Is forward osmosis a viable method for desalination of seawater?

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Introduction

Water scarcity has become a global risk and one of the most serious concerns for the scientific community. Current desalination technologies are prohibitively expensive and energy intensive. Forward osmosis (FO) is one of the emerging technologies which might become a cheaper alternative. By using a concentrated solution of high osmotic pressure called the draw solution, water can be induced to flow from saline water across the membrane, rejecting the salt. The diluted draw solution must be re-concentrated, to obtain potable water and to be recycled. This study aims to figure out whether FO, with application of the draw solutions ammonium bicarbonate (NH_4HCO_3) or magnesium chloride ($MgCl_2$), is a viable method for desalination of seawater. If FO proves to be viable it can help many countries and communities in dry regions to turn to the ocean as a source of freshwater.

Methods

Selected draw solutions – NH_4HCO_3 and $MgCl_2$ – were investigated experimentally under FO conditions. Performed steps:

- Running an FO unit.
  - Feed tank contained 0.599 M NaCl solution. Volume was varied from 0.100 to 0.250 L.
  - Draw tank contained either NH_4HCO_3 or $MgCl_2$ solution. Concentrations varied from 1.5M to 6M; volume: from 0.050 to 0.100L.

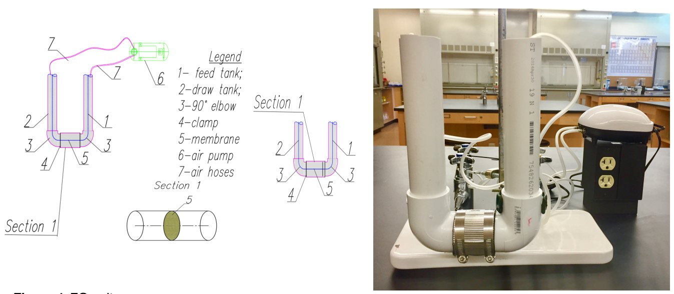

Figure 1. FO unit

- Removal of draw solute.
  - Diluted NH_4HCO_3 solution. Heating for 2-5 hours at 60-65°C. Variations of heating: a) in an open beaker, b) with air bubbling, c) in reflux unit.
  - Diluted $MgCl_2$ solution. Removal by distillation.
- Performance analysis.
  - ICP-MS → traces of N, Na, Cl and C
  - pH sensor → pH
- Effectiveness of FO process.
  - Water flow → flow of saline water through membrane
  - Salt rejection → % feed solute rejected by the membrane

Results

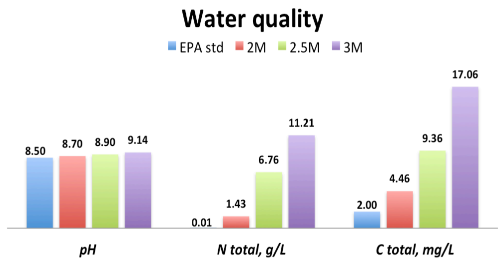

Figure 2 . Water quality analysis

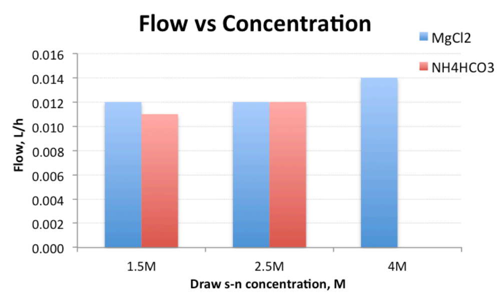

Figure 3 . Effect of draw solution concentration on water flux

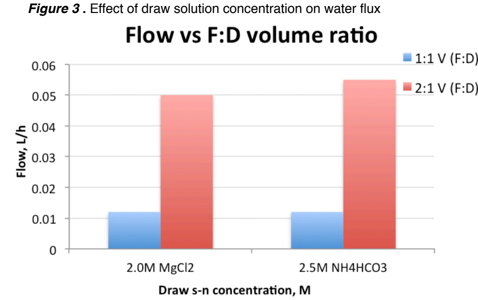

Figure 4. Effect of feed-to-draw solution volume ratio on water flux

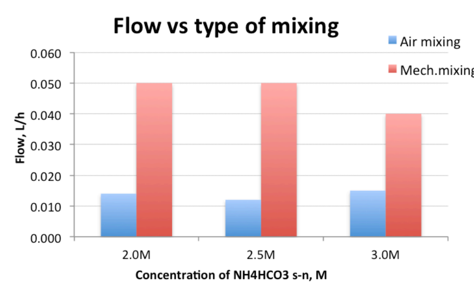

Figure 5 . Effect of type of mixing in FO process with NH_4HCO_3 solution on water flux

Discussion

Water quality. Samples distilled from the $MgCl_2$ solution comply with EPA standards. This implies that distillation can successfully be used to remove $MgCl_2$ from the diluted draw solution and obtain potable water. NH_4HCO_3 cannot produce high quality potable water. Based on the results of ICP-MS and the pH, the amount of total N and total C, and pH, are numerically much higher than EPA standards. This means that, although the applied method causes decomposition of NH_4HCO_3 into NH_3, CO_2 and H_2O, it does not contribute to its removal from water.

Effectiveness of FO process. Key factors that affect water flow are concentration of draw solution, volume ratio of feed solution to draw solution, and effective mixing. The FO process with the same concentration, but 2:1 volume ratio of feed solution to draw solution, produces almost five times better results in water flow as compared to 1:1 volume ratio. Mixing is important to prevent membrane clogging. For the $MgCl_2$ draw solution, both air and mechanical mixing results in the same flux. For the NH_4HCO_3 draw solution, only mechanical mixing is applicable, as long as air mixing results in reduction of ion concentration in the draw solution due to transformation of HCO_3^- ion into CO_2.
ICP-MS analysis determined the amounts of Na and Cl in the samples to be 0.155 mg/L and 0.572 mg/L respectively. This means salt rejection of the membrane is around 99%.

Conclusion

The results show that FO is viable in terms of water flow and salt rejection. Parameters of FO effectiveness do not depend on the type of draw solution, but instead depend on concentration, volume ratio of feed and draw solutions, and type of mixing. In terms of water quality, $MgCl_2$ is a more applicable draw solute because distillation is a viable technique for fresh water recovery. Despite many studies that use heating for NH_4HCO_3 removal (McCutcheon et al., Traisupachok et al.), this technique did not prove to be feasible for fresh water recovery.

Future Work

More experiments are required in order to develop the optimal mathematical relationship between the concentration of draw solution and volume ratio of feed solution to draw solution. Further analysis is required to identify possible techniques for NH_4HCO_3 removal from draw solution. A more upgraded FO setup should be used to obtain more accurate data.

References

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