O2 and CO2 Accuracy

White Paper

Commercial in Confidence

Revision history

Date	Rev	By	DCN	Comments	CHKD	CHKD Date	Ext. APPD	Ext. APPD Ref	Ext. APPD Date
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Warnings, Cautions and Notes

Warnings and Cautions are used in this document to highlight potential hazards and safety risks. Notes are used to provide supplementary information that is not hazard-related.

WARNING: **THIS INDICATES A POTENTIALLY HAZARDOUS SITUATION THAT, IF NOT AVOIDED, COULD RESULT IN DEATH OR SERIOUS INJURY.**

CAUTION: **THIS INDICATES A POTENTIALLY HAZARDOUS SITUATION THAT, IF NOT AVOIDED, COULD RESULT IN EQUIPMENT DAMAGE OR LOSS OF DATA.**

NOTE: **THIS INDICATES INFORMATION THAT IS CONSIDERED IMPORTANT BUT IS NOT HAZARD RELATED.**

1 Introduction

Det Norske Veritas (DNV) diving regulations OS E402 states the following accuracy requirements for oxygen (O_2) and carbon dioxide (CO_2) measurement in Section 5 of the regulations.

E 400	Oxygen analysing systems.
401	Oxygen analysing systems shall have an accuracy of at least +/-0.015 bar partial pressure oxygen.
E 500	Carbon dioxide analysing systems.
501	Carbon dioxide analysing systems shall have an accuracy of +/-0.001 bar partial pressure.

This document aims to demonstrate how the sensors used by Analox achieve these performance requirements over a range of diving depths. It is assumed that the sensors are mounted topside (typically in the saturation dive control room, or the dive control room), with sample gas being flowed across the sensors at atmospheric pressure.

It should be noted that if the sensors were to be mounted in the hyperbaric chambers, then the accuracy requirements would easily be met. However, it is common for users to arrange the gas analysis with the analyzers topside. This makes calibration and maintenance easier and does not require the chamber occupants to participate in the calibration procedure. The unfortunate knock-on effect of placing the analyzers top-side, is that the accuracy requirements at deeper depths become more stringent.

Ultimately, at deeper depths, this document shows that topside monitoring becomes problematic. Analox are confident to recommend their sensors for use in systems with depth capabilities not exceeding 350msw. For deeper use, we recommend our in-chamber hyperbaric instrumentation.

2 Sensor performance

In this document we will assume that an SDA O_2 or Analox 1000 is being used for oxygen analysis, and an SDA CO_2 or Analox 5001 is being used for carbon dioxide analysis.

2.1 Oxygen sensor performance

The basic electrochemical cell used in the SDA O_2 and Analox 1000 (and in many other Analox products) is typically specified as having an accuracy better than 1% of range. Range for the sensor is usually 0-100%.

This accuracy specification would mean that these oxygen sensors were totally unsuitable for the application. Assuming an oxygen concentration of say 0.400 bar ppO2 in a chamber, at 40barA (390msw), the oxygen concentration measured by a topside analyser would be 1% oxygen. Obviously if the sensors accuracy were +/-1% of range (1% of 100% is 1% oxygen), then the calculated oxygen indication could lie anywhere between 0 and 2% oxygen, which is clearly inadequate.

In this example, to achieve the DNV accuracy, the measured oxygen must lie between 385 and 415 mbar ppO2. This equates to the topside sample being measured between 0.9625% and 1.0375% oxygen.

Many years of use of these sensors has shown that the accuracy statement by the manufacturer is extremely pessimistic at low oxygen levels. The basic chemical reaction taking place in the cell does not become less accurate at low concentrations - indeed variants of the cell suited to lower ranges operate happily down to much lower oxygen concentrations.

Analox realised many years ago that the manufacturer's claim for the accuracy is too simple a statement. It does not consider the stringent calibration routinely performed (generally at the start of every shift) in a typical saturation diving environment. For a while, we sold cells believing that they actually had a 1% of reading error, rather than 1% of range. This puts a whole new light on the subject. We then realised that we could not sensibly claim 1% of reading, since at 0% oxygen (or let us say 0.01% oxygen), this claim would apparently state that the sensors were almost supremely accurate, which they are not. However, by simply adding a constant offset to the cell's accuracy claim, the accuracy can then reasonably be claimed as +/-1% of reading or +/-0.035% oxygen, whichever is the greater.

This is the basis on which Analox continue to use their sensors in saturation diving products.

Let us look at this in more detail. Figure 1, Figure 2 and Figure 3 show the effect of the two accuracy components for three typical chamber oxygen concentrations. They are all characterised by approaching the DNV accuracy limits at pressures of around 40barA. This means that the sensors should not be used at pressures greater than 40 barA if DNV performance requirements are applicable. If depths greater than 40 barA are required, Analox would recommend the use of hyperbaric sensors & analyzers.

Note also that these graphs assume that atmospheric pressure and temperature remain constant between calibrations. For significant changes of atmospheric pressure or temperature, an Analox 1000 the analyser ought to be recalibrated. The SDA O_2 provides atmospheric pressure compensation and so only requires recalibration if the temperature changes significantly. Generally, when installed in a typical saturation dive control room, the temperature will be fairly closely controlled, hence it is usually only atmospheric pressure changes that may cause a need to recalibrate.

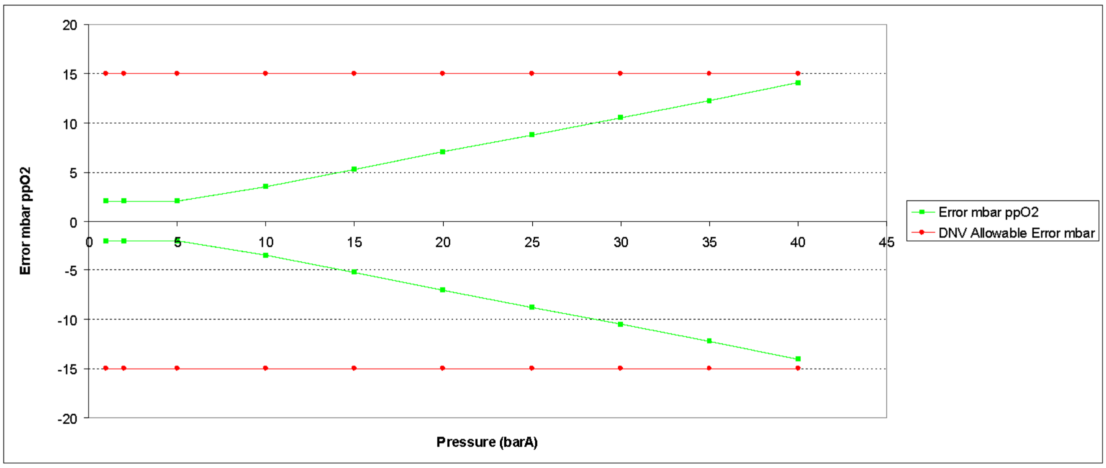

Figure 1 Chamber containing 0.200 bar ppO2

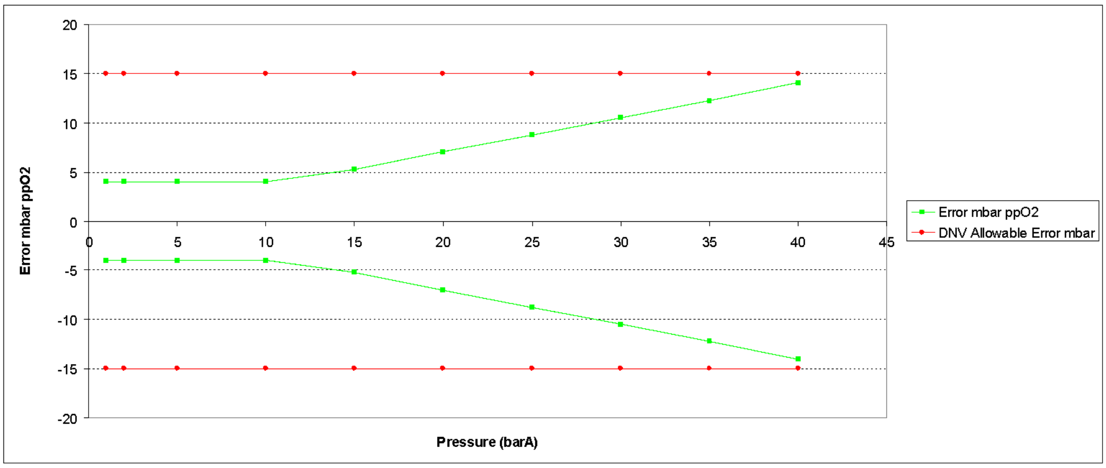

Figure 2 Chamber containing 0.400 bar ppO2

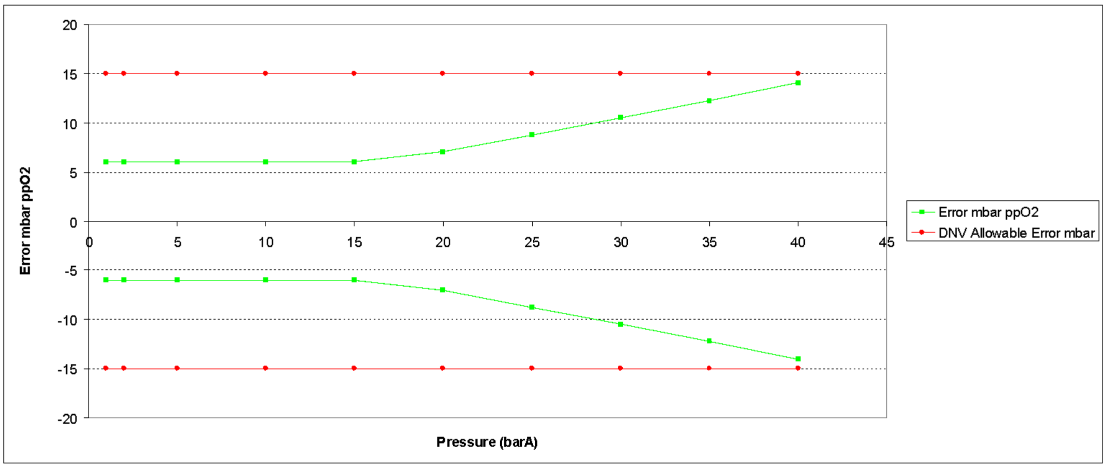

Figure 3 Chamber containing 0.600 bar ppO2

2.2 Carbon dioxide sensor performance

Most SDA CO_2 or Analox 5001 analyzers measure carbon dioxide over the range 0 to 5000 ppm CO_2. Some customers prefer to opt for a 10000ppm range, although we ourselves would advise that the 5000ppm variant is more suited to the saturation diving environment. It will, as we see below, perform better than the 10000ppm version, which in our opinion should only be used if the 5000ppm range is too restrictive.

Please note that the analysis that follows refers to all SDA CO_2 analyzers and Analox 5001 CO_2 analyzers fitted with the Analox 5S3 CO_2 sensor. This has been fitted for a couple of years now. Please refer to the previous versions of this document which referred to use of the 5S MkII sensor.

Analox's 5S3 infra-red carbon dioxide (CO_2) sensors have the following specifications:

	5000ppm	10,000ppm
Basic accuracy	±25ppm CO_2 ± 1% of reading	±50ppm CO_2 ± 1% of reading
Temperature Coefficient	±2.5ppm CO_2 / °C	±5ppm CO_2 / °C
Long term drift	<5ppm CO_2 / week	<10ppm CO_2 / week

A major advantage of the 5S3 sensor over the previous 5S MkII version is that it automatically compensates for variations in atmospheric pressure. A 10 mbar change in atmospheric pressure previously caused a 1% of reading error, which was significant certainly at deeper depths. Changes in atmospheric pressure are now essentially irrelevant. This was one of the main drivers for performing regular calibrations of the sensor. We recommend that these regular calibrations are still performed, since they are a valuable way of ensuring safety, although you should find that the sensors require much less adjustment than previously at these frequent calibration checks.

For saturation diving, we are typically concerned with measuring CO_2 levels at around 0.005 bar ppCO2 (=5mbar ppCO2), which is the point at which scrubber material would normally be replenished.

As with the oxygen sensors, it has become common practice to mount the sensors topside. This means at say a pressure of 40 barA, with a ppCO2 of 0.005 bar, the percentage of CO_2 analysed topside is 0.0125%, more commonly referred to as 125 ppm CO_2.

To achieve the DNV accuracy, the measured CO_2 in this example must lie between 0.004 and 0.006 bar ppCO2. This equates to the topside sample being measured at between 0.01% and 0.015% (or 100 to 150ppm).

Let us look at what this means across a range of depths.

Figure 4 shows the variation of basic accuracy corresponding to depth variations for a chamber at an assumed constant 5mbar ppCO2 and constant temperature. It can be seen that the 5000ppm sensor remains within the permitted DNV limits to 38 barA, whilst the 10000ppm remains within the DNV limits only to around 20 barA.

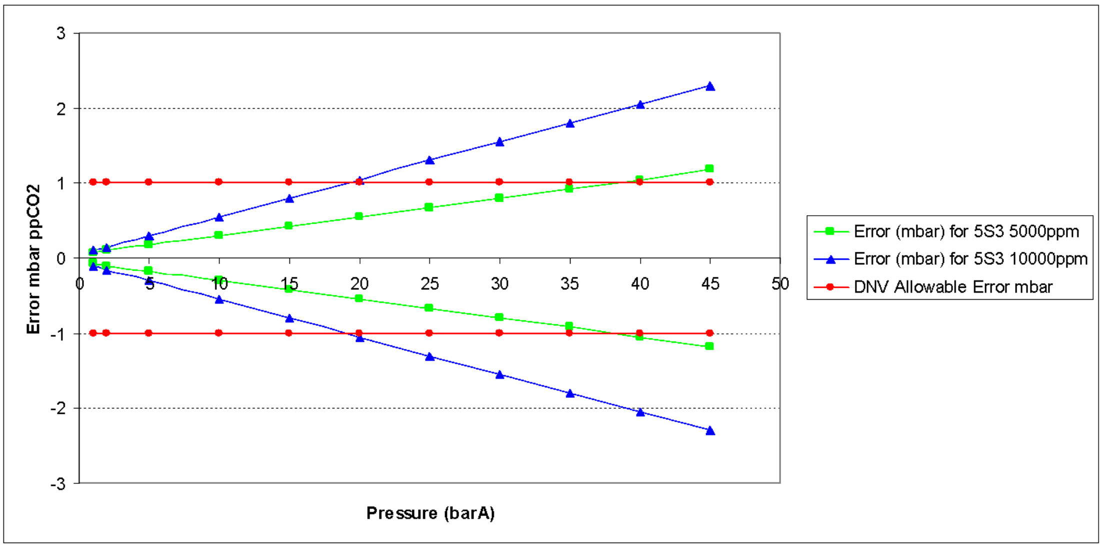

Figure 4 CO$_2$ basic accuracy requirements at constant temperature

First impressions therefore are that the 5000ppm sensor appears satisfactory for diving systems ranged to 350 msw, but that the 10000ppm sensor performance leaves a little to be desired in deeper (>200msw) saturation diving applications.

However, the situation is not quite so bad as it seems. First of all, these figures do not take account of the frequent calibration that is routinely performed in diving systems. They also do not make any allowance for the fact that when chambers are at their deepest depths, it is common practice to use calibration gas of a lower concentration, hence optimising analyser performance in the lower reaches of their characteristics. For instance, a 300ppm CO$_2$ gas mix may be used to calibrate the span of the sensor, on the proviso that when returning to shallower depths, the analyser is recalibrated on a more appropriate span gas.

To represent the performance of the systems under the regime of regular calibration and varying temperatures, we turn our attention to the other two parameters listed earlier: temperature coefficient and long-term drift.

Figure 5 shows this data for a temperature variation of +/-5°C.

Here we can see the 5000ppm sensor performing comfortably within the allowable error margins, whilst the 10000ppm sensor is now approaching a more useful 30 barA depth rating.

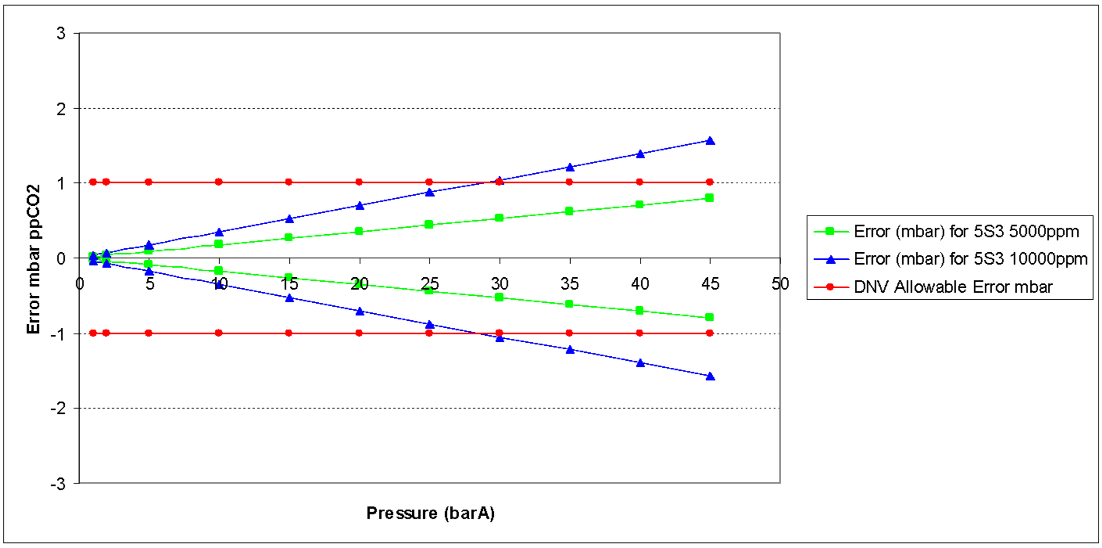

Figure 5 Drift characteristic with a +/-5 degC temperature variation

We have to be careful if we want to extract yet more performance from the 10000ppm sensor. Figure 6 shows the performance of both sensors assuming a more tightly controlled temperature environment. This graph represents a +/-3 °C variation, and we can see that we have now managed to get the 10000ppm to offer DNV compatible performance in excess of 350msw.

To reiterate the earlier advice, these graphs demonstrate that a 5000ppm sensor is better suited to meeting DNV requirements than a 10000ppm sensor. However, in situations where the increased range of the sensor is required, then with careful attention to detail, the 10000ppm sensor is capable of providing acceptable performance.

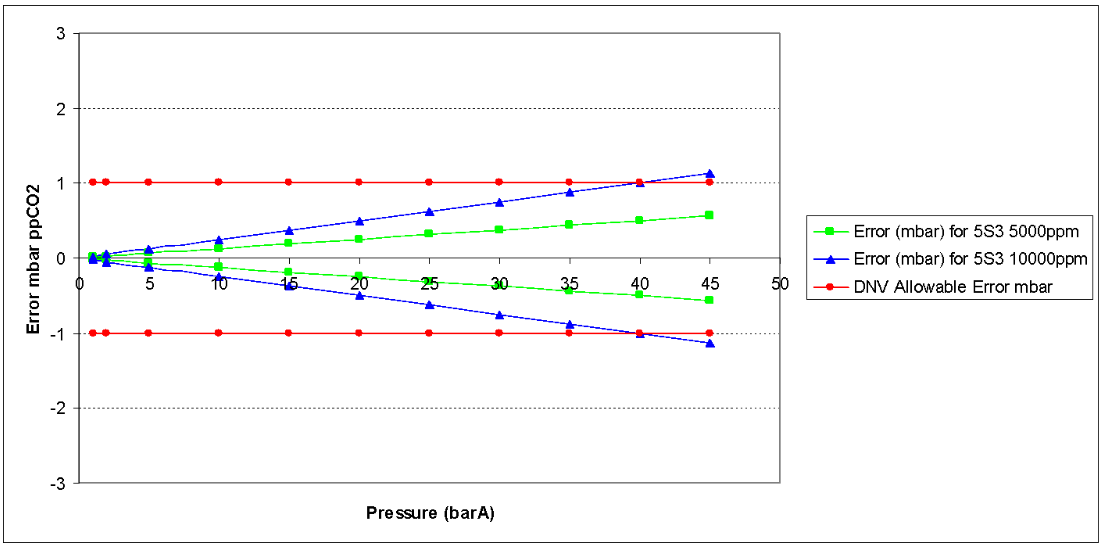

Figure 6 Drift characteristic with a +/-3 degC temperature variation