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OXYGEN MONITORING CELLS AT FERMILAB

Jay C. Theilacker
Fermi National Accelerator Laboratory*,
P.O. Box 500, Batavia, IL, 60510, USA
(630) 840-3238, Theilacker@fnal.gov

ABSTRACT

Questions have been raised about the accuracy of oxygen monitoring for personnel safety around systems containing gases with a molecular weight less than nitrogen. A study has been performed to test the accuracy of the oxygen monitoring devices used at Fermilab. Portable and fixed oxygen monitoring equipment is used throughout Fermilab for personnel safety in defined oxygen deficiency hazard (ODH) areas. The results are presented as well as corrective measures taken to ensure accuracy and maintain the proper level of personnel safety.

INTRODUCTION

A tunnel spill test at Jefferson Lab in 2001 uncovered an oxygen monitor response issue with certain oxygen cells. Following the spill test, Jefferson Lab personnel analyzed the data and suspected the oxygen monitors to be reading falsely high. As a result, they performed controlled tests on various oxygen monitoring cells used at Jefferson Lab to verify the performance [1].

It was found that some O_2 cells were sensitive to the carrier gas (non O_2 components). The cells over predicted the O_2 concentration when the carrier gas contains gas of a molecular weight lighter than nitrogen. This effect was not widely known to the users of the cell within our industry, although it is described in the manufacturer's data sheets. The data sheets describe this carrier gas effect and characterizes it by molecular weight (M) as:

$$O_{2\,Actual} = O_{2\,\mathrm{Re}\,sponse}\sqrt{\frac{M_{carrier}}{M_{nitrogen}}} \qquad (1)$$

Jefferson Lab's findings suggested that the effect is stronger than the square root. Their findings were distributed to various physics labs throughout the world to notify them of a potential problem and to ask for any additional information on the subject. This paper describes the tests performed to understand the performance of the oxygen monitoring systems used at Fermilab.

1 TEST SETUP

A test chamber was constructed to test the various oxygen cells used at Fermilab. The chamber is shown schematically in FIGURE 1. The chamber consists of a 4' long section of 3" pipe with a pipe cap welded on one end. A boss was welded into the pipe cap in order to inject the gas mixture. The electrical cables from the oxygen cells and a sampling tube for the reference instrument exited the opposite end of the chamber. The open end of the chamber was loosely bagged in order to minimize any back diffusion of air into the chamber.

Air and diluting gas sources were connected to the chamber through a flow meter and manual throttling valve. Dilution gases tested include helium, nitrogen, argon, R22 and sulfur hexafluoride. Oxygen monitoring systems are used in various locations around Fermilab to protect against releases of these gases. The flow meters were used to make relatively uniform changes in oxygen concentration, not to calculate the precise value.

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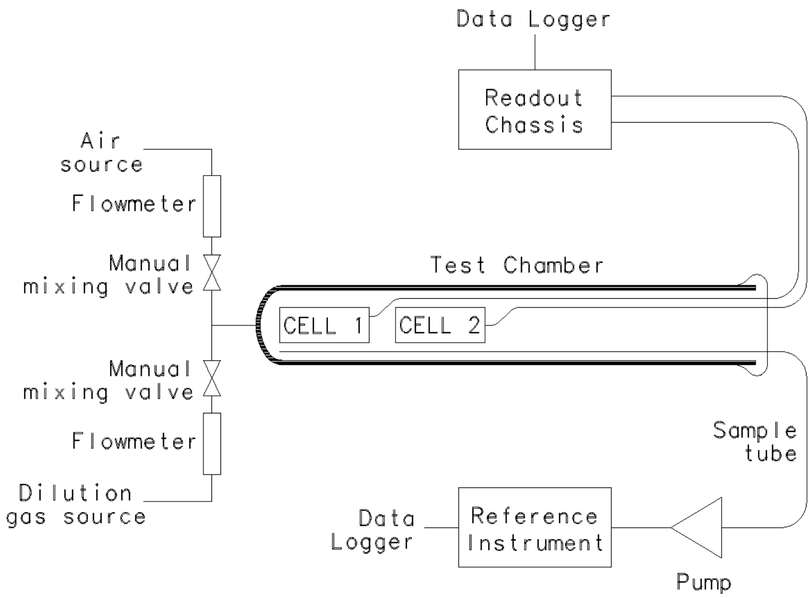

Figure 1: Schematic representation of the oxygen cell test chamber

An Illinois Instruments Model 810 oxygen analyzer was used as the absolute reference. A pump was used to draw sample gas from the test chamber and to pressurize it to levels required by the reference instrument.

The reference instrument was calibrated prior to data taking. Calibration gas, including O_2 in helium, was used to verify the accuracy of the Illinois Instruments Model 810 and to ensure that it did not suffer from the same carrier gas effect.

The electrical output from the reference instrument and two test cells were connected to the Fermilab accelerator ACNET controls system for data logging purposes. Data was logged at a 30 second interval.

2 RESULTS

The fixed oxygen monitors used at Fermilab are based on a CiTiceL 6C or CiTiceL 7OX cell manufactured by City Technology Limited. The personal oxygen monitor maintained by the ES&H Section is manufactured by Lumidor Safety Products. It utilizes a Microsensor OS-4L/2W/11MV cell manufactured by Seatronics Co. Inc. Other personal oxygen, or multigas monitors, used at the laboratory are the T80 and TMX412 manufactured by Industrial Scientific Corporation. They utilize a CiTiceL 4C and CiTiceL C/2 cell manufactured by City Technology Limited, respectively. All of the CiTiceL cells mentioned above are of the capillary design. The Seatronics cell is of a full diffusion barrier design.

A series of tests were performed on the CiTiceL 6C and CiTiceL 7OX O_2 cells used in the fixed O_2 monitors. An example is shown in Figure 2. Data was taken by setting the air flow to a fixed value. The dilution gas flow was then stepped up about every fifteen minutes from zero to a maximum value. In order to check for hysteresis, the dilution gas flow was then stepped back down to zero. Tests were initially performed with helium, nitrogen and argon as the dilution gas. This enabled us to investigate the carrier gas effect with a gas lighter, equal to and heavier than the reference gas. Tests were also performed with a large step change in oxygen concentration using each of the dilution gases.

It was verified that the CiTiceL 6C and 7OX O_2 cells do have a carrier gas effect and it is a stronger effect than square root. For helium dilution of air, the monitors over predicted the oxygen content by a sizable amount. When air was diluted with argon, the monitors under predicted the oxygen content. Interestingly, the monitors also under predicted the oxygen content when air was diluted with nitrogen. This is the reference carrier gas for which other gases are to be scaled. It should have responded correctly under these conditions.

An interesting characteristic appeared in the helium dilution data when viewed over a shorter time frame. The CiTiceL sensors initially responded to a change by the proper amount, but then deviated to its steady-state value over several minutes. It appears that it takes time to diffuse the new mixture of carrier gas into the boundary layer and/or capillaries of the cell surface. The oxygen concentration change is detected much quicker. We did not measure the response time of the cells due to the uncertainty of the response time of our reference device and the relatively long data logging rate.

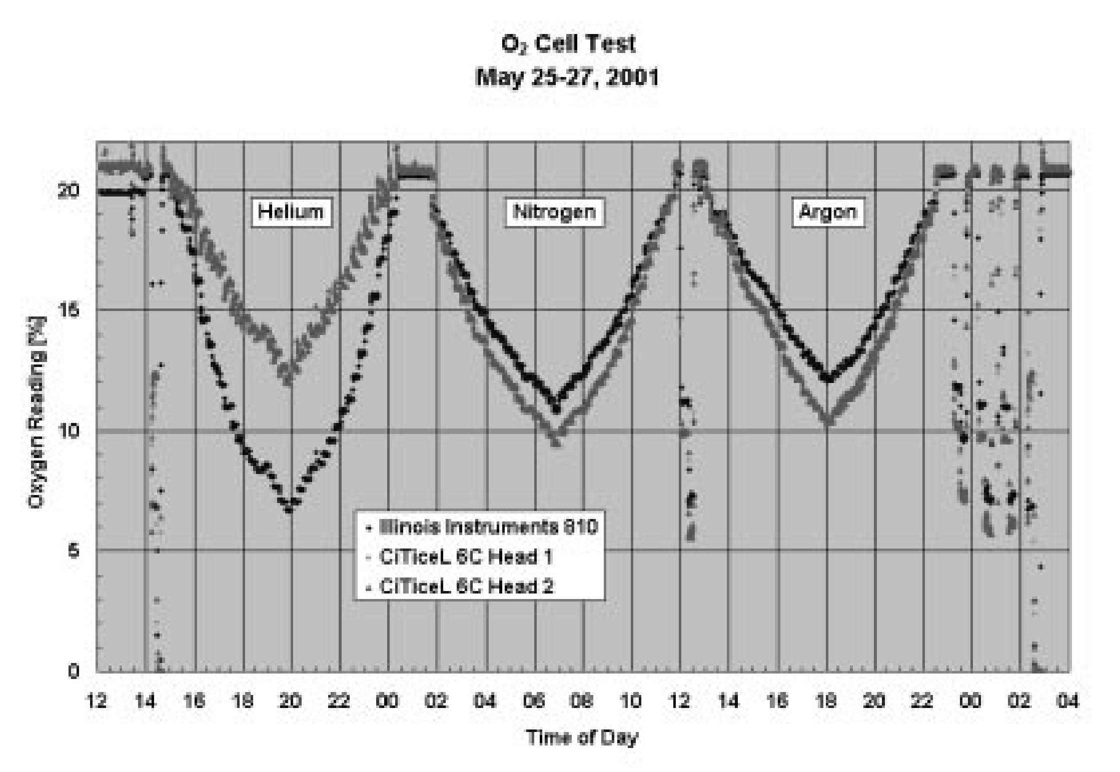

Figure 2: Fixed monitor response to dilution of air by helium, nitrogen and argon

This effect is apparent in Figure 3. When we were stepping down the oxygen concentration, the initial change in response of the CiTiceL head was correct. The response then slowly approached a higher value. Conversely, when the oxygen concentration was increased, the CiTiceL head incrementally responded correctly to a higher value and then slowly decreased to a lower steady state value.

Figure 4 is a detailed view of one large step change, clearly showing this effect. Again, each data point represents 30 seconds. The CiTiceL heads initially responded identically to the reference device and then increased to its steady state value over about three minutes. The Figure also shows that the heads read correctly at zero oxygen concentration (100% helium). When stepping from zero oxygen concentration (100% helium) to 21 % oxygen in standard air, the heads initially greatly over responded and then settled down to 21% over about five minutes. This over response is due to the initial saturation of the boundary layer with helium, allowing oxygen to reach the head at a higher rate. As nitrogen diffuses into the boundary layer, the response approaches 21%.

The Lumidor Safety Products personal O_2 monitor was also tested by mixing air and helium. The units used at the lab have Seatronics O_2 cells installed. To within the accuracy of the device readout (0.5% increments), it was found to not be sensitive to the same carrier gas effect as shown in Figure 5. Since these are hand-held devices, data logging of the response was not possible.

Similar testing showed that the Industrial Scientific Instruments TMX 412 and T80 personal O_2 monitors have the same carrier gas effect as the CiTiceL 6C. Preliminary data suggests that the CiTiceL 7OX, used in CDF and D0, also have the same carrier gas effect.

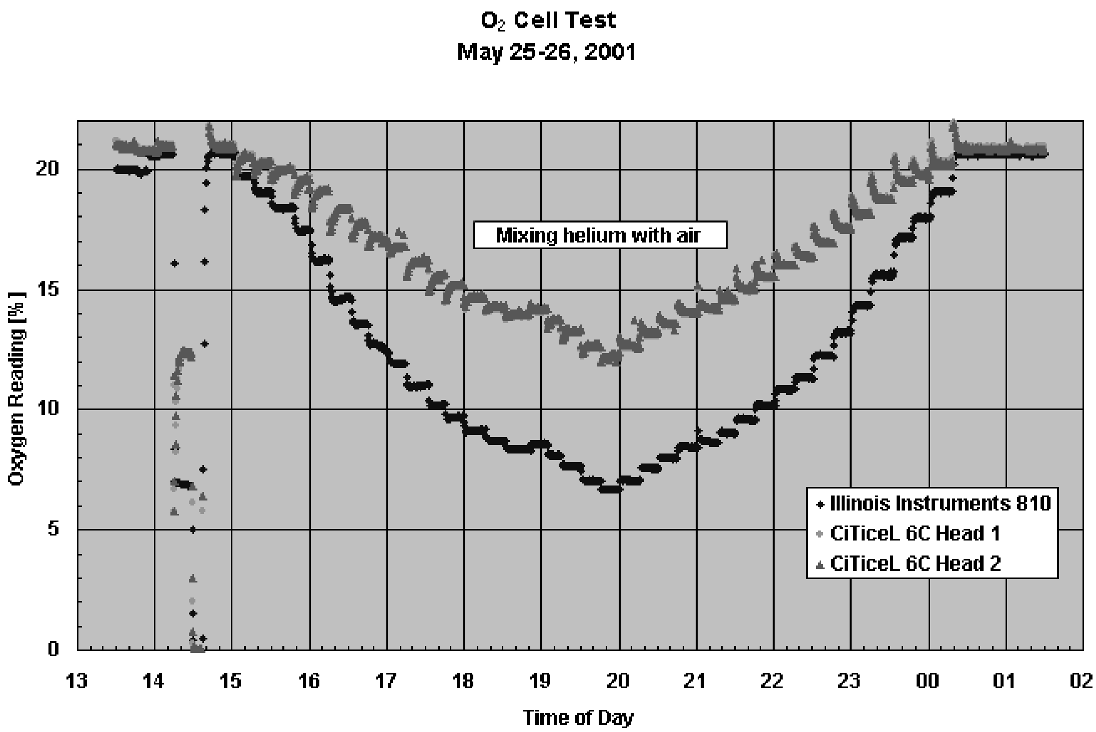

Figure 3: Fixed monitor response to helium dilution of air

The fixed monitors used at Fermilab are set to alarm at 18% oxygen concentration. Figure 6 shows that when helium dilutes air, the actual oxygen concentration at this alarm point would be about 14%. Even if the alarm set points were reset to 19.5%, the actual response with helium dilution would be about 17%. Clearly a different solution was required.

Since it was found that the Seatronics cell used in the portable monitor responded correctly with helium dilution of air, the cell electrical characteristics were investigated for possible application in the fixed monitors. It was found to be a direct electrical replacement. The only modification necessary was associated with the mechanical mounting of the cell. Several fixed monitors were modified to use the Seatronics cells. One was inserted into our test chamber for analysis. The results are shown in Figure 7. For comparison purposes, a CiTiceL 6C cell was tested at the same time.

The Figure shows that the Seatronics based fixed oxygen monitor followed the reference device very closely. Tests were repeated for nitrogen and argon, which were also found to also follow the reference device. We were confident that we had found a viable replacement for our fixed oxygen monitors, as long as there were no long-term drifting effects that would compromise reliability.

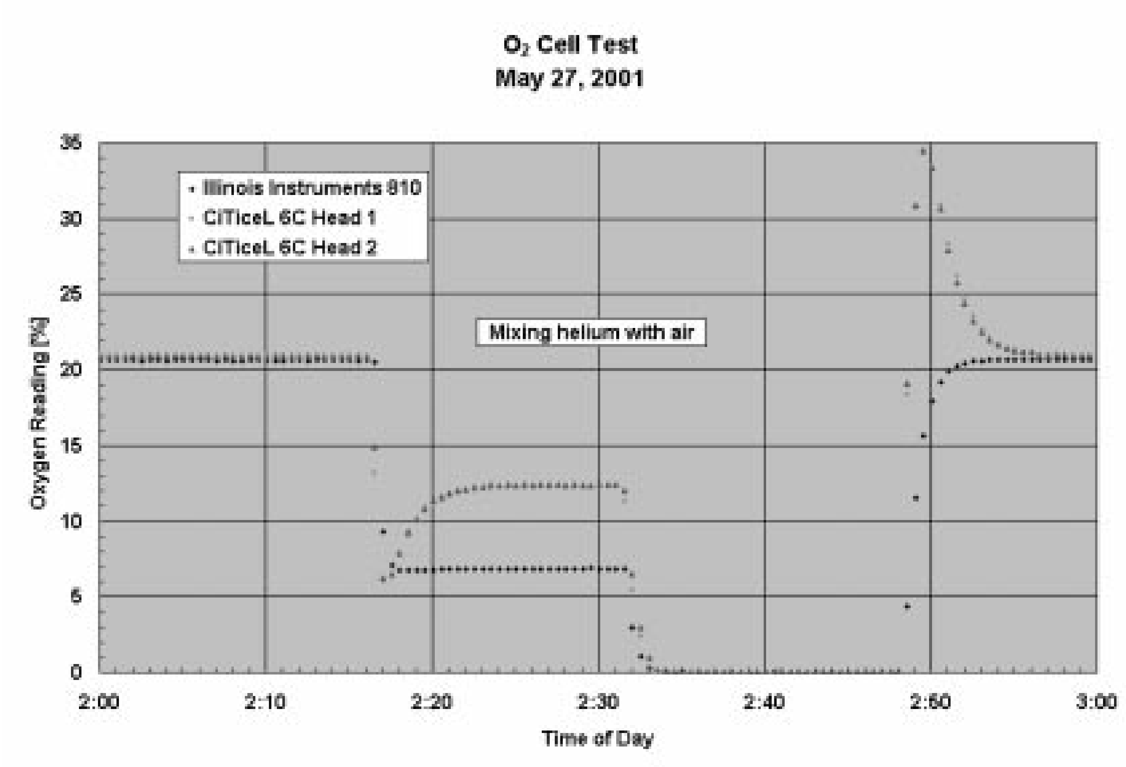

Figure 4: Fixed monitor response to a large step change in helium dilution of air.

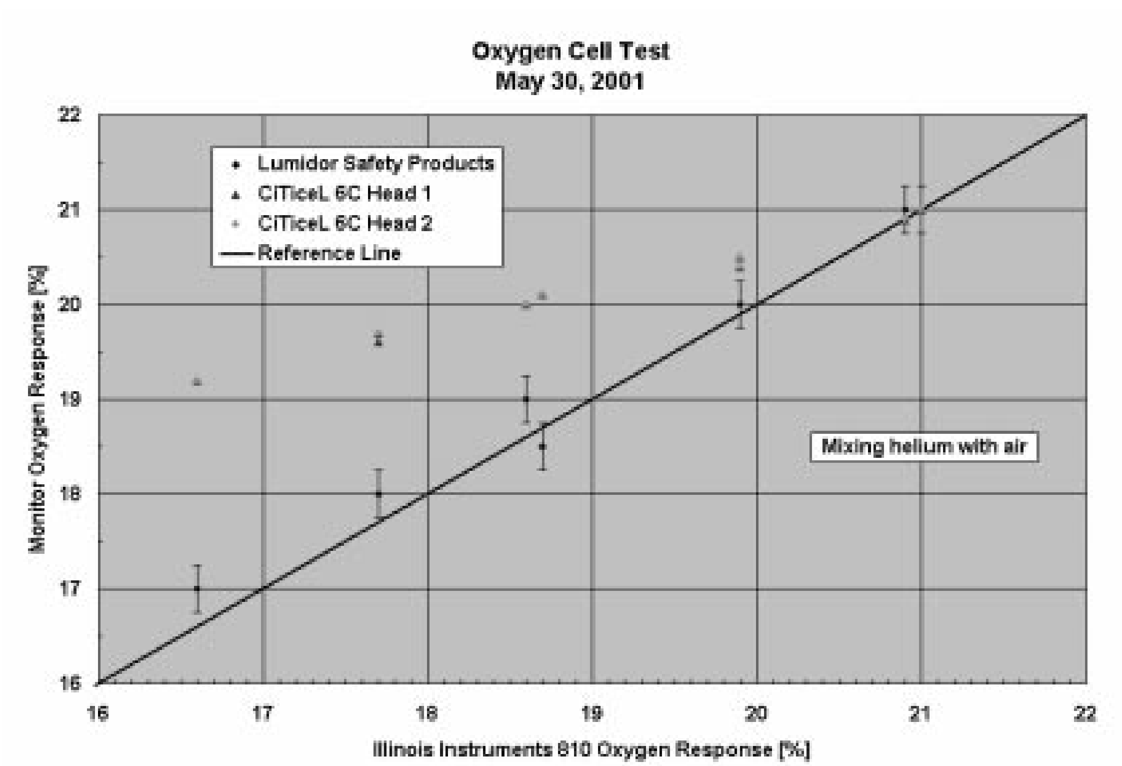

Figure 5: Fixed and portable monitor response to helium dilution of air

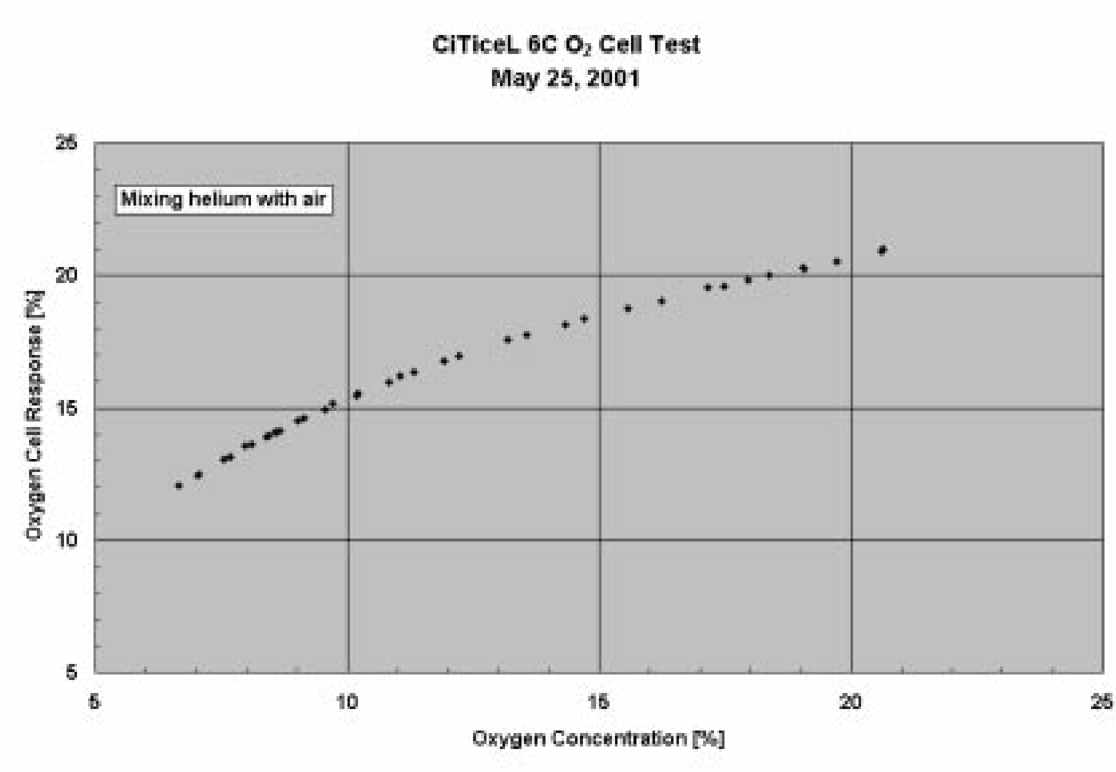

Figure 6: Fixed monitor response when diluting air with helium

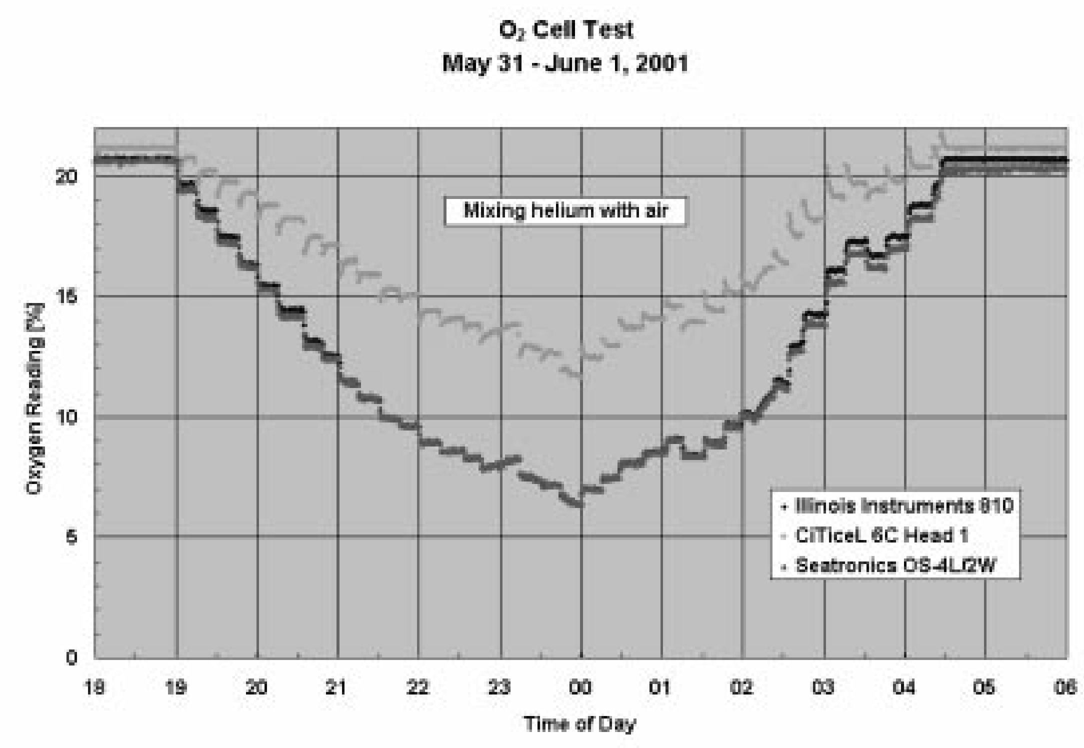

Figure 7: Fixed monitor response using different cells when diluting air with helium

In order to validate the long-term reliability of a Seatronics based fixed oxygen monitor, two modified heads were installed in a Tevatron satellite refrigerator. Temperature and humidity sensors were added near the cells to compliment an atmospheric pressure transducer which already existed. All devices were data logged in the ACNET controls system at a 30 second time interval.

The atmospheric conditions at the cells were logged in order to calculate the expected fluctuations in an uncorrected partial pressure sensing device. Figure 8 shows over two weeks of data for the two cells as well as the standard CiTiceL 6C cell. Also included is the theoretical response of a partial pressure device assuming it was calibrated in a standard atmosphere (dry air at 15°C and 101.325 kPa).

The two Seatronics based fixed monitors exhibited periodic noise from adjacent high frequency equipment. The underlying trend of these devices closely followed the trend of the theoretical curve. The offset between the theoretical curve and cell readings was due to the cells not being initially calibrated at standard atmospheric conditions.

Figure 8 also shows that the variation in response of the CiTiceL based monitor tended to be less, peak-to-peak, and out of phase with the Seatronics based monitors and partial pressure theory. This is due, in part, to temperature compensation built into the CiTiceL sensor.

Long-term testing showed that the Seatronics heads drifted over several months. This is not an issue within our portable monitors, since procedure calls for checking and setting the device to 21% prior to use in an ODH area. For our fixed monitors, for which there are over 200 installed, this drifting becomes a considerable labor intensive task which is deemed unacceptable. As a result, alternative cells are being investigated which will give a proper response with the various gases and cryogens used at Fermilab without long-term drifting.

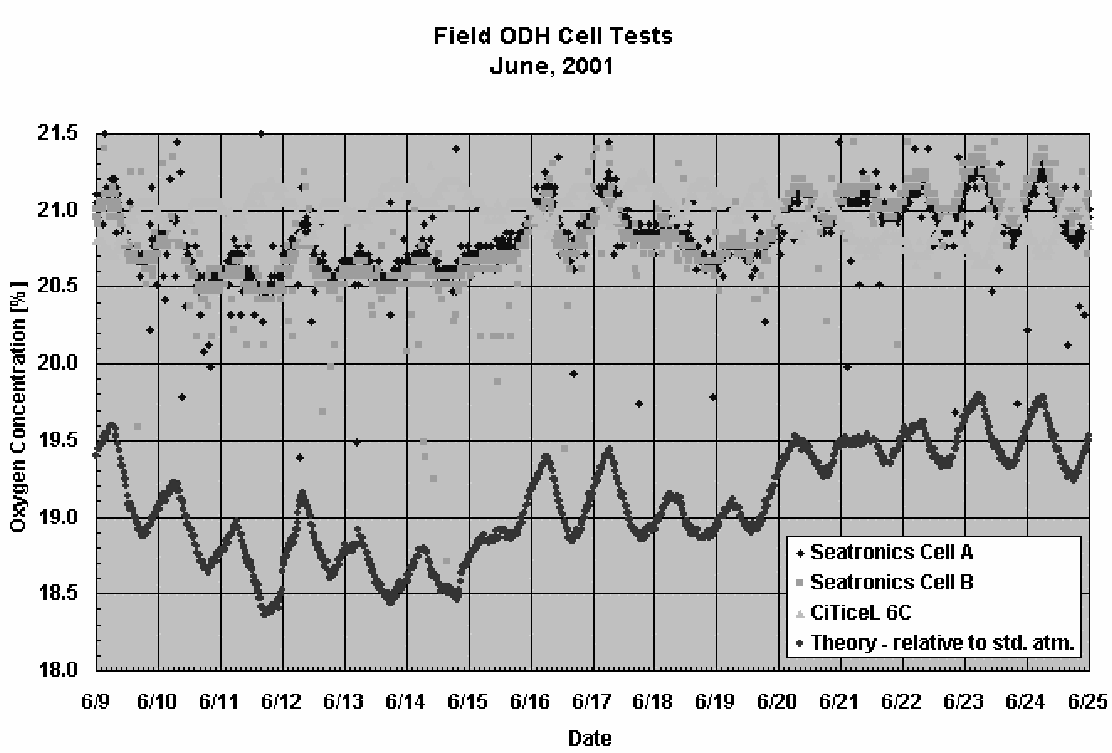

Figure 8: Fixed monitor response to atmospheric conditions in a field test

An automotive grade oxygen cell, CiTiceL AO2, was tested in hopes of achieving a long-term stability. The cell performed well in all previously tested background gases, but exhibited the same drifting after several months.

CONCLUSIONS

The oxygen monitoring cells used at Fermilab have been tested for proper response with various potential background gases used at the laboratory. The cells used within the fixed oxygen monitor systems were found to be sensitive to the background gas. Helium as a background gas resulted in an over prediction of oxygen concentration, a situation which is unacceptable for life safety systems.

Alternative cells were tested that exhibited a proper response with the possible background gases found at Fermilab. The electrical characteristics of the cell as well as their physical size proved to be a relatively easy modification to the existing cell enclosures. Long-term drift of the cells still remains an open issue which needs to be addressed. Alternative cells will be tested as they become available. The goal is to achieve a two year minimum lifetime without the requirement of recalibration due to long-term drifting.

ACKNOWLEDGEMENTS

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