Investigating the hollow fiber membrane contactor performance in CO_2 stripping from water in a bipolar membrane electrodialysis (BPME) set-up

1- Introduction

To limit global warming to 2°C with negative global CO_2 emissions (on balance) by 2050, climate models indicate that negative emissions technologies (NETs) must be deployed.[1,2] NETs are climate intervention technologies that remove CO_2 from its sinks e.g. atmosphere and the ocean. These methods include: ocean liming, afforestation and reforestation, direct air capture (DAC) of CO_2, bioenergy with carbon capture and storage (BECCS), and indirect ocean capture (IOC).[3]
Among all these technologies IOC is an emerging technology which can be viewed as a hybrid between DAC and ocean liming. In IOC, the ocean-atmosphere equilibrium is leveraged through controlling the pH of the seawater to extract the (dissolved) CO_2.[3] This carbonate equilibrium (resulted from dissolution of the atmospheric CO_2 in the ocean) is strongly dependent on the pH (**Figure 1 (a) and (b)**). The carbon content of the oceans in the form of dissolved inorganic carbon (DIC) is 140 times greater by volume than the carbon in the atmosphere in the form of gaseous carbon.[3] Thus, IOC is an interesting technique for decarbonization which in a closed loop cycle enables returning CO_2-free brine to the ocean for additional CO_2 absorption from the air.

2- Project description

In electrochemical IOC, the ocean carbonate equilibrium is manipulated through addition of acid and base (i.e. pH-swing) that are produced via a bipolar membrane electrodialysis system (BPMED). A bipolar membrane consists of an anion and a cation exchange membrane and can dissociate water into OH^- and H^+ if sufficient current is applied (**Figure 1 (c)**). Via an acidic route, the DIC in ocean water or brine is converted to dissolved CO_2 ($CO_{2(aq)}$) followed by gas stripping of CO_2. For removal of dissolved CO_2 from the aqueous stream, hydrophobic membrane contactors (MCs) are used. In MCs the aqueous fluid flows on one side of the membrane and a sweep gas/vacuum is applied to the other side (**Figure 1(c) right**). The hydrophobic membrane does not allow passage of liquid water through the pores into the gas side, thus providing a gas-liquid interface at the pore. By adjusting the partial pressure of the gas in contact with water, gas can be selectively removed from water.[4] Alternative to the acidic route, through a basic route, the carbonate buffer system shifts towards oversaturation of the carbonate ions promoting precipitation such as $CaCO_3$ or $MgCO_3$ (**Figure 1(c) left**).

3- Objectives

The focus of this project is more on the acidic route and the goal is to investigate one of the most cost-sensitive parameters, i.e. number and configuration of the CO_2 extraction hollow fibre membrane contactor modules. The CO_2 extraction efficiency will be investigated upon application of sweep gas as well as vacuum with different pressure levels. The long-term efficiency of the membrane contactor modules will be studied based on the onset of pore wetting (failure) by the aqueous phase. If it fits within the project time schedule, the effect of membrane modification on the long-term efficiency will be also investigated. In this modification scheme, the membrane pores are pre-filled with a fluorinated oil (making so-called liquid-infused membrane[5,6]) which can possibly prevent pore wetting and membrane failure at later stages. Mass transfer analysis/modelling needs to be performed further to better compare the performance of pristine and modified hydrophobic membranes in CO_2 stripping from water.

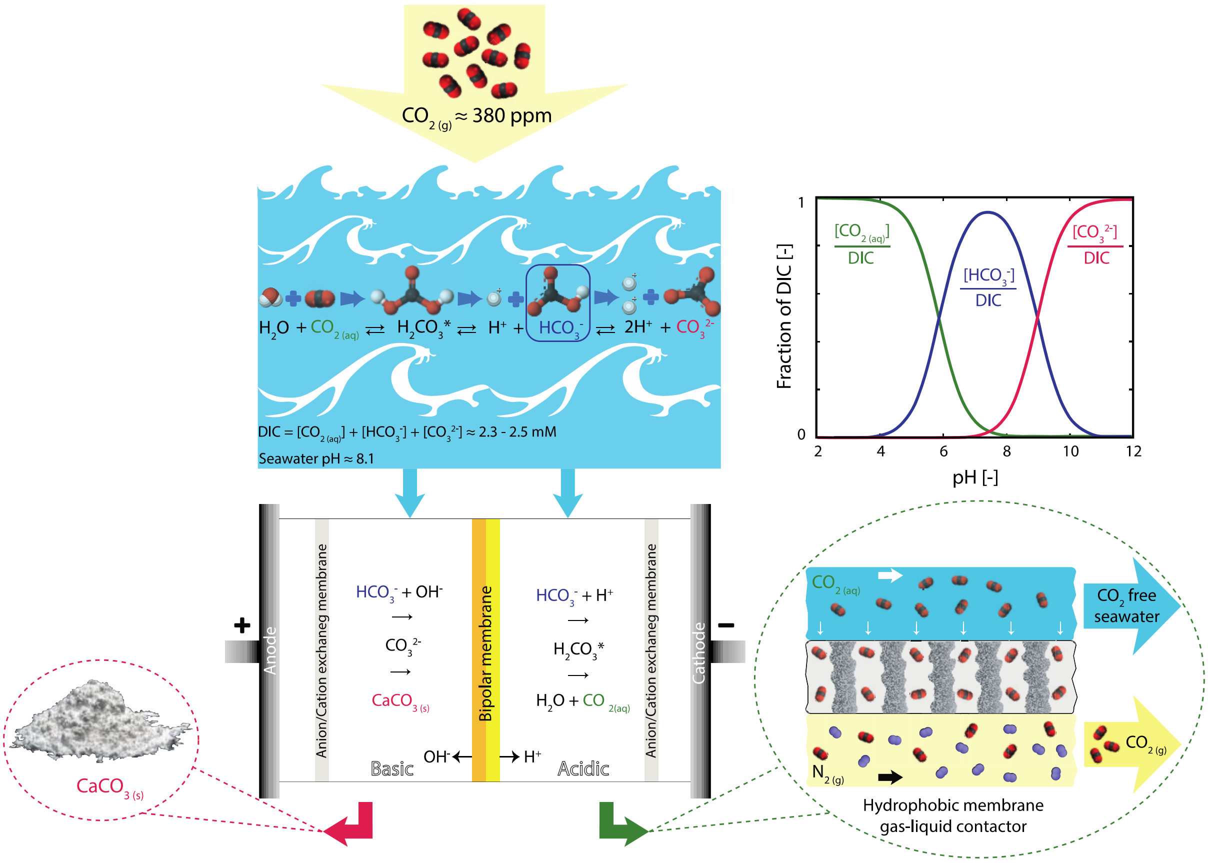

Figure 1. Schematic illustration of IOC process by pH control. **(a)** The ocean carbonate system where carbonic species exist together in equilibrium. **(b)** Carbonate equilibrium for a closed system when DIC is kept constant and **(c)** bipolar membrane electrodialysis (BPMED) producing acid and base from water dissociation which enables removing $CO_{2(aq)}$ in gaseous form or as solid $CaCO_3$ upon subsequent change in pH on acidic and basic sides respectively.

References

[1] Rogelj, J., den Elzen, M., Höhne, N. et al. Paris Agreement climate proposals need a boost to keep warming well below 2 °C. *Nature* 534, 631-639 (**2016**).

[2] Smith, P., Davis, S., Creutzig, F. et al. Biophysical and economic limits to negative CO2 emissions. *Nature Clim Change* 6, 42-50 (**2016**).

[3] de Lannoy, C. F., Eisaman, M. D., Jose, A. et. al. Indirect ocean capture of atmospheric CO2: Part I. Prototype of a negative emissions technology. *International Journal of Greenhouse Gas Control* 70, 243-253 (**2018**).

[4] Wisler, F., Hoeschst Celanese Corp. (**2003**), *Membrane contactors: an introduction to the technology*, Talls oak publishing Inc. ISSN: 0747-8291.

[5] Bazyar, H., Javadpour, S., Lammertink, R. G. H. On the gating mechanism of slippery liquid infused porous membranes, *Adv. Mater. Interfaces*, 3, 1600025 (**2016**), doi:10.1002/admi.201600025.

[6] Bazyar, H., Lv, P., Wood, J. A. et. al. Liquid–liquid displacement in slippery liquid-infused membranes (SLIMs), Soft Matter, 14, 1780-1788 (**2018**).