MEMBRANE BIOREACTORS FOR IN SITU CARBON UPCYCLING. J. Vanneste[1], C.A. Marks[1], C. Billingsley[1], A.J. Pieja[2], M.C. Morse[2], T.Y. Cath and J. Munakata Marr[1]
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Introduction: Methane is a potent greenhouse gas released from oil and gas operations, landfills and anaerobic digesters. Most methane emissions are currently flared or at best valorized as a fuel either for heat or electricity generation. Novel processes are being developed that can convert methane into polymers which have higher value and extended use of these polymers would also keep the carbon sequestered. The methanotrophic bacteria culture optimized by Mango Materials can convert methane and oxygen gas into intracellular polyhydroxybutyrate (PHB) [1]. This process would be very useful for missions to Mars or the Moon to synthesize PHB that can be used for instance to 3D print tools or construction materials. Mars has a CO_2 atmosphere that can be converted to CH_4 via the Sabatier process. The ice found on the moon even contains a decent amount of CH_4 (0.4 w%), but contains up to 9.3 w% carbon species that can be readily converted into CH_4. The oxygen gas can be obtained through water electrolysis. Gas transfer in bioreactors for instance for wastewater aeration is nowadays most commonly achieved by bubble diffusers. Bubble diffusers require a lot of energy and recycling gases to increase efficiency is cumbersome. Moreover, for space applications the gas transfer efficiency drops with decreasing gravitational pull. Integration of a gas-liquid membrane contactor has the potential to dramatically increase gas utilization. Due to high packing densities of membrane systems also mass transfer and hence production per reactor volume can be increased. And lastly, membrane contactors do not require a gravitational field for operation. In this study, CSM designed and built a membrane-aerated reactor to proof the concept.

Results: The oxygen flux and pressure drop of seven different commercial and custom-built membrane modules were measured as a function of liquid flow rate through the module. Higher fluxes will lead to lighter gas transfer systems while higher pressure drop will require more mass in associated energy systems. As a result, for each membrane module an optimal liquid flow rate could be determined, minimizing the total payload for a mission to Mars (Figure 1). Feeding an oxygen-methane mixture with a ratio outside the explosion limits had a much better transfer than having two separate oxygen and methane modules in series.

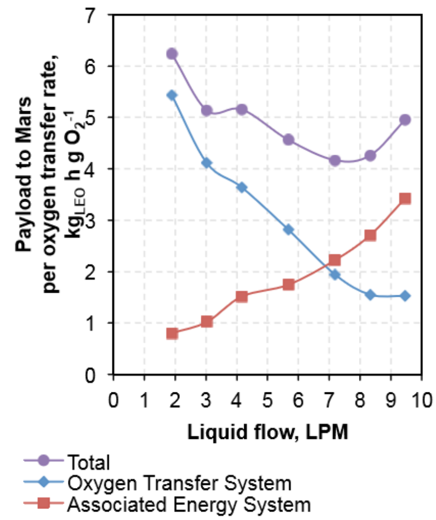

Figure 1: Oxygen transfer specific equivalent mass in LEO of membrane-based oxygen transfer system and associated energy system as a function of liquid flow rate for the Microdyn membrane module. Oxygen supply rate and temperature were maintained at 0.5 LPM and 30 °C, respectively. Energy consumption for liquid pumping was calculated based on a pump efficiency of 70%. A cost equivalency factor of 3.77 kg LEO kg^{-1} Mars was used for the transfer system and 87 kg LEO kW^{-1} Mars for the energy system

A bench-scale reactor was inoculated with a consortium of type II methanotrophic bacteria. Growth trials that used a flat-sheet membrane module produced bacteria with 22% PHB per dry cell mass. Growth trials using hollow fiber modules from Minntec produced bacteria with 47% PHB per dry cell mass. These results confirmed that membranes are capable of providing sufficient gas transfer for growth and production of PHB by methanotrophic bacteria.

References:

[1] Pieja A. J. et al. Methane to bioproducts: the future of the bioeconomy? *Curr Opin Chem Biol.* (2017)*, 41,* 123-131.

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