DESIGN VERIFICATION OF THE TOLERANCE OF DEEP LIFE REBREATHER OXYGEN CELLS TO CARBON DIOXIDE

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APPROVALS	
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The tests in this report were carried out by the Baltic Assessment Institute under direction from Deep Life Ltd.

Quality Safety Environment

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Revision History

Revision	Date	Description
A0	10th Jan 2011	Initial results
A1	25th Jan 2011	Further test data added. Checked and passed for draft release.
A2	12th Apr 2011	8% CO2 test data added.
A3	15th Apr 2011	Linearity check at end of 8% CO2 test added

Table of Contents

1 PURPOSE AND SCOPE

This document is a design verification study to determine the effect of CO2 exposure on oxygen galvanic cells used in Deep Life rebreathers.

This document reports the effect of exposure to CO2 on AII oxygen cells PSR-11-39-DL (manufactured October 2009).

This is a verification document within Deep Life Quality Procedure QP-20.

2 APPLICATION

The oxygen cells in a rebreather are exposed to CO2. The amount of CO2 the cells are exposed to depends where they are located within the breathing loop.

For cells downstream of the scrubber, the cells exposure to CO2 will be under 1% SEV during the dive. At the end of the dive if the sensors are far from the scrubber then the sensors may sit in an environment of around 2% SEV until the rebreather is cleaned, if they are close to the scrubber the CO2 will fall to zero as the scrubber slowly removes the residual CO2.

For cells upstream of the scrubber, the CO2 will be around zero until the dive starts, whereupon it will increase to around 4% SEV, and may reach 8% SEV during the dive. At the end of the dive the CO2 will reduce rapidly to zero.

Deep Life's oxygen cells are produced by AII to a Deep Life specification, PSR-11-39-DL. The output voltage range of the cell in millivolts at 1ATM air and 25℃ should be from 4.18mV to 6.9mV, and the cells should be linear over the span to 2.3 ATM PPO2. For these tests, 26 month old cells were used, as the failure mode is likely to be more prevalent at the end of the cell's life: the tests were over a 4 month period so the cells were 30 months old when the tests concluded.

3 FAILURE MODES REPORTED

The oxygen cells used in rebreathers are galvanic cells containing a strong base (alkali) as the electrolyte. Strong bases react with CO2: rebreather scrubbers exploit this to remove CO2 from the inspired gas. However, if the same effect occurs in the oxygen cells, that will affect the cell, causing it to fail prematurely.

There are oxygen cells designed for use in high levels of CO2 and these use an acidic electrolyte. However, historically these have not been suited to measuring high levels of oxygen so an alkaline electrolyte is used in the cells used in rebreathers.

The electrolyte in the AII PSR-11-39-DL cells is a 15% Potassium Hydroxide (KOH) solution. CO2 will react with KOH to form K_2CO_3, i.e. Potassium Carbonate (Pearlash, the main component of Potash). Potassium Carbonate is soluble in water, insoluble in alcohol. The CO2, KOH reaction is:

$$2KOH + CO_2 \rightarrow K_2CO_3 + H_2O$$

At low levels of exposure, the Potassium Carbonate will dissolve, but at high levels of exposure, a carbonate film forms and will precipitate over the lead anode, reducing the cell's output. If left in air for a period that depends on the duration and concentration of CO2 exposure, the Potassium Carbonate will dissolve and the cell function will be restored.

For very high levels of exposure over long durations, the KOH may be depleted, or the anode completely covered with the precipitated carbonate.

One cell manufacturer [2] has reported that Lead Carbonate is formed: this reaction seems unlikely – Lead Carbonate is a whitish crystalline compound that does not dissolve in either water or alcohol. It is unlikely because the reaction with KOH would remove the CO2 before it gets close to the anode.

It is accepted that exposures of less than 1% CO2 seem to have no material effect on the cells. Deep Life has carried out extensive endurance test runs with scrubbers in dual rebreathers lasting up to 10 hours with the sensors exposed to exhale gas which has up to 8 % SEV of CO2 and, and in these tests no degradation of the cells from CO2 exposure has ever been observed. For the tests reported here, pure CO2 (or more precisely, 99.9% CO2) is used.

Units for PPO2 are in atmospheres (ATM), and units for CO2 are in % SEV, which is numerically the same as kPa. The selection of units derives from the manner in which the exposure arises and is calibrated.

Different cells and cell manufacturers use different membranes: the tests results reported here are specific to the AII PSR-11-39-DL cells.

4 EQUIPMENT USED

The test equipment used is listed below.

Equipment	Serial Number	Calibration Next Due
DL Oxygen Monitor	0105-C1	N/A (Used as display only, PPO2 calculated from manometer in these tests)
Bench Test chamber 160mm	A10	Next hydrostatic test Aug 2011
Highly Precise Digital Manometer LEX1	002333	16 July 2012

Oxygen cells at the end of their storage life were chosen, as these should provide the worst case. Analytical Industries Inc PSR-11-39-DL oxygen cells were used - batch N1: sample 1 s/n 910 53381, sample 2 s/n 910 53368 and sample 3 s/n 910 53369 are shown in Figure 1; batch N2 : batch N1: sample 4 s/n 910 51095, sample 5 s/n 910 51147 and sample 6 s/n 910 53370 are shown in Figure 2.

Figure 1: Oxygen sensor test batch N1, manufactured in October 2009, tested in January 2011 to a Deep Life Procurement Specification [1]. When new, these have an output of nominally 5mV in air. These cells are not temperature compensated internally: they are used with external digital temperature compensation.

Figure 2 Oxygen sensor test batch N2, manufactured in October 2009, tested in February, March, April 2011 to a Deep Life Procurement Specification [1]. When new, these have an output of nominally 5mV in air. These cells are not temperature compensated internally: they are used with external digital temperature compensation.

5 METHOD

The primary tool used for this study is an OSEL Oxygen Monitor Pod (Figure 3) which logs the cell voltage and temperature data each second, and provides a clear display of the output of each cell after temperature compensation. The monitors calibrate the sensors automatically when open and exposed to air.

Figure 3: Oxygen Monitor with O2 cells prior to test (cell holder disconnected and seen on top left of image to provide a clear view of the cells).

The Oxygen Monitor was calibrated in air, then placed into a 160mm diameter bench-top pressure chamber. The oxygen sensor linearity was checked up to > 5ATM PPO2 by pressurising the chamber with pure oxygen (1ATM of air + 5Bar of O2). The pressure was controlled and monitored with a Keller LEX1 precise manometer, to enable the actual PPO2 to be determined from the pressure.

The actual PPO2 (ATM) was calculated from the pressure gauge reading as:

$$\text{actualPPO2} = (\text{Pair} * 0.2095 + \text{Pch} - \text{Pair})/ 1.01325,$$

where

- Pair is atmosphere pressure, bar;
- Pch is pressure in chamber after filling with pure oxygen, bar;
- 0.2095 is PPO2 in one atmosphere, bar.
- 1.01325 is the conversion factor from bar to atm.

To provide a pure CO_2 environment the chamber depressurised, then closed and the chamber was pressurised with pure CO_2, and then depressurised. The flushing procedure was repeated ten times to achieve a CO_2 environment of 99.9%

The oxygen sensors were stored in the pure CO_2 environment at 1ATM pressure for 1, 2, 4, 6, 8, 16 and 24 hours i.e. 1, 3, 7, 13, 21, 37 and 61 hours in total. After each exposure to CO_2 they were stored in air to recover voltage and their linearity was checked again. The recovery period was monitored and logged.

The PPO2 reading (ATM) readings prior to temperature compensation are calculated as:

$$PPO2reading = (Pair * 0.2095 \ / \ Vair * V) / 1.01325,$$

where

- Pair is atmospheric pressure, bar;
- Vair is the oxygen cell output voltage in atmosphere, mV;
- 0.2095 is the PPO2 in atmosphere, bar;
- V is the oxygen cell output voltage in chamber after filling with pure oxygen, mV;

Figure 4: Oxygen Monitor in desktop 160mm chamber.

The sensor screening algorithm in the Oxygen Monitor rejects all the cells after a 4 hour exposure to CO_2, and it requires the recovery period before the cells are accepted by the monitor. This does not occur with shorter exposures.

The sensor fusion algorithm in the Oxygen Monitor takes the highest PPO2 value and displays it, during these tests. The Oxygen Monitor relies on sensor screening algorithms to filter out cells that fail in a high state, and then assumes all failures are failure low. The CO_2 failures reported herein, are all failure low states.

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6 Effect of Pure CO2 Exposure on Linearity

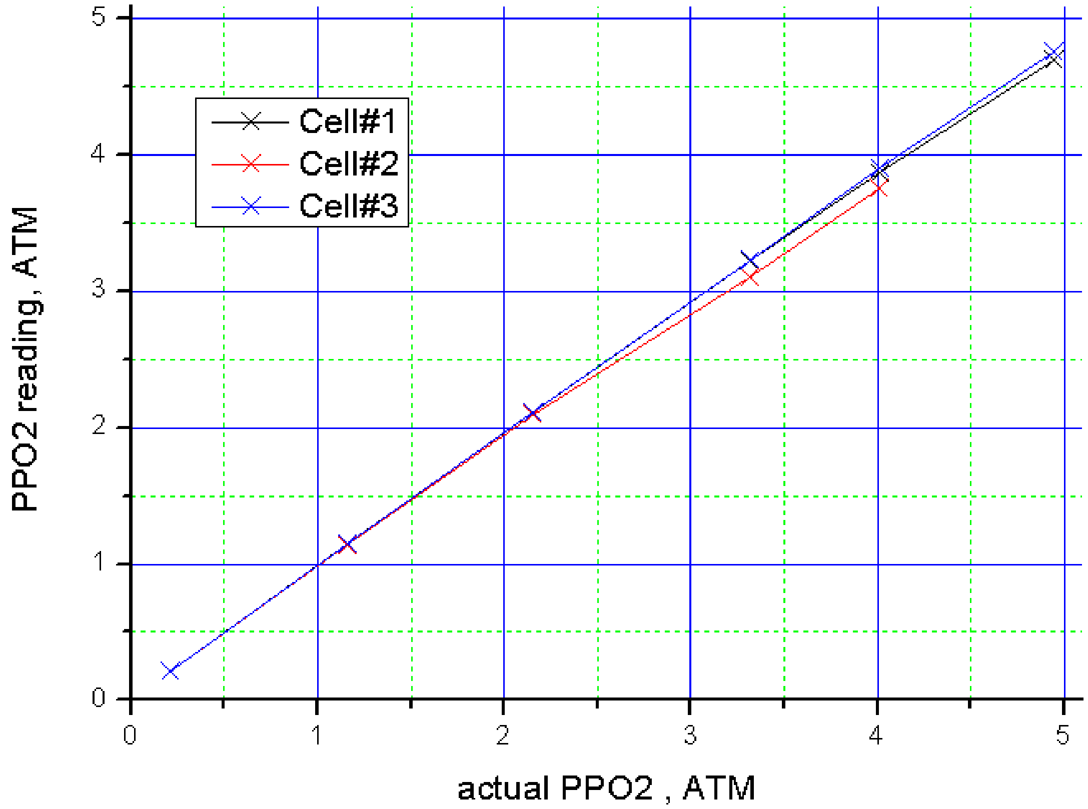

Figure 5: Linearity of cells to PPO2 prior to CO2 exposure

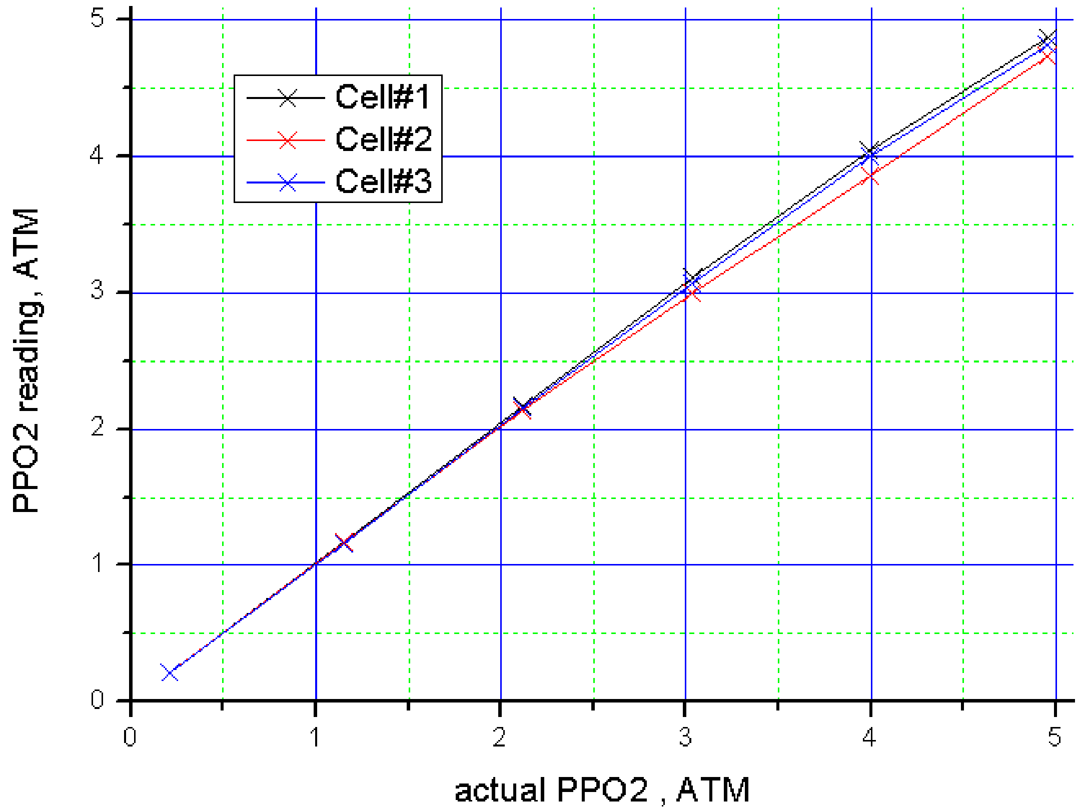

Figure 6: Linearity of cells after 1 hour of exposure to pure CO2

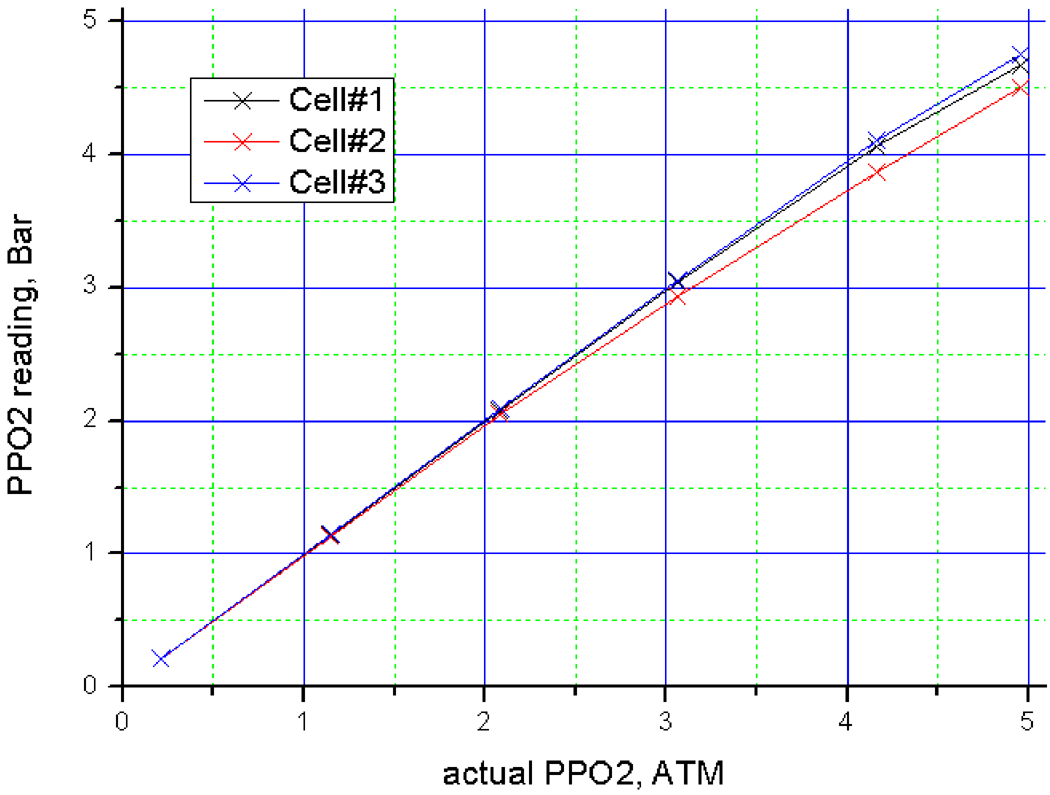

Figure 7: Linearity of cells after 3 hours of exposure to pure CO2

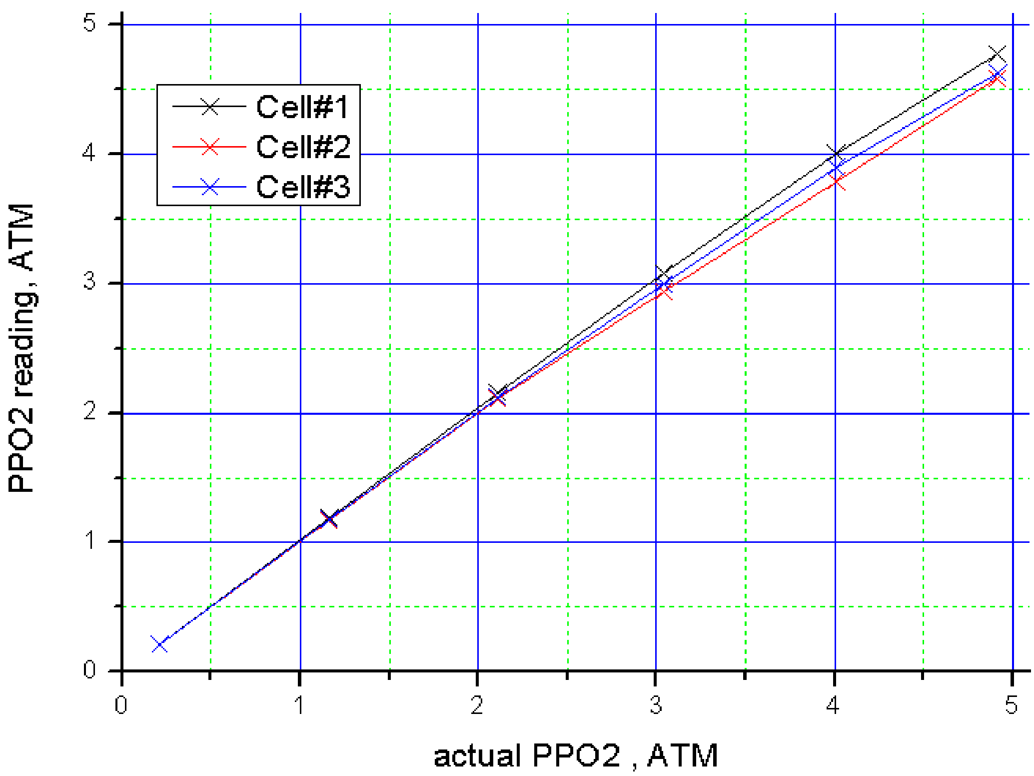

Figure 8: Linearity of cells after 7 hours of exposure to pure CO2

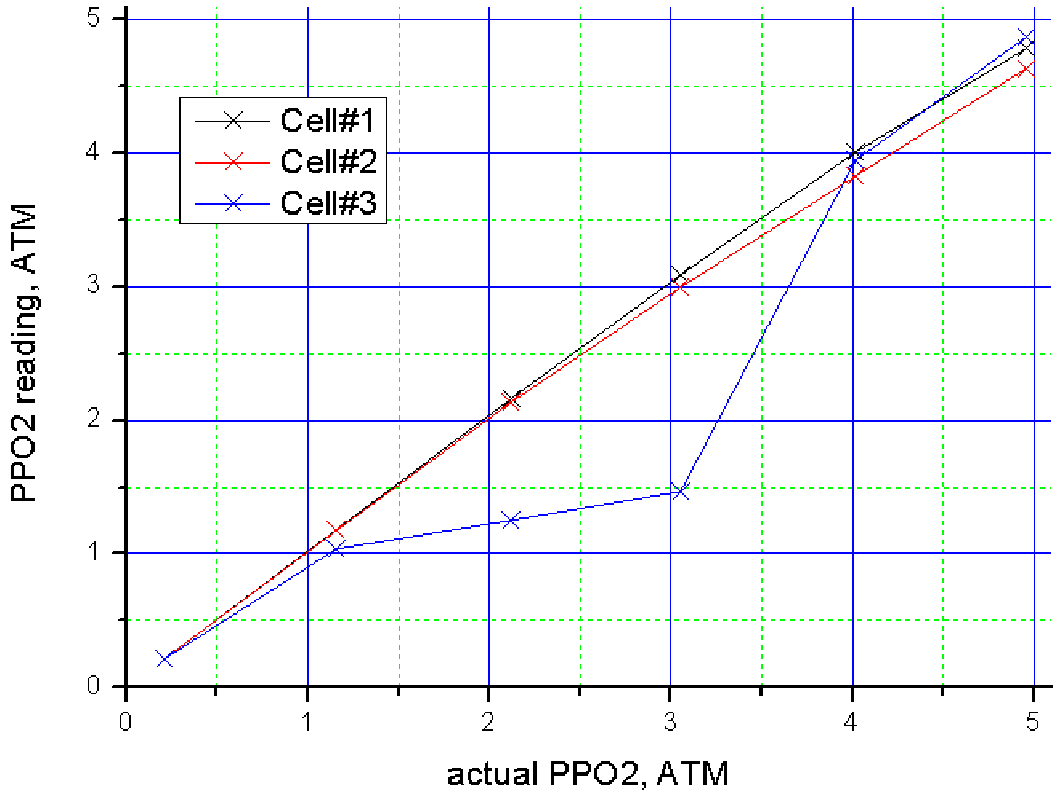

Figure 9: Linearity of cells after 13 hours of exposure to pure CO2. Note Cell 3.

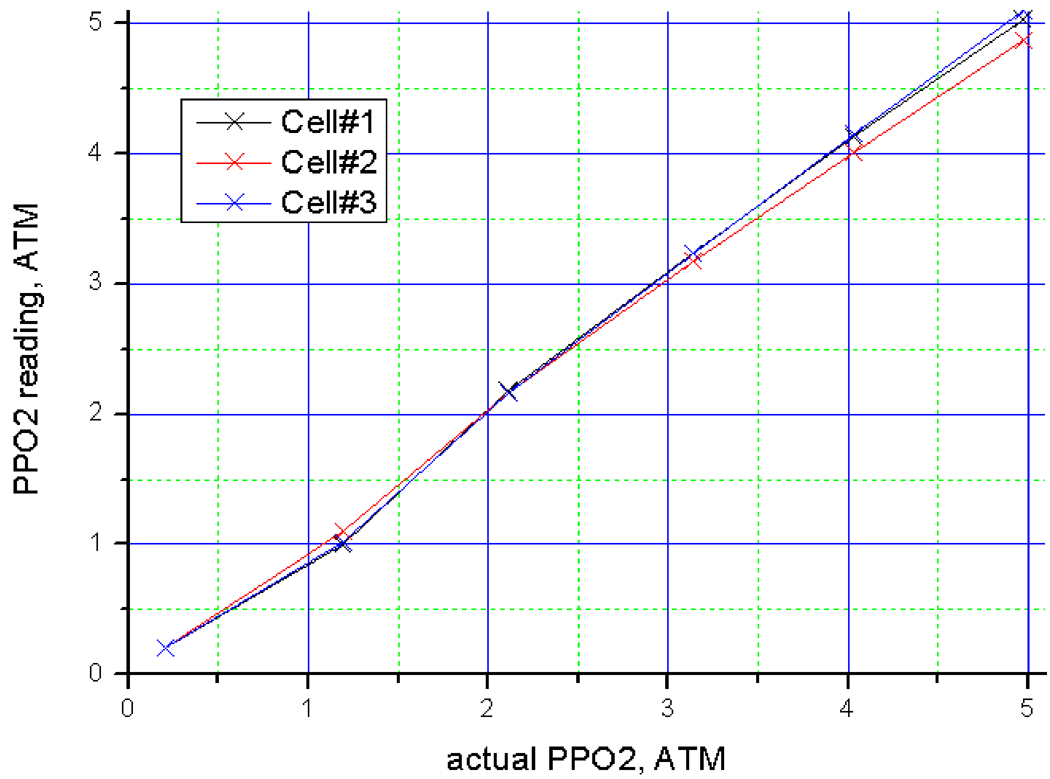

Figure 10: Linearity of cells after 21 hours of exposure to pure CO2

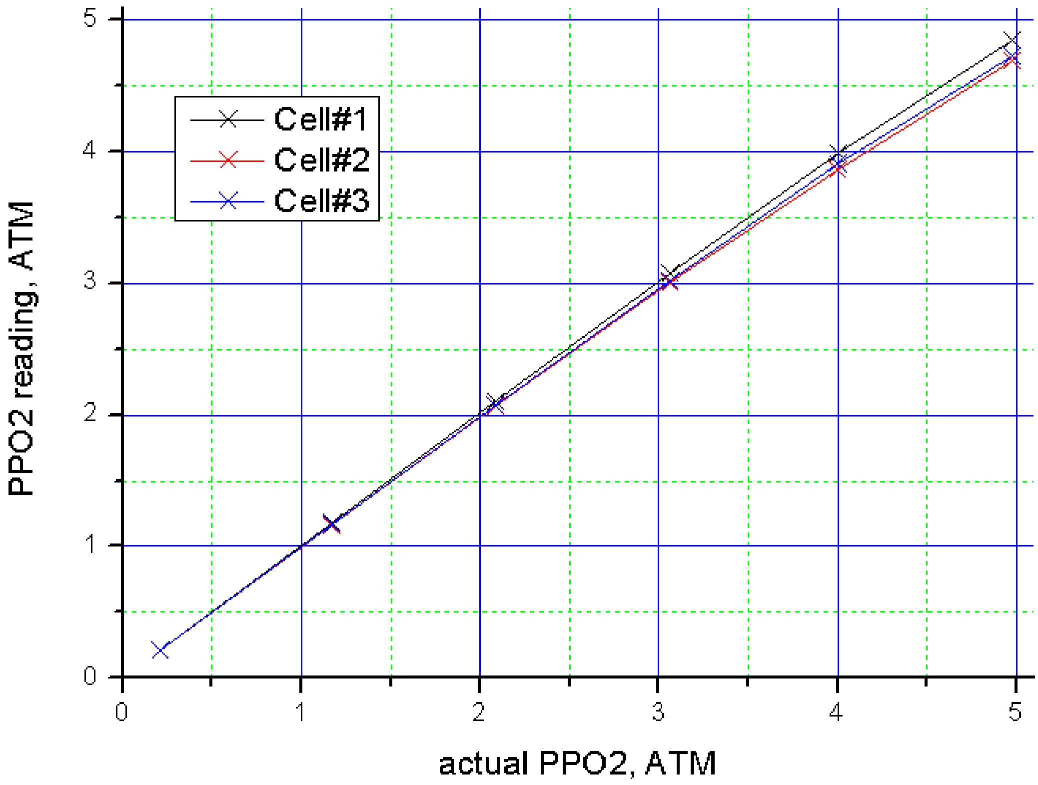

Figure 11: Linearity of cells after 37 hours of exposure to pure CO2

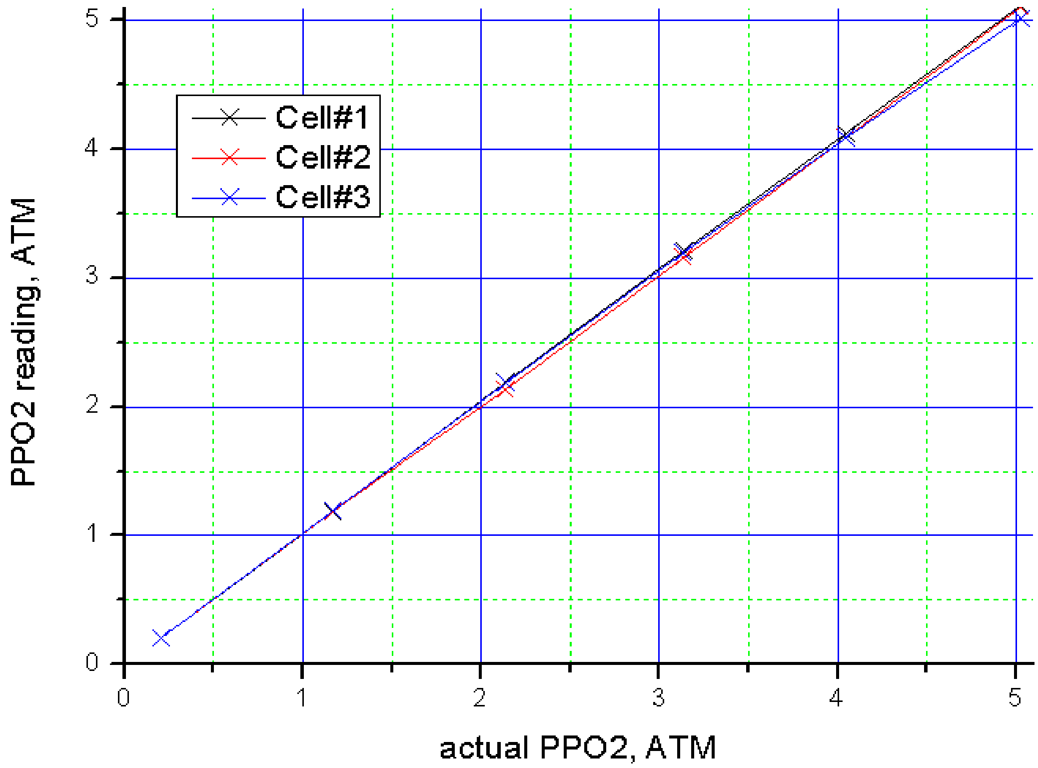

Figure 12: Linearity of cells after 61 hours of exposure to pure CO2

7 EFFECT OF EXPOSURE TO PURE CO2

Voltages were measured during each linearity check. They are tabulated in the Table 1.

Table 1 Oxygen cells linearity measurement raw data

Item	Chamber pressure, bar	Cell#1 voltage, mV	Cell#2 voltage, mV	Cell#3 voltage , mV	Temperature, C
1.Initial Cell Voltages (cell voltage is corrected with temperature in O2 pod firmware)	1.018	5.7	6.066	5.507	-
	1.98	31.086	32.887	30.004	-
	2.986	57.209	60.358	55.341	-
	4.166	87.379	89.538	84.46	-
	4.868	104.916	108.277	102.221	-
	5.815	127.259	-	124.538	-
2. Cell Voltages after 1-hour of total exposure to pure CO2	1.015	6.104	6.533	5.963	27.95
	1.97	34.182	36.321	32.935	28.05
	2.948	63.095	66.597	61.173	28.25
	3.878	90.511	93.293	87.254	27.85
	4.849	117.598	120.07	113.676	27.95
	5.822	141.78	147.512	136.855	27.65
3. Cell Voltages after 3-hour of total exposure to pure CO2	1.012	5.848	6.335	5.596	28.65
	1.964	31.834	34.163	30.668	27.85
	2.911	58.086	61.941	55.921	26.95
	3.903	84.92	88.811	81.718	26.45
	5.018	113.604	117.092	109.87	25.85
	5.822	130.684	136.421	127.158	25.05

4. Cell Voltages after 7-hour of total exposure to pure CO2	1.02	6.258	6.835	6.175	29.95
	1.986	35.245	37.99	34.461	29.15
	2.946	64.023	68.431	62.029	29.25
	3.887	91.467	95.241	87.812	28.55
	4.868	118.823	122.781	114.145	28.45
	5.785	141.74	148.809	135.536	28.25
5. Cell Voltages after 13-hour of total exposure to pure CO2	1.016	5.736	6.247	5.167	31.15
	1.975	32.201	34.852	25.485	30.45
	2.952	59.054	63.508	30.756	29.85
	3.896	84.338	89.135	36.051	29.35
	4.871	109.427	113.873	97.07	28.35
	5.825	130.715	137.904	119.884	27.85
6. Cell Voltages after 21-hour of total exposure to pure CO2	1.006	4.852	5.412	4.449	30.15
	2.004	23.279	28.632	21.758	30.05
	2.936	50.9	56.262	46.234	29.45
	3.975	75.574	82.569	69.12	28.85
	4.88	96.438	104.346	88.77	28.45
	5.834	117.404	126.858	109.138	28.15
7. Cell Voltages after 37-hour of total exposure to pure CO2	1.029	5.138	4.859	5.226	32.75
	1.999	28.455	26.555	28.596	31.85
	2.928	50.867	47.257	50.936	31.45
	3.915	74.255	68.655	74.17	30.55
	4.868	96.328	88.243	96.023	29.85
	5.858	117.118	107.224	116.2	28.35

7. Cell Voltages after 61-hour of total exposure to pure CO2	1.006	4.22	2.463	5.105	33.85
	1.981	24.045	14.067	29.23	33.65
	2.963	44.463	25.277	53.589	33.05
	3.973	65.205	37.396	78.456	33.15
	4.894	83.647	48.437	100.355	32.65
	5.888	103.822	60.453	123.198	32.15

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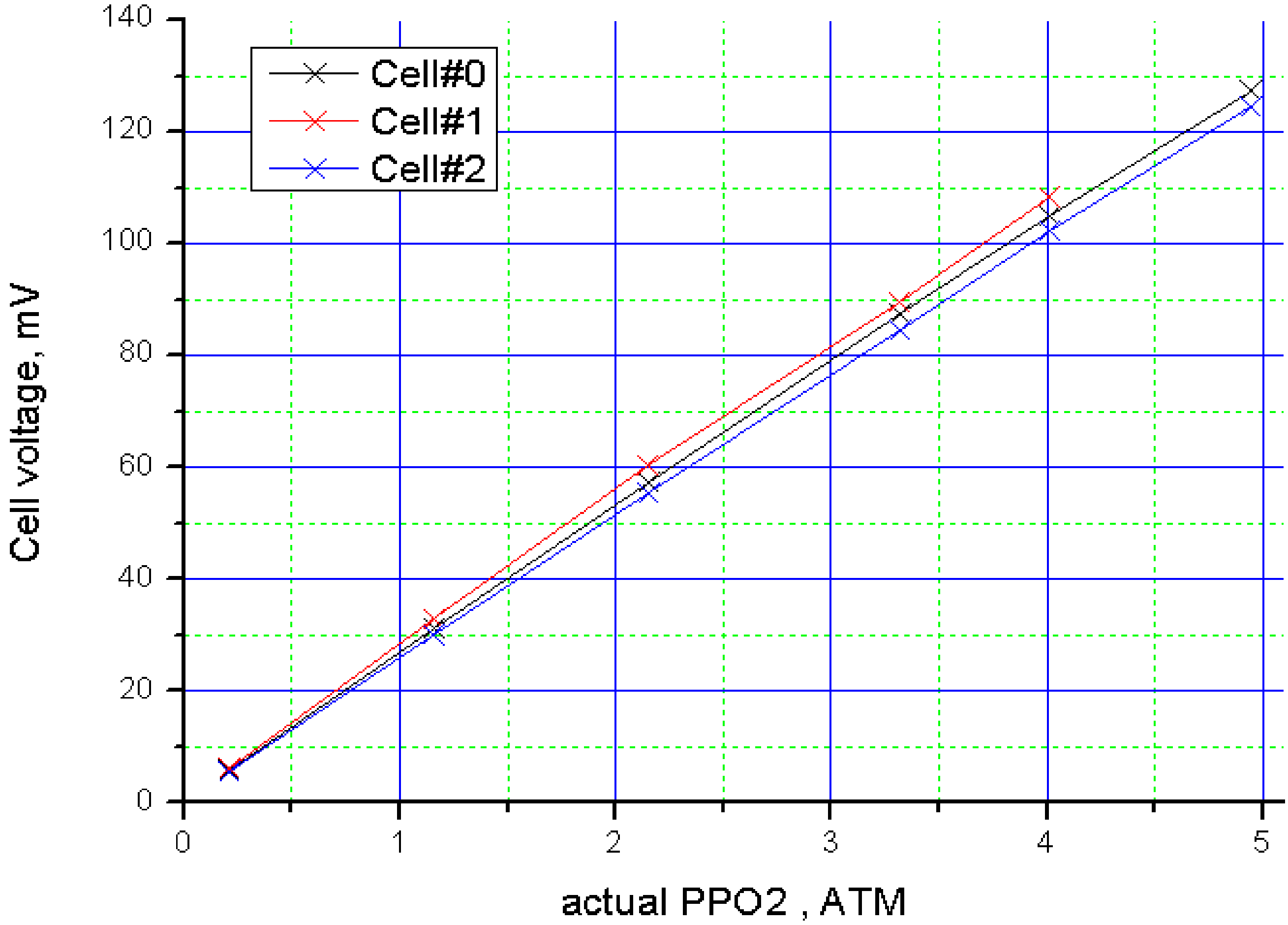

Figure 13: Oxygen cell output voltage (temperature compensated) under initial conditions versus actual PPO2 .

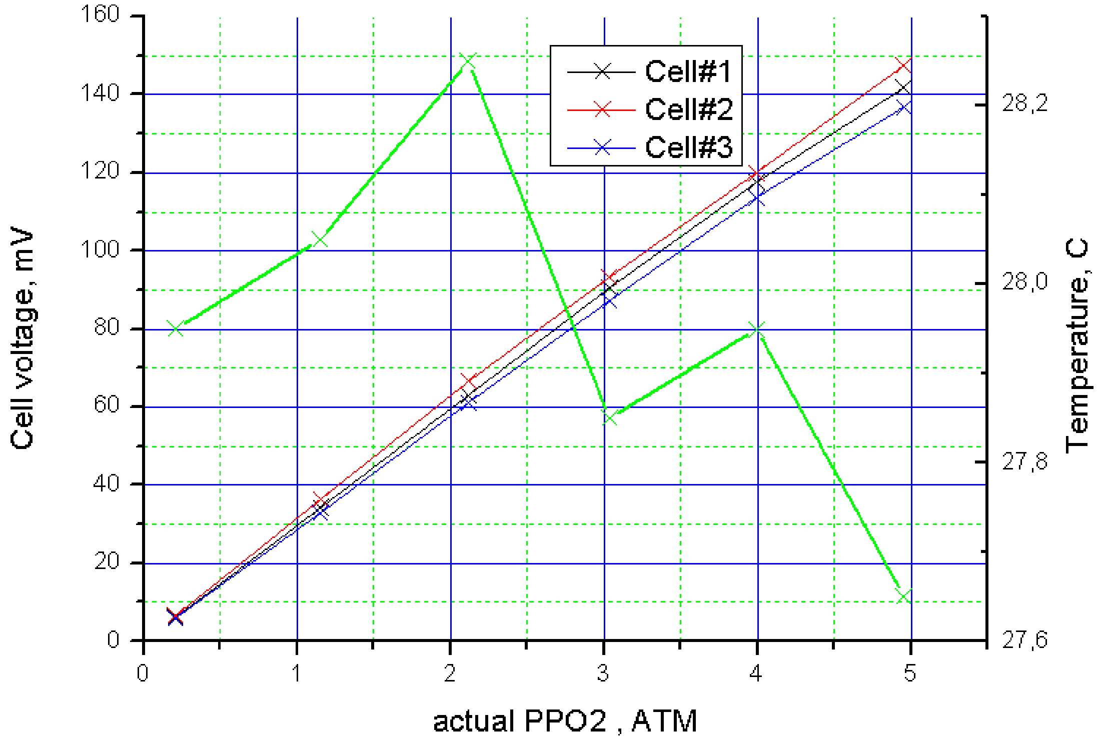

Figure 14: Oxygen cell output voltage after 1 hour of total exposure to pure CO2 versus actual PPO2 and corresponding cell temperature (green)

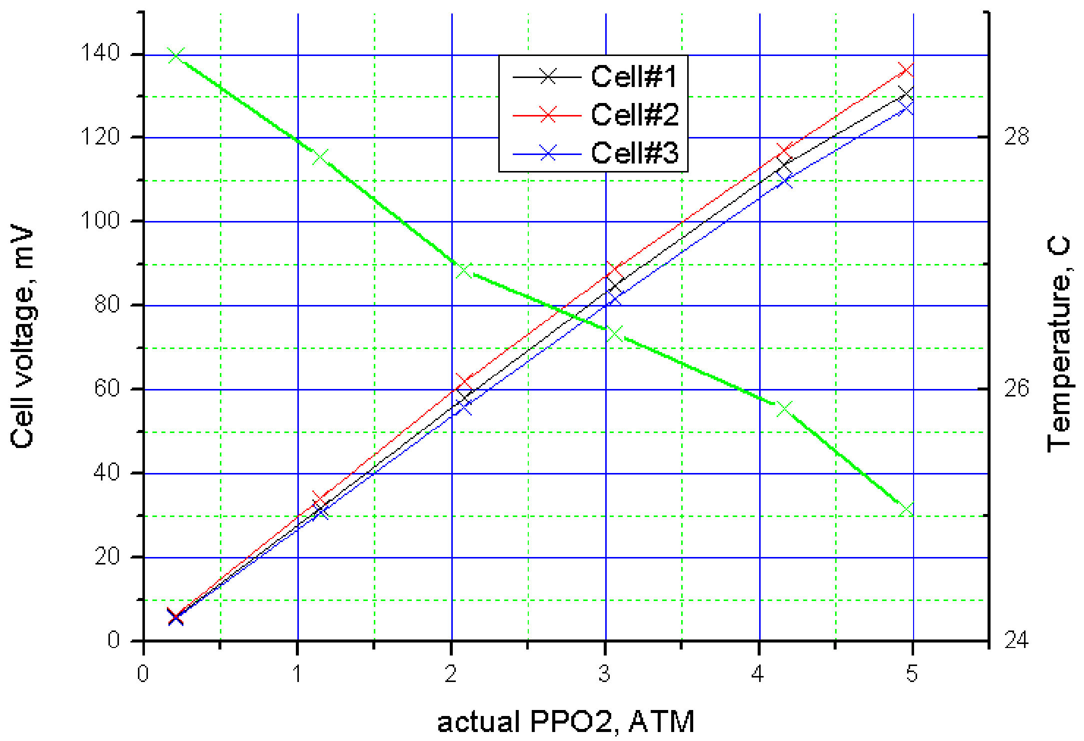

Figure 15: Oxygen cell output voltage after 3 hours of total exposure to pure CO2 versus actual PPO2 and corresponding cell temperature (green)

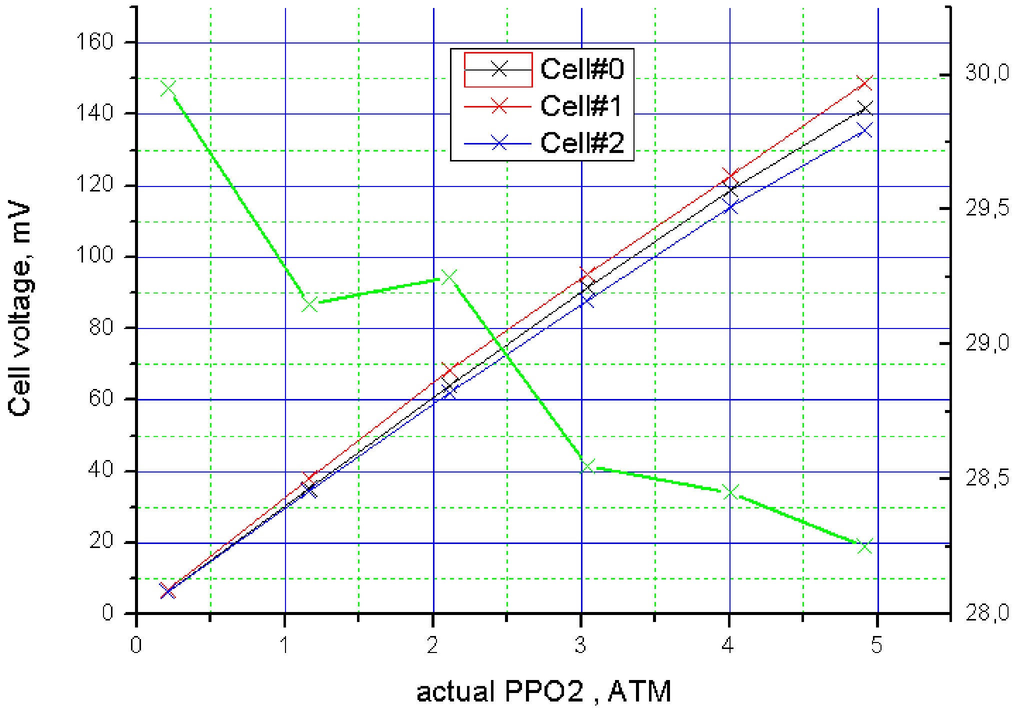

Figure 16: Oxygen cell output voltage after 7 hours of total exposure to pure CO2 versus actual PPO2 and corresponding cell temperature (green)

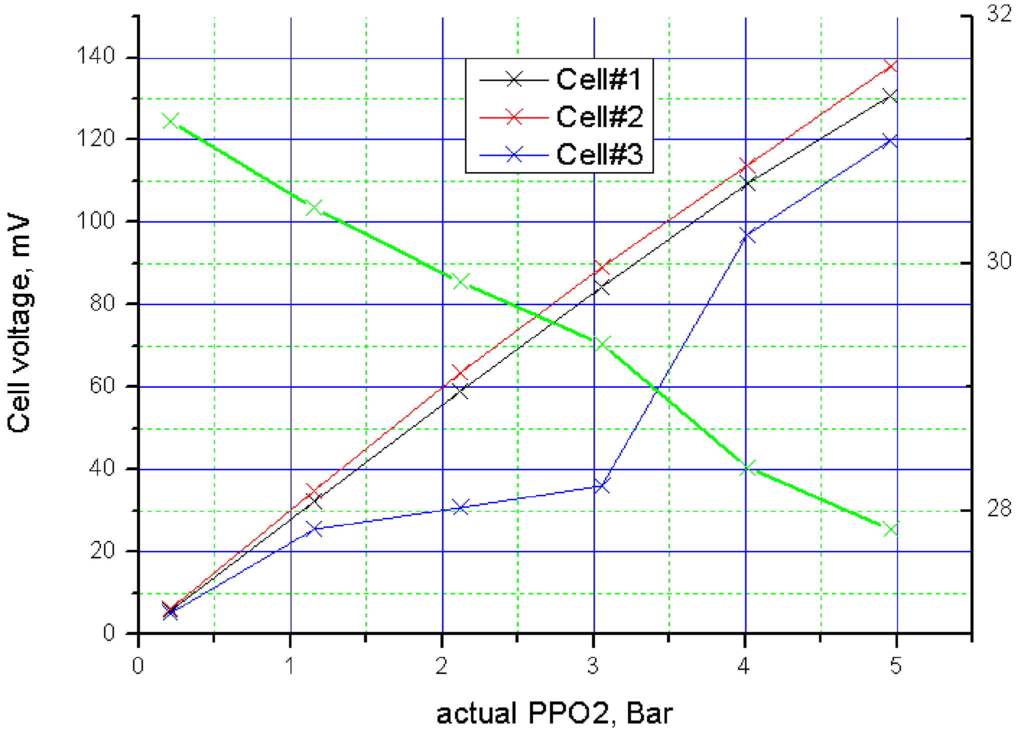

Figure 17: Oxygen cell output voltage after 13 hours of total exposure to pure CO2 versus actual PPO2 and corresponding cell temperature (green)

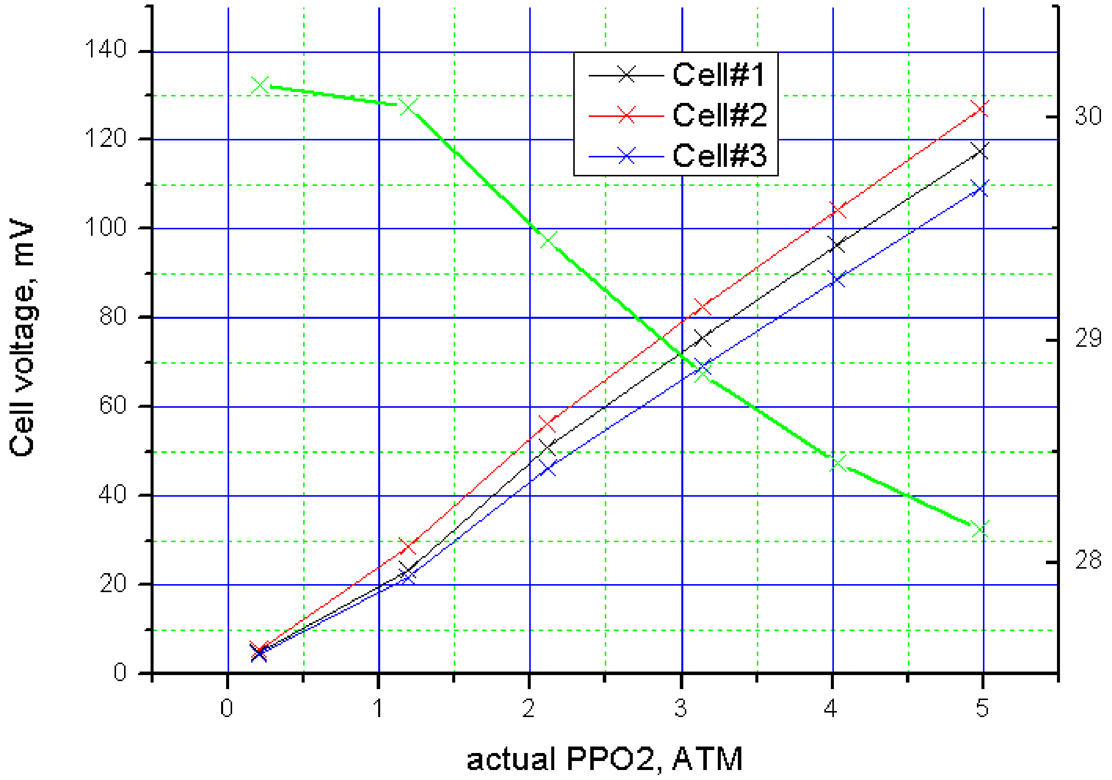

Figure 18: Oxygen cell output voltage after 21 hours of total exposure to pure CO2 versus actual PPO2 and corresponding cell temperature (green)

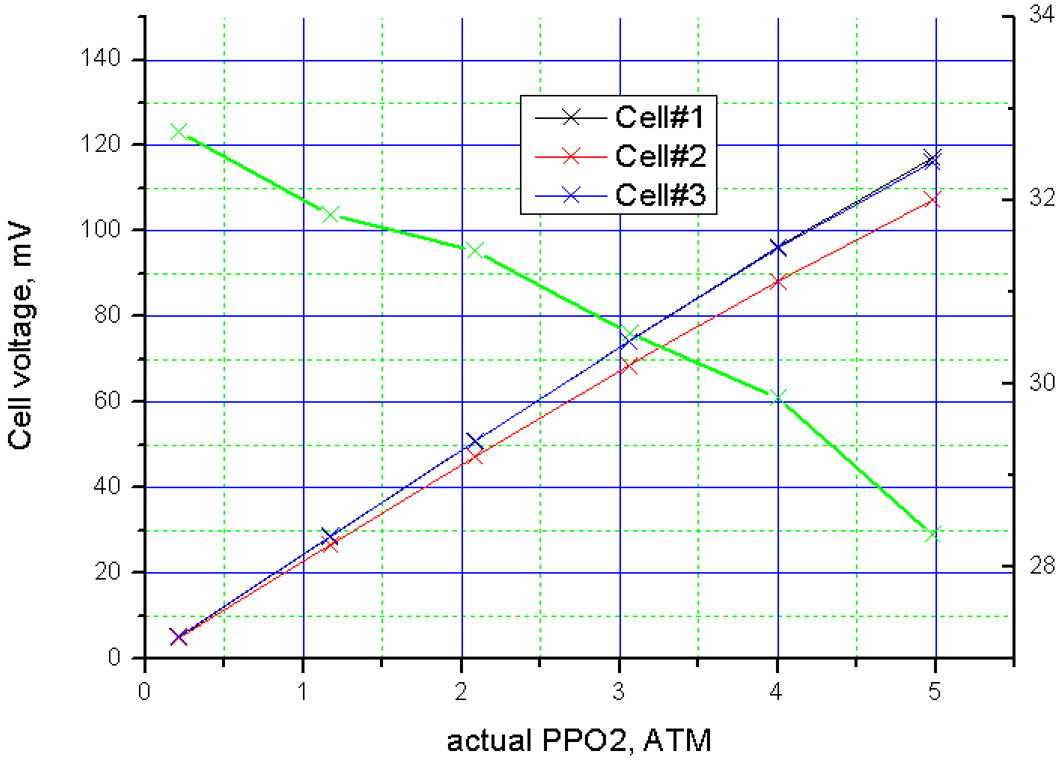

Figure 19: Oxygen cell output voltage after 37 hours of total exposure to pure CO2 versus actual PPO2 and corresponding cell temperature (green)

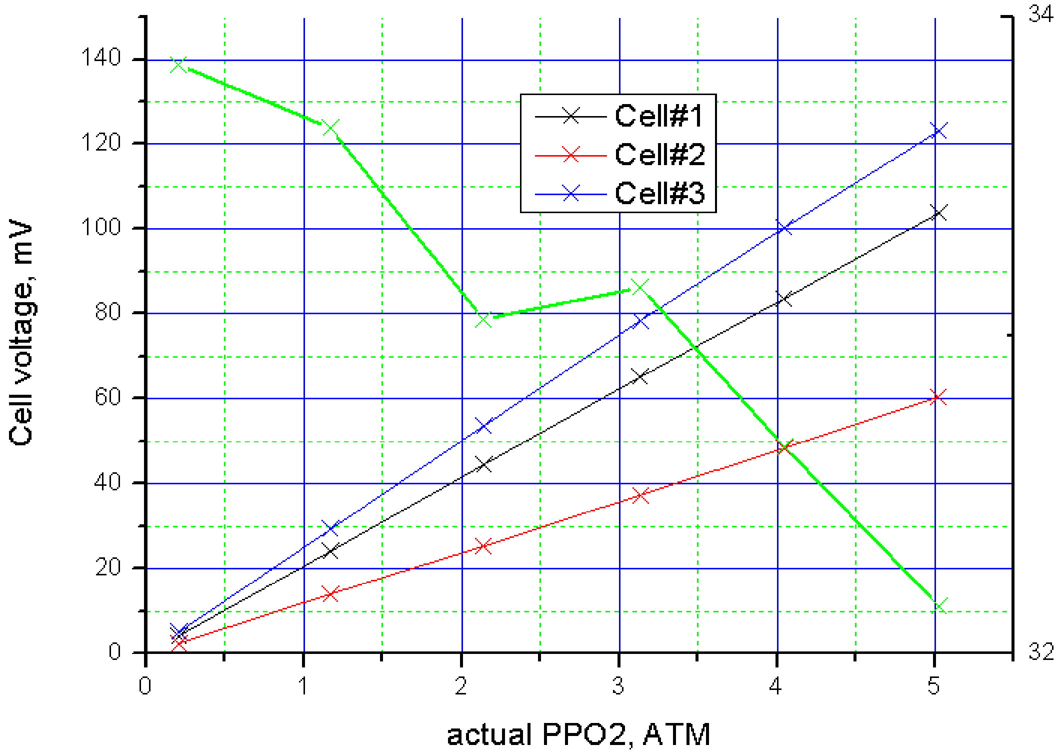

Figure 20: Oxygen cell output voltage after 61 hours of total exposure to pure CO2 versus actual PPO2 and corresponding cell temperature (green

8 Cell Recovery after Exposure to Pure CO2

Cell voltages during recovery in the atmosphere after exposure to pure CO2 are shown in the figures below.

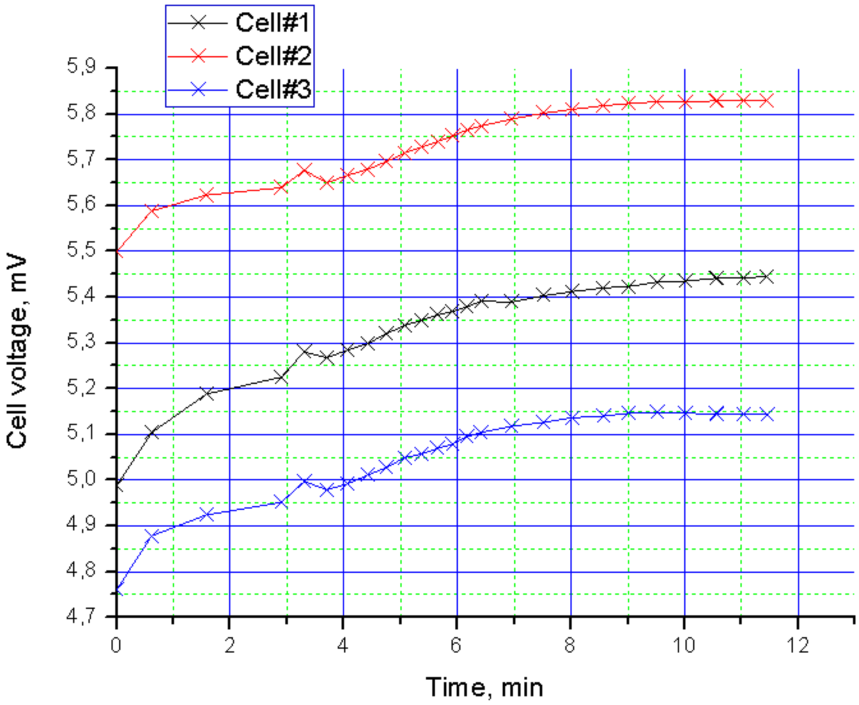

Figure 21: Oxygen cell output voltage (temperature corrected) during recovery in atmosphere after 1 hour of total exposure to pure CO2.

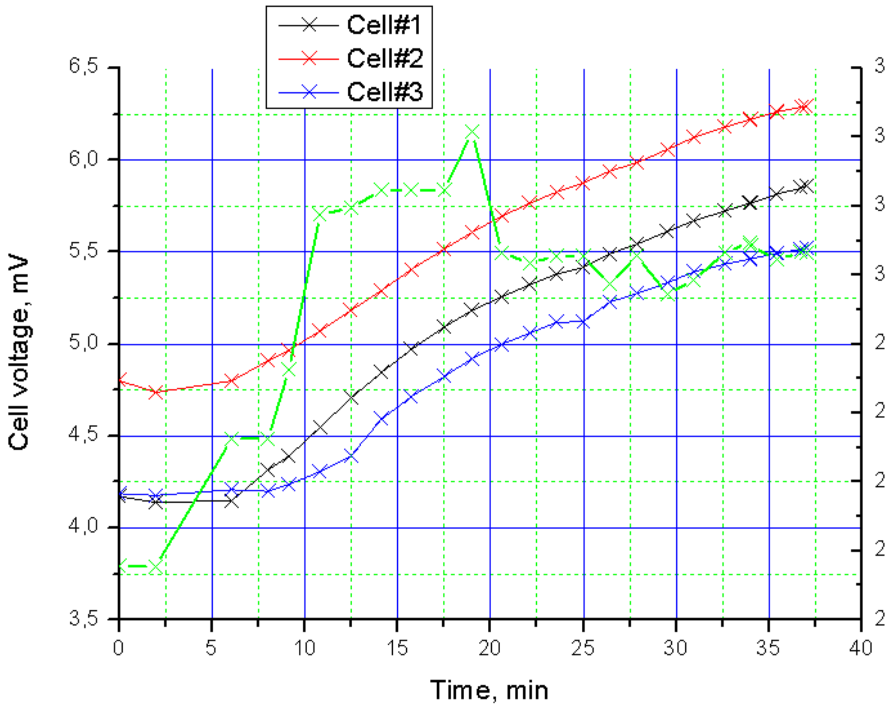

Figure 22: Oxygen cell output voltage during recovery in atmosphere after 3 hours of total exposure to pure CO2 and corresponding cell temperature (green)

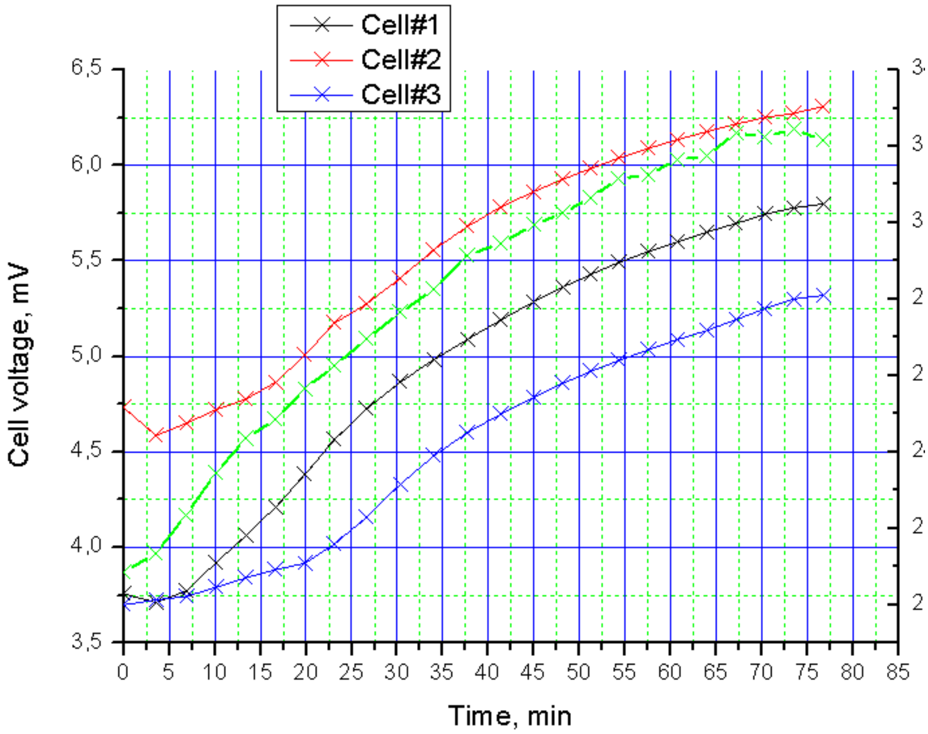

Figure 23 Oxygen cell output voltage during recovery in atmosphere after 13 hours of tot:al exposure to pure CO2 and corresponding cell temperature (green).

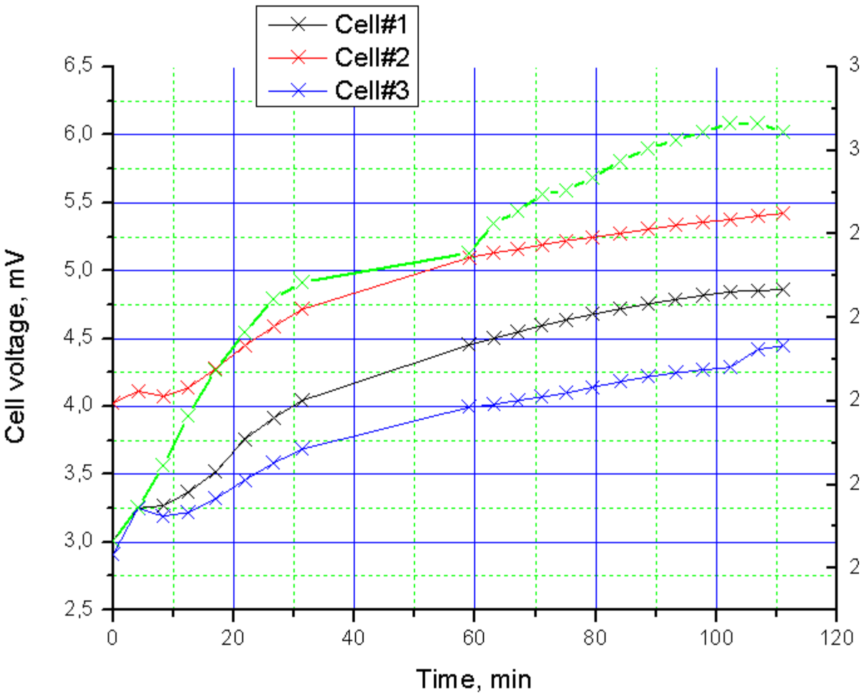

Figure 24 Oxygen cell output voltage during recovery in atmosphere after 21 hours of total exposure to pure CO2 and corresponding cell temperature (green).

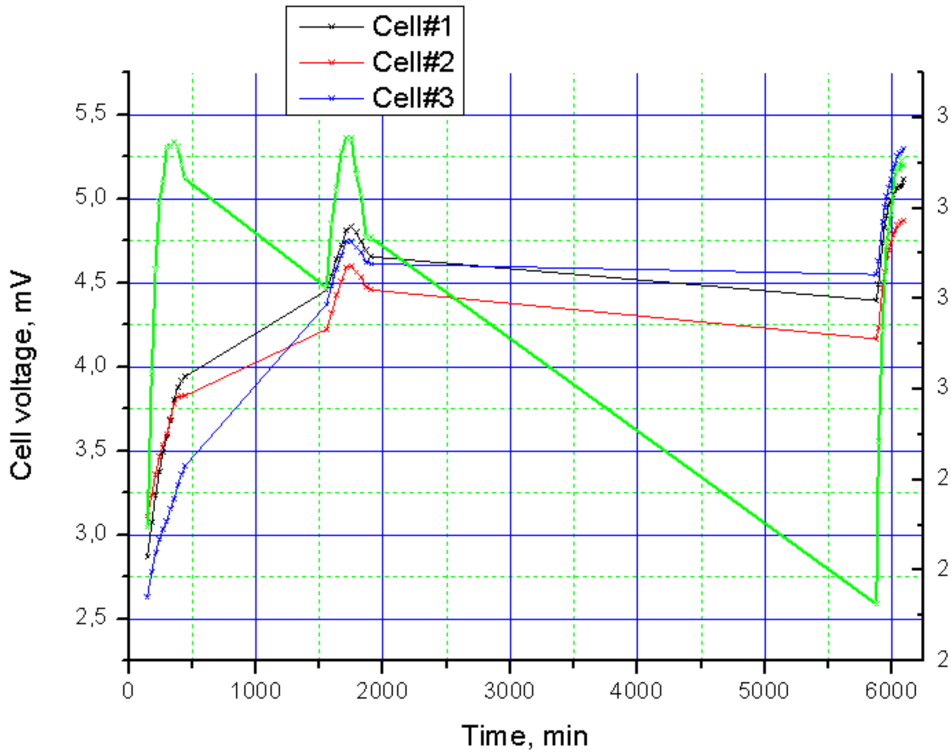

Figure 25 Oxygen cell output voltage during recovery in atmosphere after 37 hours of total exposure to pure CO2 and corresponding cell temperature (green). Straight lines are interpolation lines, covering the period the cell is exposed to CO2.

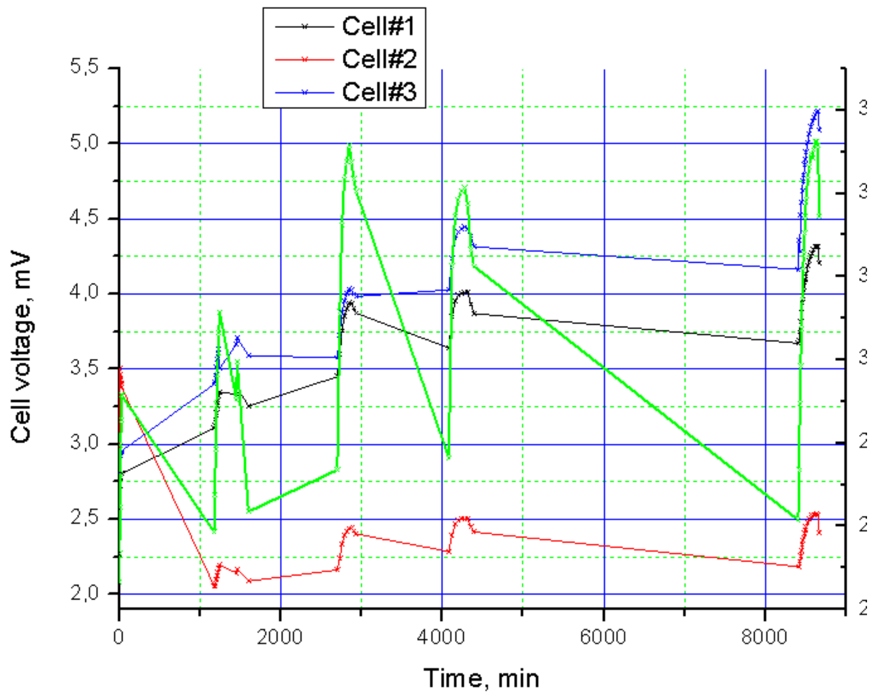

Figure 26 Oxygen cell output voltage during recovery in atmosphere after 61 hours of total exposure to pure CO2 and corresponding cell temperature (green). Straight lines are interpolation lines, covering the period the cell is exposed to CO2.

9 EFFECT OF LONG TERM EXPOSURE TO 8% CO2

Three cells were tested by exposure to 8% CO2 at one atmosphere pressure, for two months, and the output voltage monitored for a predefined PPO2.

To perform this experiment an Apocalypse Type IV Oxygen sensor pod fitted with three oxygen cells from cell batch N2, labeled Cells 4 to 6 (Figure 27), was placed in a 160mm diameter chamber (Figure 28). The pressure, cell voltages and temperature were read over the USB interface. The USB interface also allowed the oxygen pod to be switched on and off. A fan in the chamber was switched on during data logging to ensure there was adequate gas mixing and an even temperature within the chamber.

Figure 27: O2 cell bath N2 in the pod, cell retainer removed to provide unobstructed view of the oxygen cells.

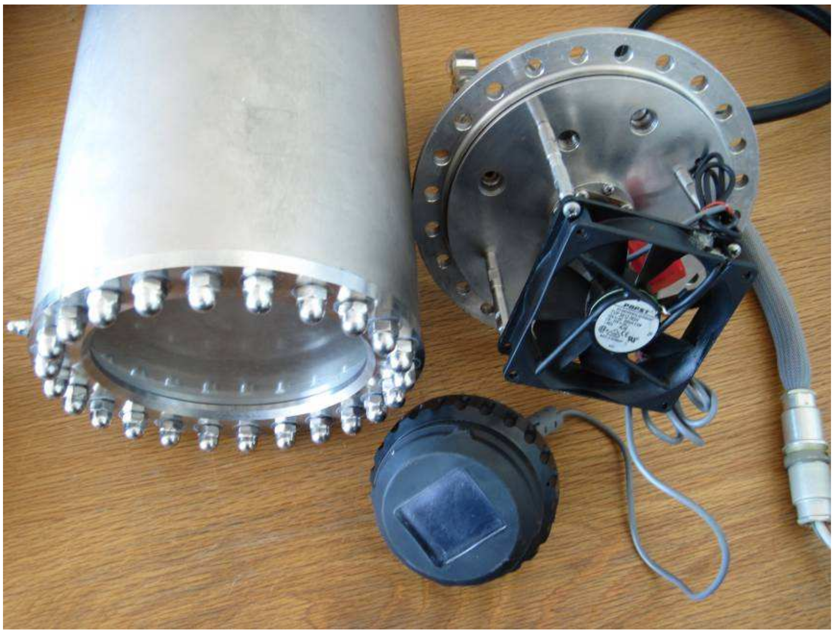

Figure 28: The test fixture used to study the effect of long term 8% CO2 exposure on cell voltages.

The air in the chamber was pressurised with pure CO2 from 1.008 bar to 1.098bar. The chamber pressure was the equalised to atmospheric pressure. This provided a F(CO2) in the chamber of 8.22% at atmospheric pressure.

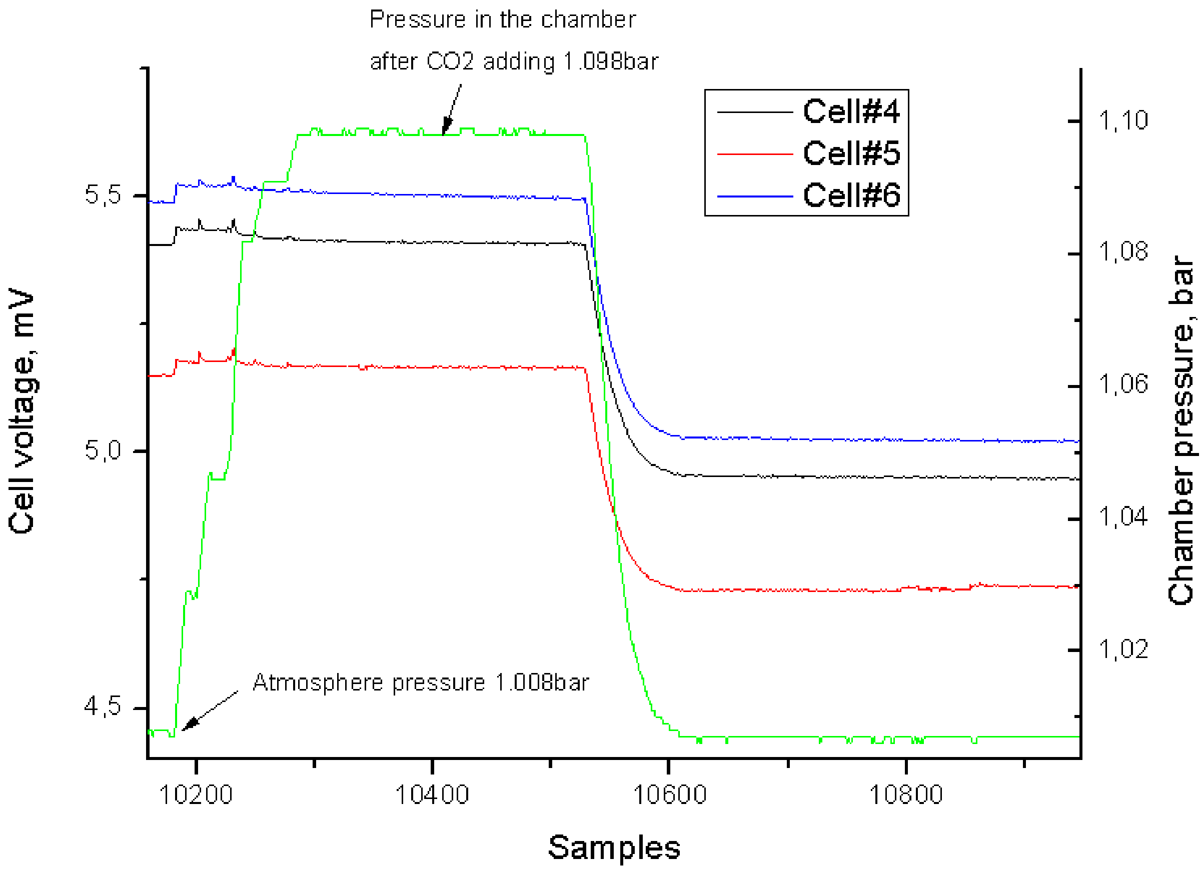

Figure 29: Cell outputs during the process in which a 8.22% CO2 mixture was created, by adding pure CO2 and then equalizing to atmospheric pressure. Y axis shows the cell voltages after temperature compensation in mV, and pressure in bar (green curve). The X axis shows time in seconds. The temperature was 29C.

The O2 pod was switched on once a day. Its temperature increased slightly during the period of observation because of power consumption. The data was logged until the temperature indicated 29.05C and the data was read with PC. The cell voltages (temperature compensated and uncompensated) are tabulated in Table 2 for the two month period of the test. The data is tabulated for the same temperature 29.05C to eliminate any temperature dependence.

The pressure in the chamber steadily decreased during the period of test from 1.006 bar to 0.973 bar (changing 3.3%). This is due to the gas consumption with O2 cells: the information provided by Teledyne on http://www.teledyne-ai.com/tsfaq/faq_sensors.asp#q9 with a capture date of 3rd March 2011 states that the cells can each consume 0.5cc of O2 per hour: in theory this would deplete the chamber of oxygen in a two month period – this was not observed, but there was a reduction in the oxygen as indicated by the pressure changes.

The fist row of the table is measurement data in air before the test. The last row of the table is measurement data in air after the test. The cells were two years old at the start of the test, to establish worst case conditions, and some droop is expected.

Measurement data changed during the two month test in 8% CO_2 is shown in Table 3. The fist row is measurement changing in the 8% CO_2 gas mixture. The second row is measurement changing in air (before and after test).

Table 2 Effect of 8% CO2 exposure on cell voltages.

Time, GMT	Chamber pressure, bar	Temperature compensated Cell#4 voltage, mV	Cell#4 voltage, mV	Temperature compensated Cell#5 voltage, mV	Cell#5 voltage, mV	Temperature compensated Cell#6 voltage , mV	Cell#6 voltage, mV	Temperature, C
07.02.11 13:41:58 In Air	1.006	5.37	5.846	5.107	5.56	5.471	5.956	29.05
07.02.11 14:08:41	1.006	4.948	5.46	4.74	5.231	5.021	5.541	29.05
08.02.11 11:32:39	1.003	4.88	5.355	4.678	5.133	4.986	5.472	29.05
14.02.11 12:59:13	0.998	4.622	5.081	4.531	4.981	4.886	5.372	29.05
15.02.11 11:15:49	0.998	4.585	5.038	4.513	4.959	4.884	5.367	29.05
16.02.11 10:55:33	0.998	4.553	5.026	4.501	4.969	4.875	5.381	29.05
17.02.11 12:17:44	0.997	4.530	4.990	4.476	4.930	4.857	5.350	29.05
18.02.11 11:59:50	0.997	4.498	4.954	4.455	4.907	4.853	5.345	29.05
21.02.11 11:45:21	0.994	4.365	4.804	4.397	4.840	4.819	5.305	29.05
22.02.11 10:59:13	0.994	4.332	4.766	4.381	4.821	4.813	5.295	29.05
24.02.11 10:19:00	0.993	4.286	4.718	4.358	4.797	4.810	5.295	29.05
25.02.11 10:10:53	0.993	4.257	4.678	4.337	4.766	4.843	5.322	29.05
28.02.11 11:49:32	0.991	4.285	4.702	4.300	4.718	4.822	5.291	29.05
01.03.11 12:46:15	0.991	4.265	4.692	4.304	4.735	4.814	5.298	29.05
02.03.11 11:56:44	0.990	4.263	4.678	4.293	4.711	4.811	5.279	29.05
03.03.11 11:50:27	0.990	4.254	4.673	4.287	4.709	4.829	5.305	29.05
04.03.11 08:39:47	0.976	4.032	4.418	4.027	4.413	4.532	4.966	29.05
09.03.11 10:58:47	0.986	4.222	4.637	4.209	4.623	4.782	5.252	29.05

10.03.11 12:25:32	0.986	4.210	4.642	4.199	4.630	4.757	5.245	29.05
11.03.11 12:40:51	0.985	4.204	4.625	4.187	4.606	4.746	5.221	29.05
14.03.11 10:52:32	0.984	4.206	4.623	4.191	4.606	4.724	5.193	29.05
15.03.11 13:31:18	0.984	4.238	4.675	4.184	4.616	4.715	5.202	29.05
16.03.11 10:32:19	0.983	4.225	4.642	4.175	4.587	4.709	5.174	29.05
17.03.11 13:56:47	0.982	4.246	4.656	4.155	4.556	4.703	5.157	29.05
21.03.11 11:35:42	0.981	4.264	4.706	4.156	4.587	4.681	5.167	29.05
22.03.11 12:24:15	0.980	4.245	4.666	4.141	4.551	4.670	5.133	29.05
23.03.11 12:15:37	0.974	4.136	4.497	4.018	4.368	4.557	4.954	29.05
24.03.11 11:43:52	0.980	4.277	4.697	4.149	4.556	4.668	5.126	29.05
25.03.11 12:55:29	0.980	4.302	4.716	4.165	4.566	4.702	5.155	29.05
28.03.11 11:19:40	0.979	4.315	4.733	4.158	4.561	4.662	5.114	29.05
29.03.11 11:45:36	0.976	4.307	4.721	4.140	4.537	4.633	5.078	29.05
30.03.11 09:19:45	0.976	4.316	4.735	4.132	4.532	4.619	5.066	29.05
31.03.11 12:59:20	0.975	4.312	4.735	4.119	4.523	4.612	5.064	29.05
01.04.11 10:44:11	0.975	4.306	4.733	4.124	4.532	4.608	5.064	29.05
04.04.11 10:47:50	0.973	4.295	4.716	4.152	4.559	4.588	5.038	29.05
05.04.11 12:14:00	0.973	4.310	4.759	4.146	4.578	4.582	5.059	29.05
06.04.11 10:44:40	0.973	4.312	4.752	4.146	4.568	4.585	5.052	29.05
07.04.11 09:39:06 In Air	0.996	4.963	5.412	4.672	5.095	5.197	5.667	29.05

It can be seen from the table above, there is no significant change of the cells voltages in air due to a two month exposure to 8% CO_2.

Table 3 Measurement data change during the two month test in 8% CO2.

Condition	Change in Pressure %	Change in Temperature compensated Cell#4 voltage %	Change in Cell#4 voltage %	Change in temperature compensated Cell#5 voltage %	Change in Cell#5 voltage %	Change in Temperature compensated Cell#6 voltage %	Change in Cell#6 voltage %	Change in Temperature %
In 8% CO2	-3.3	-12.8	-12.9	-12.5	-12.6	-8.7	-8.8	0
In Air (atmospheric change over the 2 months)	-0.99	-7.6	-7.4	-8.5	-8.4	-5	-4.9	0

10 LINEARITY FOLLOWING EXPOSURE TO 8% CO2

The linearity of the cells was checked following the 2 month exposure to 8% CO2 by putting them in to the 160mm chamber with air, pressurising with pure oxygen up to 6.35bar (chamber pressure) and then depressurising to atmospheric pressure.

Sample 4 and Sample 5 showed high linear output characteristics (Figure 30). Sample 6 was nonlinear if actual PPO2 was higher than 2 ATM: this is not unexpected as the cells were 30 months old at the time of the test.

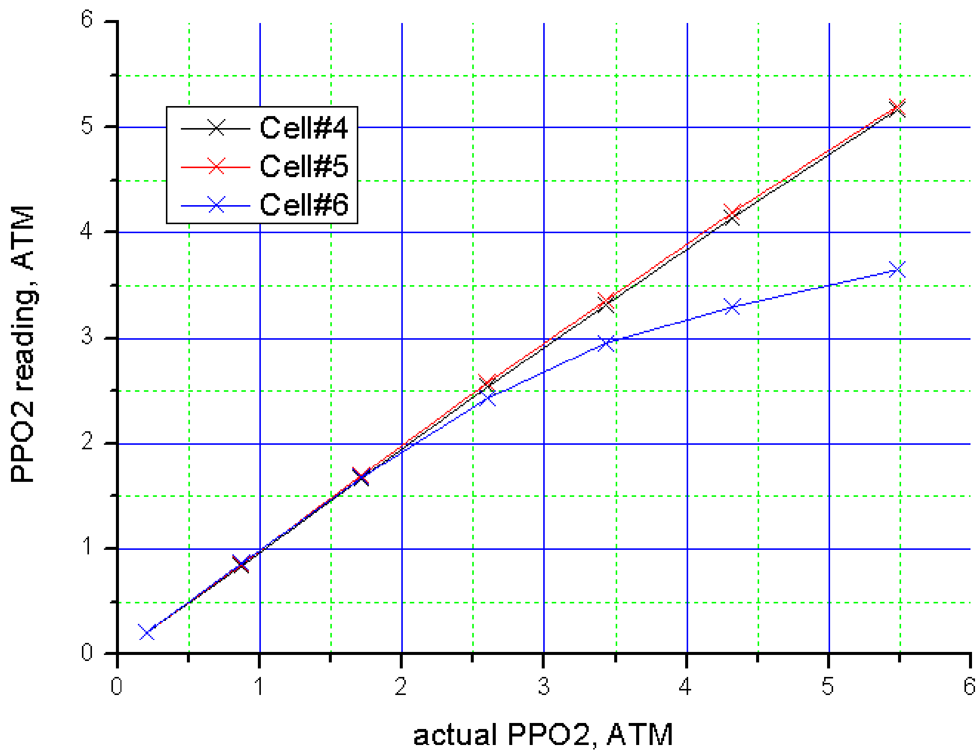

Figure 30 Linearity of cells after two month of exposure to 8% CO2

11 CONCLUSION

The PSR-11-39-DL oxygen cells tolerate high levels of CO2 exposure, far beyond that which could possibly occur during a dive.

Both the CO2 concentration and the exposure duration must be long for the cells to fail from CO2, and the cells recover after being exposed to air for a period of hours, or even days.

PPO2 linearity is not affected by storage in pure CO2 of up to 61 hours. Therefore, after a period of CO2 exposure, if the cells are calibrated then they can be expected to operate faithfully for the dive.

Each hour of exposure to pure CO2, is much worse than 20 hours in a rebreather where the cells are positioned upstream of the scrubber: low levels of CO2 were not observed to cause problems, but very high levels do: the tests were performed in pure CO2 (more than 99.99% CO2). The ratio of pure CO2 exposure to recovery time indicates that the critical CO2 concentration, where the Potassium Carbonate is generated at a faster rate than can be absorbed by the electrolyte at room temperature, is around 30% SEV CO2.

The output voltage of the cell for a given PPO2, decreases after storage in CO2. This output voltage recovers in time: the recovery period in air depends on the duration of the exposure to CO2 and the CO2 concentration: it varies form 10 minutes for a one hour exposure to pure CO2, up to several days after a 24 hour CO2 exposure.

12 REFERENCES

1. Deep Life Rebreather Galvanic Oxygen Sensor Procurement Specification. ES_OROxygenSensor_090803.pdf
2. What happens when a Teledyne sensor such B1.B2.B3 or C3 is exposed to high percentage levels of CO2? http://www.teledyne-ai.com/tsfaq/faq_sensors.asp#q18