Separating and Reattaching Microbial Fuel Cells on Sediment Bottom

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***Abstract*—Experimental data is presented demonstrating how microbial fuel cells (MFC's) could survive temporary (60 min) sediment separation and reattachment without any adverse effects from oxygen exposure. Mud-enclosed anodes, housed in open bottom chambers, were detached or "unplugged" from the sediment with no change in their open circuit voltage levels. For reattaching MFC devices on the sediment, oxygen content that could be inadvertently trapped or ingested by the MFC platform was shown to be consumed within 1 day using a 1% mud/seawater solution.**

***Index Terms*—microbial fuel cell, anodes, oxygen exposure**

I. Introduction

Sediment or Benthic Microbial Fuel Cells have received much attention in the last decade as a renewable maritime energy source that can power ocean sensors[1-3]. Typically buried inches deep within the bacteria-rich sediment (see Fig. 1), MFC's generate power by creating a natural electrical circuit between:

1) In-sediment anodes that capture electrons liberated via microbial breakdown of organic nutrients
2) Electrical load (e.g. sensor or battery)
3) Seawater exposed cathodes that reject the electrons to dissolved oxygen content

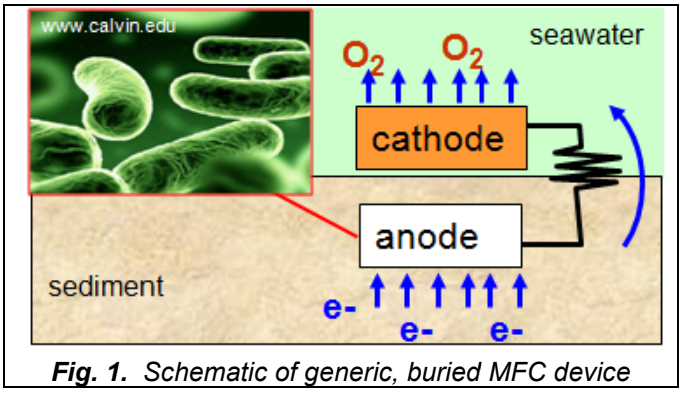

***Fig. 1.** Schematic of generic, buried MFC device*

Burying the MFC platform in sediment provides a natural bifurcation between the anaerobic sediment and oxygen-rich seawater to yield an open-circuit voltage potential of about 0.7 volts. An MFC device designed to be permanently buried could be readily integrated with fixed, bottom mounted sensor applications.

However, could MFC's be designed to separate or "unplug" temporarily (10-15 min) from the anaerobic sediment and then intake or ingest oxygen/sediment nutrient mix after resettling on the bottom (see Fig 2)?

If oxygen averse anodes could be protected from exposure to dissolved oxygen content when a) separating from the sediment and b) ingesting sediment nutrients upon resettling, then an MFC device could potentially charge a bottom resting, pop-up sensor platform that conducts water column measurements.

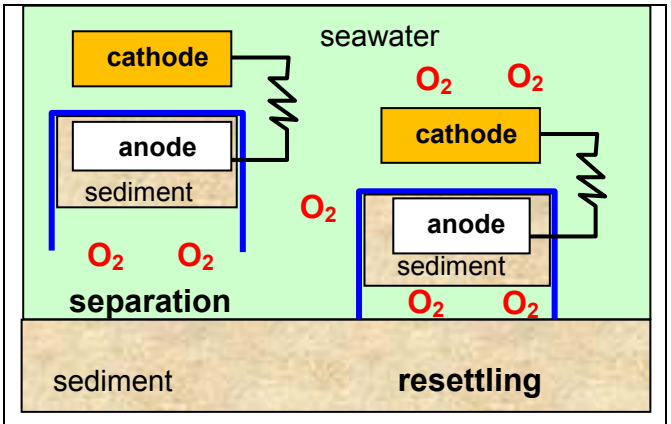

***Fig. 2.** This research evaluated (left) how mud-covered anodes could survive temporary separation from sediment without O_2 poisoning and (right) how O_2 content trapped during MFC resettling could be consumed via mud exposure.*

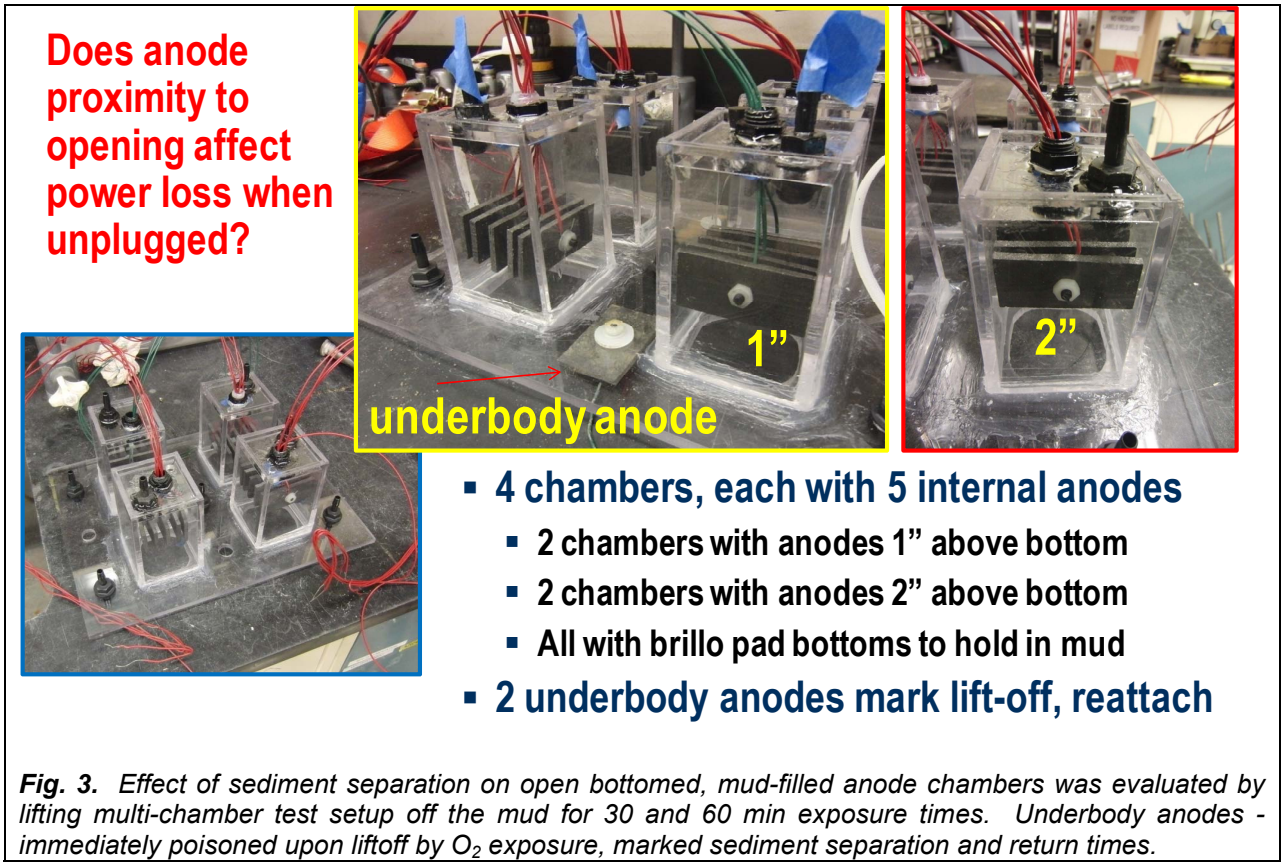

Fig. 3. *Effect of sediment separation on open bottomed, mud-filled anode chambers was evaluated by lifting multi-chamber test setup off the mud for 30 and 60 min exposure times. Underbody anodes - immediately poisoned upon liftoff by O_2 exposure, marked sediment separation and return times.*

To enable MFC charged devices that could separate from and then return to the sediment, SPAWAR System Center Pacific (SSC Pac) evaluated how mud-coated anodes could be unplugged from the sediment for 30 to 60 min without adverse oxygen contamination and how the oxygen content of seawater could be removed or “detoxed” with a simple mixing of 1 – 2% mud content.

Mud filled, open-bottomed chambers were previously demonstrated (2012) by the authors to allow for slow pumping (intake) of sediment nutrients into the above-sediment anode chamber to double the power output of buried control anodes[4]. This prior demonstration of mud filled anode chambers did not evaluate how or if chamber lift off from the sediment could disrupt power production.

II. SEPARATING FROM SEDIMENT

This paper presents FY13 results from a four chamber test setup (see Fig. 3) that evaluated how anode voltages were affected when the chambers were separated daily from the mud for 30 or 60 min periods over three days. Each of the chambers was filled with mud that was held in place with a bottom mounted brillo pad (for sediment water infusion).

The test objective was to determine if the mud-filled anode chambers could survive a 30-60 min lift off period in which oxygen could diffuse through 1” or 2” mud layers to poison or short out the anode voltages. Exposed, underbody anodes served to mark when lift-off occurred as they would exhibit immediate changes in voltage, indicating oxygen shorting.

If negligible oxygen diffusion into the mud-filled chambers could be proven, this would imply that MFC chambers could be safely separated from the mud bottom for brief periods without compromising anode voltages and hence power production.

Figure 4 plots open circuit voltages for the two underbody anodes and five mud-enclosed anodes from within one chamber (similar to other three chambers) as the test platform is separated from the sediment. Results showed that:

- Underbody anodes clearly marked oxygen exposure with voltage spikes (indicating loss of electrons due to oxygen shorting)
- Mud-enclosed anodes within the chamber suffered no change in open circuit voltage, even during a 60 minute separation (Day 3).
- Underbody anodes returned to normal within 24 hrs after being re-bottomed into sediment.

The lack of any change in open circuit voltages for the in-chamber, mud enclosed anodes showed that an MFC powered device can be safely separated or “unplugged” from the sediment for brief 30 to 60 min periods, even with only a simple mud barrier to prevent oxygen intrusion.

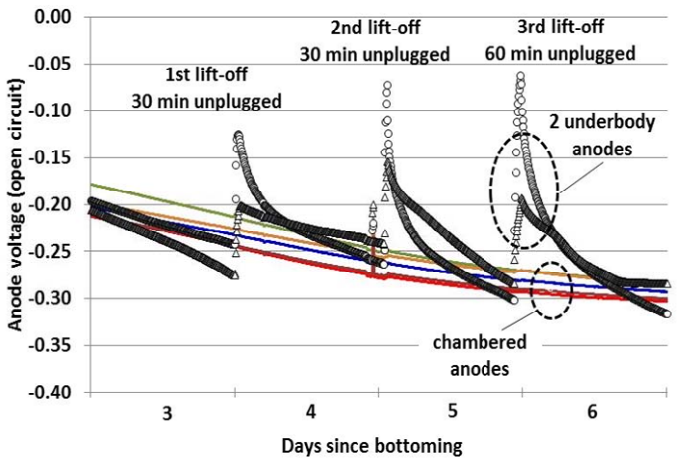

Fig. 4. *Open circuit voltages for underbody and in-chamber (mud-enclosed) anodes from test setup on Fig. 3. Sediment separation periods of 30 and 60 min -- clearly marked by voltage spikes for the underbody anodes, appear to have no effect on mud-filled anode chambers.*

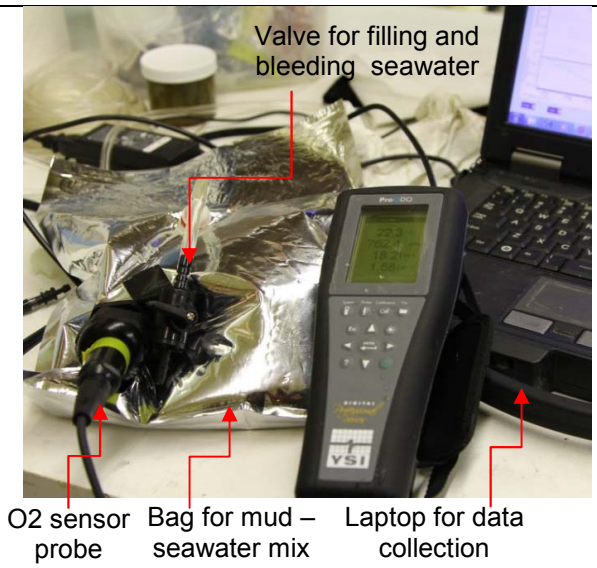

Fig. 5. *Test setup for evaluating consumption of seawater oxygen using small (1%) mud content.*

For MFC designers, this implies that active valves need not be employed to sequester anode chambers from oxygen rich seawater; a simple and passive mud barrier will be adequate.

III. RESETTLING ON SEDIMENT

Upon resettling on the sediment (see Fig. 2 right), the MFC will eventually need to pump or ingest sediment nutrients to sustain microbial activity within the chamber—any O_2 trapped under the MFC device would likely be ingested to poison the anode chamber. This would be a far more challenging threat than simply surviving oxygen diffusion while separated.

To measure the rate at which seawater O_2 levels could be consumed under an MFC platform--e.g., within a "detox" or holding chamber, a collapsible 2L bladder was fitted with an oxygen sensor probe, and a valve for filling and bleeding the bag of seawater (see Fig. 5).

Figure 6 shows time traces of O_2 levels in the bladder of seawater (with 1% mud content) as measured by the sensor probe. Initial data collected on 13 July showed that the bladder O_2 levels could be influenced by trapped air pockets. More experience in using the setup produced new data on 16 July showing a much more rapid and stable consumption of O_2 when the bag is first bled to eliminate air pockets.

Data from Fig 6 would imply that O_2 content trapped under the MFC device upon resettling could be consumed within a day, allowing for subsequent pumping (ingesting) of sediment nutrients without little threat of O_2 poisoning.

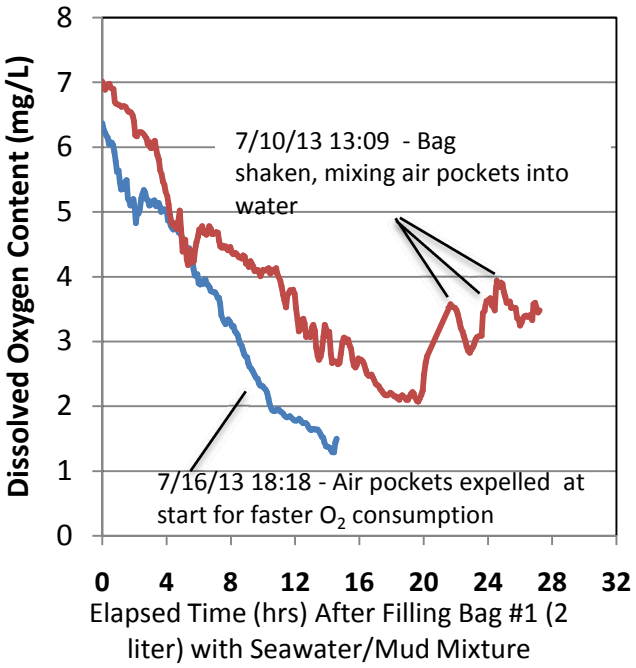

Fig. 6. *Time traces of dissvolved oxygen content for seawater with 1% mud solution.*

IV. CONCLUSIONS

In this microbial fuel cell (MFC) research, we have successfully demonstrated the capability for mud-enclosed anodes to be separated and reattached with the sediment bottom without any adverse effects of oxygen poisoning.

- During 30 and 60 min sediment separation periods, the mud-enclosed anodes were suspended in seawater and unaffected by the exposure to the oxygen content..
- For reattaching an anode chamber on the sediment bottom, it was shown that any oxygen content trapped underneath the MFC device could be naturally consumed with exposure to a 1% mud solution.

These demonstrations have shown that it is feasible for an MFC device to temporarily depart and then return to the sediment surface without adverse oxygen poisoning from the ambient seawater or sediment surface.

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REFERENCES

[1] B. Logan, Microbial Fuel Cells. Hoboken, NJ: John Wiley and Sons, 2008

[2] www.microbialfuelcell.org (accessed 2 May 2013)

[3] http://www.keegotech.com (accessed 2 May 2013)

[4] W. Liu, J. Kagan, L. Hsu, D. Chadwick, "Pumping microbial fuel cells", IEEE OCEANS 2012, Hampton Roads, VA, 14-19 Oct 2012