Analox 50^{TM} CO_2 monitor

- Use at high altitude

Analox Sensor Technology Ltd
15 Ellerbeck Court, Stokesley Business Park
North Yorkshire, TS9 5PT, UK

T: +44 (0)1642 711400 **F:** +44 (0)1642 713900
W: www.analox.net **E:** info@analox.net

Contents

1. Introduction

The Analox 50^{TM} instrument is configured to measure carbon dioxide (CO_2) in a variety of ranges which are specified at the time of ordering. The instrument is also programmed with two alarm setpoints. Information is provided in the technical manual allowing the customer, if necessary, to re-programme the alarm setpoints.

The sensor within the Analox 50^{TM} is affected by altitude. Therefore there is a need for customers using an Analox 50^{TM} in high altitude locations to understand the effect of altitude on the instrument. This may entail altering the alarm setpoints to more appropriate values.

Having read this document, any users still unsure what to do about altitude, should contact Analox for further advice.

2. Health and safety legislation

The UK Health and Safety Executive (HSE) publish a document, EH40, titled 'Workplace Exposure Limits'.

The US Occupational Safety and Health Administration (OSHA) publish a standard, 1910.1000, titled 'Occupational Safety and Health Standards'

Both of these documents quote a figure of 5000ppm CO_2 as the maximum limit for the long term exposure limit (8 hour time weighted average reference period). In the UK, a short term exposure limit (15 minute reference period) is quoted as 15000ppm.

3. What do the numbers mean?

One unfortunate thing about the numbers quoted in the health and safety documents is that the numbers are somewhat simplified. They actually refer only at normal atmospheric pressure. There are arguments about what is normal atmospheric pressure. It is usually taken to be 760mm Hg, which in other units equates to any of the following – 101.325 kPa, 1013.25 mBar or 1 ATA. However, for the sake of the following description, and to keep the mathematics simple, let us adopt the standard atmosphere as being 1000mBar (100kPa).

In terms of a deep sea diver it is well understood that the quoted 5000ppm figure would be positively lethal if a diver were exposed to this level of CO_2 say at a pressure of 20 Bars. It is actually the number of CO_2 molecules present that cause a problem to our metabolic condition. Therefore the deep sea diver can only tolerate the same number of CO_2 molecules as he could do at sea level. Therefore at 20 Bar pressure, a deep sea diver would be concerned if the CO_2 level rose above 5000/20 ppm (which equates to 250ppm). A very much smaller fraction!

From our early school years we may recall Dalton's Law which states that the total pressure exerted by a gaseous mixture is equal to the sum of the partial pressures of each individual component in a gas mixture. The partial pressure of a gas is a very convenient way for us to measure a gas.

If atmospheric pressure was 1000mBar, then we could describe 0.5% CO_2 as having a partial pressure of 0.5/100 * 1000, which equates to 5 mBar partial pressure of CO2, commonly abbreviated to 5 mBar $ppCO_2$.

It is this partial pressure that is of concern to the deep sea diver, so when we said the CO_2 content was 250ppm at 20 Bar, we can see that this equates to 0.025% of 20 Bar = 5 mBar.

The opposite of deep sea diving is to climb a mountain, or go hot-air ballooning. The atmosphere becomes thinner as the altitude increases, and the atmospheric pressure therefore decreases.

So let's look now at altitude.

4. Variation of atmospheric pressure with altitude

Figure 1 shows the generally accepted variation of atmospheric pressure with altitude. Read from the left hand scale for altitude in feet, and read from the right hand scale for altitude in metres.

Remember, that just as atmospheric pressure varies with weather conditions at sea level, it also varies with such conditions at all altitudes. Therefore, this graph shows only the normal or typical atmospheric pressure.

Since there are very few installations of the Analox 50^{TM} likely to be at altitudes in excess of 10000 feet, Figure 2 shows a rescaled version of the same graph. We can see from Figure 2 that at say an altitude of 10000 feet, the atmospheric pressure is approximately 0.7 Bar.

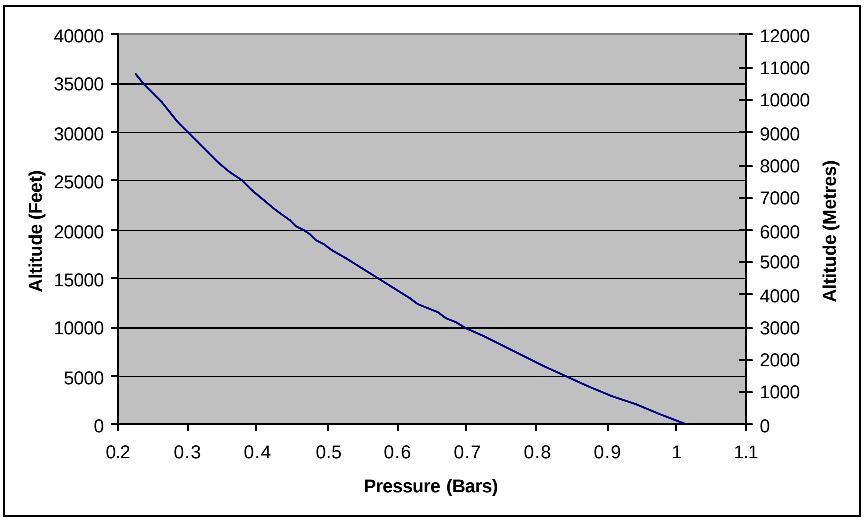

Figure 1: Variation of Atmospheric Pressure with Altitude to 35000 feet

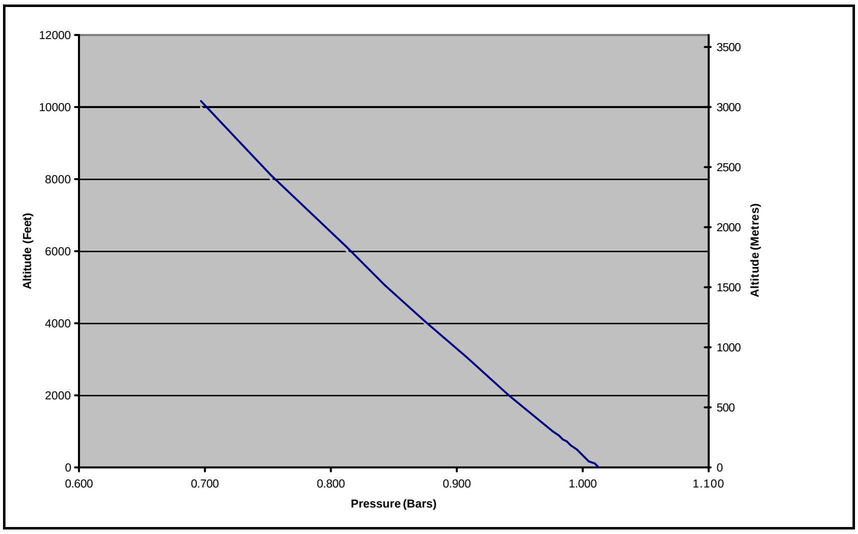

Figure 2: Variation of Atmospheric Pressure with Altitude to 10000 feet

5. What are the relevant safety figures at high altitude?

Let’s think back now to the 5mBar $ppCO_2$ thresh-hold that poses a threat to humans.

At 10000 feet altitude, if the atmospheric pressure is 0.7 Bar, then the percentage of CO_2 in the atmosphere which meets this thresh-hold is then calculated as 0.005/0.7 *100 = 0.7143% (or 7143ppm).

The health and safety guidelines don’t actually tell you this. Taking them literally, they are still saying that the danger level is 0.5% or 5000ppm. This equates at 10000 feet altitude (0.7 Bar) to 0.5/100*700 mBar $ppCO_2$ = 3.5mBar $ppCO_2$.

The actual truth is probably somewhere between these numbers. 3.5mBar $ppCO_2$ is the ultra-cautious, whereas the 5mBar $ppCO_2$ figure ought probably to be scaled back a bit to account for the fact that our bodies will actual experience less oxygen than normal, and hence could be less tolerant of the CO_2. In the case earlier of the diver, we can assume that the diver is always supplied the right amount of oxygen, or at least more than a minimum allowed level.

Perhaps also 10000 feet is a fairly extreme case. There are around 50 major cities in the world above 1000 feet, of which 10 are above 4000 feet, and only 4 are above 6000 feet (Mexico City, 7400 feet; Bogota, 8700 feet; Quito, 9200 feet; La Paz, 10500 feet).

Between sea level and around 600 feet, the effects on the Analox 50^{TM} are essentially negligible, and amount to no more than the basic accuracy of the instrument.

6. What does an Analox 50^{TM} actually measure?

Let's consider a typical Analox 50^{TM}. By far the most common variant is one which measures CO_2 in the range 0 to 5% CO_2. This version is particularly suited to monitoring for the presence of CO_2 in pub cellars and breweries.

The Analox 50^{TM} is described as displaying or responding to the percentage of CO_2 present. So for instance we talk of setting alarms at typically 0.50% CO_2 (5000ppm) and 1.50% CO_2 (15000ppm).

We too have taken the simple route that the health and safety authorities have done. Generally we find that customers understand the concept of percentage much more easily than worrying about partial pressures.

However the CO_2 sensor within the Analox 50^{TM} doesn't understand such 'simplifications'. It works on the principle of infra-red absorption by CO_2. It generates infra red radiation at one end of an optical bench, and measures how much of that energy arrives at the other end of the bench. Increasing levels of CO_2 will absorb more infra red, and hence reduce how much infra red is detected. It is the number of CO_2 molecules present, or the partial pressure of the CO_2 that dictates how much absorption takes place. The number of other molecules doesn't have very much effect, although we'll come back to this later (refer Section 8).

So essentially, the sensor is responding to the partial pressure of CO_2.

First of all let us think about the sensor being used at sea level, and what happens to the reading as weather patterns alter the atmospheric pressure.

Let us assume that the atmospheric pressure is 1000mBar and we expose the sensor to a sample of gas taken from a calibration gas bottle which contains 0.50% CO_2 in either synthetic air (CO_2 free) or nitrogen (it doesn't matter which). So 0.5% of the 1000mBar comprises CO_2, and we say that the partial pressure of CO_2 is 0.5/100 * 1000 mBar $ppCO_2$, which in this case equates to 5mBar $ppCO_2$.

We'll say the sensor is perfectly calibrated so it will read 0.50%, but it is actually measuring the 5mBar partial pressure of CO_2 and interpreting it as 0.50%.

If the weather were to alter such that the pressure was now 1030 mBar, our calibration gas will still contain 0.5% CO_2, therefore the partial pressure of CO_2 now experienced by the sensor will now be 0.5/100 * 1030 (=5.15 mBar, which ideally would be interpreted as 0.515%).

Conversely, if the weather now resulted in a pressure of 970 mBar, the partial pressure of CO_2 now experienced by the sensor will now be 0.5/100 * 970 (=4.85 mBar, which ideally would be interpreted as 0.485%).

Now making a more substantial change to the pressure, let's take the same instrument and calibration gas to a higher altitude. This will make a more significant change to the pressure.

We'll use our earlier example of 10000 feet at an atmospheric pressure of 0.7Bar (700 mBar). At this altitude, the partial pressure of CO_2 experienced by the sensor will be 0.5/100 * 700 (=3.5mBar, which will ideally be interpreted as 0.35%).

7. So, what is the problem?

In the example above, we've described an Analox 50^{TM} which has been calibrated at sea level and then installed at an altitude of 10000 feet.

It is reading 0.35% when exposed to 0.50% CO_2 test gas. This means that to go into alarm, we will require a higher concentration of test gas. As described earlier (refer Section 5), we showed that the percentage of CO_2 in the atmosphere at 10000 feet which poses danger is 0.7143% (or 7143ppm).

It is actually this test gas that we might expect to be required to raise the alarm at 10000 feet altitude.

Now actually, that's not a bad thing, because that is the concentration of gas that we have to worry about at this altitude. But there's a catch… now let's look at that.

8. The catch

We said in Section 6 that we would come back to discuss what happens when there are other gas molecules present.

In truth, it doesn’t matter whether those other molecules are oxygen or nitrogen, or any of the other more abundant gases in the Earth’s atmosphere. It just matters how many of them there are. The total number of molecules present dictates the pressure. And pressure has another effect on the CO_2 molecule and its ability to absorb infra red.

It is the atomic bonds between the carbon and oxygen atoms that actually absorb infra red. As the pressure is increased, these bonds become a little more strained, and actually absorb more infra red as the pressure increases. Likewise as the pressure decreases, the bonds are less stressed and absorb less infra red. We don’t intend to discuss the physics of this, but instead we’ll simply acknowledge that it happens.

This means that although the CO_2 sensor responds to the partial pressure of CO_2, it doesn’t quite do so in an ideal manner.

9. Does that matter? Let’s look at the numbers.

9.1. Warning alarm (Alarm 1)

Figure 3 shows the typical performance of the Analox 50^{TM} around the health and safety 5000ppm (0.50%) long term exposure limit, assuming that the instrument has been set up at or near to sea level.

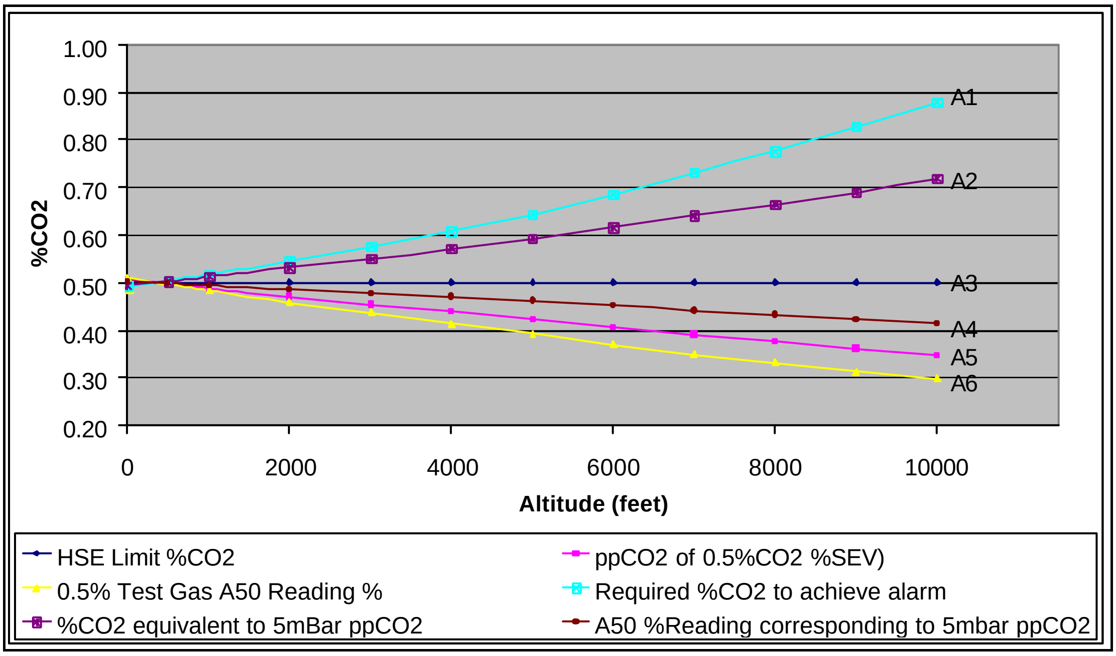

Figure 3 : Operation around 0.5% CO2 Alarm Setpoint

The horizontal line (A3) represents the published safety limit. The lower line (A6) represents the reading of the Analox 50^{TM} when exposed to test gas equal to the safety limit. The uppermost line (A1) represents the required concentration of test gas to just operate the warning alarm (ie to make the instrument read 0.50%).

So far that’s easy. But what are the other lines?

Line A2 represents the percentage test gas which corresponds to the 5mBar $ppCO_2$ safety limit. Likewise, line A5 represents the surface equivalent percentage of CO_2 relating to 0.5% test gas. The surface equivalent percentage of CO_2 is calculated as ($ppCO_2$ mBar /10).

Take the point at 5000 feet altitude, we have the pressure as 843 mBar, therefore for a 0.5% test gas, the partial pressure of CO_2 present is 0.5/100*843 = 4.215mBar $ppCO_2$, or 0.4215%SEV CO_2. [To use the same scale as the rest of the graph we can use %SEV CO_2 where 10mBar ppCO_2 = 1.0 %SEV CO_2].

In more simple terms, the difference between A5 and A6 represents the error (due to altitude) between the actual CO_2 present, and the measured value of CO_2. So it can be seen that the instrument under-reads the actual CO_2 present, by a small amount (about 0.05% CO_2).

If we had used a test gas equivalent to 5mBar ppCO_2 (Line A2), the instrument will similarly under-read that gas. Line A4 shows the reading that the instrument would give for a test gas of this value.

This shows in fact that the instrument performance is only slightly below that required to ensure an alarm for a 5mBar ppCO_2 sample gas. The error rises linearly with altitude reaching almost 0.1% at 10000 feet.

Alternatively from this data we can also deduce the appropriate test gas with which to calibrate or test the Analox 50^{TM} if it is desired to achieve better compliance with the health and safety limits. Section 11 details which calibration gas to use depending upon the location at the time of calibration.

9.2. Danger alarm (Alarm 2)

Figure 4 shows the typical performance of the Analox 50^{TM} around the health and safety 15000ppm (1.50%) long term exposure limit, assuming that the instrument has been set up at or near to sea level.

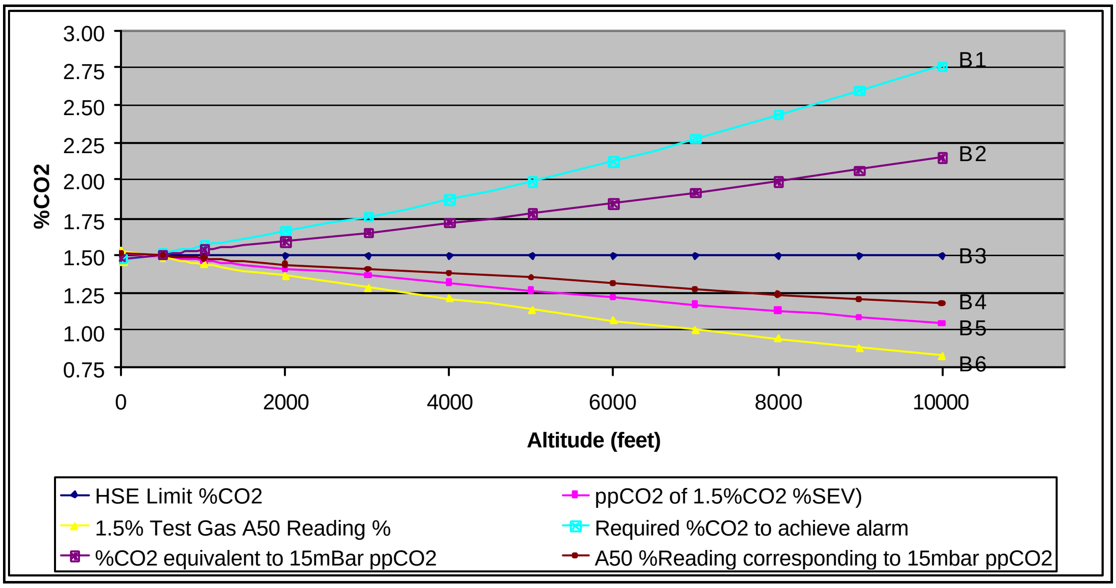

Figure 4: Operation around 1.5% CO2 Alarm Setpoint

This graph is constructed in the same way, so we can now see that the instrument performance is only slightly below that required to ensure an alarm for a 15mBar $ppCO_2$ sample gas. The error rises linearly with altitude reaching almost 0.3% at 10000 feet.

As before we can also deduce the appropriate test gas with which to calibrate or test the Analox 50^{TM} if it is desired to achieve better compliance with the health and safety limits (refer Section 11).

10. How to test the alarm settings

We will assume here that a standard instrument (ie calibrated normally at or near to sea level) is being used at high altitude. The user wishes to test that the alarms operate, but is content to leave the alarm setpoints at their original settings. What test gas should be used?

Quite simply, for the 1st alarm setpoint, the required %CO_2 concentration can be taken from Figure 3, line A1, or Table 1, Line A1.

And for the 2nd alarm setpoint, the required %CO_2 concentration can be taken from Figure 4, B1, or Table 1, Line B1

Table 1: Selection of Test Gas at various altitudes (for a standard instrument)

	LINE A1	LINE B1
Altitude (feet)	1st alarm (0.5%) Ideal Test Gas	2nd alarm (1.5%) Ideal Test Gas
0	0.491	1.468
500	0.504	1.513
1000	0.518	1.561
2000	0.546	1.659
3000	0.576	1.762
4000	0.607	1.870
5000	0.642	1.987
6000	0.685	2.129
7000	0.730	2.278
8000	0.777	2.433
9000	0.826	2.597
10000	0.878	2.766

For test purposes it is normal to use a slightly higher value still. This allows for any errors in the measurement, the altitude assumptions, the gas concentration etc. Typically the test gas will have a concentration of between 0.25% and 0.5% greater than the appropriate value selected above.

11. How to alter the alarm settings

Here we are discussing how to go about changing the alarm settings if it is deemed unreasonable to rely on the factory settings.

The alarms can be configured by subjecting the Analox 50^{TM} to a test gas and following the procedure in the technical manual. The choice of test gas is paramount in determining the alarm setpoint. Let us assume that we want to adhere strictly to the health and safety published figures of 0.5% and 1.5%.

We also have to note the altitude at which the instrument is being set up, and the altitude at which the instrument is to be used. We will consider two cases here.

i) an instrument being set up at or near to sea level to be used later at a known altitude
ii) an instrument being set up at a known high altitude for use at that same location.

	1st Alarm (0.50%)	2nd Alarm (1.50%)
Analox 50^{TM} at sea level	Use Test Gas from Figure 3, A6, or Table 2, Line A6	Use Test Gas from Figure 4, B6, or Table 2, Line B6
Analox 50^{TM} at high altitude	Use 0.5% Test Gas	Use 1.5% Test Gas

Table 2: Selection of Calibration Gas for later use at various altitudes

	LINE A6	LINE B6
Altitude (feet)	1st Alarm (0.5%)	2nd Alarm (1.5%)
0	0.510	1.532
500	0.497	1.487
1000	0.483	1.442
2000	0.459	1.357
3000	0.436	1.279
4000	0.415	1.207
5000	0.394	1.138
6000	0.371	1.065
7000	0.350	0.998
8000	0.331	0.937
9000	0.314	0.881
10000	0.298	0.830

12. Summary

Altitude has a definite effect on the carbon dioxide sensor. The effect increases with altitude. Except at extreme altitudes this is generally considered to be within acceptable accuracy limits.

However, at higher altitudes users may consider either

a) specifying the operating altitude prior to purchase, such that Analox can set up the alarms for the intended use,
b) accepting the basic performance of the Analox 50^{TM} and acknowledge that alarms will be raised at slightly above the normally accepted levels.

or

c) set the alarms up themselves by purchasing appropriate test gas for the relevant altitude.