Advanced Research Projects Agency–Energy
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An Innovative Zero-Liquid Discharge Intermediate-Cold-Liquid Eutectic-Freeze Desalination System

Produced Water Working Group

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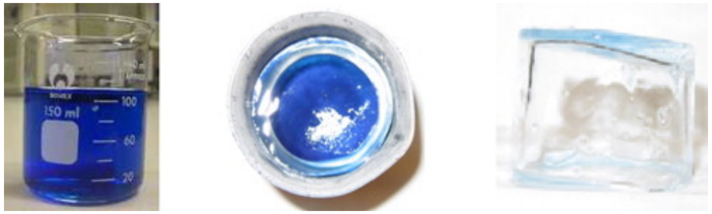
Outline

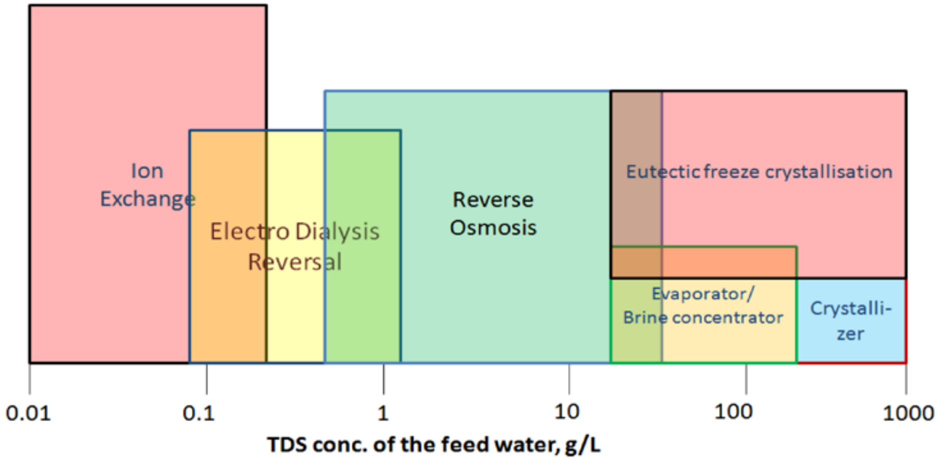
- Overview of Freeze-Desalination Technology
- Introduction to OU's Concept
- Thermo-Economic Analysis
- Experimental Setup and Sample Results

Eutectic-Freeze Desalination

- Very old method of producing fresh water. Sailors in cold climates melted the frozen seawater to get fresh water on board ships.
- Application in food industries, wastewater treatment and seawater desalination.



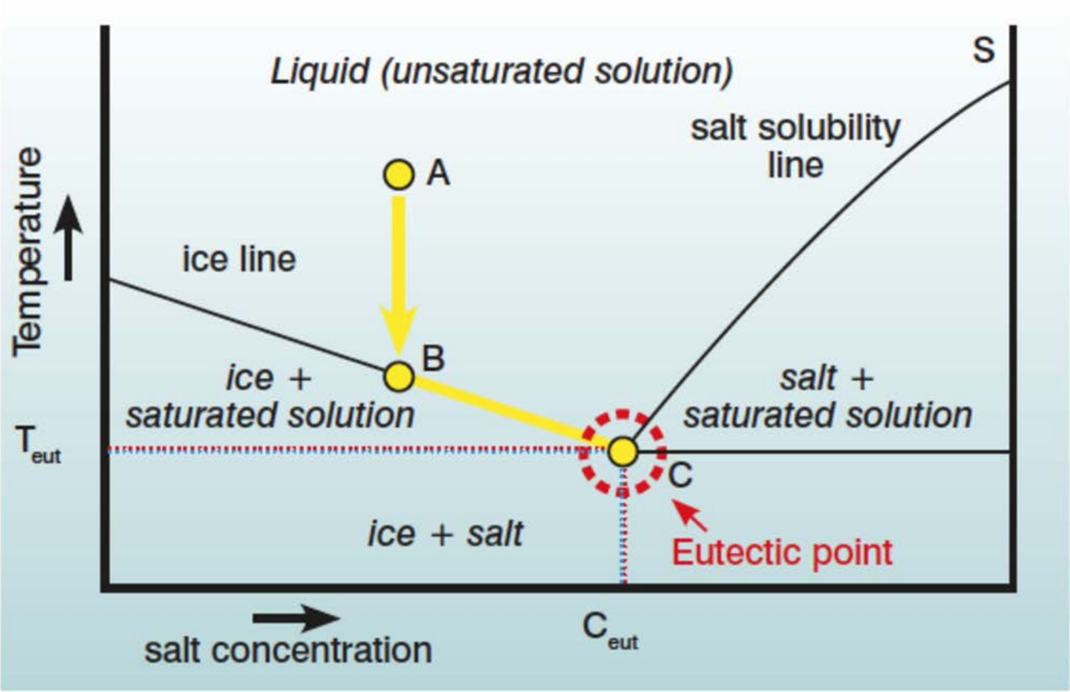
Freeze separation with blue dye [2]



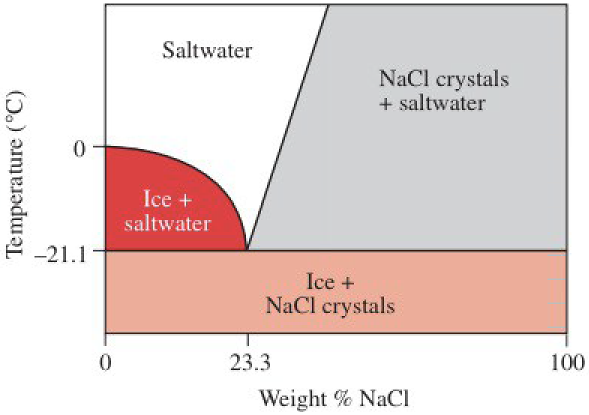
Applicability of various desalination technologies [1]

[1] Verbeek, B., Eutectic Freeze Crystallization on Sodium Chloride, Masters Thesis, Delft University of Technology, 2011.
[2] Williams, P.M., Ahmad, A., Connolly, B.S., Oatley-Radcliffe, D.L., Technology for freeze concentration in the desalination industry, Desalination 356 (2015), 314–327.

Principle of Operation



Phase diagram of a binary salt-water system



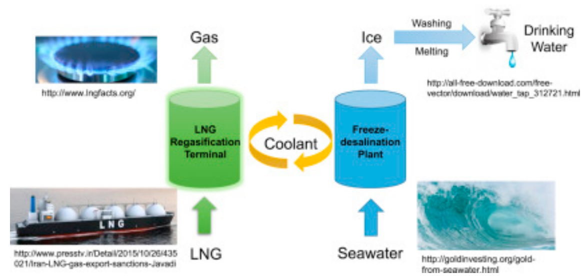
State-of-the-Art of Freeze-Desalination Technologies

- The major technologies:

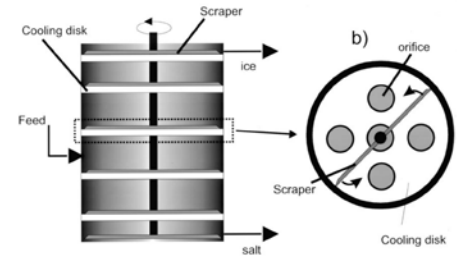
(i) direct contact freezing

(ii) vacuum freezing

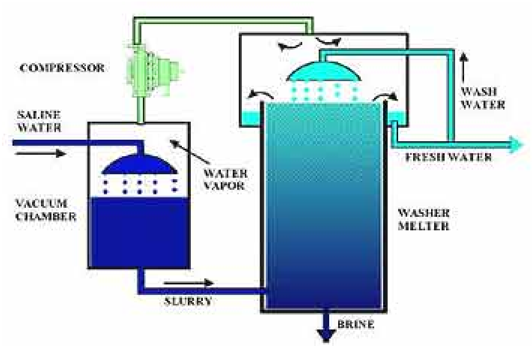
(iii) indirect contact freezing



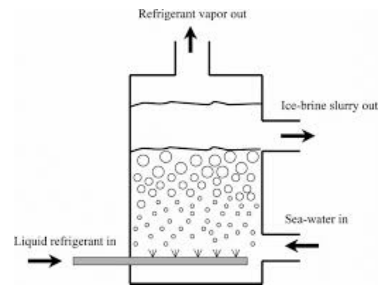
Freeze desalination of seawater using LNG cold energy [3]



Indirect Contact Freeze [4]



Vacuum Freeze [1]



Direct Contact Freeze [2]

Simple; good heat transfer
Requires significant compressor power

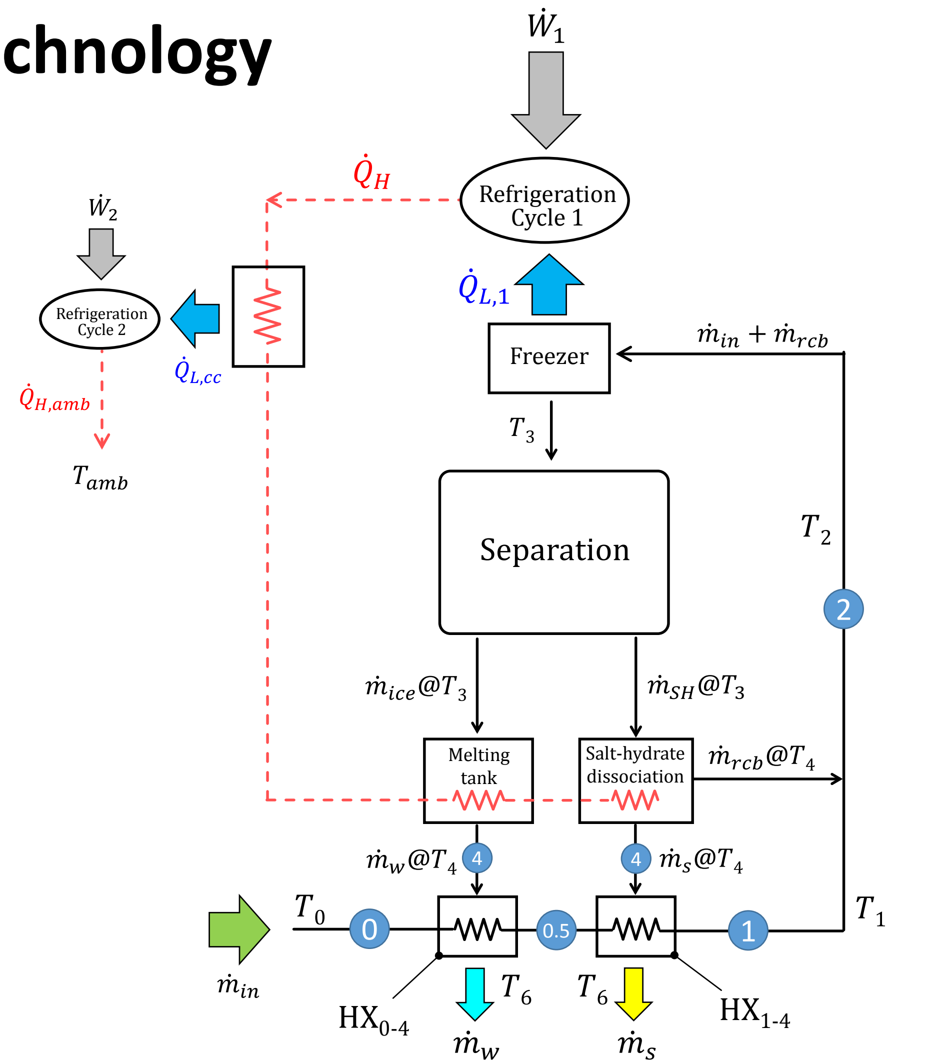
Superior heat transfer
Low quality water (the coolant forms chemical bonds with water)

High quality ice
Poor heat transfer due to ice layer

[1] TheWaterTreatmentPlant.com http://archive.li/SX9dO#selection-1371.31-1375.26
[2] Rahman, M.S., Ahmed, M., Dong Chen, X., Freezing-Melting Process and Desalination: I. Review of the State-of-the-Art, Separation & Purification Reviews, Volume 35, 2006.
[3] Chang, J., Zuo, J., Lu, K-J, Chung, T-S, Freeze desalination of seawater using LNG cold energy, Water Research Volume 102, 282-293, 2016.
[4] van der Ham, F. Witkamp, G.J. , de Graauw, J., van Rosmalen, G.M., Eutectic freeze crystallization: Application to process streams and waste water purification, Chemical Engineering and Processing 37 207–213, 1998.

OU's Freeze-Desalination Technology

- Utilizes an immiscible inert liquid to remove heat from the brine by direct mixing
- Benefits from the superior heat transfer of direct contact freezing systems
- No attachment of ice to the cooling surfaces
- No chemicals
- Atmospheric Pressure



Schematic representation of the innovative freeze-desalination technology

Lab-Scale Freeze-Desalination Test Setup

Sample Experimental Results

The ice crystals formed from freezing a 10,000 ppm brine solution, (left) ice crystals transported to the settling tank from the freezing chamber, and (right) the ice crystals accumulated at the bottom of the freezing chamber.

Preliminary Results of Thermo-Economic Performance Analysis

		Brine TDS = 200,000 ppm					
		Heat Exchanger Effectiveness					
		ε = 1	ε = 0.9	ε = 0.8	ε = 0.7	ε = 0.6	ε = 0.5
100% Sep. efficiency	LCOW ($/ton of brine)	$1.98	$2.02	$2.06	$2.12	$2.20	$2.32
	LCOW ($/barrel of brine)	$0.39	$0.40	$0.40	$0.41	$0.43	$0.45
90% Sep. efficiency	LCOW ($/ton of brine)	$2.03	$2.06	$2.11	$2.16	$2.25	$2.38
	LCOW ($/barrel of brine)	$0.40	$0.40	$0.41	$0.42	$0.44	$0.47
80% Sep. efficiency	LCOW ($/ton of brine)	$2.08	$2.12	$2.17	$2.23	$2.32	$2.45
	LCOW ($/barrel of brine)	$0.41	$0.42	$0.42	$0.44	$0.45	$0.48
70% Sep. efficiency	LCOW ($/ton of brine)	$2.16	$2.20	$2.25	$2.31	$2.40	$2.54
	LCOW ($/barrel of brine)	$0.42	$0.43	$0.44	$0.45	$0.47	$0.50

- Considering a plant capacity of 1000 ton brine/day and 30 years lifetime
- Considers the additional cost of deep-well disposal of rejected brine
- Based on current industrial electricity prices in Oklahoma
- Based on actual brine compositions from Beaver County in Oklahoma