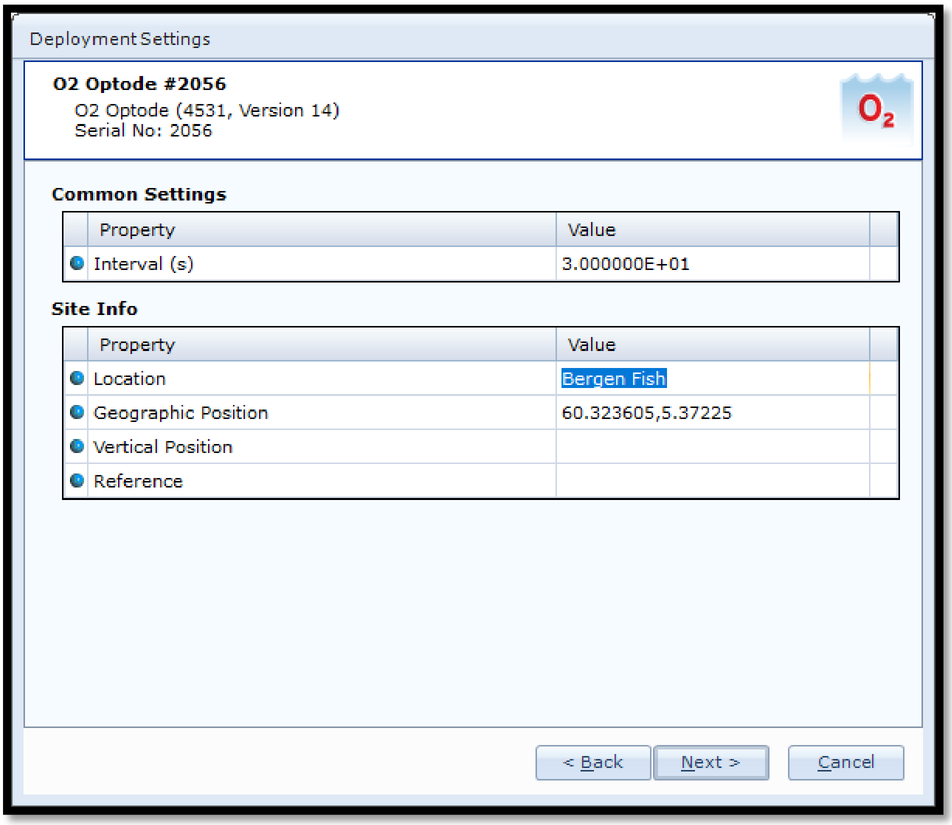
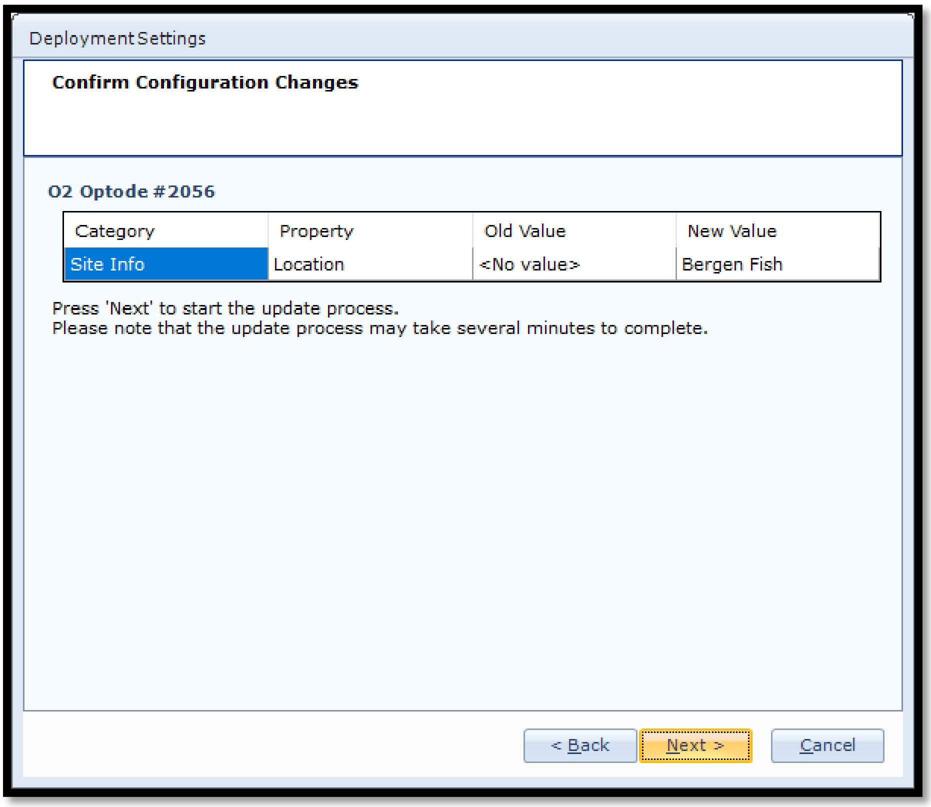


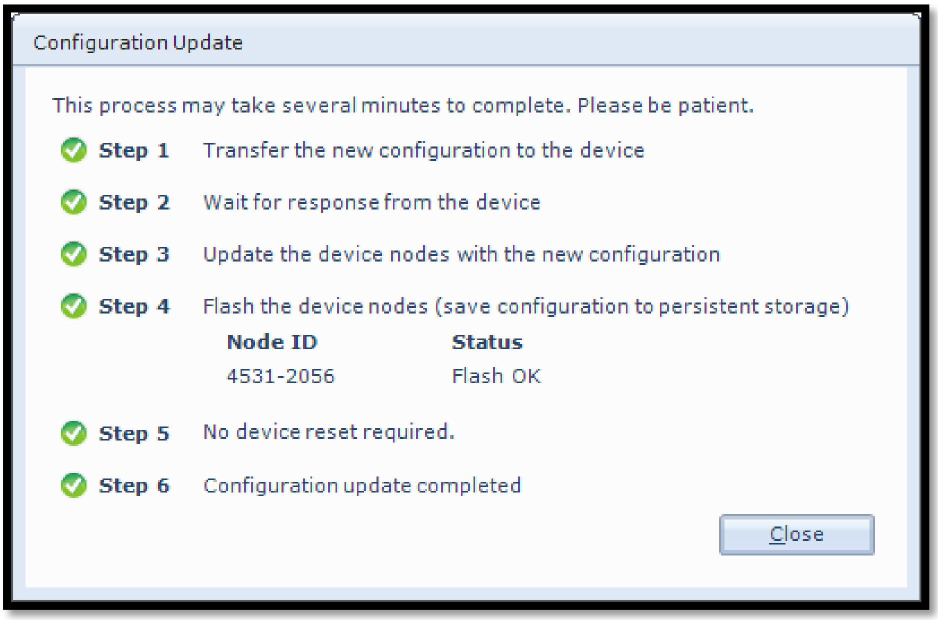
Figure 4-5 Change value.

To change a property enter the text or number in the value box, select a value from the drop-down menu or check/uncheck boxes. Then press ***Next.***



In the 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

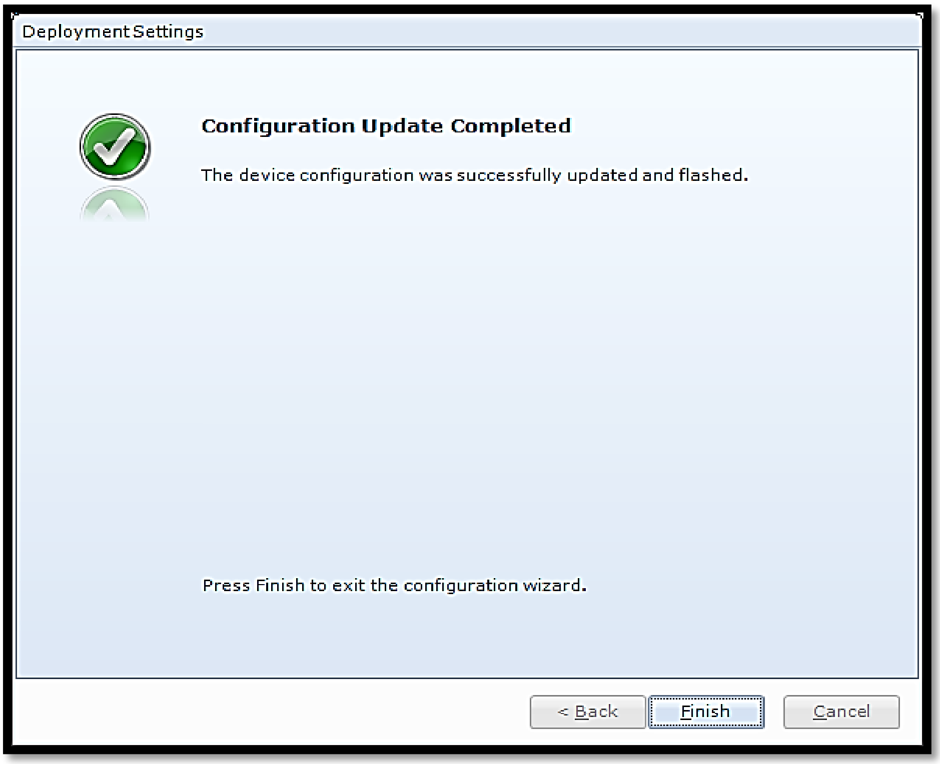


Figure 4-8 Configuration Update Completed

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.

Note! Any changes are not stored before you press the finish button. If power is shut off before the complete saving is finished the changes might be lost.

4.3 Deployment Settings

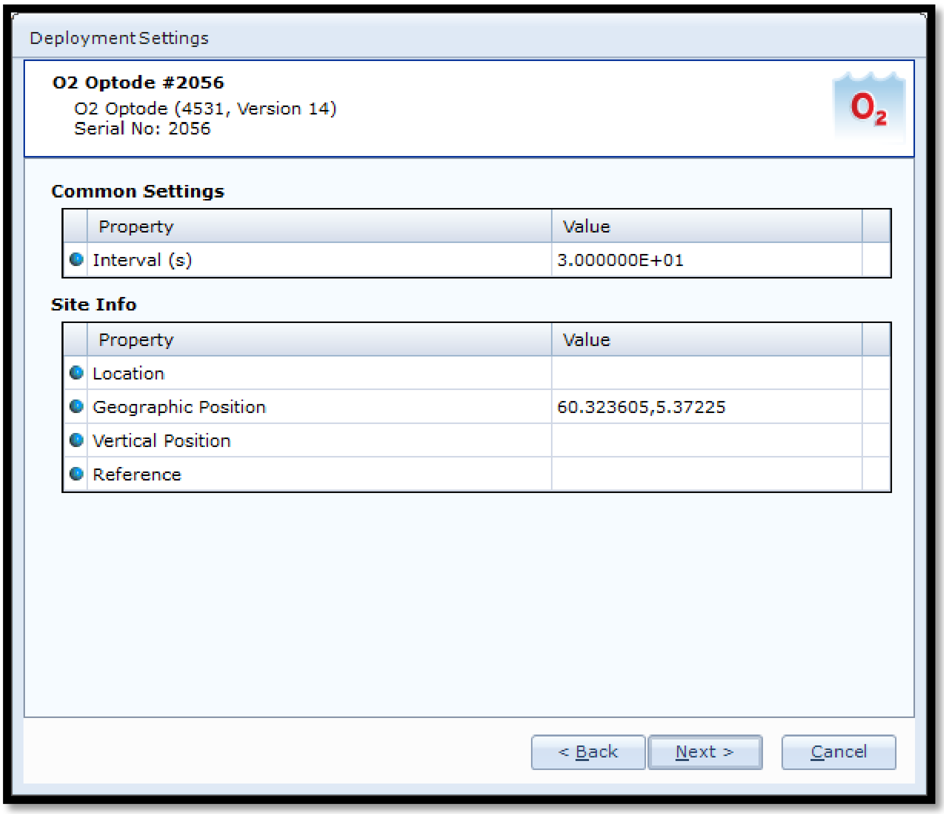


Figure 4-9: Deployment Settings

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

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

All parameters are also listed in ***Table 1-7.***

4.3.1 Common Settings

Figure 4-10: Common Settings

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.

4.3.2 Site Info

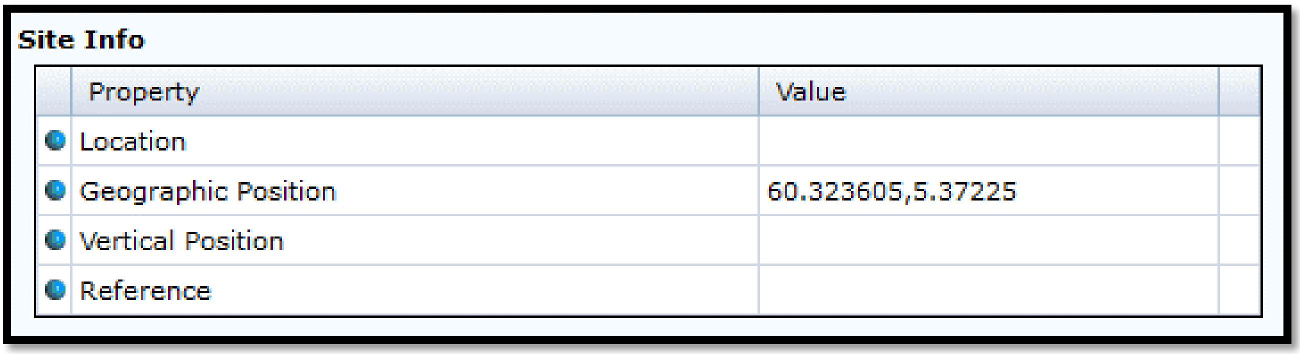


Figure 4-11: Site info

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 used 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

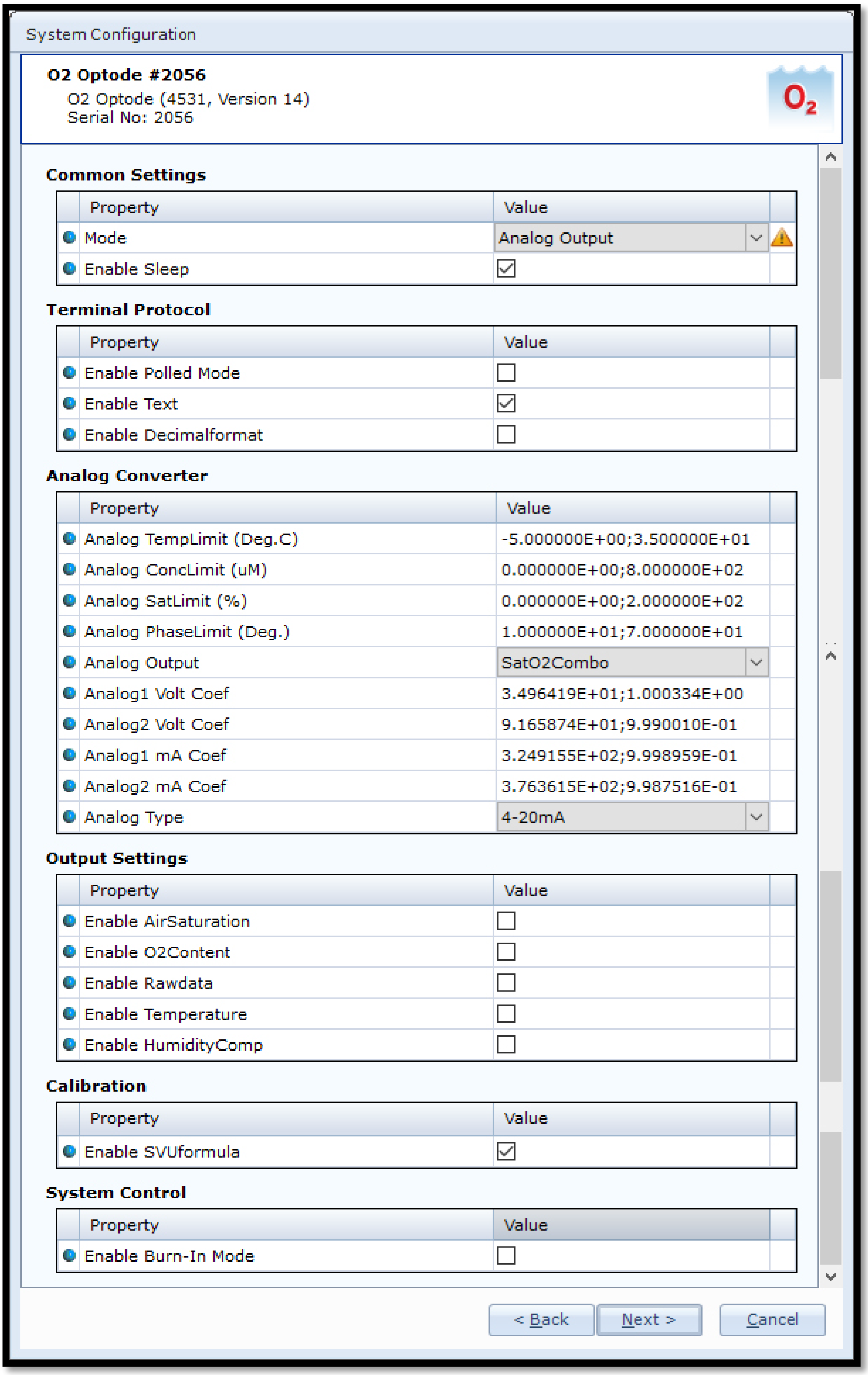


Figure 4-12: System Configuration

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

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

See ***chapter 4.4*** through ***chapter 4.4.6*** 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 1-8.***

4.4.1 Common settings

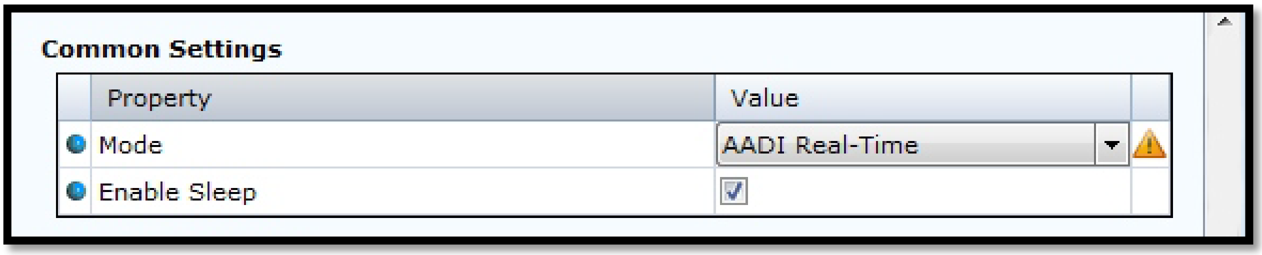


Figure 4-13: Common Settings in System Configuration

The ***Common Settings*** are available as shown in ***Figure 4-13***.

Mode: The communication protocol must be defined under "***Mode".*** There are four different choices:

- ***AADI Real-Time*** is the correct mode (protocol) when used together with ***AADI 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 ***AADI 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 6.***

- ***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 like an older version of the sensor.

- ***Analog Output*** is used when you want an analog output in addition to the RS-232.

  Notice that the sensor always must be reset when the protocol/mode has been changed.

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

4.4.2 Terminal Protocol settings

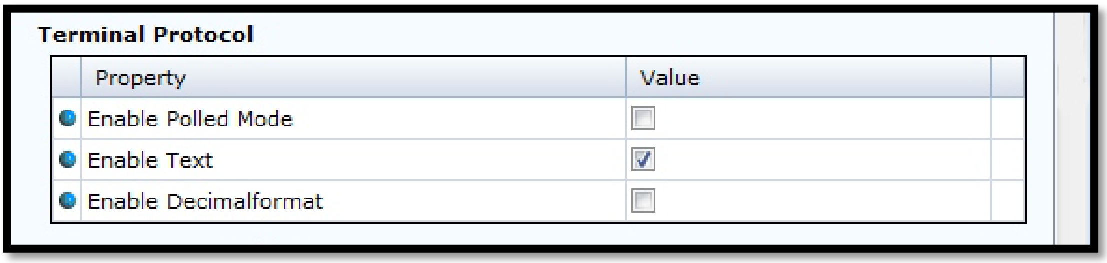


Figure 4-14: Terminal Protocol settings in System Configuration

The ***Terminal Protocol*** settings are available as shown in ***Figure 4-14*** but are only used if the sensor is set to ***Smart Sensor Terminal*** protocol.

If the ***Enable Polled Mode*** is enabled then the sensor outputs data when the user/system polls for data with a ***Do Sample ()*** command. The sensor only output data every time you send a ***Do Sample ()***. This mode is used to save power since it goes to sleep between each ***Do Sample ().***

Enable Text and ***Enable Decimalformat*** control the output string in Smart Sensor Terminal.

With ***Enable Text*** enabled the sensor will output a string with parameter name together with each reading. If disabled a string with only parameter values will be sent.

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)	-5.000000E+00;3.500000E+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	SatO2Combo
Analog1 Volt Coef	3.496419E+01;1.000334E+00
Analog2 Volt Coef	9.165874E+01;9.990010E-01
Analog1 mA Coef	3.249155E+02;9.998959E-01
Analog2 mA Coef	3.763615E+02;9.987516E-01
Analog Type	4-20mA

Figure 4-15: Analog Converter in System Configuration

Analog TempLimit(Deg.C) settings 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 4-15*** the range is set from -5 Deg.C. to 35 Deg.C. Default Range is -5 Deg.C to 35 Deg.C. A narrower range will increase the resolution.

Analog ConcLimit(uM) is used to set the range for ***O2Concentration*** 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 ***O2Concentration***.

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. Selects what parameter to present on the ***Analog output 1*** and ***2***. If ***SatO2Combo*** is selected ***Output 1*** will always be ***Air Saturation*** in ***%*** and ***Output 2*** will be ***O2Concentration*** in ***mg/l***. Any other settings of ***Analog Output*** will output ***Temperature*** as ***Output 2*** and then dependent on selected parameter give ***O2Concentration, Air Saturation, Fixed 1, Fixed 2***, or ***CalPhase*** as ***Output 1***.

Fixed 1 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

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. 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

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*****,** and then select the ***Analog Type***.

4.4.4 Output Settings

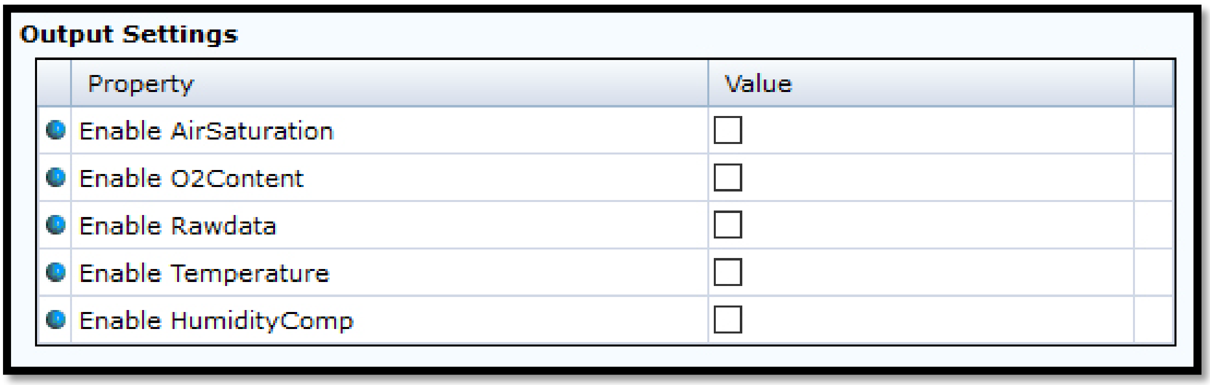


Figure 4-16: Output settings in System Configuration

The first four 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 ***AirSaturation*** parameter from the output string.

Enable O2Content. This setting is used to enable or disable the ***O2Concentration*** in ***mg/l*** parameter from the output string. ***O2Concentration*** in ***µM*** will always be a part of the Output string. This parameter cannot be switched off.

Enable Rawdata. This setting toggles on and off a set of raw data readings from the serial output string. These raw data 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*** from the output string. The temperature reading is used to compensate for internal temperature drift when oxygen level is calculated. This compensation is independent of this setting.

Enable HumidityComp. This property enables compensation of vapor 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*** as default.

4.4.5 Calibration

Figure 4-17: Calibration settings in System Configuration

Enable SVUformula. 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 4-18: System Control settings in System Configuration

Enable Burn-in Mode are used 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

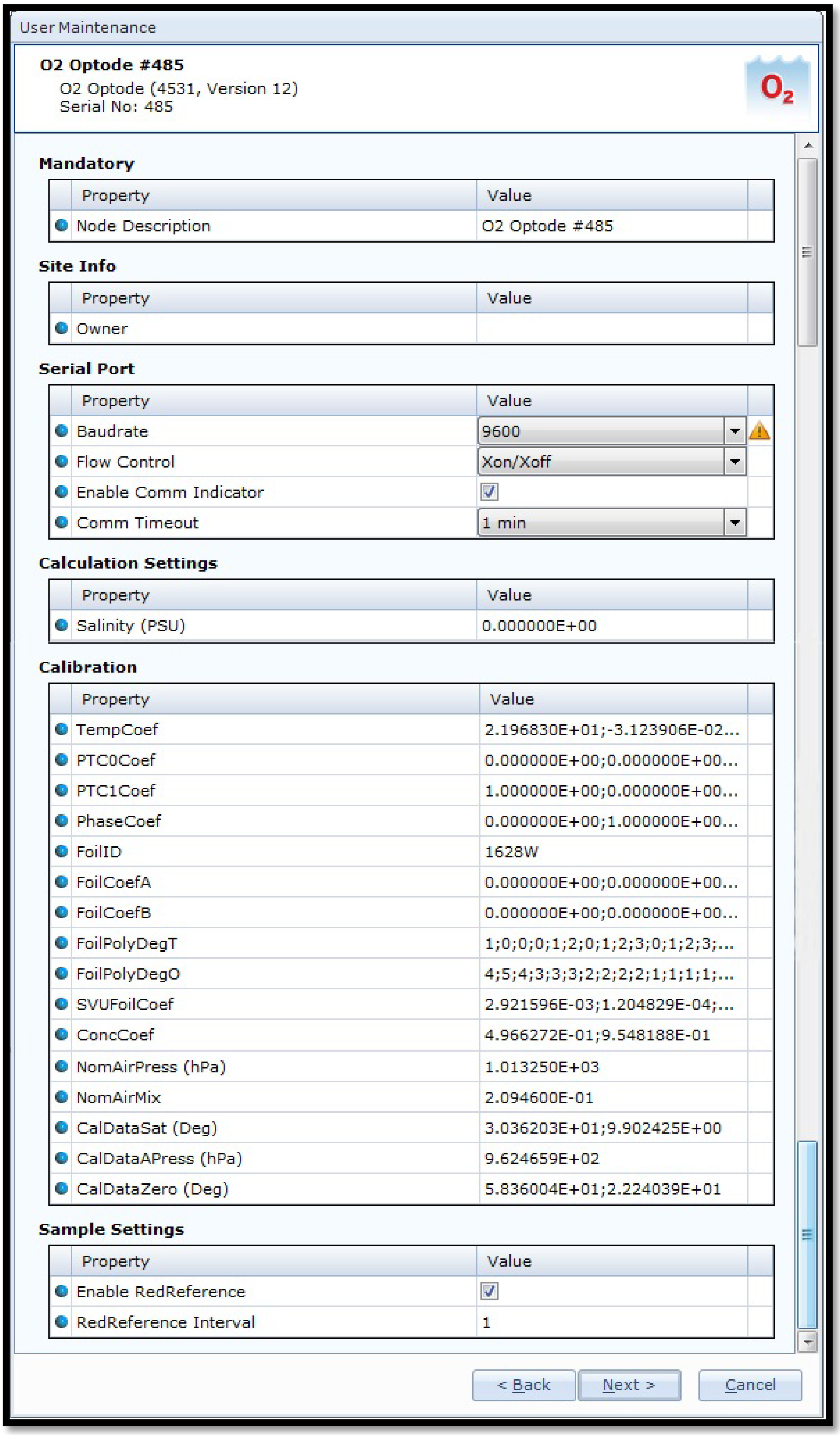


Figure 4-19: User Maintenance

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 4.5.1*** through ***chapter 4.5.6.***

All parameters are also listed in ***Table 1-9.***

4.5.1 Mandatory

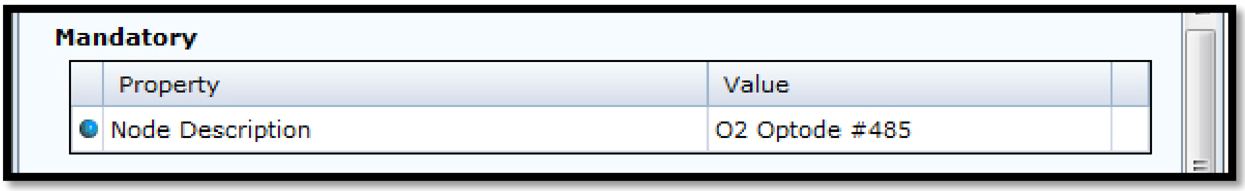


Figure 4-20: Mandatory in User Maintenance

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 saved to the corrupt sector if possible.

4.5.2 Site Info

Figure 4-21; Site Info in User Maintenance

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

4.5.3 Serial Port

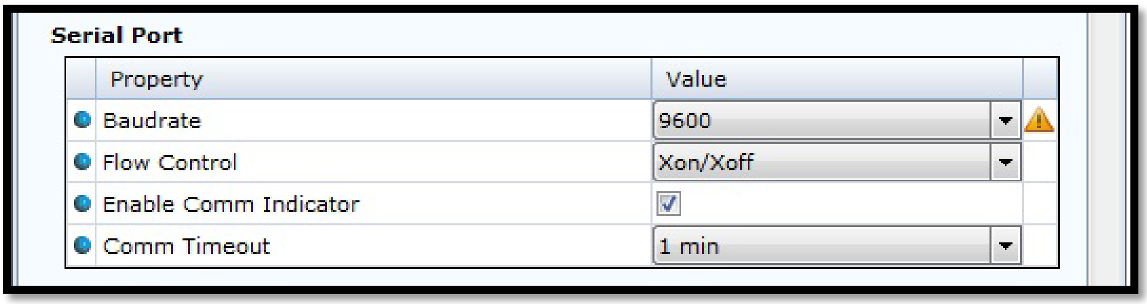


Figure 4-22: Serial Port settings in User Maintenance

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. Xon/Xoff secure communication with sensor even at short intervals and low baudrate. But in some cases with external noise it might cause the sensor to stop especially if you have a cable with unconnected Tx/Rx conductors working as an antenna. ***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 Yes for ***Enable Comm Indicator*** and 1 min for ***Comm Timeout***.

4.5.4 Calculation Settings

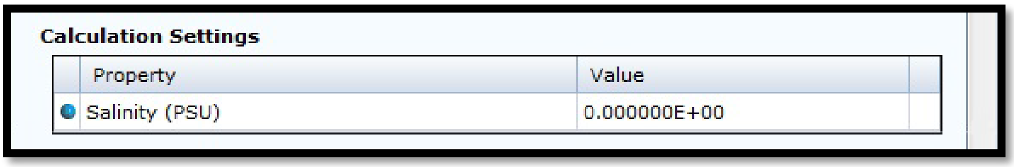


Figure 4-23: Calculation Settings in User Maintenance

Salinity (PSU) is used for salinity compensation of ***O2concentration***. If the salinity variation on site is minor (less than ±1ppt), the ***O2concentration*** can be corrected inside the sensor by setting the internal property ***Salinity*** to the average salinity at the measuring site. See ***chapter 2.8*** for more info. If you are post compensating for the salinity, you should set the property value to 0. The default setting is ***0***. When measuring ***Air Saturation*** in ***%*** the value does not need to be salinity compensated, this is only for ***O2concentration.***

4.5.5 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 4-24: 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 or a certified calibration laboratory.

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 7.3*** for a full procedure how to change the foil. If you change to another foil type a full calibration is needed.

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

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 7.3.

CalDataAPress(hPa) is a property that holds the actual air pressure set by the user during the two-point calibration procedure refer chapter 7.3.

CalDataZero(Deg) are a property that stores data obtained at the 0% calibration point during the two-point calibration procedure refer chapter, 7.3.

4.5.6 Sample Settings

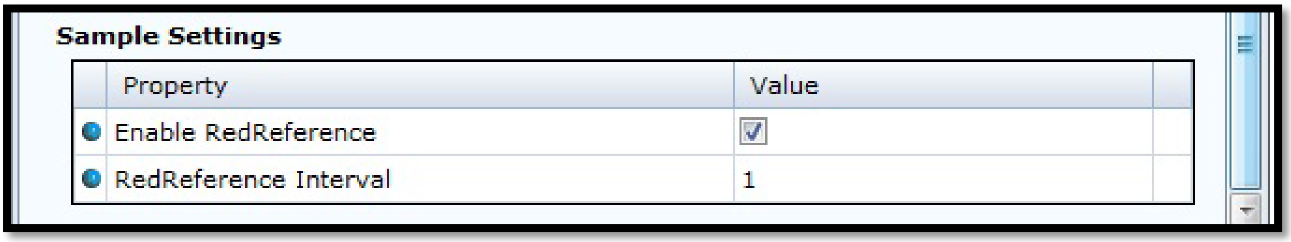


Figure 4-25: Sample Settings in User Maintenance

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 default set to *Yes* before calibration.

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 **Logging data via AADI Real-Time Collector**

5.1 Logging data on PC

Refer ***CHAPTER 3*** for how to connect the sensor to your PC.

The ***AADI Real-Time Collector*** can save the incoming data to file if the sensor is in ***AADI Real-Time mode***, either to a txt-file or xml-files.

5.1.1 Enabling file output

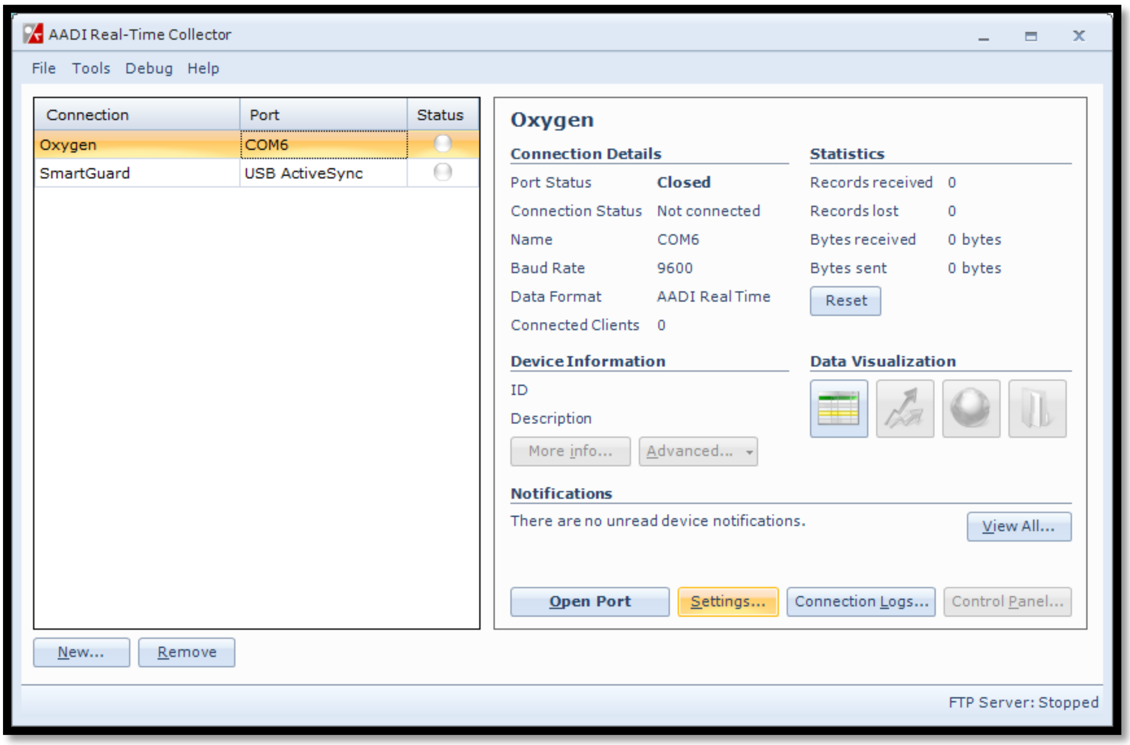


Figure 5-1: AADI Real-Time Collector start up menu.

If your connection is open (status is green in the ***AADI Real Time Collector*** main menu), then close the port first to be able to change the file output settings.

Click on the connection you are using. Then click on the ***"Settings…"*** button.

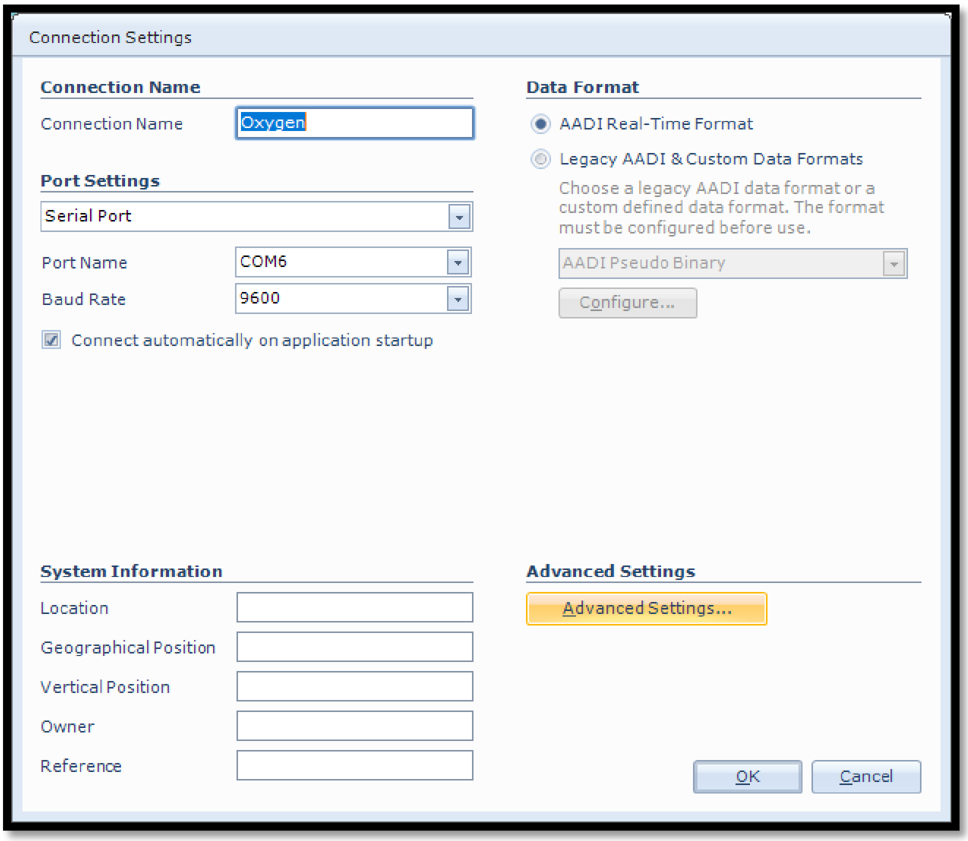


Figure 5-2: Connection settings menu

In the ***Connection Settings*** window select Connection Name and ***Port Settings. Connection Name*** you may select as you want either to make it general for more similar sensor or special for exact this one.

Port Setting will be ***Serial Port*** for all 4531 sensors.

Port Name depends on the connection to your PC and ***Baud Rate*** must be equal to the sensor setting, default ***9600***.

Then click on the ***"Advanced Settings…"*** button and ***OK.***

.

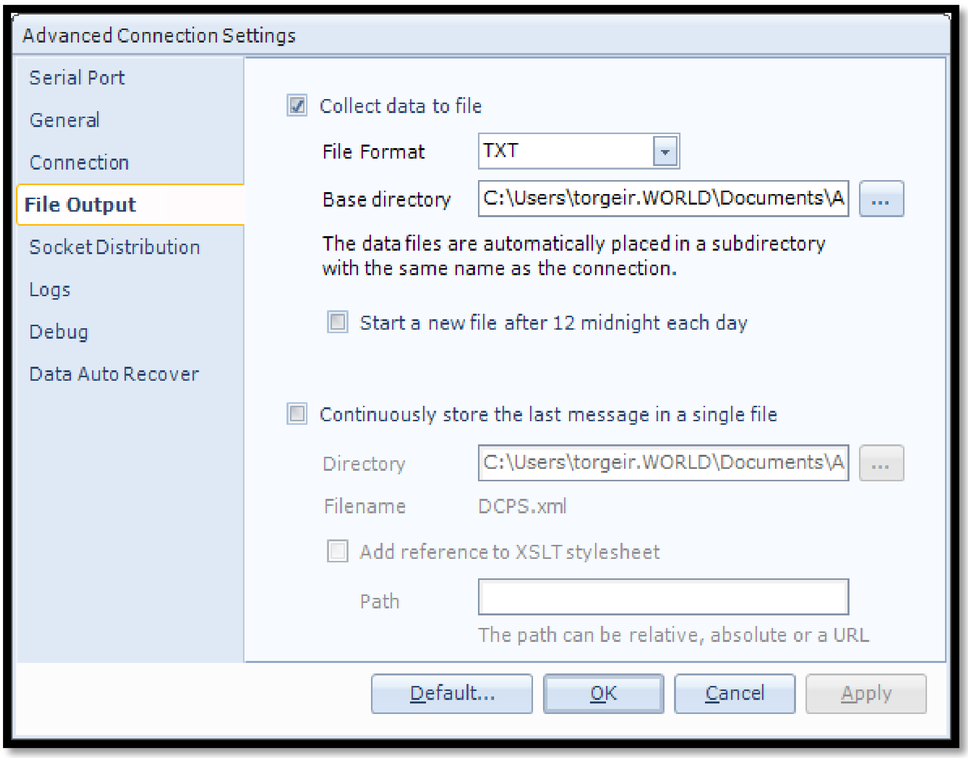


Figure 5-3: Advanced connection settings / File Output

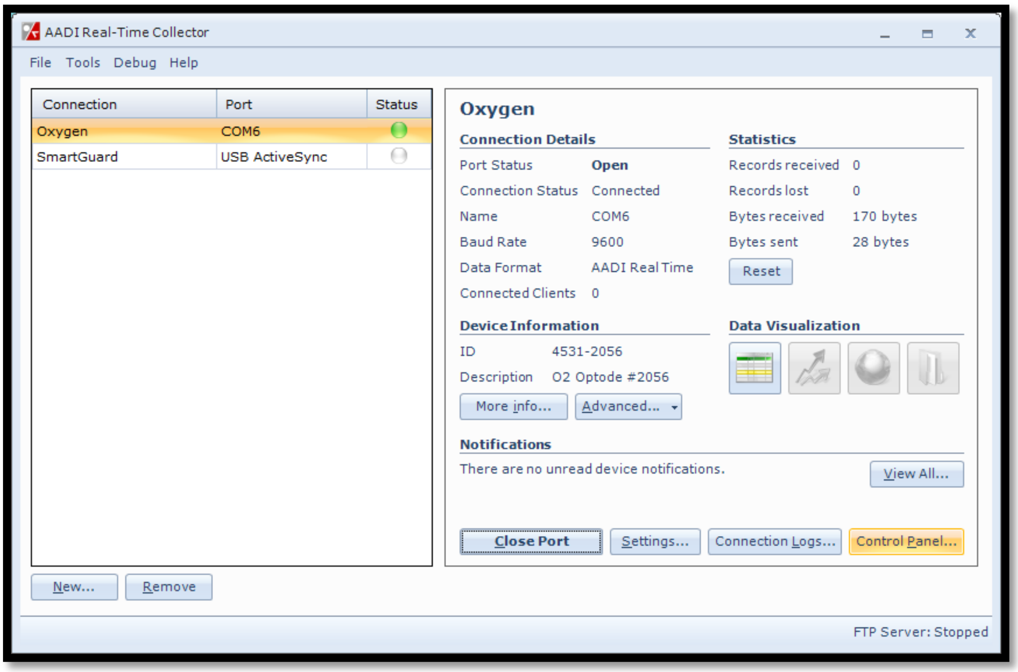
Choose ***File Output*** from the list on the left side.

Check the "***Collect data to file"*** box to enable file output. Select a file format either XML or TXT and choose a base directory where you want the file to be saved.

Alternatively you may select "***Continuously store the last message in a single file***".

Click "**OK**" in the ***Advanced Connection Settings*** window, and "***OK***" in the ***Connection Settings*** window.

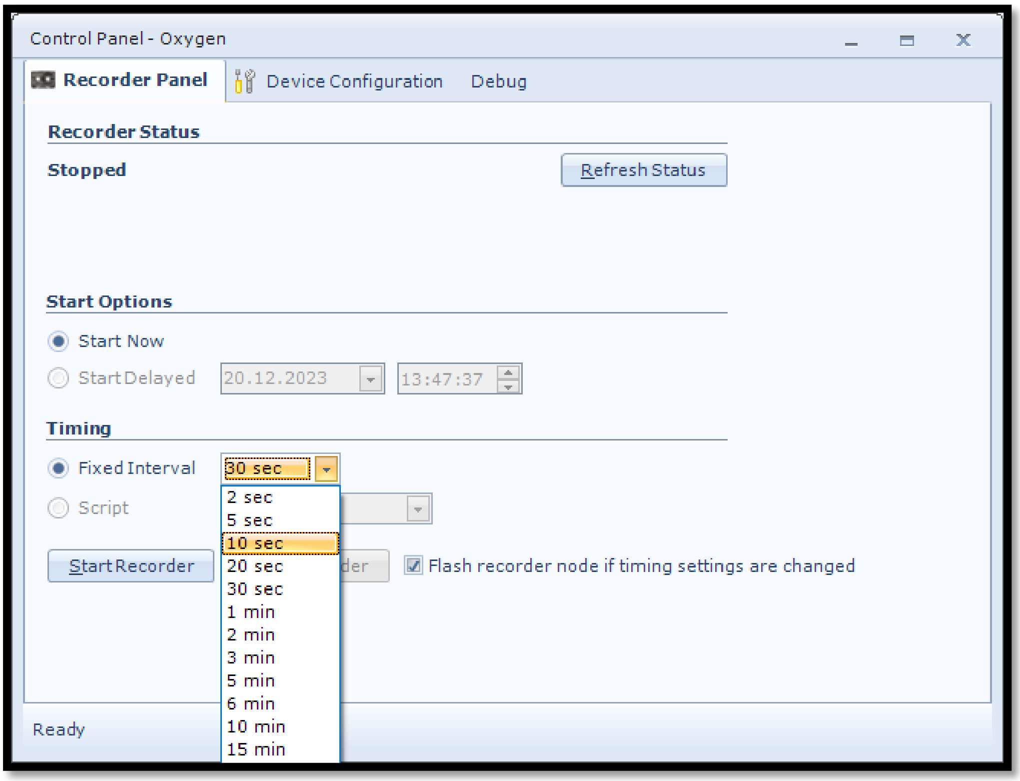
5.1.2 Starting the sensor and logging to file



Select your connection in the connection list and then press "***Open Port***". The Status turns green when the sensor is connected.

Click on the "**Control Panel…"** button in the lower right corner.

Figure 5-4: AADI Real-Time Collector start up menu.



If your sensor is recording, you first need to press ***Stop Recorder***.

Then select the interval duration and click the "***Start Recorder***" button.

This configuration is only available if the sensor is in ***AADI Real-Time*** mode.

Figure 5-5: Recorder panel

Data will start logging in the defined directory. If it is a txt-file, the easiest way to view it is using Excel. gives an example of an obtained data file. The different parameters are organized in columns.

Description	O2 Optode #2056									
Product Name	O2 Optode									
Product Number	4531									
Serial Number	2056									
Device ID	4531-2056									
Session ID	4531-2056-5.3.2-0-63									
Location										
Geographic Position	60.323605,5.37225									
Vertical Position										
Owner										
Reference										
		O2 Optode #2056								
Record Time	Record Nu	Sensor Sta	O2Concen	Status	O2Conten	Status	AirSaturat	Status	Temperat	Status
15.01.2024 14:30	1	(0) OK	2.521257E+02		8.068024E+00		9.597598E+01		2.401647E+01	
15.01.2024 14:30	2	(0) OK	2.520957E+02		8.067062E+00		9.597510E+01		2.402234E+01	
15.01.2024 14:31	3	(0) OK	2.521288E+02		8.068122E+00		9.599439E+01		2.402607E+01	
15.01.2024 14:31	4	(0) OK	2.520934E+02		8.066989E+00		9.599259E+01		2.403257E+01	
15.01.2024 14:31	5	(0) OK	2.520854E+02		8.066732E+00		9.599931E+01		2.403800E+01	
15.01.2024 14:31	6	(0) OK	2.521693E+02		8.069417E+00		9.603545E+01		2.404031E+01	
15.01.2024 14:31	7	(0) OK	2.521535E+02		8.068912E+00		9.603959E+01		2.404596E+01	

Figure 5-6: Data file example.

5.2 Viewing incoming data in real-time

When the sensor is running, the incoming data can be viewed under "**Connection Logs…**" in the main AADI Real-Time Collector menu. Double-click on one of the Record numbers to see data.

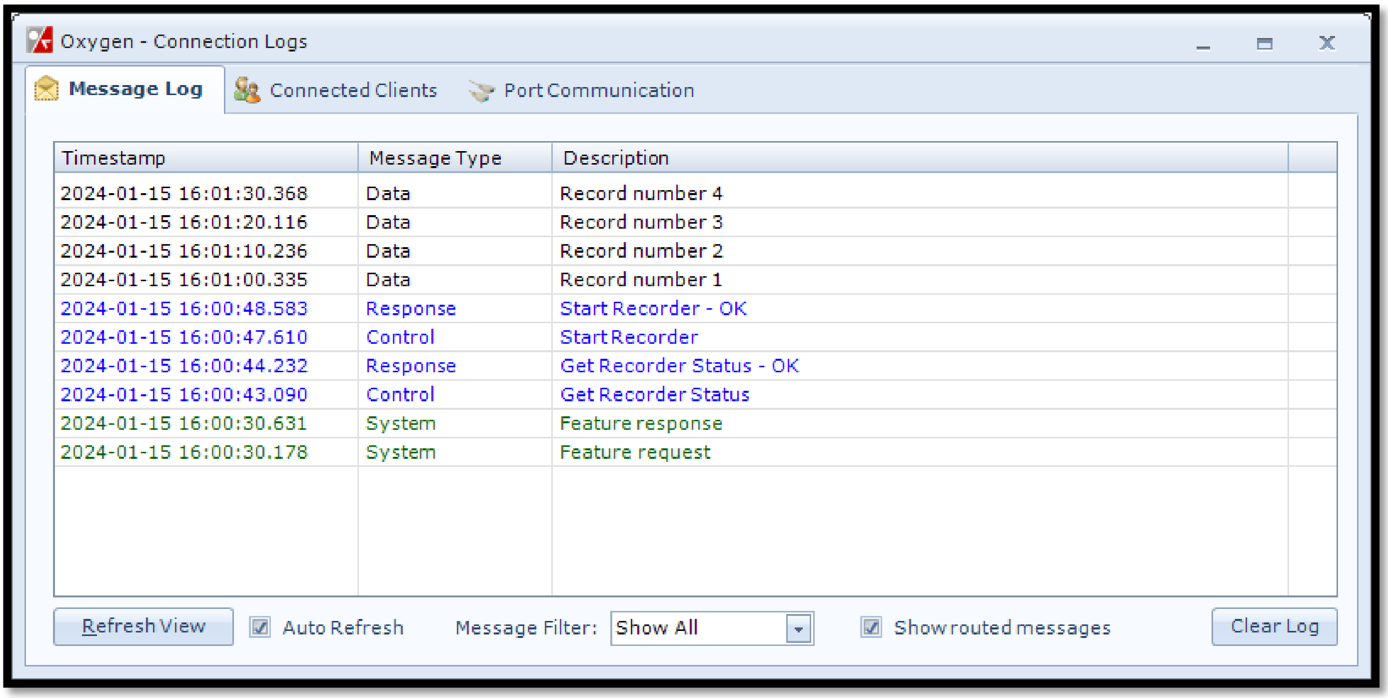


Figure 5-7: Connection Logs

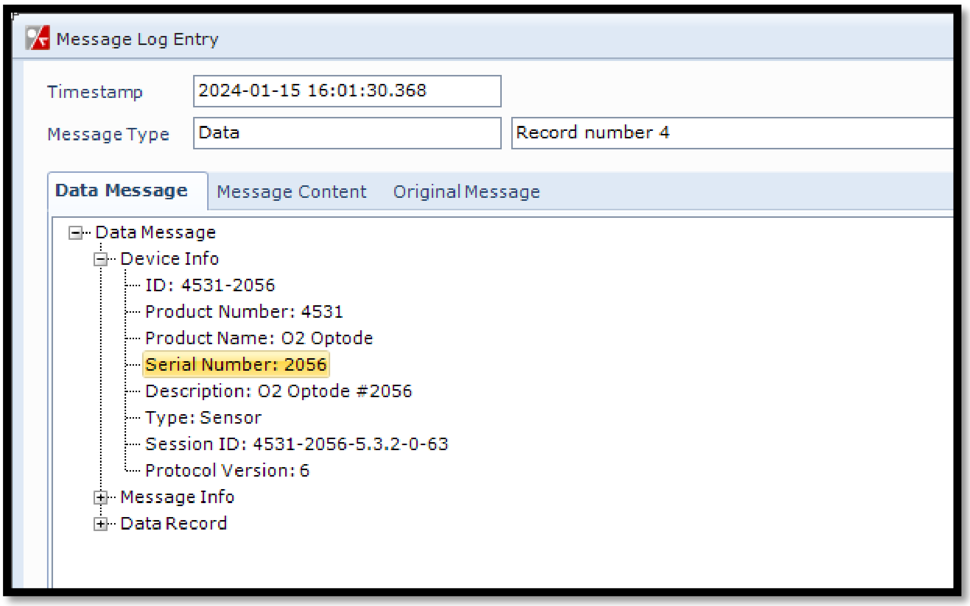


Figure 5-8: Message Log Entry

Click on the + signs to open and see all the data in the message.

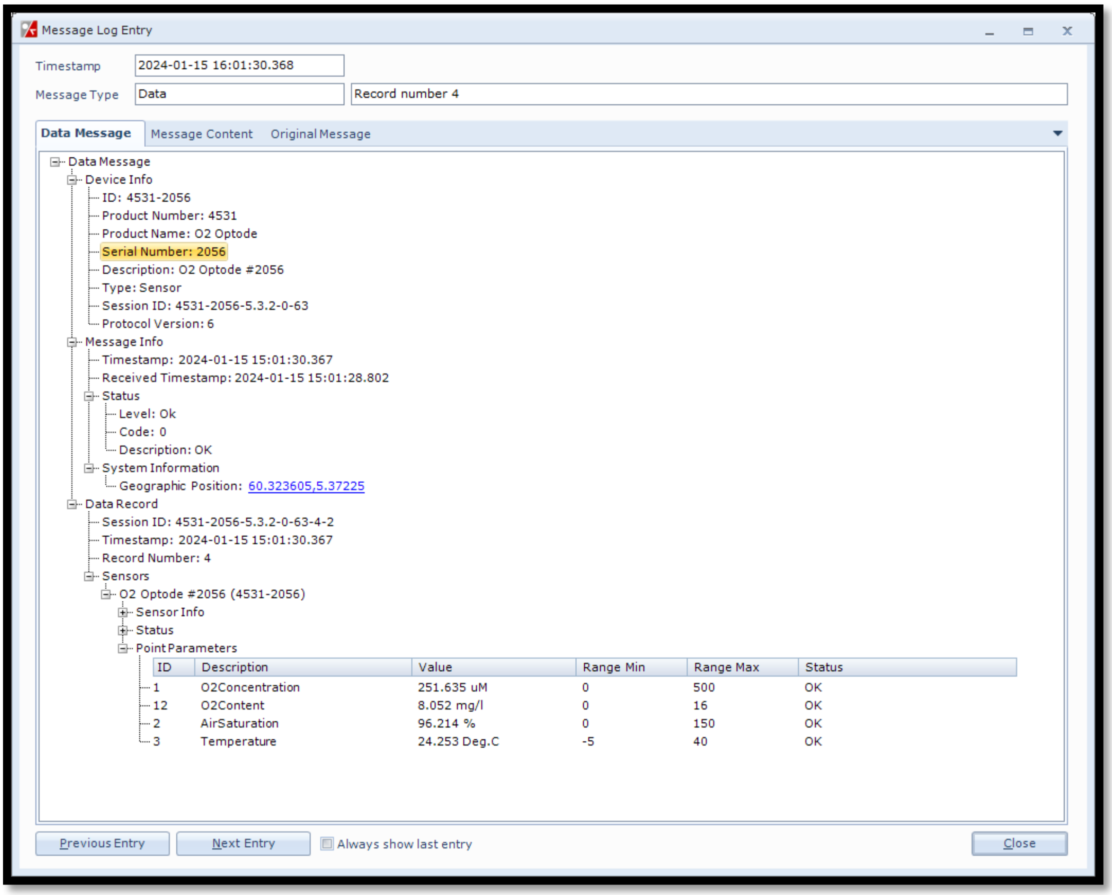


Figure 5-9: Visualization of incoming data from the sensor in real time

Previous records or newer records can be viewed by clicking on ***Previous Entry*** button or ***Next Entry button***. An automatic update to the last data message can be enabled by checking the Always show last entry check box.

The original message content can be seen if clicking on the Original Message tab.

CHAPTER 6 **Smart Sensor Terminal operation**

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

6.1 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.

6.1 Sensor startup

You will be able to communicate with the sensor via the Terminal software regardless of which mode the sensor is set to. However, the output string from the sensor will depend on the mode setting. The final structure of the output string will also depend on settings like Enable Text, Enable Decimal Format, Enable Raw Data, and so on. The sensor will continue to output measurements after the first startup info. The output frequency will be according to the interval setting. Some properties will not have any effects in all modes but they will still be available. Some properties may also have different effects depending on the mode.

6.2 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 6-1***. 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 6.3***.

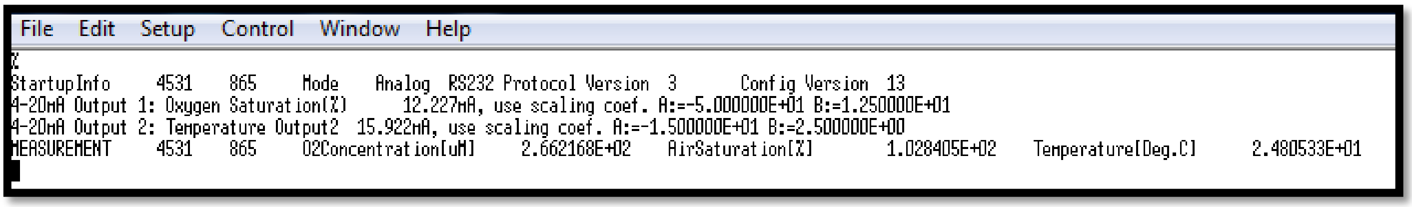


Figure 6-1 Startup info in analog mode

6.3 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 6-2***. This does not apply for Polled operations.

To minimize the power consumption, 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 6-2 Startup info in Smart Sensor Terminal

6.4 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 6-3*** and then after first interval it will perform a measurement and display the xml message including sensor data and parameters.

File Edit Setup Control Window Help


```
▪%{{++!!000000BEEF360=4531-865;1=4531;2=865;3=02 Optode;4=02 Optode #865;5=AADI;6=2;7=3;10=1;11=6.0;20=1;21=1;22=0;23=5000;30=1;80=102:110:111:140:201:202:20360FB!!--}}{{++!!0001109020<?xml version="1.0"
<Device ID="4531-865" SessionID="4531-865-5.0.4-0-51" Descr="02 Optode #865" SerialNo="865" ProdNo="4531" ProdName="02 Optode" DeviceType="Sensor" ProtocolVer="6" xmlns="http://www.aadi.no/RTOutSchema">
        <Time>1900-01-01T00:00:00Z</Time>
        <StatusCode>0</StatusCode>
        <Notifications>
                <Notification ID="100" Time="1900-01-01T00:00:00Z">
                        <Info>Power up</Info>
                        <NotificationValues>
                                <NotificationValue ID="0" Descr="Reason" Type="VT_I2">0</NotificationValue>
                                <NotificationValue ID="1" Descr="DeviceReady" Type="VT_BOOL">true</NotificationValue>
                        </NotificationValues>
                </Notification>
        </Notifications>
</Device>A1F7!!--}}{{++!!0002109020<?xml version="1.0" encoding="utf-8"?>
<Device ID="4531-865" SessionID="4531-865-5.0.4-0-51" Descr="02 Optode #865" SerialNo="865" ProdNo="4531" ProdName="02 Optode" DeviceType="Sensor" ProtocolVer="6" xmlns="http://www.aadi.no/RTOutSchema">
        <Time>1900-01-01T00:00:00Z</Time>
        <StatusCode>17</StatusCode>
        <SystemInformation>
                <SystemInfo ID="21" Descr="Geographic Position" Type="VT_BSTR">60.323605,5.37225</SystemInfo>
        </SystemInformation>
        <Data SessionID="4531-865-5.0.4-0-51-8-0">
                <Time>1900-01-01T00:00:00Z</Time>
                <RecordNumber>2</RecordNumber>
                <SensorData ID="4531-865" SerialNo="865" ProdNo="4531" ProdName="02 Optode" Descr="02 Optode #865" Adr="3991808" ProtocolVer="6" GeoPosition="60.323605,5.37225" NodeTypeID="2040">
                        <StatusCode>0</StatusCode>
                        <Parameters>
                                <Point ID="1" Descr="02Concentration" Type="VT_R4" Unit="uM" Format="%0.3f" RangeMin="0" RangeMax="500">
                                        <Value>2.630590E+02</Value>
                                </Point>
                                <Point ID="2" Descr="AirSaturation" Type="VT_R4" Unit="%" Format="%0.3f" RangeMin="0" RangeMax="150">
                                        <Value>1.028041E+02</Value>
                                </Point>
                                <Point ID="3" Descr="Temperature" Type="VT_R4" Unit="Deg.C" Format="%0.3f" RangeMin="-5" RangeMax="40">
                                        <Value>2.543321E+01</Value>
                                </Point>
                        </Parameters>
                </SensorData>
        </Data>
</Device>965E!!--}}
```


Figure 6-3: Startup info in AADI Real-Time mode.

6.5 Communication sleep

To minimize the power consumption, the sensor normally enters a power down mode after each sampling; the sensor can be awake by any characters and will stay awake for a time set by the ***Comm TimeOut*** property after receiving the last character.

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 characters 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.

The ***Communication Sleep Indicator***, ***'%',*** will be transmitted when the serial communication is deactivated, and the ***Communication Ready Indicator, '!'*** is outputted after activation (electronics require up to 500ms start up time). 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.

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.
- 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.

6.6 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 after 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).

6.7 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 6-1***.

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 6-1***. E.g.:

Set passkey(1000)

Table 6-1 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 has 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.

6.8 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. The ***Save*** command takes about 20 seconds to complete (indicated with the character '#').

Always send a ***Reset*** command when a new configuration has been saved (or switch the power OFF and then back ON), or else calculated parameters may be corrupted. This forces the sensor to start up with the new configuration input. If the ***Enable Sleep*** property is set to ***Yes*** and the ***Comm TimeOut*** property is not set to ***Always On*** the sensor enters sleep mode after reset.

At startup/reset the sensor performs measurements according to the interval setting if the mode is ***Smart Sensor Terminal.***

If ***Enable Text*** is set to ***Yes***, the ***Startup Info*** is presented. If the ***Save*** command is executed the new setting will be stored in the internal Flash memory. Property changes will be lost when the sensor is reset or loses power unless you type the ***Save*** command.

Refer to ***Figure 6-4***. The number of parameters in the list depends on which parameters are enabled.

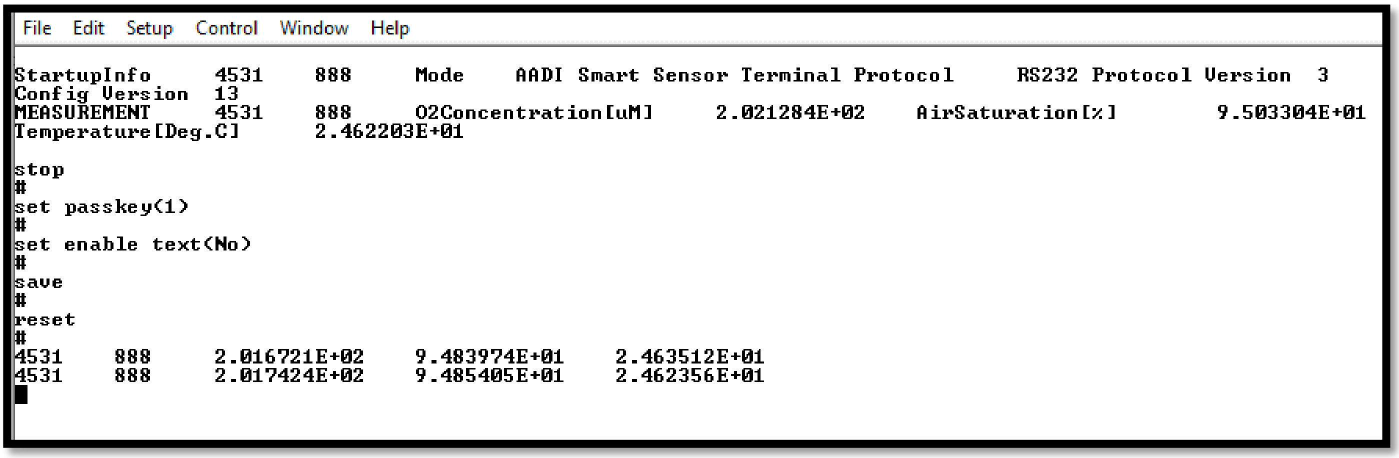


Figure 6-4 Save and reset in Tera Term.

6.9 Available commands for the Oxygen Optodes

Available commands and properties for the Oxygen Optode are given in ***Table 6-2***

Table 6-2 Main RS-232 commands available for the Oxygen Optode.

Command	Description
Start	Start a measurement sequence according to current configuration
Stop	Stop a measurement sequence
Do Sample	Execute an oxygen measurement and presents the result
Do Output	Presents the last set of calculated measurement data (normally only used in polled mode).
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
Get All Parameters	Output information about all parameters value
Set *Property(Value,.. Value)*	Set Property to Value,… Value
Set *Passkey(Value)*	Set passkey to change access level
Save	Store current settings
Load	Reloads previous stored settings
Reset	Resets the sensor with new configuration
Help	Print help information
;	Comment string, following characters are ignored
//	Comment string, following characters are ignored

[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.

6.9.1 The Get command.

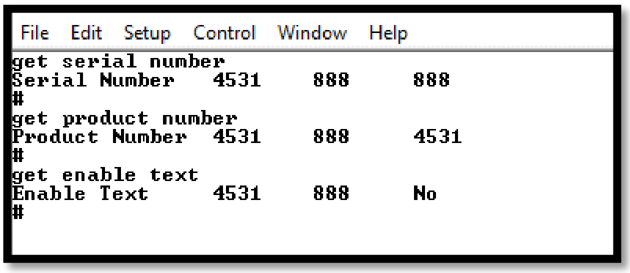
The *Get* command is used for reading the value/values of a property and for reading the latest value of a parameter.

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 6-5***.

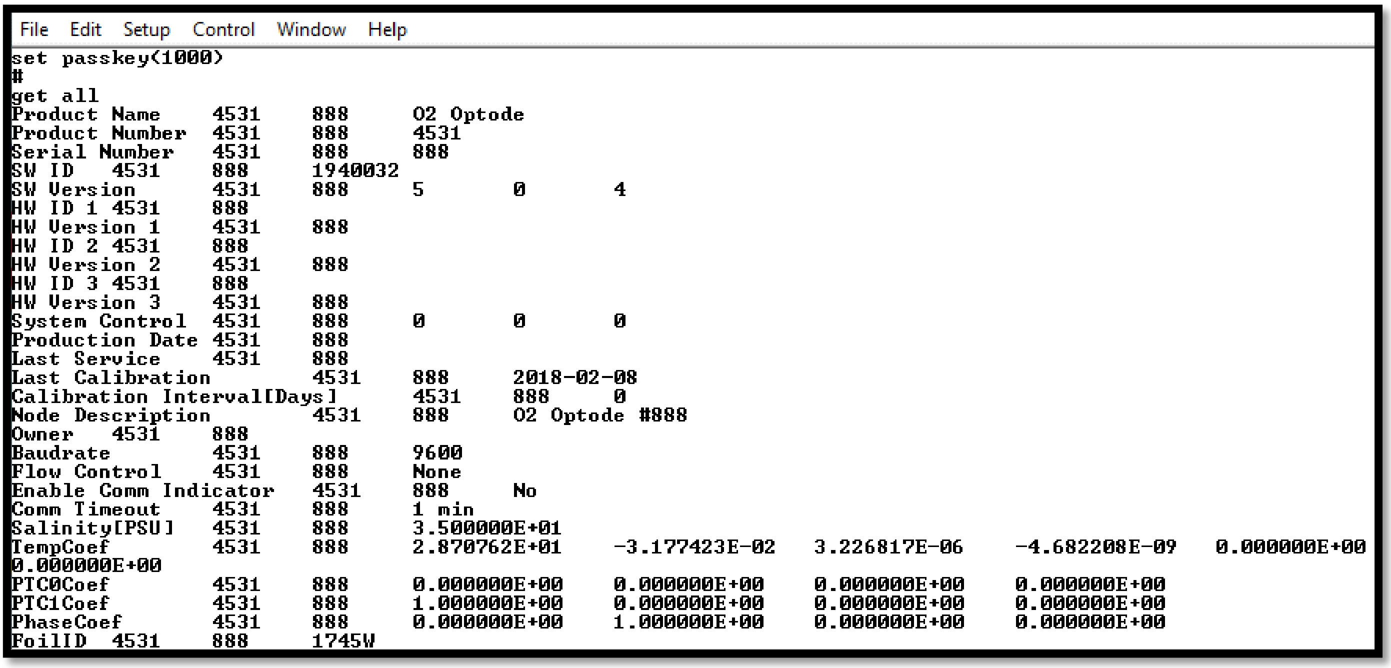
The command name ***Get*** followed by a parameter returns the name and unit of the parameter, the product and serial number of the sensor, and finally the latest parameter reading, refer example in ***Figure 6-5***.



```
File   Edit   Setup   Control   Window   Help
get serial number
Serial Number    4531     888      888
#
get product number
Product Number   4531     888      4531
#
get enable text
Enable Text      4531     888      No
#
```

Figure 6-5 Examples of the Get command.

A special version, ***Get All***, reads out all available properties in the sensor. Some properties are passkey protected and will not be shown without first writing the passkey. To see all user accessible properties, use ***passkey(1000).***



```
File   Edit   Setup   Control   Window   Help
set passkey(1000)
#
get all
Product Name     4531     888      O2 Optode
Product Number   4531     888      4531
Serial Number    4531     888      888
SW ID    4531    888      1940032
SW Version       4531     888      5        0        4
HW ID 1 4531     888
HW Version 1     4531     888
HW ID 2 4531     888
HW Version 2     4531     888
HW ID 3 4531     888
HW Version 3     4531     888
System Control   4531     888      0        0        0
Production Date  4531     888
Last Service     4531     888
Last Calibration          4531     888      2018-02-08
Calibration Interval[Days]         4531     888      0
Node Description          4531     888      O2 Optode #888
Owner    4531    888
Baudrate         4531     888      9600
Flow Control     4531     888      None
Enable Comm Indicator     4531     888      No
Comm Timeout     4531     888      1 min
Salinity[PSU]    4531     888      3.500000E+01
TempCoef         4531     888      2.870762E+01     -3.177423E-02     3.226817E-06     -4.682208E-09     0.000000E+00
0.000000E+00
PTC0Coef         4531     888      0.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
PTC1Coef         4531     888      1.000000E+00     0.000000E+00     0.000000E+00     0.000000E+00
PhaseCoef        4531     888      0.000000E+00     1.000000E+00     0.000000E+00     0.000000E+00
FoilID   4531    888      1745W
```

Figure 6-6: Get all command

6.9.2 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 6-7***.

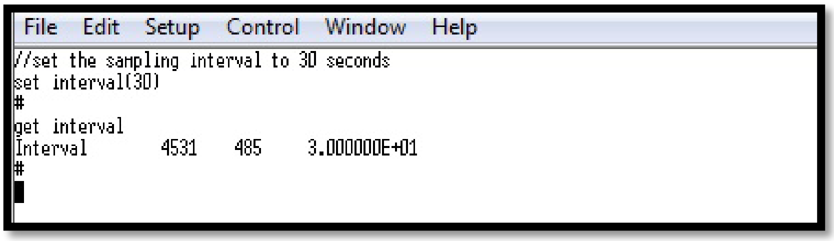


Figure 6-7 Example of the Set command.

Use the ***Save*** command to store the new property value. Some properties will require a ***Reset*** before the change is executed. Remember to always wait for the acknowledge character '#' after a save before switching off power to the sensor. If the power is lost while saving, the previous configuration saved to flash is used by the sensor.

The ***Mode*** and ***Baudrate*** property will require a ***Reset*** before the change is executed. All other property changes will be executed immediately.

Some properties are passkey protected and will not be accessible without first writing the passkey. If the passkey is needed you get the error message***: "ERROR PROTECTED PROPERTY".*** Using ***passkey 1000*** opens all user accessible property settings.

The property called ***Enable DecimalFormat*** controls the format of the output values, either as decimal numbers (***Yes***), or in exponential format (***No***).

6.9.3 XML commands

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

Get DataXML presents all the enabled parameters in XML format.

The ***XML-output*** is a general format shared by all Aanderaa smart sensors; the output from different types of smart sensors can be read and presented as e.g. in a general smart sensor setup program.

6.10 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.

6.11 Sensor configuration

The sensor configuration consists of sensor settings and customized presentation of data. Refer ***chapter 1.14*** .for a list of all sensor properties and the input format; refer ***chapter 4.3*** through ***4.5*** 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 7.***

6.12 Example – How to configure sensor.

In the following examples several configuration changes are shown. The command ***Stop*** is recommended to avoid output strings while configuring the sensor. If the sensor has started to transmit data when the user tries to communicate, it may take a while before the command response is sent from the sensor. This depends on configuration, timing and number of output parameters etc.

6.12.1 Example 1: Configure sensor with all output parameters selected.

//Press Enter to start communicating with the sensor

↵//Press Enter

Stop ↵//Wait for ack #. Repeat if necessary.

Set Passkey(1) ↵//wait for ack #

Set Mode(Smart Sensor Terminal) ↵//wait for ack #

Set Enable Sleep(No) ↵//wait for ack #

Set Enable Text(Yes) ↵//wait for ack #

Set Enable Decimalformat(Yes) ↵//wait for ack #

Set Enable AirSaturation(Yes) ↵//wait for ack #

Set Enable O2Content(Yes) ↵//wait for ack #

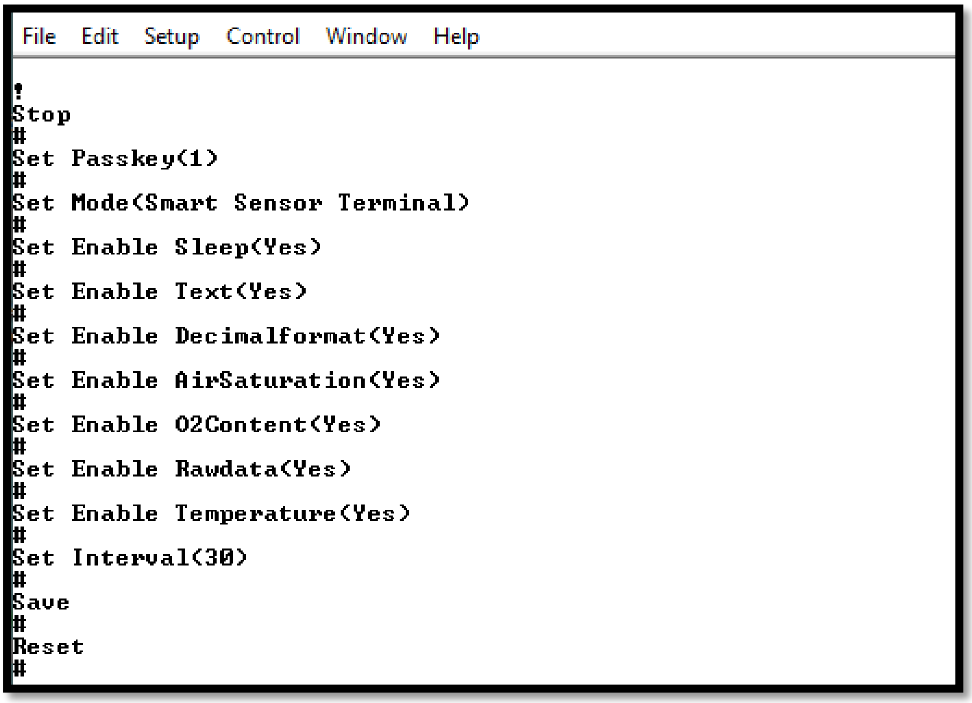
Set Enable Rawdata(Yes) ↵//wait for ack #

Set Enable Temperature(Yes) ↵//wait for ack #

Set Interval(1 min) ↵//wait for ack #

Save ↵// wait for ack #

Reset ↵// the sensor will restart with new settings.



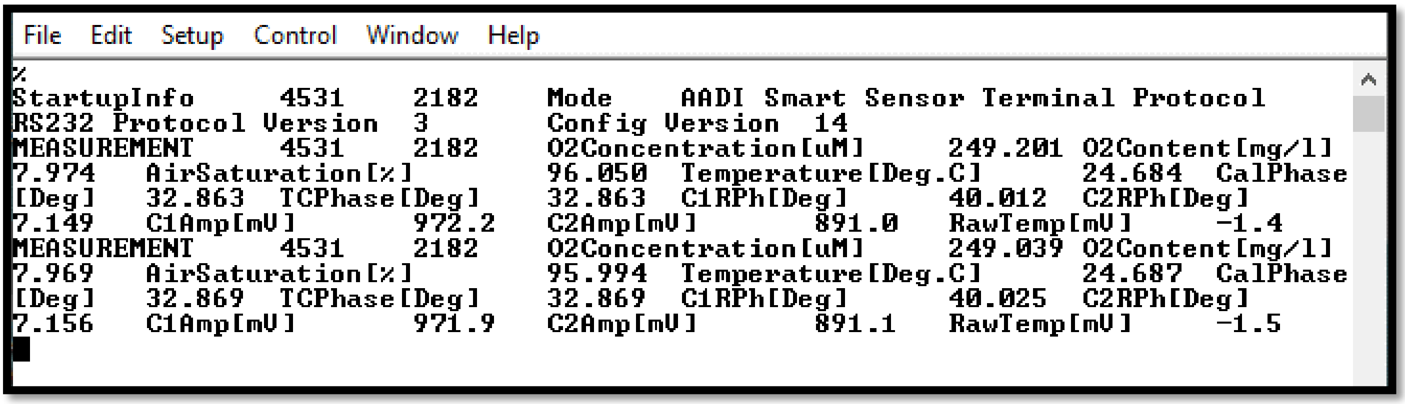
```
File  Edit  Setup  Control  Window  Help
!
Stop
#
Set Passkey(1)
#
Set Mode(Smart Sensor Terminal)
#
Set Enable Sleep(Yes)
#
Set Enable Text(Yes)
#
Set Enable Decimalformat(Yes)
#
Set Enable AirSaturation(Yes)
#
Set Enable O2Content(Yes)
#
Set Enable Rawdata(Yes)
#
Set Enable Temperature(Yes)
#
Set Interval(30)
#
Save
#
Reset
#
```

Figure 6-8: Example 1

Comments to example 1:

In this example all available output parameters are enabled. A total of 11 parameters is then presented. Some setting has only one parameter while others have more.

The available/selectable values for each parameter can be found by sending the command ***Help***. This gives a printout from the sensor showing a short help text. Setting a value which is not shown here for enumerated properties gives an error message ***(*ERROR ARGUMENT ERROR***).



```
File  Edit  Setup  Control  Window  Help
%
StartupInfo     4531    2182    Mode    AADI Smart Sensor Terminal Protocol
RS232 Protocol Version  3       Config Version  14
MEASUREMENT     4531    2182    O2Concentration[uM]     249.201 O2Content[mg/l]
7.974   AirSaturation[%]        96.050  Temperature[Deg.C]      24.684  CalPhase
[Deg]   32.863  TCPhase[Deg]    32.863  C1RPh[Deg]      40.012  C2RPh[Deg]
7.149   C1Amp[mV]       972.2   C2Amp[mV]       891.0   RawTemp[mV]     -1.4
MEASUREMENT     4531    2182    O2Concentration[uM]     249.039 O2Content[mg/l]
7.969   AirSaturation[%]        95.994  Temperature[Deg.C]      24.687  CalPhase
[Deg]   32.869  TCPhase[Deg]    32.869  C1RPh[Deg]      40.025  C2RPh[Deg]
7.156   C1Amp[mV]       971.9   C2Amp[mV]       891.1   RawTemp[mV]     -1.5
```

Figure 6-9: Result from Example 1

6.12.2 Example 2: How to enable polled mode.

In non-polled mode Enable Polled Mode(No) the sensor will output all selected parameters at a regular time given by the Interval() parameter. If Enable Polled Mode(Yes) the sensor will output a string every time a Do Sample are sent to the sensor. This mode is normally used to reduce power consumption or if you need fresh measurement at irregular intervals.

//Press Enter to start communicating with the sensor

↵ //press Enter

Stop ↵//Wait for ack #. Repeat if necessary

Set Passkey(1) ↵ //wait for ack #

Set Mode(Smart Sensor Terminal) ↵ //wait for ack #

Set Enable Sleep(Yes)↵//wait for ack #

Set Enable Polled Mode(Yes) ↵//wait for ack #

Save ↵// wait for ack #

Reset ↵// the sensor will restart with new settings.

↵ //press Enter

Do Sample ↵// will trigger a new measurement.

Do Sample ↵// will trigger a new measurement.

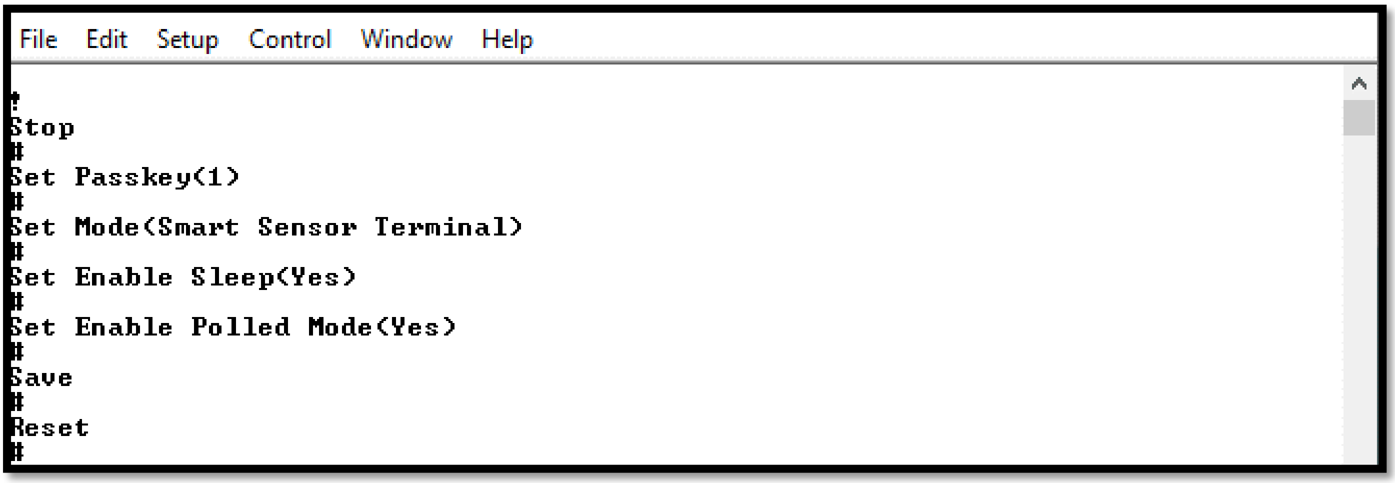


Figure 6-10: Example 2

Comments to example 2:

Polled mode is used when you want to trigger a reading at irregular interval e.g. if you want a measurement controlled by an external clock or on request from a remote operating system. Please notice that if the time between to ***Do Sample*** commands are longer that ***Comm Timeout*** then you need to send a Enter or other character to wake up before ***Do Sample***.

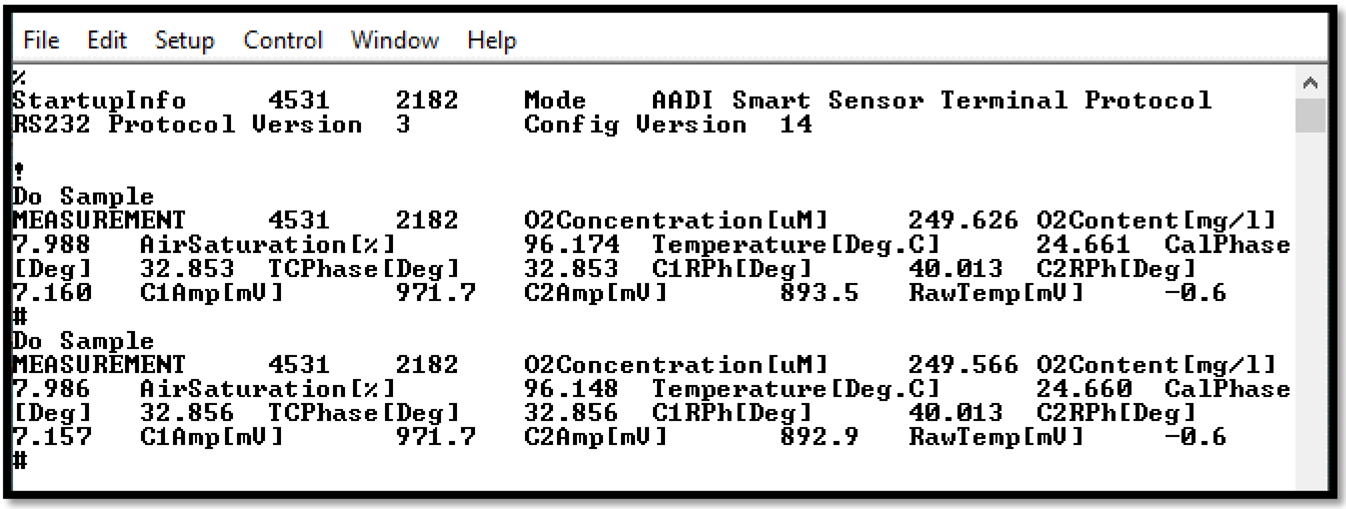


Figure 6-11: Result from Example 2.

6.12.3 Example 3: Configure the sensor for Analog Output

In this example we show how to typical configure the sensor for analog output. Most of the settings and calibration is preset from the factory and if necessary to alter please refer to ***chapter 2.2*** or contact ***Aanderaa.Support@xylem.com.***

//Press Enter to start communicating with the sensor.

↵ //press Enter

Stop ↵// Stop current measurement. Wait for ack #. Repeat if necessary.

Set Passkey(1) ↵//wait for ack #

Set Mode(Analog Output) ↵//wait for ack #

Set Analog Output(Air Saturation) ↵//wait for ack #

Set Analog Type(4-20mA) ↵//wait for ack #

Set Interval(10 sec) ↵

Save ↵// wait for ack #

Reset ↵// the sensor will restart with new settings.

```
File   Edit   Setup   Control   Window   Help

!
Stop
#
Set Passkey(1)
#
Set Mode(Analog Output)
#
Set Analog Output(Air Saturation)
#
Set Analog Type(4-20mA)
#
Set Interval(10)
#
Save
#
Reset
#
```

Figure 6-12: Example 3

Comments example 3:

When sensor is set to Analog Output mode you may also set Analog Output and Analog Type to decide what parameter to output in each of the two Analog Output: The Enable O2Content() setting will also decide what alternatives you have for the two output. Analog Type can be set to either 0-5V or 4-20mA.

```
File   Edit   Setup   Control   Window   Help
Reset
#
%
StartupInfo     4531    2182    Mode    Analog  RS232 Protocol Version  3
Config Version  14
4-20mA Output 1: Oxygen Saturation(%)     11.718mA, use scaling coef. A:=-5.000
000E+01 B:=1.250000E+01
4-20mA Output 2: Temperature Output  15.912mA, use scaling coef. A:=-1.500000E+0
1 B:=2.500000E+00
MEASUREMENT     4531    2182    O2Concentration[uM]     249.837 O2Content[mg/l]
7.995   AirSaturation[%]        96.470  Temperature[Deg.C]      24.781  CalPhase
[Deg]   32.803  TCPhase[Deg]    32.803  C1RPh[Deg]      39.965  C2RPh[Deg]
7.162   C1Amp[mV]       967.4   C2Amp[mV]       884.3   RawTemp[mV]     -4.5
MEASUREMENT     4531    2182    O2Concentration[uM]     249.831 O2Content[mg/l]
7.995   AirSaturation[%]        96.469  Temperature[Deg.C]      24.782  CalPhase
[Deg]   32.803  TCPhase[Deg]    32.803  C1RPh[Deg]      39.963  C2RPh[Deg]
7.161   C1Amp[mV]       967.3   C2Amp[mV]       884.0   RawTemp[mV]     -4.5
```

6.12.4 Example 4: Changing foil

//Press Enter to start communicating with the sensor.

↵ //press Enter

Stop ↵// Stop current measurement. Wait for ack #. Repeat if necessary.

Set Passkey(1000) ↵//wait for ack #

Set Enable FoilID(xxxx) ↵//wait for ack # insert the new batch number from your new foil.

Set SVUFoilCoef(x,x,x,x,x,x,x,x) ↵//wait for ack # insert new coefficients from calibration certificate following the foil kit.

Save ↵// wait for ack #

Reset ↵// the sensor will restart with new setting.

```
File   Edit   Setup   Control   Window   Help

Stop
#
Set Passkey(1000)
#
Set FoilID(1745W)
#
Set SVUFoilCoef(3.016088E-03, 1.231625E-04, 2.182339E-06, 1.629228E+02,
 -2.611209E-01, -4.584489E+01,3.294785E+00)
#
Save
#
Reset
#
%4531   888     2.083403E+02    9.738964E+01    2.428592E+01
```

Figure 6-13: Example of output message with text off and decimal format

Comments example 4:

This example shows what you need to do if you change Foil and using the same type of Foil but with another batch number. The calibration coefficients you will find in the calibration certificate following the foil kit. After changing the Foil, you need to perform a 1- or 2-point calibration. If you change to a new foil with the same batch number, you don't need to update the coefficient only perform a 1-point calibration. If you change to a different foil version you need to follow the instruction in ***chapter 7.3***

CHAPTER 7 **Maintenance**

The Oxygen Optode requires limited maintenance. The Foil should never be changed unless it's damaged. This is related to the fact that the Foil get more and more stable with use.

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.

The Optode housing can be cleaned using a brush and clean water. Carefully, use a cotton pin or soft brush 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 hours 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 7-1 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 if 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 the sensor

The fluorescence lifetime 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 7-2*** typical drift versus the number of excitations (samples) is depicted.

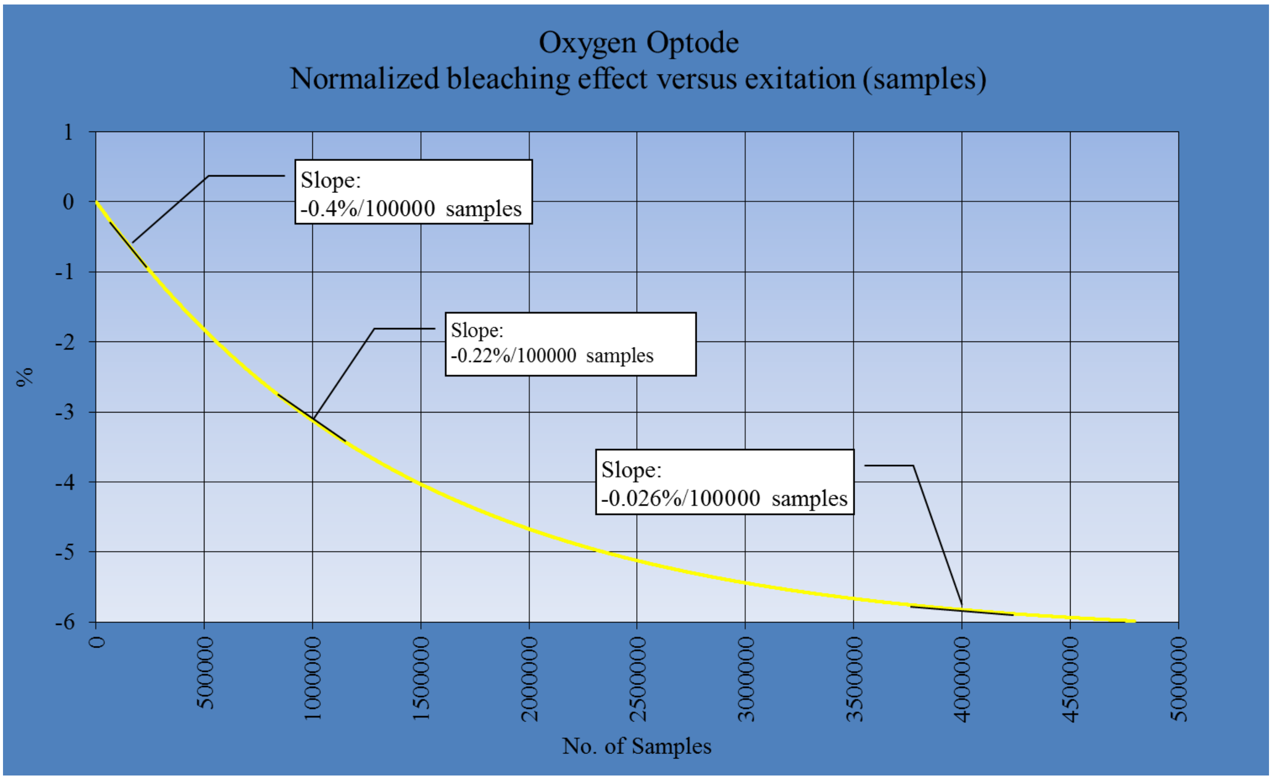


Figure 7-2: Normalized bleaching effect versus number of excitations.

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@xylem.com or our local representative, refer Services page at www.aanderaa.com

7.1 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, and a 1- or 2-point calibration performed.

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

7.1.1 Foil Kit

If you need to change the foil Aanderaa offers different options depending on what version you have. To avoid extra work with entering the coefficients we recommend the user to keep a stock with spare foils from the same batch as your sensors. You may also ask for a specific batch number when you order spare kit and we will try to supply this if available. Foil version and batch number on your existing foil can be found by sending a ***get all*** or ***get FoilID*** command to the sensor. This can also be found in the calibration certificate but please note that this will not be updated if you have changed foil after last calibration.

Table 7-1 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.

7.1.2 Procedure for changing foil.

Using foil kit 4733/5551:

- The sensor foil is changed by unscrewing the 2 torx screws holding the securing plate. Remove the securing plate and the old foil.
  - 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.
- If necessary use a scissor to slice of a small bite on each side of the foil to better fit between the screws holding the window. See ***Figure 7-3***.
- Remount the securing plate.
- Optical signal level of the new version foil and the old version foil might be 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 7-4***. 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 7.3***.
- Recalibrate the sensor if necessary, refer ***chapter 7.3***.

Figure 7-3: Foil prepared for use.

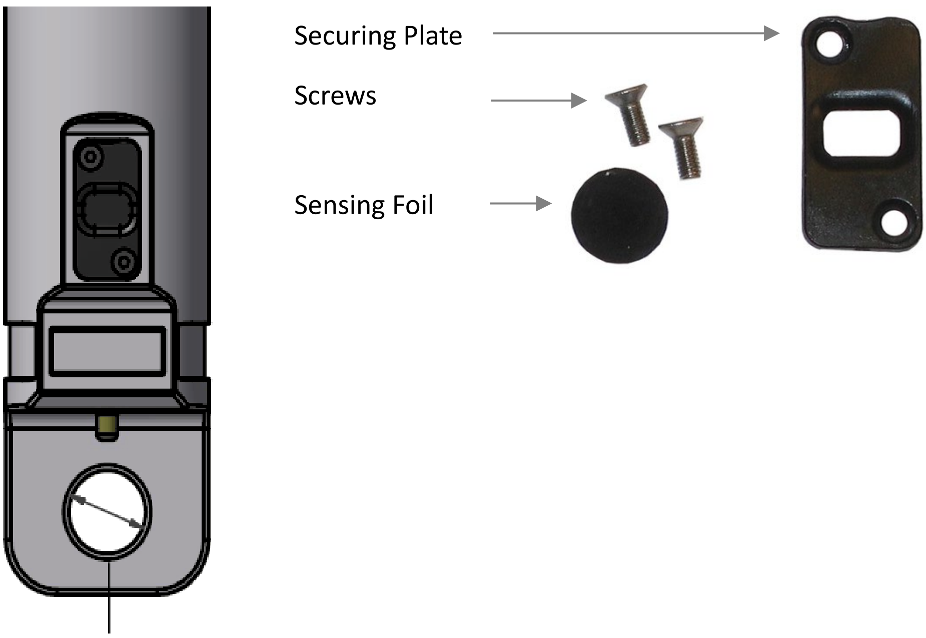


Figure 7-4: Removing the securing plate and change foil.

```
File  Edit  Setup  Control  Window  Help
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 7-5: Adjust Gain.

7.2 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 at 1013.25 dbar atmospheric pressure. But it may vary from 90 to 110 %, depending on air pressure. On our web-site https://www.aanderaa.com/oxygen-sensors under ***Documents*** and then ***Technical Notes*** you will find a calculator called ***Oxygen AirSaturation Calculator*** that helps you to find the expected ***Nominal Air Saturation*** based on the actual ***Air Pressure***. You may find the actual ***Air Pressure*** on the web site from your local metrological institute.

Local oxygen production or consumption may also influence on the measured ***AirSaturation***.

You should also make sure that the temperature sensor measurements are representative to the temperature of the foil. If the difference between water temperature and air temperature is significant, we recommend that you do this test immediately after you recover the sensor and softly dry it with soft paper or wait until the temperature has stabilized to make sure the temperature measurement from the temperature is equal to the foil temperature.

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

The measured temperature should be according to the ambient temperature.

7.1 Status Codes

The sensor produces some status codes if there are some errors with the sensor or with the quality of collected data. These status codes are either shown in the data string or when using post-processing software. Each status code has both a hexadecimal value and a decimal value shown in table below. The status codes are separated in three groups. ***Ok*** is when everything is normal and this status code will not be visible. An ***Error*** status code is critical state and requires normally a service and repair on the sensor. ***Warnings*** are more temporary errors that may reduce the data quality for a shorter period and normally don't need a factory service but it still important to investigate and remove the cause.

Parameter	***Hex***	***Status Code***	***Description***
Ok	0	0	Ok

Errors

Parameter	***Hex***	***Status Code***	***Description***
InvalidVectorError	41	65	Internal use only
AccessError	42	66	Access error
RequestTimeError	43	67	Input time is shorter than the processing time
NotValidError	44	68	Some internal fails
CopyDataError	45	69	Recorder error

Warnings

Parameter	***Hex***	***Status Code***	***Description***
OutOfMeasureRange	51	81	Data outside range. The data is not reliable
OutOfCalibRange	52	82	Data Outside Calibration range. The data can be reliable, but out of calibration range
ReducedQuality	53	83	e.g. supply voltage to low
NotReady	54	84	e.g., timeseries is not finish to the first recording
NotImplemented	55	85	Not a valid parameter
StoredDataWarning	56	86	e.g. Storing data that reduce precision
LowQuality	57	87	Indicates lower quality than reduced quality
DiscardData	58	88	Data useless, can be discarded

7.2 Calibration

To ensure the optimum accuracy a yearly calibration is recommended. However if the sensor foil has not been changed and the sampling frequency is moderate the Aanderaa Optode will normally provide stable data for years. 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. Methods are in place to after-cure all foils before they are mounted on the Optodes and calibrated. A sensor is 40-point calibrated as standard when delivered from factory. For recalibration a 40-point calibration is not necessary. A 1-point or 2-point calibration is easier to perform and are sufficient to compensate for drift.

Each batch of sensing foils is delivered with calibration data describing the behavior with respect to oxygen concentration and temperature. All newer sensors are using the SVU Formula. When this formula is enabled a total of 7 calibration coefficients are stored in.

SVUFoilCoef$_{0\text{-}6}$

For older sensors without SVU Formula the calibration coefficients are stored in:

FoilCoeffA$_{0\text{-}13}$
FoilCoeffB$_{0\text{-}13}$

These coefficients are found in the Calibration Certificate for the Sensing Foil 4733/5551 if you miss the actual coefficient for your foil batch number, please contact aanderaa.support@xylem.com

In addition to the above mentioned coefficient update a one- or two-point calibration are needed due to the different drift in the two foils. 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 water bath 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 water bath of the same water (as for air saturation) and dissolving 5g of sodium sulfite (Na_2SO_3) in 500ml water.

7.2.1 Calibration procedure using a terminal program.

Most 4531 sensors are using a WTW FDO701 foil. A WTW foil is identified with a W following the 4-digit batch number.

NOTE! To obtain the highest accuracy on a Presens PSt3 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. The wetting effect is because the foil swells when in water. This is only related to the 4733 foil from Presence and not to the 5551 foil from WTW.

1. Prepare a suitable container with fresh water. Aerate (apply bubbling) to the water using an ordinary aquarium pump together with an air-stone, 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
4. Start a terminal program, i.e. 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*** or ***SVUFoilCoef*** properties accordingly to the Calibration Certificate for the sensing foil in use.

Type ***Get All*** to verify the new coefficients.

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 8 **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 wavelength). 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.

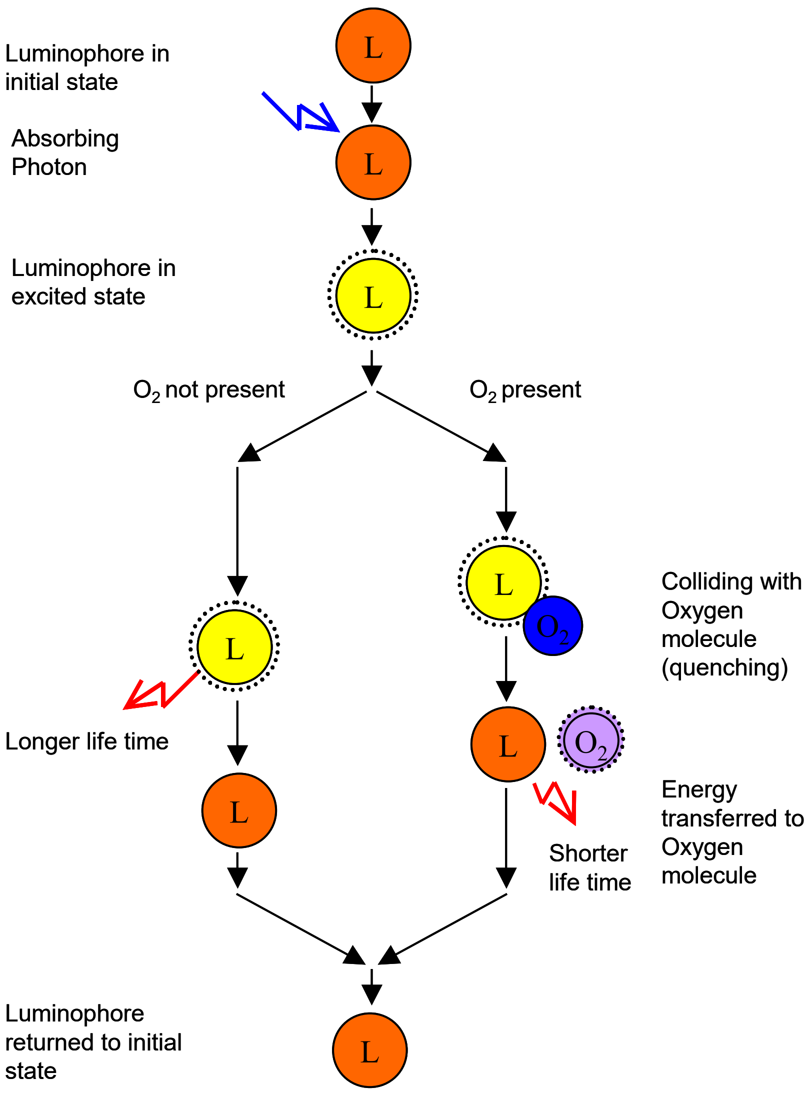


Figure 8-1 Dynamic luminescence quenching.

The luminophore will then transfer parts of its excitation energy to the colliding molecule, with the result that less photons (giving a shorter lifetime) 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.

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.

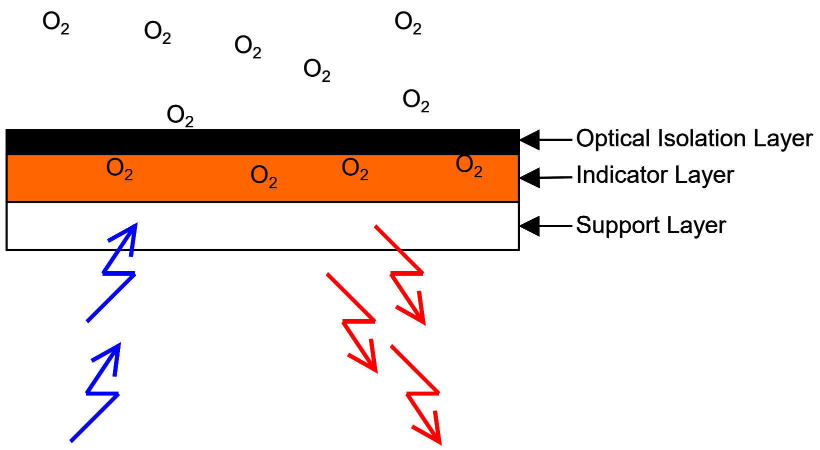


Figure 8-2 Sensing foil.

Luminescence Decay Time

Due 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)

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 8-3 shows a typical relationship between the phase measurement and O_2-concentration.

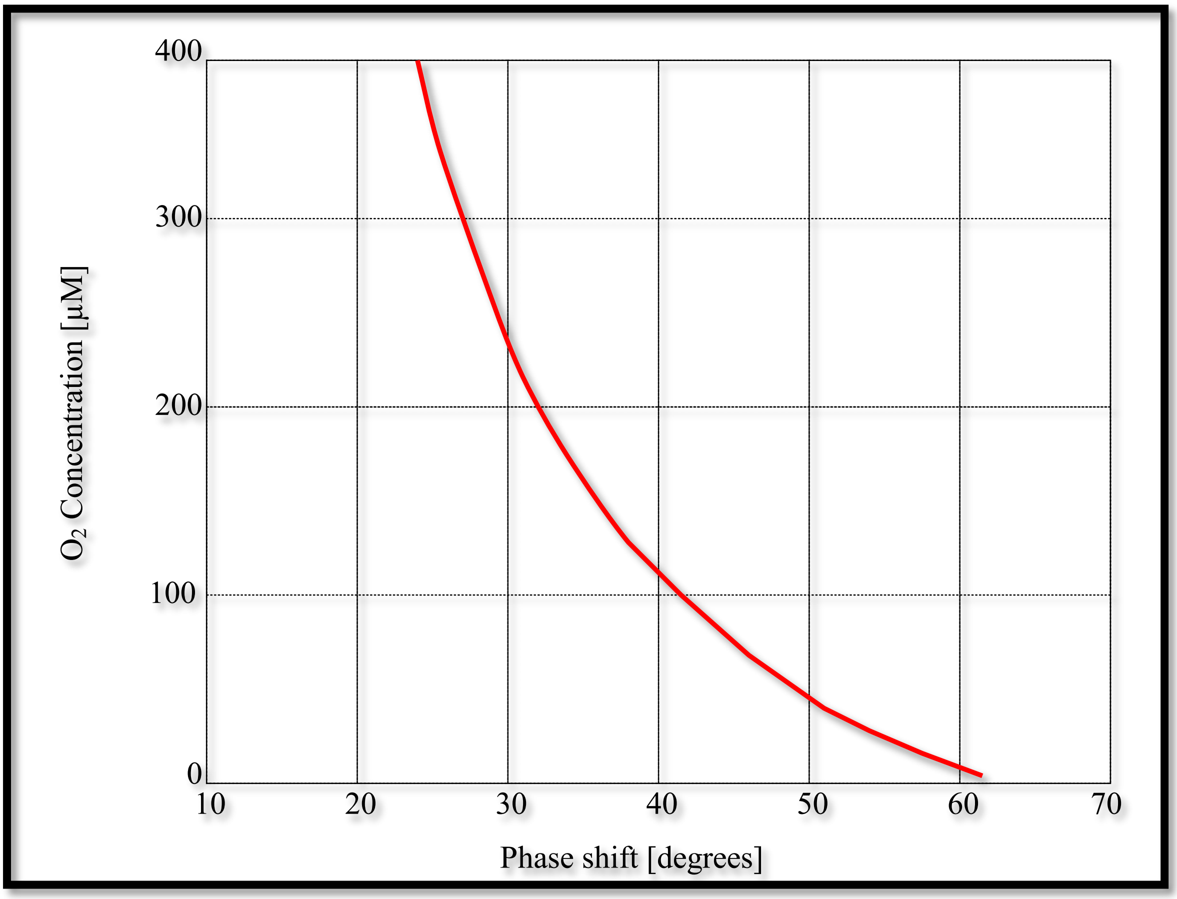


Figure 8-3 Typical phase/O2 response.

8.1 The optical design

An illustration of the optical design is given in ***Figure 8-4***.

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

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

Even 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 8-5***.

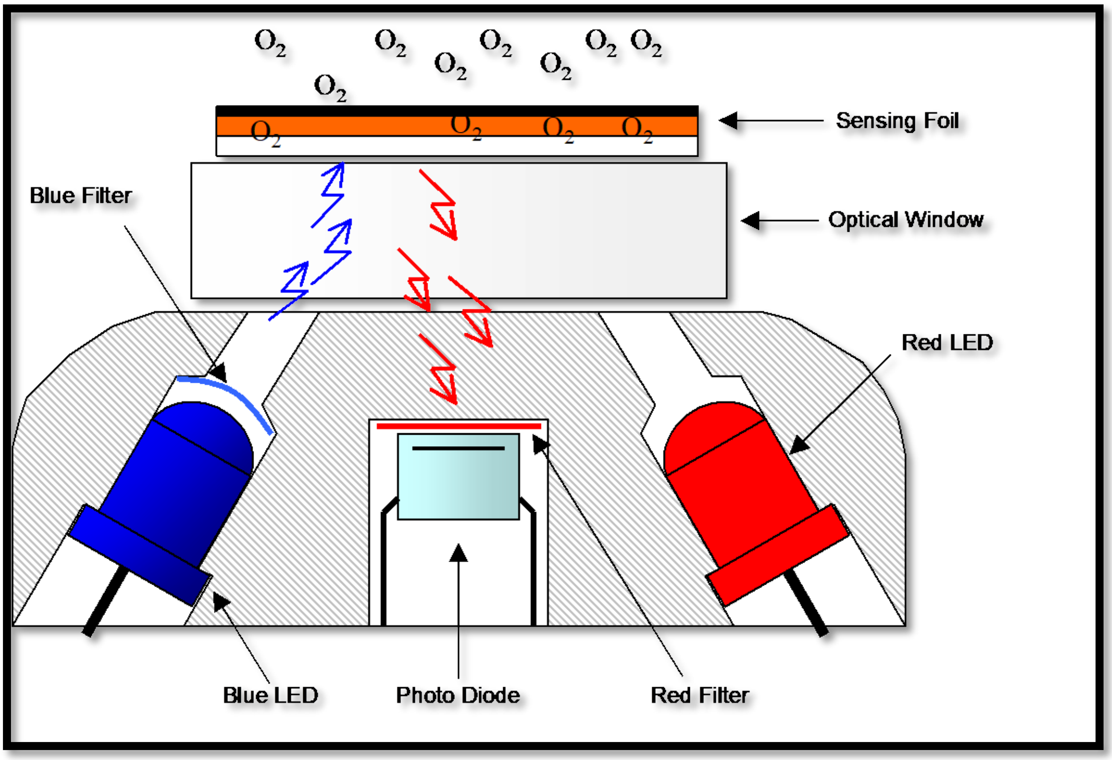


Figure 8-4: The Optical Design

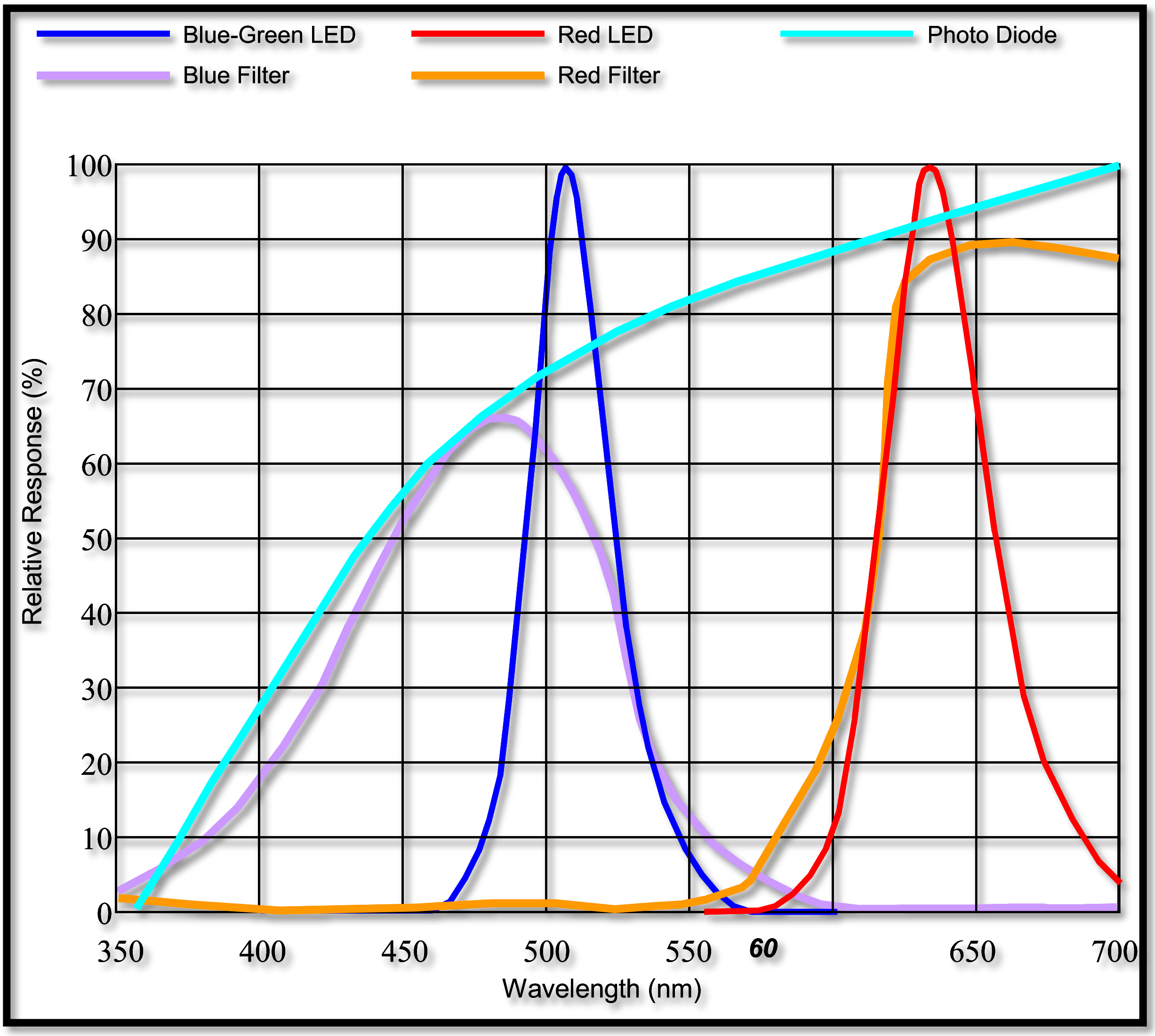


Figure 8-5: An example of Spectral Response

8.2 Electronic design

Figure 8-6 illustrates the main functions of the electronics.

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

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

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

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

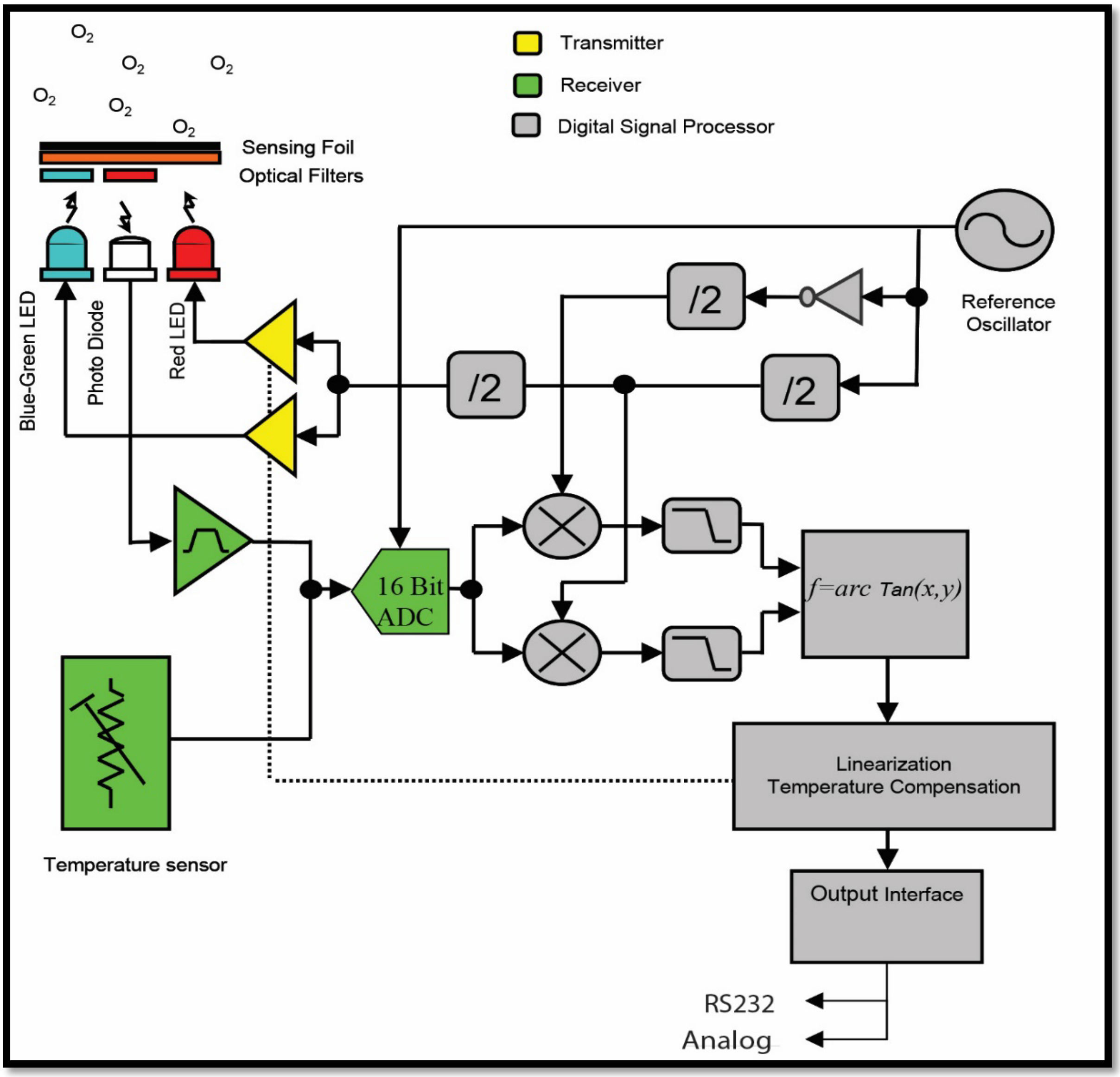


Figure 8-6: Functional Diagram

8.3 Mechanical design of Oxygen Optode 4531

Refer 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 7.1 for instructions concerning changing the Sensing Foil.

Note! The sensor should not be opened! Opening the sensor housing may limit the warranty.

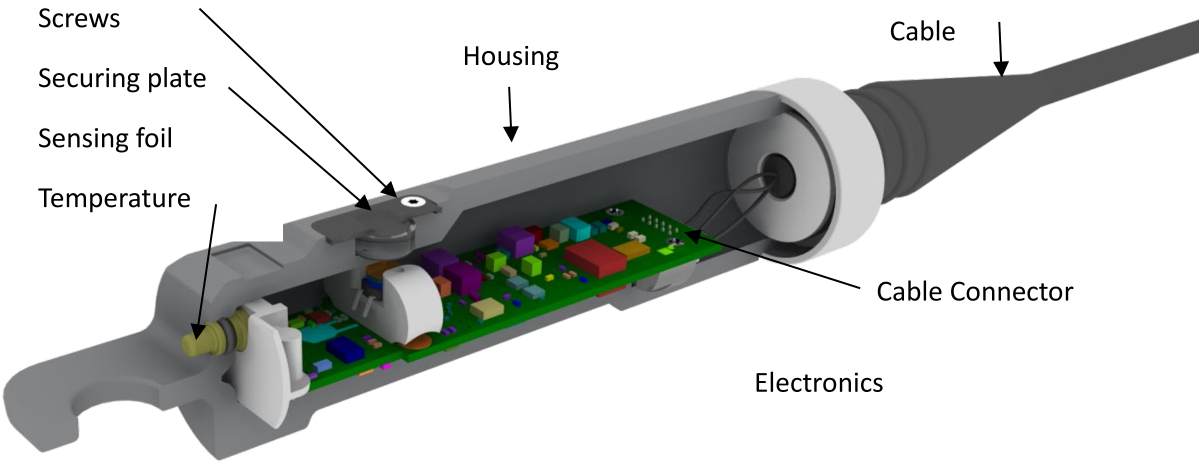


Figure 8-7: Inside view of Oxygen Optode 4531.

CHAPTER 9 **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:

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

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:

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

and:

$$K_{SV} = c_0 + c_1 t + c_2 t^2$$

$$P_0 = c_3 + c_4 t$$

$$P_c = c_5 + c_6 P_r$$

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:

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

For new optodes the two-point calibration procedure will adjust the *ConcCoef* coefficients.

CHAPTER 10 **Multipoint Calibration**

The standard calibration for the oxygen Optodes is based on a common characterization of a production batch of sensing foils with an additional two-point adjustment for individual Optodes and foils.

For application demanding higher accuracy an individual multipoint calibration is available. The Optodes are then placed in a temperature regulated bath where the oxygen saturation is changed by diffusing different mixtures of O2 and N2 into the water. The gas mixture is controlled by use of high accuracy Mass Flow Controllers. The water is stirred vigorously to provide homogeneity and oxygen concentration is referenced to three reference sensors that are calibrated with respect to high quality Winkler titrations. For a standard multipoint calibration the oxygen is changed from 0 to 120% air saturation in 10 steps, and temperature from 1 to 30 °C in 4 steps, resulting in 40 individual calibration points. Based on these data 7 coefficients (c0 to c6) in the modified Stern-Volmer formula derived by Uchida et al, 2008 [17] is calculated:

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

and:

$$K_{SV} = c_0 + c_1 t + c_2 t^2$$

$$P_0 = c_3 + c_4 t$$

$$P_c = c_5 + c_6 P_r$$

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

After the calibration sequence the performance of all sensors are verified in 20 points covering the complete calibration range.

CHAPTER 11 **Example of Test & Specifications sheet and Certificates**

AANDERAA a xylem brand

TEST & SPECIFICATIONS

Form No. 838, November 2013

Layout No:
Circuit Diagram No:
Program Version: 5.3.1

Product: Oxygen Optode 4531
Serial No: Demo

Visual and Mechanical Checks:

1.1 Soldering quality
1.2 Visual surface
1.3 Galvanic isolation between housing and electronics

Current Drain and Voltages:

2.1	Average current drain at 0.5 Hz sampling (Max.: 20 mA)	mA
2.2	Average current drain at 0.5 Hz with analog current output enabled (Max.: 33 mA)	26.2mA
2.3	Quiescent Current drain (Max.: 4mA)	3.49 mA
2.4	DSP IO voltage, J4.18 (3.3 ±0.15V)	3.28 V
2.5	DSP Core voltage, J4.17(1.8 ±0.05 V)	1.81 V
2.6	Excitation driver voltage, C4 Analog Board (4.32 ±0.1 V)	4.34 V

Performance test:	**Channel:**	**BLUE**		**RED**	
3.1	Average of Receiver readings (0±150mV)	-0.3	mV	0.2	mV
3.2	Standard Deviation of Receiver readings (Max.: 45mV/10mV)	5.7	mV	2.4	mV
3.3	Amplitude with non- fluorescence foil (<60mV/650-1200mV)	6.3	mV	912.2	mV
3.4	Amplitude with fluorescence foil (700-1200mV)	856.4	mV	915.8	mV
3.5	Raw data Temperature in room temperature: (-100 ±200mV)	100.7	mV		

Analog Output test:

4.1	Output 1, 1V test (1±0.01 V)	1.00	V
4.2	Output 1, 4V test (4±0.01 V)	4.00	V
4.3	Output 2, 1V test (1±0.01 V)	1.00	V
4.4	Output 2, 4V test (4±0.01 V)	4.00	V
4.5	Output 1, 7.2 mA test (7.2±0.14mA)	7.20	mA
4.6	Output 1, 16.8 mA test (16.8±0.14mA)	16.80	mA
4.7	Output 2, 7.2 mA test test (7.2±0.14mA)	7.20	mA
4.8	Output 2, 16.8 mA test (16.8±0.14mA)	16.80	mA

Date: 09 Jan 2023

Sign: Magnus Holsen

Magnus Holsen, System Engineer

Figure 11-1: Test and Specification Sheet

AANDERAA
a xylem brand

CALIBRATION CERTIFICATE

Form No 830, March 2021

Certificate no:
4531_Demo_00225410
Foil batch no: 2404WM

Product: 4531
Calibration date: 11.04.2024

Serial no: Demo
Page 1 of 2

Index	Temperature reference(°C)	[O2] Reference(µM)	Temperature raw data(mV)	Phase reading(°)
0	31.205	4.69	-266.347	60.85
1	21.221	5.51	43.560	61.68
2	11.128	6.94	371.977	62.44
3	1.899	9.22	663.310	63.05
4	1.926	59.31	662.493	56.04
5	1.930	101.79	662.380	51.41
6	1.934	139.33	662.253	48.10
7	1.936	197.50	662.187	44.05
8	1.947	290.25	661.833	39.38
9	1.961	381.11	661.413	36.04
10	1.965	481.77	661.300	33.24
11	11.030	54.09	375.147	53.67
12	11.016	80.50	375.607	49.93
13	11.008	110.85	375.893	46.45
14	11.001	155.99	376.087	42.42
15	10.976	231.38	376.907	37.65
16	10.978	304.22	376.833	34.37
17	10.980	392.52	376.767	31.45
18	21.081	42.20	48.073	52.35
19	21.073	63.64	48.313	48.36
20	21.070	88.08	48.433	44.75
21	21.068	123.87	48.507	40.70
22	21.074	185.70	48.300	35.86
23	21.087	244.76	47.900	32.65
24	21.090	321.59	47.800	29.70
25	31.286	33.84	-268.753	51.07
26	31.300	52.45	-269.173	46.69
27	31.314	71.99	-269.613	43.13
28	31.352	102.26	-270.747	38.97
29	31.414	152.44	-272.587	34.26
30	31.442	203.49	-273.427	31.05
31	31.448	266.58	-273.613	28.30

Giving these coefficients

Index	0	1	2	3	4	5	6
SVUFoilCoef	3.32420E-03	1.37144E-04	2.32918E-06	2.20259E02	-2.28426E-01	-6.72095E01	4.43792E00
TempCoef	2.25798E01	-3.13056E-02	2.92917E-06	-4.12625E-09	0.00000E00	0.00000E00	

Page 1

Figure 11-2: Multipoint Calibration Part 1

AANDERAA
a xylem brand

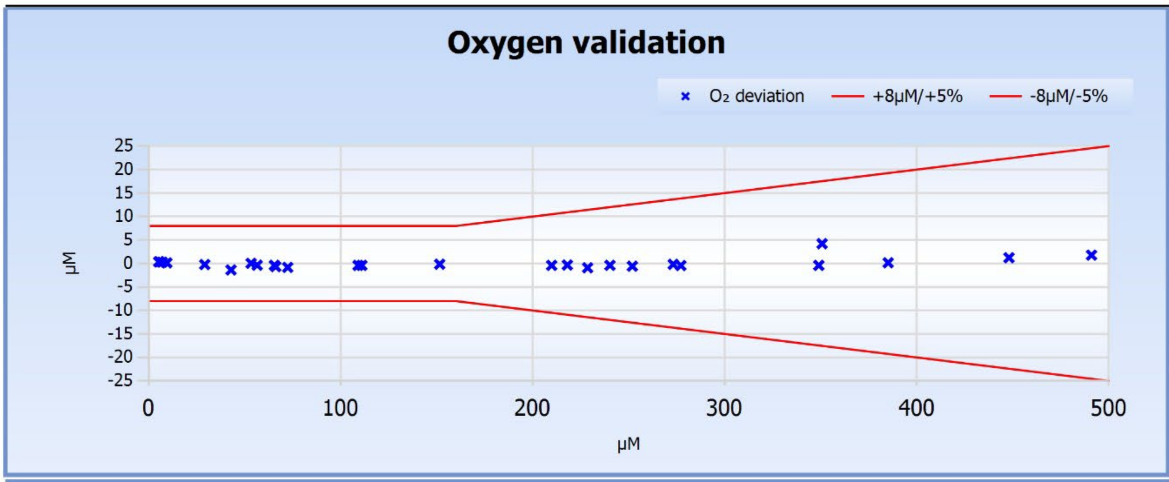
CALIBRATION CERTIFICATE

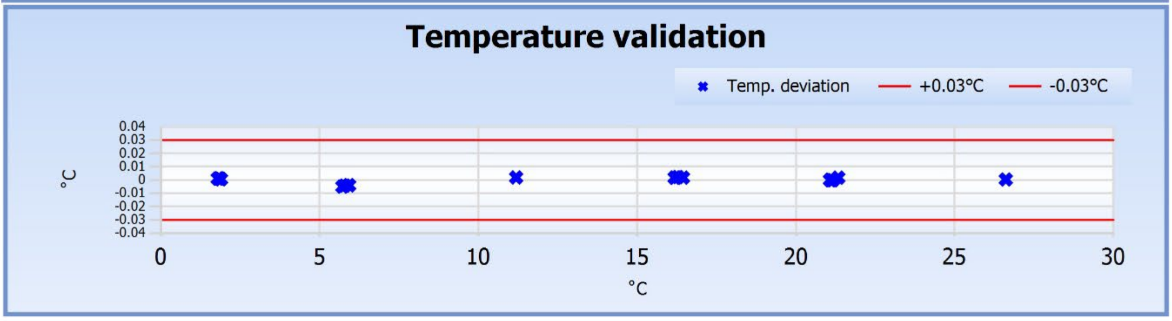
Form No 830, March 2021

Certificate no:
4531_Demo_00225410
Foil batch no: 2404WM

Product: 4531
Calibration date: 11.04.2024

Serial no: Demo
Page 2 of 2





With following settings

Index	0	1	2	3
PhaseCoef	0.00000E00	1.00000E00	0.00000E00	0.00000E00

Index	0 (Offset)	1 (Slope)
ConcCoef	0.00000E00	1.00000E00
Salinity	0.00	
Firmware Version	5.3.3	

Date:11.04.2024

Page 2

Figure 11-3: Multipoint Calibration Part 2

CHAPTER 12 **Examples of scientific papers using Aanderaa Optodes**

(Only first authors listed, full references in list, updated July 2018.)

Commercially available oxygen optodes for oceanographic application were introduced by Aanderaa in 2002. The proven long-term stability (years) and reliability of these sensors have revolutionized oxygen measurements and several thousand are in use in applications ranging from streams (Birkel 2013) and buried in the river bed (Malcolm 2006,2009,2010, Vieweg 2013) to the deepest trenches (12 000 m) on earth, from aquaculture (Thomas, 2017) to wastewater, from polar ice (Mowlem 2013, Bagshaw 2016) to earthquake areas (Oguri 2016). This document gives examples of published scientific investigations in which Aanderaa optodes have played a central role.

The basic technique and an evaluation of its functioning in aquatic environments were presented in Tengberg (2006), Bittig (2014,2015A,2018). Other studies include use on autonomous floats Joos (2003), Körtzinger (2004,2005,2008), Kihm (2010), Koelling (2017), Johnson (2009,2010,2015), Alkire (2012), Bittig (2015B,2017), Bushinsky (2016), Fiedler (2013), Takeshita (2013), D'Asaro (2013), Nikolov (2015), Plant (2016), Wolf (2018), Sarma (2018) on gliders (Nicholoson 2008,2017, Karstensen 2015, Pizarro 2016, DeYoung 2018, Queste 2018) on Autonomous Underwater Vehicles (Clark 2013), animal-borne (Baileul 2015), autonomous sail buoy (Ghani 2014), long-term monitoring in coastal environments with high bio-fouling (Martini 2007), on crab pots (Shearman 2012), on coastal buoys (Jannasch 2008, Johnson 2010, Bushinsky 2013), on Ferry box systems (Hydes 2008,2009, Hartman 2014), on cabled CTD instruments for profiling down to 6000 m including suggestions for improved calibrations, pressure effect and compensation for slow response (Uchida 2008) and in chemical sensor networks (Johnson et al 2007). In the Hypox project multiple optodes were used on multiple platforms to study Hypoxia (Friedrich 2013). Lo Bue (2011) pointed at potential artifacts in oxygen readings in environments with low currents. It has been found that the lower readings are caused by oxygen consumption occurring when metals are corroding (e.g. one sacrificial Zn anode with a weight of 130 g can consume all oxygen in 700 l of water). In Bittig et al. (2012) a seagoing multipoint Winkler free optode calibration system is described and used. McNeil (2014) suggested calibration methods based on physical properties of the sensing foil. Drazen (2005) presented a novel technique to measure respiration rates of deep sea fish and Sommer (2008) described an automatic system to regulate oxygen levels and to measure sediment-water fluxes during in-situ sediment incubation at vent sites. Wikner (2013) measured respiration rates of oligotrophic waters and pointed out potential artifacts from oxygen dissolved in plastic incubators and Rabouille (2009) benthic O_2 consumption. Also Pakhomova (2007), Almroth (2009,2012), Viktorsson (2013), Cathalot (2012), Caprais (2010), Noffke (2016), Niemisto (2018), Sommer (2009,2016,2017) used the same type of optodes on autonomous landers to perform sediment-water incubations on natural and fish farm affected sediments and with and without the introduction of sediment resuspension. In Wesslander (2011) the dynamics and coupling of carbon dioxide (CO_2) and oxygen weres investigated in coastal Baltic Sea waters and McGillis (2011) described a novel method to assess the productivity of coral reefs using boundary layer and enclosure methods. Champenois (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. Viktorsson (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. In Atamanchuk (2014,2015A,2015B) and Peeters (2016) pCO_2 optodes were described and used in parallel with O_2 optodes to study biogeochemical processes in fjords, lakes and at Carbon Capture and Storage. Glud (2016) studied nutrient turn-over and mineralization in a Scottish loch and Hamme (2015) O_2 and N_2 dynamics in the Saanich inlet.

12.1 Literature cited.

1. Almroth, E., Tengberg, A., Andersson, J. H., Pakhomova, S., & Hall, P. O. J. (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*(5-6), 807-818. doi:10.1016/j.csr.2008.12.011
2. Almroth-Rosell, E., Tengberg, A., Andersson, S., Apler, A., & Hall, P. O. J. (2012). Effects of simulated natural and massive resuspension on benthic oxygen, nutrient and dissolved inorganic carbon fluxes in loch creran, scotland.*Journal of Sea Research, 72*, 38-48. doi:10.1016/j.seares.2012.04.012
3. Asaro, E. A., & Mcneil, C. (2013). Calibration and stability of oxygen sensors on autonomous floats. *Journal of Atmospheric and Oceanic Technology, 30*(8), 1896-1906. doi:10.1175/JTECH-D-12-00222.1
4. Atamanchuk, D., Kononets, M., Thomas, P. J., Hovdenes, J., Tengberg, A., & Hall, P. O. J. (2015). Continuous long-term observations of the carbonate system dynamics in the water column of a temperate fjord. *Journal of Marine Systems, 148*, 272-284. doi:10.1016/j.jmarsys.2015.03.002
5. Atamanchuk, D., Tengberg, A., Aleynik, D., Fietzek, P., Shitashima, K., Lichtschlag, A., . . Stahl, H. (2015). Detection of CO2 leakage from a simulated sub-seabed storage site using three different types of pCO2sensors.*International Journal of Greenhouse Gas Control, 38*, 121-134. doi:10.1016/j.ijggc.2014.10.021
6. Atamanchuk, D., Tengberg, A., Thomas, P. J., Hovdenes, J., Apostolidis, A., Huber, C., & Hall, P. O. (2014). Performance of a lifetime-based optode for measuring partial pressure of carbon dioxide in natural waters. *Limnology and Oceanography: Methods, 12*(FEB), 63-73. doi:10.4319/lom.2014.12.63
7. Bagshaw, E. A., Beaton, A., Wadham, J. L., Mowlem, M., Hawkings, J. R., & Tranter, M. (2016). Chemical sensors for in situ data collection in the cryosphere. *TrAC - Trends in Analytical Chemistry, 82*, 348-357. doi:10.1016/j.trac.2016.06.016
8. Bailleul, F., Vacquie-Garcia, J., & Guinet, C. (2015). Dissolved oxygen sensor in animal-borne instruments: An innovation for monitoring the health of oceans and investigating the functioning of marine ecosystems. *PLoS ONE,10*(7) doi:10.1371/journal.pone.0132681
9. Birkel C., C. Soulsby, I. Malcolm and D.Tetzlaff (2013) Modeling the dynamics of metabolism in montane streams using continuous dissolved oxygen measurements. Water Resources Research, 49, 1–16.
10. Bittig, H. C., Fiedler, B., Fietzek, P., & Körtzinger, A. (2015). Pressure response of aanderaa and sea-bird oxygen optodes. *Journal of Atmospheric and Oceanic Technology, 32*(12), 2305-2317. doi:10.1175/JTECH-D-15-0108.1
11. Bittig, H. C., Fiedler, B., Scholz, R., Krahmann, G., & Körtzinger, A. (2014). Time response of oxygen optodes on profiling platforms and its dependence on flow speed and temperature. *Limnology and Oceanography: Methods,12*(AUG), 617-636. doi:10.4319/lom.2014.12.617
12. Bittig, H. C., Fiedler, B., Steinhoff, T., & Körtzinger, A. (2012). A novel electrochemical calibration setup for oxygen sensors and its use for the stability assessment of aanderaa optodes. *Limnology and Oceanography: Methods,10*(NOVEMBER), 921-933. doi:10.4319/lom.2012.10.921
13. Bittig, H. C., & Körtzinger, A. (2015). Tackling oxygen optode drift: Near-surface and in-air oxygen optode measurements on a float provide an accurate in situ reference. *Journal of Atmospheric and Oceanic Technology, 32*(8), 1536-1543. doi:10.1175/JTECH-D-14-00162.1
14. Bittig, H. C., & Körtzinger, A. (2017). Technical note: Update on response times, in-air measurements, and in situ drift for oxygen optodes on profiling platforms. *Ocean Science, 13*(1), 1-11. doi:10.5194/os-13-1-2017
15. Bittig HC, Körtzinger A, Neill C, van Ooijen E, Plant JN, Hahn J, Johnson KS, Yang B and Emerson SR (2018). Oxygen Optode Sensors: Principle, Characterization, Calibration and Application in the Ocean. *Front. Mar. Sci.* **4**:429. doi: 10.3389/fmars.2017.00429
16. Bushinsky, S. M., & Emerson, S. (2013). A method for in-situ calibration of aanderaa oxygen sensors on surface moorings. *Marine Chemistry, 155*, 22-28. doi:10.1016/j.marchem.2013.05.001

17. Bushinsky, S. M., Emerson, S. R., Riser, S. C., & Swift, D. D. (2016). Accurate oxygen measurements on modified argo floats using in situ air calibrations. *Limnology and Oceanography: Methods, 14*(8), 491-505. doi:10.1002/lom3.10107
18. Cathalot C., B. Lansard, P.O.J. Hall, A. Tengberg, E. Almroth-Rosell, A. Apler, L. Calder, E. Bell and C. Rabouille (2012) Spatial and Temporal Variability of Benthic Respiration in a Scottish Sea Loch Impacted by Fish Farming: A Combination of In Situ Techniques. Aquatic Geochemistry, 18:515–541.
19. Caprais, J. -., Lanteri, N., Crassous, P., Noel, P., Bignon, L., Rousseaux, P., . . Khripounoff, A. (2010). A new CALMAR benthic chamber operating by submersible: First application in the cold-seep environment of napoli mud volcano (mediterranean sea). *Limnology and Oceanography: Methods, 8*(JUNE), 304-312. doi:10.4319/lom.2010.8.304
20. Champenois, W., & Borges, A. V. (2012). Seasonal and interannual variations of community metabolism rates of a posidonia oceanica seagrass meadow. *Limnology and Oceanography, 57*(1), 347-361. doi:10.4319/lo.2012.57.1.0347
21. Clark, C. M., Hancke, K., Xydes, A., Hall, K., Schreiber, F., Klemme, J., . . . Moline, M. (2013). Estimation of volumetric oxygen concentration in a marine environment with an autonomous underwater vehicle. *Journal of Field Robotics, 30*(1), 1-16. doi:10.1002/rob.21421
22. 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.
23. Felisberto, P., Jesus, S. M., Zabel, F., Santos, R., Silva, J., Gobert, S., . . . Borges, A. V. (2015). Acoustic monitoring of O2 production of a seagrass meadow. *Journal of Experimental Marine Biology and Ecology, 464*, 75-87. doi:10.1016/j.jembe.2014.12.013
24. Fiedler, B., Fietzek, P., Vieira, N., Silva, P., Bittig, H. C., & Körtzinger, A. (2013). In situ CO2 and O2 measurements on a profiling float. *Journal of Atmospheric and Oceanic Technology, 30*(1), 112-126. doi:10.1175/JTECH-D-12-00043.1
25. Friedrich, J., Janssen, F., Aleynik, D., Bange, H. W., Boltacheva, N., Çagatay, M. N., . . . Wenzhöfer, F. (2014). Investigating hypoxia in aquatic environments: Diverse approaches to addressing a complex phenomenon.*Biogeosciences, 11*(4), 1215-1259. doi:10.5194/bg-11-1215-2014
26. Ghani, M. H., Hole, L. R., Fer, I., Kourafalou, V. H., Wienders, N., Kang, H., . . . Peddie, D. (2014). The sailBuoy remotely-controlled unmanned vessel: Measurements of near surface temperature, salinity and oxygen concentration in the northern gulf of mexico. *Methods in Oceanography, 10*, 104-121. doi:10.1016/j.mio.2014.08.001
27. Glud, R. N., Berg, P., Stahl, H., Hume, A., Larsen, M., Eyre, B. D., & Cook, P. L. M. (2016). Benthic carbon mineralization and nutrient turnover in a Scottish sea loch: An integrative in situ study. *Aquatic Geochemistry, 22*(5-6), 443-467. doi:10.1007/s10498-016-9300-8
28. Hamme, R. C., Berry, J. E., Klymak, J. M., & Denman, K. L. (2015). In situ O2 and N2 measurements detect deep-water renewal dynamics in seasonally-anoxic Saanich inlet. *Continental Shelf Research, 106*, 107-117. doi:10.1016/j.csr.2015.06.012
29. Hull, T., Greenwood, N., Kaiser, J., & Johnson, M. (2016). Uncertainty and sensitivity in optode-based shelf-sea net community production estimates. *Biogeosciences, 13*(4), 943-959. doi:10.5194/bg-13-943-2016
30. Hydes, D. J., Hartman, M. C., Bargeron, C. P., Campbell, J. M., Curé, M. S., & Woolf, D. K. (2008). A study of gas exchange during the transition from deep winter mixing to spring bloom in the Bay of Biscay measured by continuous observation from a ship of opportunity. *Journal of Operational Oceanography, 1*(2), 41-50. doi:10.1080/1755876X.2008.11020102
31. Hydes, D. J., Hartman, M. C., Kaiser, J., & Campbell, J. M. (2009). Measurement of dissolved oxygen using optodes in a FerryBox system. *Estuarine, Coastal and Shelf Science, 83*(4), 485-490. doi:10.1016/j.ecss.2009.04.014
32. Jannasch, H. W., Coletti, L. J., Johnson, K. S., Fitzwater, S. E., Needoba, J. A., & Plant, J. N. (2008). The land/ocean biogeochemical observatory: A robust networked mooring system for continuously monitoring complex biogeochemical cycles in estuaries. *Limnology and Oceanography: Methods, 6*(JUL), 263-276.

33. Johnson, K. S. (2010). Simultaneous measurements of nitrate, oxygen, and carbon dioxide on oceanographic moorings: Observing the redfield ratio in real time. *Limnology and Oceanography, 55*(2), 615-627. doi:10.4319/lo.2009.55.2.0615
34. Johnson, K. S., Berelson, W. M., Boss, E. S., Chase, Z., Claustre, H., Emerson, S. R., . . . Riser, S. C. (2009). Observing biogeochemical cycles at global scales with profiling floats and gliders: Prospects for a global array. *Oceanography, 22*(SPL.ISS. 3), 216-225. doi:10.5670/oceanog.2009.81
35. Johnson, K. S., Needoba, J. A., Riser, S. C., & Showers, W. J. (2007). Chemical sensor networks for the aquatic environment. *Chemical Reviews, 107*(2), 623-640. doi:10.1021/cr050354e
36. Johnson, K. S., Plant, J. N., Riser, S. C., & Gilbert, D. (2015). Air oxygen calibration of oxygen optodes on a profiling float array. *Journal of Atmospheric and Oceanic Technology, 32*(11), 2160-2172. doi:10.1175/JTECH-D-15-0101.1
37. Johnson, K. S., Riser, S. C., & Karl, D. M. (2010). Nitrate supply from deep to near-surface waters of the north pacific subtropical gyre. *Nature, 465*(7301), 1062-1065. doi:10.1038/nature09170
38. Karstensen, J., Fiedler, B., Schütte, F., Brandt, P., Körtzinger, A., Fischer, G., . . . Wallace, D. (2015). Open ocean dead zones in the tropical North Atlantic Ocean. *Biogeosciences, 12*(8), 2597-2605. doi:10.5194/bg-12-2597-2015
39. Kihm, C., & Körtzinger, A. (2010). Air-sea gas transfer velocity for oxygen derived from float data. *Journal of Geophysical Research: Oceans, 115*(12) doi:10.1029/2009JC006077
40. Koelling, J., Wallace, D. W. R., Send, U., & Karstensen, J. (2017). Intense oceanic uptake of oxygen during 2014–2015 winter convection in the Labrador Sea. *Geophysical Research Letters, 44*(15), 7855-7864. doi:10.1002/2017GL073933
41. 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.
42. Körtzinger, A., J. Schimanski, U. Send, and D.W.R. Wallace (2004). The ocean takes a deep breath. Science, 306: 1337.
43. Körtzinger, A., Send, U., Wallace, D. W. R., Karstensen, J., & de Grandpre, M. (2008). Seasonal cycle of O2 and pCO2 in the central Labrador Sea: Atmospheric, biological, and physical implications. *Global Biogeochemical Cycles,22*(1) doi:10.1029/2007GB003029
44. Lo Bue, N., Vangriesheim, A., Khripounoff, A., & Soltwedel, T. (2011). Anomalies of oxygen measurements performed with Aanderaa optodes. *Journal of Operational Oceanography, 4*(2), 29-39. doi:10.1080/1755876X.2011.11020125
45. Malcolm I.A., C.A. Middlemas, C. Soulsby, S.J. Middlemas and A.F. Youngson (2010) Hyporheic zone processes in a canalised agricultural stream: implications for salmonid embryo survival. Fundam. Appl. Limnol., Arch. Hydrobiol. Vol. 176/4, 319–336.
46. Malcolm I.A, C. Soulsby and A.F. Youngson (2006) High-frequency logging technologies reveal state-dependent hyporheic process dynamics: implications for hydroecological studies. Hydrological Processes, 20, 615–622.
47. Malcolm I.A, C. Soulsby, A.F. Youngson and D. Tetzlaf (2009) Fine scale variability of hyporheic hydrochemistry in salmon spawning gravels with contrasting groundwater-surface water interactions. Hydrogeology Journal, 17, 161-174.
48. Mantikci, M., Hansen, J. L. S., & Markager, S. (2017). Photosynthesis enhanced dark respiration in three marine phytoplankton species. *Journal of Experimental Marine Biology and Ecology, 497*, 188-196. doi:10.1016/j.jembe.2017.09.015
49. Martini, M., Butman, B., & Mickelson, M. J. (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*(11), 1924-1935. doi:10.1175/JTECH2078.1
50. 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.
51. McNeil, C. L., & D'Asaro, E. A. (2014). A calibration equation for oxygen optodes based on physical properties of the sensing foil. *Limnology and Oceanography: Methods, 12*(MAR), 139-154. doi:10.4319/lom.2014.12.139

52. Moreau, S., Kaartokallio, H., Vancoppenolle, M., Zhou, J., Kotovitch, M., Dieckmann, G. S., . . . Delille, B. (2015). Assessing the O_2 budget under sea ice: An experimental and modelling approach: Assessing the O budget under sea ice. *Elementa, 3* doi:10.12952/journal.elementa.000080
53. Mowlem, M. C., Tsaloglou, M. -., Waugh, E. M., Floquet, C. F. A., Saw, K., Fowler, L., . . . Woodward, J. (2013). Probe technology for the direct measurement and sampling of Ellsworth subglacial lake. *Antarctic subglacial aquatic environments* (pp. 159-186) doi:10.1002/9781118670354.ch10
54. Nicholson, D. P., & Feen, M. L. (2017). Air calibration of an oxygen optode on an underwater glider. *Limnology and Oceanography: Methods, 15*(5), 495-502. doi:10.1002/lom3.10177
55. 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.
56. Niemisto J., M. Kononets, N. Ekeroth, P. Tallberg, A.Tengberg, P.O.J. Hall (2018) Benthic fluxes of oxygen and inorganic nutrients in the archipelago of Gulf of Finland, Baltic Sea – Effects of sediment resuspension measured in situ. Journal of Sea Research, 135, 95–106
57. Nikolov, N., & Pandelova, A. L. (2015). Calculation of oxygen concentration in the Black Sea using data from argo automatic profiling floats. *Bulgarian Chemical Communications, 47*, 350-355.
58. Noffke, A., Sommer, S., Dale, A. W., Hall, P. O. J., & Pfannkuche, O. (2016). Benthic nutrient fluxes in the eastern Gotland basin (Baltic Sea) with particular focus on microbial mat ecosystems. *Journal of Marine Systems, 158*, 1-12. doi:10.1016/j.jmarsys.2016.01.007
59. Oguri, K., Furushima, Y., Toyofuku, T., Kasaya, T., Wakita, M., Watanabe, S., . . . Kitazato, H. (2016). Long-term monitoring of bottom environments of the continental slope off otsuchi bay, northeastern japan. *Journal of Oceanography, 72*(1), 151-166. doi:10.1007/s10872-015-0330-4
60. Pakhomova, S. V., Hall, P. O. J., Kononets, M. Y., Rozanov, A. G., Tengberg, A., & Vershinin, A. V. (2007). Fluxes of iron and manganese across the sediment-water interface under various redox conditions. *Marine Chemistry,107*(3), 319-331. doi:10.1016/j.marchem.2007.06.001
61. Peeters, F., Atamanchuk, D., Tengberg, A., Encinas-Fernández, J., & Hofmann, H. (2016). Lake metabolism: Comparison of lake metabolic rates estimated from a diel CO2-and the common diel O2- technique. *PLoS ONE, 11*(12) doi:10.1371/journal.pone.0168393
62. Plant, J. N., Johnson, K. S., Sakamoto, C. M., Jannasch, H. W., Coletti, L. J., Riser, S. C., & Swift, D. D. (2016). Net community production at ocean station papa observed with nitrate and oxygen sensors on profiling floats. *Global Biogeochemical Cycles, 30*(6), 859-879. doi:10.1002/2015GB005349
63. Rabouille, C., Caprais, J. -., Lansard, B., Crassous, P., Dedieu, K., Reyss, J. L., & Khripounoff, A. (2009). Organic matter budget in the southeast atlantic continental margin close to the congo canyon: In situ measurements of sediment oxygen consumption. *Deep-Sea Research Part II: Topical Studies in Oceanography, 56*(23), 2223-2238. doi:10.1016/j.dsr2.2009.04.005Sarma,
64. Sarma, V. V. S. S., & Udaya Bhaskar, T. V. S. (2018). Ventilation of oxygen to oxygen minimum zone due to anticyclonic eddies in the Bay of Bengal. Journal of Geophysical Research: Biogeosciences, 123. https://doi.org/ 10.1029/2018JG004447
65. Sommer, S., Clemens, D., Yücel, M., Pfannkuche, O., Hall, P. O. J., Almroth-Rosell, E., . . . Dale, A. W. (2017). Major bottom water ventilation events do not significantly reduce basin-wide benthic N and P release in the eastern gotland basin (Baltic Sea). *Frontiers in Marine Science, 4*(FEB) doi:10.3389/fmars.2017.00018
66. Sommer, S., Gier, J., Treude, T., Lomnitz, U., Dengler, M., Cardich, J., & Dale, A. W. (2016). Depletion of oxygen, nitrate and nitrite in the Peruvian oxygen minimum zone cause an imbalance of benthic nitrogen fluxes. *Deep-Sea Research Part I: Oceanographic Research Papers, 112*, 113-122. doi:10.1016/j.dsr.2016.03.001
67. Sommer, S., Türk, M., Kriwanek, S., & Pfannkuche, O. (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*(1), 23-33. doi:10.4319/lom.2008.6.23

68. Sommer, S., Linke, P.,Pfannkuche, O., Schleicher, T. ,Deimling, J .Schneiderv, Reitz, A., Haeckel, M.,Flögel, S.,Hensen, C. (2009). Seabed methane emissions and the habitat of FrenulateTubeworms on the captain Arutyunov mudvolcano (gulf of Cadiz). Mar.Ecol.Prog.Ser. 382, 69–86. http://dx.doi.org/10.3354/meps07956.
69. Takeshita, Y., Martz, T. R., Johnson, K. S., Plant, J. N., Gilbert, D., Riser, S. C., . . . Tilbrook, B. (2013). A climatology-based quality control procedure for profiling float oxygen data. *Journal of Geophysical Research: Oceans, 118*(10), 5640-5650. doi:10.1002/jgrc.20399
70. 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.
71. Thomas, P. J., Atamanchuk, D., Hovdenes, J., & Tengberg, A. (2017). The use of novel optode sensor technologies for monitoring dissolved carbon dioxide and ammonia concentrations under live haul conditions. *Aquacultural Engineering, 77*, 89-96. doi:10.1016/j.aquaeng.2017.02.004
72. Uchida, H., Kawano, T., Kaneko, I., & Fukasawa, M. (2008). In situ calibration of optode-based oxygen sensors. *Journal of Atmospheric and Oceanic Technology, 25*(12), 2271-2281. doi:10.1175/2008JTECHO549.1
73. Vieweg, M., Trauth, N., Fleckenstein, J. H., & Schmidt, C. (2013). Robust optode-based method for measuring in situ oxygen profiles in gravelly streambeds. *Environmental Science and Technology, 47*(17), 9858-9865. doi:10.1021/es401040w
74. Viktorsson, L., Almroth-Rosell, E., Tengberg, A., Vankevich, R., Neelov, I., Isaev, A., . . . Hall, P. O. J. (2012). Benthic phosphorus dynamics in the Gulf of Finland, Baltic Sea. *Aquatic Geochemistry, 18*(6), 543-564. doi:10.1007/s10498-011-9155-y
75. Viktorsson, L., Ekeroth, N., Nilsson, M., Kononets, M., & Hall, P. O. J. (2013). Phosphorus recycling in sediments of the central Baltic Sea. *Biogeosciences, 10*(6), 3901-3916. doi:10.5194/bg-10-3901-2013
76. Wesslander, K., Hall, P., Hjalmarsson, S., Lefevre, D., Omstedt, A., Rutgersson, A., . . . Tengberg, A. (2011). Observed carbon dioxide and oxygen dynamics in a Baltic Sea coastal region. *Journal of Marine Systems, 86*(1-2), 1-9. doi:10.1016/j.jmarsys.2011.01.001
77. Wikner, J., Panigrahi, S., Nydahl, A., Lundberg, E., Båmstedt, U., & Tengberg, A. (2013). Precise continuous measurements of pelagic respiration in coastal waters with oxygen optodes. *Limnology and Oceanography: Methods,11*(JAN), 1-15. doi:10.4319/lom.2013.11.1

12.2 Testimonials of Aanderaa optode stability.

Aanderaa oxygen optodes have been used in numerous scientific studies published in peer-reviewed journals (see appendix 1 below for full references). Some of these studies focused on details in the performance of the Aanderaa optodes (see references and citations above):

- **Joos et al (2003)**: *”Initial field tests have shown exceptional sensitivity and excellent stability (A. Körtzinger and D.W. R.Wallace, University of Kiel,unpublished data, 2002). The new technology seems well suited to deployment on long-term in-situ moorings, profiling floats, and other autonomous platforms.”*
- **Körtzinger et al (2004):** *“The initial results from the first six months of operation are presented. Data are compared with a small hydrographic oxygen survey of the deployment site. They are further examined for measurement quality, including precision, accuracy, and drift aspects. The first 28 profiles obtained are of high quality and show no detectable sensor drift.”*
- **Nicholoson et al. (2008):** *“The optode sensor showed no sign of drift when compared to Winkler measurements over the nine months of deployment. Seaglider 021, equipped with the same optode sensor, was stable from its initial February deployment through the end of its second deployment in November, without requiring any recalibration between deployments (data not shown). The optode on glider 020 showed similar stability over its shorter deployment.”*
- **Jannasch et al. (2008):** “*Oxygen optode (Aanderaa, 3930). Similar to nitrate, oxygen concentrations within estuaries can vary widely (0 to 400 µM O2). We have found the optode to be resistant to fouling as previously suggested (Tengberg et al. 2006) and to be extremely stable. Sensors were calibrated prior to deployment using the factory-suggested, two-point calibration. There was no noticeable drift in instrument accuracy before and after deployment”.*
- **Hydes et al. (2009):** *“The optodes maintained good stability with no evidence of instrumental drift during the course of a year. Over the observed concentration range (230–330 mMm^{-3}) the optode data were approximately 2% low in both years. By fitting the optode data to the Winkler data the median difference between the optode and Winkler measurements is reduced to less than 1 mMm^{-3} (0.3%) in both years.”* Comment: Measurements were done every 30 s. Sensors were operated one year at a time, which equals more than 1 Million samples.
- **Johnson et al. (2010)**: *“The oxygen sensor shows no evidence of drift, but it seems to have a small accuracy bias (≤10 µmol/l), as reported for earlier applications of Aanderaa Optode sensors on profiling floats and gliders.”* The deployment period was more than 600 days.
- **Champenois and Borges (2012)** *“The comparison of O_2 measured by optodes and by Winkler titration allowed us to determine the accuracy of O_2 measurements by optodes, which was better than ±2.0 mmol kg^{-1}. The accuracy was not significantly different among the three O_2 optodes and remained stable during the study period. The precision of O_2 measurements by the O_2 optodes was better than ±0.1 mmol kg^{-1}, based upon the standard deviation on the mean of 30 measurements during 30 s, which is the standard configuration of measurements used.”* Comment: The deployment period was more than 1100 days. Sensors were logged hourly which equals approximately 26,000 samples.
- **Johnson et al. (2015)**: *“Aanderaa optode sensors for dissolved oxygen show remarkable stability when deployed on profiling floats, but these sensors suffer from poor calibration because of an apparent drift during storage (storage drift).* Comment: In this paper results from 47 floats were presented and methods for in air calibration on Argo floats suggested.

CHAPTER 13 **Frequently Asked Questions – FAQ**

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 for older sensors has a set of 28 constants C_0 to C_4 (FoilCoefA$_{0-13}$,FoilCoefB$_{0-13}$, 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.

CCAP8
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%.

CCAP9
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.

CCAP10
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 11
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: 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 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.

MR 9
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 10
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 at 10 seconds interval the sensor can operate for at least 5 years.

MR 11
Q: Can the sensor be used down to full ocean depth just by connecting it to a standard titanium connector from Aanderaa?
A: The sensor is available in different versions with different depth ratings from 100 meter and down to 11000 meter.

MR 12
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.
A: Yes, It is not a problem to connect and log the sensor like this. For long-term applications you should use a Titanium connector. Please ask Aanderaa for more information.

MR 13
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 14
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 15
Q: Is there a difference in the sensor response if the foil is wet or dry?
A. For Presens foil. Yes the sensor is and should be calibrated in a wet environment and it takes hours for the foil to become completely wet or dry.
Taking a sensor which has been sitting in a dry environment for several hours and introducing it into water to make a spot measurement can lead to an error of maximum 2%.
Keeping the sensor in a humid environment for at least 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.
For WTW foil there is no difference if the foil is wet or not.

MR 16
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 17

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 18

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 19

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). Newer sensor can also be configured to output (mg/l)
Depending on the background and tradition of the user converting into other units might be useful. To obtain ml/l the obtained values in (µmol/l) have to be divided by 31.25. 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.

MR 20
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 21
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 AADI Real-Time Collector 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 22
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 23
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 24

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 25

Q: Does the sensor react to changes in salinity?

A: No, The sensor is measuring 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 26

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

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

MR 2

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 28

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 RCM9/RC118, can I mount the Optode and log it with SeaGuard?

A: Older sensor communication with logger used SR-11 while SeaGuard use AiCaP. However both sensor has RS-232 if this is used

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.

CHAPTER 14 **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:

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.

Copies of Unisense AS tables for *solubility of oxygen in seawater* are given in ***Figure 14-1, Figure 14-2*** and ***Figure 14-3.***

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 14-1: 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 14-2: Copy of Data Table 7 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)																				
(‰)	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 14-3: Copy of Data Table 8 by Niels Ramsing and Jens Gundersen: 100% Oxygen Solubility @1013 mbar pressure.

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