Carbon Dioxide
Sensing Module

CO2x

Operations Manual

Rev A

December 2009

This manual should be read in conjunction with the Sentinel Operations Manual, the Intelligent Secondary Manual, the VR3, VRx and NHeO manuals

Premise

There is little confirmed data on actual absorbent durations typical for sports diving rebreather use. Sports divers often push the absorbent duration beyond the published CE durations, because they assume that they will not be creating as much CO2 as the CE trials or operate at the same temperature or depths. Also, much of a decompression dive is at a shallower depth than the CE trial, and this can also help achieve a longer absorbent life.

The problem can arise that if a diver has gone deep and works hard, perhaps to rescue another diver; when the absorbent duration is near its limit, the extra depth and work rate push the CO2 levels dangerously high at an ever increasing rate.

The CO2x sensor will help by giving feedback in this scenario, and advise of the high CO2 levels. The diver should then reduce their work rate and reduce their depth and finish the dive as safely as possible. The relatively fast rise in CO2 readings is also an indication that the absorbent can not be pushed any harder without causing even higher CO2 levels.

A question asked already by many divers who have seen the system in operation, is "Can the CO2 reading be used to determine the duration remaining in the filter?"

The answer in principle is yes. However with the current knowledge and data available, there is no practical system to achieve this. The duration of the absorbent changes with CO2 generation, temperature and depth (and rebreather design). People have achieved over 8 hours duration with relatively small absorbent loads, but this has been in warm water, with low breathing rates and shallow depths. It is currently not known what the effects are when an absorbent filter working at a CO2 level of say 2mBar that has been used in a shallow scenario is taken deeper and the work rate is increased. We know that the CO2 would increase, but not know how fast. In field tests, we have seen the CO2 jump quickly from 3mBar to 6mBar just by the diver going deeper near the end of absorbent duration. This same rise will not occur if the filter is at the start of its life. So duration will be possible with time and more testing this is not currently the main function of the CO2x. Its' current functionality is as an active warning device for CO2 absorbent system issues. It can detect for bad absorbent, no absorbent, high work rates and general CO2 seal issues.

Currently the CO2x sensor reading should not be used a duration meter for the rebreather.

Our bodies produce the same CO2 quantities independently of depth. So just staying shallow does not reduce CO2. It can however, help the CO2 absorbent perform more efficiently. Therefore a low CO2 reading on a filter that has been used in shallow water for some time may rapidly increase if (towards the end of its' life) it is taken deeper or the work rate increases. Be aware that the CO2 reading can rise dramatically for higher work rates and deeper depths, especially when an absorbent has been used for over 50% of its recommended duration.

Therefore, in order of priority, the Sentinel is fitted with an hours timer (based on CE results), a metabolism 'click' counter (providing an estimate of oxygen consumed, hence CO2 generated) and a TPM giving an indication of thermal activity within the filter. These three features give a more accurate indication of absorbent life remaining.

The prime use of the CO2x readings are three fold;

1. To ensure active absorbent has been fitted
2. To ensure the absorbent sealing systems are operative
3. To warn of reducing absorbent efficiency in order to give the diver time to respond by reducing depth, temperature or work rate to avoid an incident occurring.

The CO2x should NOT be used to determine absorbent duration.

As more actual dive data becomes available it may be possible to model the CO2 curves and generate some level of prediction of remaining absorbent life. This is currently a work in progress.

CO2x – Carbon Dioxide sensor for Sentinel and VRx systems

This document describes the operation of the CO2x - VR Technology's CO2 sensor, as fitted to the Sentinel rebreather series, and available as an accessory to the VRx dive computer.

The CO2x is the world's first commercially available carbon dioxide sensor proofed and designed for operation in a high humidity, high oxygen rebreather breathing loops.

The CO2x actively measures carbon dioxide while the user is breathing on the loop. It can thus warn of high CO2 levels before unconsciousness or other symptoms occur, in time for the user to perform remedial tasks such as finishing a dive, reducing activity or even bailing out to other gas sources.

Background
It should be noted that this is the first use of a CO2 sensor in an active-user breathing loop. As such, new data on CO2 levels will be obtained that will identify areas of adjustment of common practice and improved use of the CO2 readings.

Much of the research in CO2 poisoning has been conducted with military levels of exertion and requirements. From this research the 5 to 10mBar limits for CO2 were formalised as the upper working range for CO2 by a diver undergoing considerable exertion. Thus the alarm levels within the CO2x have been initially set as 5mB and 10mB. As the user moves into the 5mB+ range, although no symptoms may occur, it is highly advisable to be very circumspect regarding the further use of the CO2 filter.
It is assumed that CO2 levels in the region of 15 – 20mB are potentially very dangerous, and the user could easily lose consciousness in a manner that is very hard for the user to detect, and as such it is potentially extremely dangerous to work at any CO2 level above the 10mb range.

Main Features

The CO2x consists of a proprietary combination of filters and sensors that together provide a robust CO2 monitoring system for breathing loops in rebreathers.

The CO2x is able to compensate for pressure and humidity environments as normally achieved in a diving rebreather system.

The CO2x Sentinel version is powered from the main support units' (Sentinel/Vrx etc) battery system or in some applications from an external power source.

The CO2x requires occasional calibration. VR Technology have a sophisticated logging system that minimises the number of calibrations. It also removes the need to use CO2 calibration gasses.

What will I expect to see on the CO2x readings?

Because this is the first practical use of CO2 sensors in an active breathing loop, some user education is required to understand the benefits, features and limitations of the device. From this standpoint, it is worth the user taking a short time to understand a little more of how CO2 is dealt with in the breathing loop.

As the user pushes the CO2 absorbent filter towards and past the end of its CE limits, the levels of CO2 in the loop may be surprisingly high, compared to CE accepted levels and may accelerate rapidly dependant on the rebreather design. As this is essentially new research, different conclusions can be considered at this time as to how divers are able to currently get extended durations from their CO2 filters compared to the manufacturers' specified limits.

Some divers feel they are getting more duration because they are not producing as much CO2 as that used in CE trials or that other environmental issues are less extreme.

Information from Beta trials with the CO2x suggests that the filter durations are actually quite close to the CE durations and the 5mB CO2 point. However, 5mBar of CO2 is not fundamentally damaging. Metabolism and respiration can occur to some degree even up to 20mB CO2. However, the amount of exertion and other pressure related effects mean that this is unadvisable, and CO2 poisoning and death may occur at levels in the 10-20mB range in some cases. So some of the extended durations currently experienced are due to the user taking the CO2 level into the 5-10mB range, without any obvious symptoms of CO2 poisoning.

The user must be aware however, that strenuous exertion when CO2 is at these elevated levels can quickly cause the CO2 levels to rise rapidly. As the symptoms of CO2 poisoning are almost impossible for the user to recognise – they will just pass out and may drown. However, the readings from the CO2x sensor showing that CO2 levels are rising (while still not exhibiting symptoms) should be used as much as anything to limit the strenuous activity and further use of the filter after the dive has finished. New dives should not be performed on the filter once CO2 levels in the 5-10mB region have occurred, no matter for how short a duration. Some rebreather fatalities can be attributed to users pushing the CO2 filter with strenuous activity near the end of the filter life.

Increased depth or reductions in temperature when the CO2 filter is near the end of its life are also not advised, as the filter is less able to cope with high CO2 levels. So increased depth coupled with muscular activity and cold are a very bad combination when near the end of filter life where CO2 levels are already raised.

CO2x Operation

The filter is given a factory calibration. The values associated with this calibration are stored in the Sentinel or VRx etc. These values can be restored using the FacDef option in the CO2 Cal screen. (found in the main menu).

The CO2x will benefit from calibrations every week or so. Certainly a calibration should be done every month or when having not been used for over a month.

With the CO2x in Auto cal mode, the sensor should remain well calibrated. However, as anomalies can occur in any system, the user should check the approximate validity of the CO2 readings regularly, ideally prior to any dive. Simple testing by breathing directly onto the sensor should see the reading rise within about 1 minute. **Also exposure to clean fresh outside air should give a reading in the order of 0.4mB**. So the user must familiarise themselves with the operation and ballistics of the system to be confident the device is working correctly. **Consult the factory if in doubt.**

If you wish to calibrate the unit you must ensure you are in fresh ventilated (outside) air. Do not calibrate in a closed room. To force a calibration select NOW in the calibrate screen and then push the right hand button (air) once.

Mechanical fitting
The sensor should be fitted into the Sentinel breathing loop head assembly or the relevant adapter for other units (available Winter 09).
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Check the O ring is not damaged. Ensure the O ring is lightly greased. Perform a loop pressure test as per the rebreathers' operations manual.

Ensure the special filter is correctly attached into the front of the CO2x sensor prior to fitting in the rebreather. The filter should be periodically checked for water or mechanical damaged. It is advised to keep spare replacement filters. The filter is the main protection for the sensor from the breathing loops general environment. If damage occurs to the filter or it becomes exhausted, then damage will result to the co2 sensor itself! So always keep in it good condition.

Post a dive-day, remove the module from the rebreather and unscrew the filter. Keep the filter in a dry environment (air conditioning if possible) until the next dive.

The estimated change-out period for the filter is after 20 dives. This is estimated because diving environments and durations vary greatly. If you suspect the filter of nearing the end of its' life due to unexpected readings being displayed during a dive, you should change the filter.

Once the filter is properly attached, gently push the CO2x assembly into the rebreather head/housing.

Then secure the CO2x in the head using the screws.

Before plugging the cable into the head connector/VR, check both mating parts are clean and that the O rings are free from damage or grit etc. When satisfied that everything is perfect, the cable can be plugged into the head connector/VRx. The mating parts for this connector should always be checked that they are clean and dry prior to insertion. Any water in this connector will result in instant corrosion of the connector pins and will inhibit operation of the sensor and charging and download systems. So always keep the connectors clean.

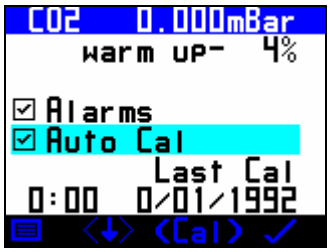
Menus and setup

Once connected, the Sentinel / VRx can be turned on and the CO2 readings checked. Check that the CO2 PIN number has been installed correctly. From the PIN number screen, a '2' should be seen in the list of installed options.

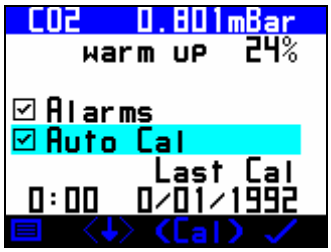
For the VRx, the Xfunc needs to be set to CO2 in the Dvo screen. In the Sentinel, CO2 will automatically appear in the Dvo and Options menus when the PIN is installed.

CO2 Modes screen

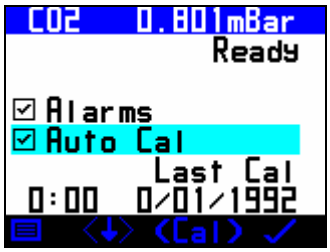
The CO2 Modes screen allows adjustment of the alarms and calibration mode.



Warm up negative = no comms



Sensor warming up



Sensor 'Ready'

In the Sentinel, with Alarms not checked, the HUD and alarms will not respond to CO2 problems. When unchecked, once the Sentinel finishes a dive, or is restarted, the alarms will be turned back on.

In the VRx, with Alarms not checked, the Message area alarms will not be activated by CO2 problems. Unlike the Sentinel, the VRx alarms will not be reset to on at the end of a dive or when the VRx is restarted.

If AutoCal mode is checked, then calibration takes place in the background when very low CO2 readings are detected.

Alarms

The VRx and Sentinel Rebreather systems will generate an alarm at 5mb of CO2 (Filter CO2 Hi). This will generate a green/blue alarm on the HUD and display Filter CO2 Hi on the Primary display indicating the users should complete the dive as soon as possible. This alarm can be disabled so that the user does not experience alarm overload and such that higher priority alarms (low PO2 etc.) are not masked.

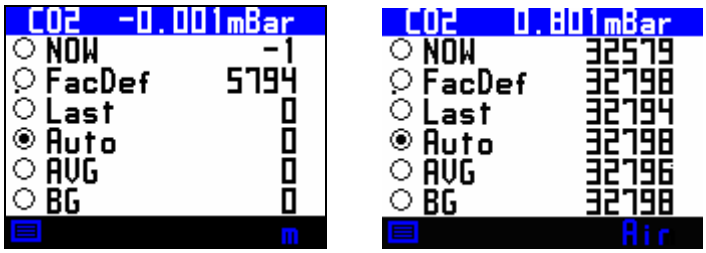
The second level of alarm is at 10mb CO2 (filter CO2 VHi). This generates a red alarm status on the HUD and display Filter CO2 VHi on the Primary display. This is an indication that the user should consider an open circuit bailout if they have symptoms. It is generally accepted that CO2 levels of up 20mb are not potentially life threatening in most cases, hence this level of alarm can again be deactivated for the above reasons but repeats every 5 minutes.

Warm up counter

This changes to 'Ready' when the CO2 sensor has warmed up. A negative reading shows that the system can not communicate with the CO2x sensor. If this is the case, check that the connector system is plugged in correctly. The cable could also be damaged, or the connector corroded.

The manual calibration can not be activated until the system is warmed up and Ready. The AutoCal system will not perform any calibration until the system is warmed up and ready.

CO2 Calibrate Screen



If AutoCal is unchecked, then the unit can be manually calibrated using a selection of different values:

- NOW
- FacDef
- Last
- Auto
- AVG
- BG

NOW = current reading from sensor
FacDef = Values set at factory
Last = values from previous calibration, if known
Auto = value that would have been used if Auto Cal mode was active
AVG = Average value from last few minutes
BG = Best value from the above readings

At the time of writing, in general the Auto or AVG values are usually the most appropriate to use. However, because this is such a new product, there could be occasions when some level of user override would suggest another value should be used. In particular, if the user has a known zero CO2 calibration gas, then the NOW

value can be used given a reasonable period of stability and exposure. This is usually in the order of 5 minutes.

In fresh air (at zero CO2), the reading should be in the range 32000 to 33000, this equates to 0.4mb or below. If the readings are outside this range, check:

1. Filter is fresh and dry
2. CO2 sensor is warmed up and properly connected
3. The electrical connector is dry
4. You are in a well vented area (outside)

Recovery from high CO2 contamination

If the CO2x is exposed to a very high carbon dioxide concentration as might be the result of a contaminated diluent gas flush or use without CO2 absorbent (not advised this is very dangerous), then extra recovery time will be required to purge the CO2 out of the system and filter.

The filter is especially sensitive to excessively high CO2, and will tend to retain CO2 for some time after the contamination has been removed. Leaving it to flush in moving fresh air is best. **At the start of a follow on dive the sensor may show high CO2 readings at the surface until the prebreathe is completed.**

The system can be purged in two ways.

1. Leave the loop exposed to clean, moving air for an hour or so. Cycle clean air through the loop to help remove the local CO2 build-up in the humidity filter.

2. To speed up the process, the filter can be removed from the module (and the loop) and exposed to fresh air. As the CO2x will be less protected at this stage, ensure that no moisture can enter the sensor housing.

Be aware that CO2 sensing of diluent and oxygen fills has not been available before in-field, so some problem fills may also be highlighted, where before no warning was available. **If you suspect a contaminated gas fill do not use it.**

CE Testing

Gaseous CO2 sensor module.

Tests conducted at ANSTI test systems on 11/5/09. Witness Ian Himmens.

As can be seen from the graph below, the CO2 sensor readings keep in close correlation with the ANSTI Teledyne Lab CO_2 analyser. The Blue trace is the ANSTI detector. The pink, is the CO2 sensor. The quick occasional changes to the Blue ANSTI trace are calibration tests to ensure accuracy of the measured readings.

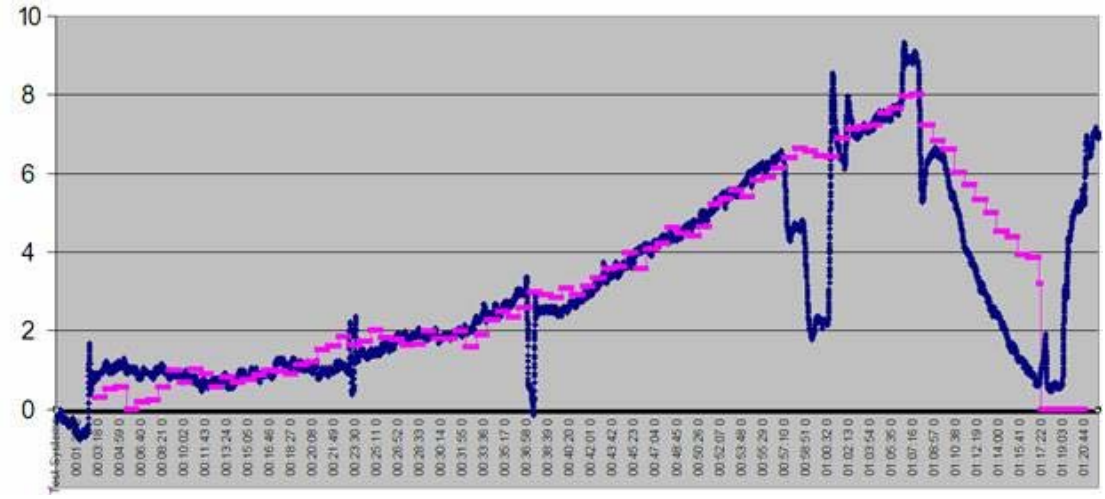


Fig 4.1 CO_2 graph matching
BLUE = ANSTY, PINK = GSS C20 inside breathing loop
Y scale = CO2 mBar

It can be seen from the graph that after 60 minutes there is less correlation between the in loop and ANSTI readings. This is due to the rapid ascent rate pressure change causing a temporary temperature drop. The CO2 sensor will quickly recover from the temperature drop. This state can be detected from other readings from the sensor and warned to the diver that the CO_2 readings are temporarily unavailable or less accurate.

To a lesser extent, there is also the reverse condition at the beginning of the dive, where the chamber is being pressurised and the temperature is rising. Within a few minutes the readings are correlated.