Turbo-Expander Based Process for Eutectic Water Desalination

GE Global Research

Kim Hammer
Vitali Lissianski
Chennan Li

DOE Award # DE-FE002402
PM: Barbara Carney
January 2015 – June 2016

April 18, 2016

Imagination at work.

“This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.”

Take Away Points

- Technology described in this presentation based on freezing brine
- Potential for 100% water recovery
- Most promising technology application is Zero Liquid Discharge
- Potential for 40% cost of water treatment reduction in comparison with thermal crystalyzer
- Technology is in early stage of development (TRL3)

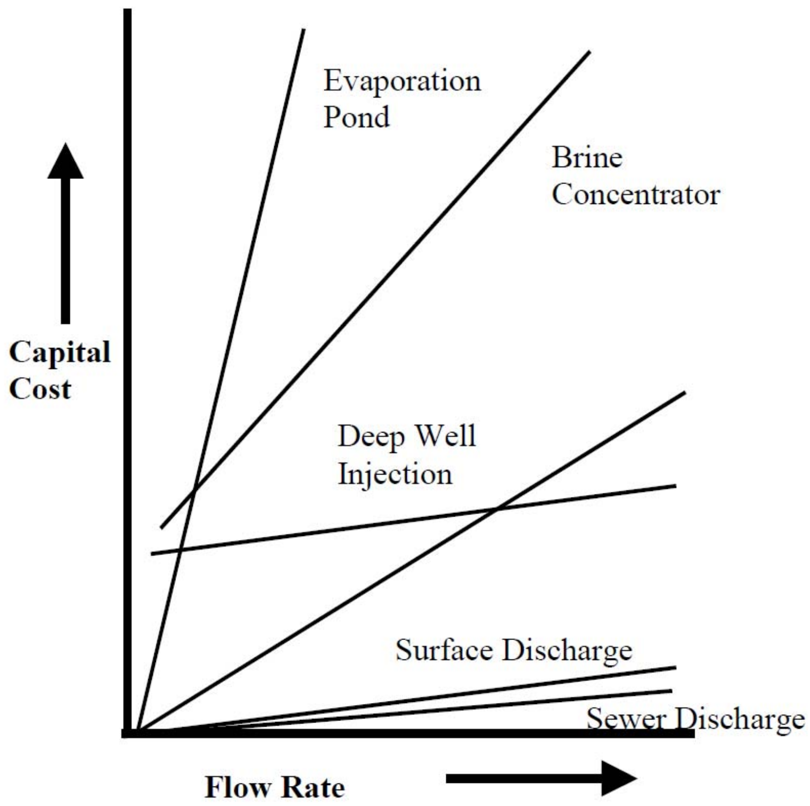
Problem statement

Problem Statement: Zero Liquid Discharge (ZLD) systems have high capital and operational costs.

Technical Problem Statement: Main options for high TDS treatment include 1) evaporation ponds, 2) brine concentration followed by deep well injection, and 3) brine concentration followed by crystalyzer

- Evaporation ponds are expensive to construct and require large land area
- Water re-injection has environmental concerns
- Thermal crystallizers are energy-intensive with high capital and operating costs

Relative CAPEX of Different Disposal Options[1]



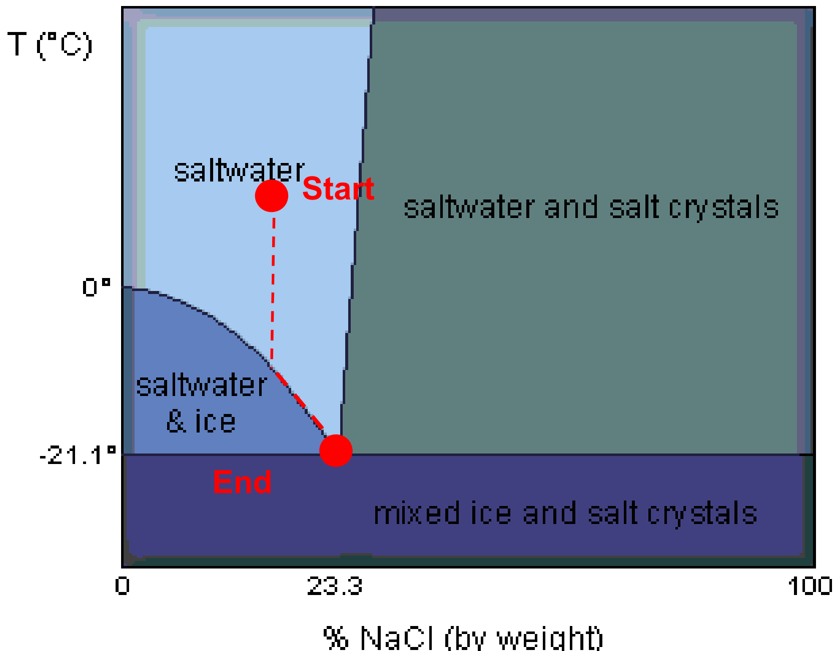
Low cost disposal options have environmental concerns

Technology Vision: A ZLD technology that utilizes water freeze (eutectic desalination)

[1] Xu, P., Cath, T, Wang, G., Drewes, J.E. and Dolnicar, S. 2009. *Critical assessment of implementing desalination technology*. AwwaRF Project 4006. Published by American Water Works Association Research Foundation, Denver, CO.

Eutectic Water Desalination

Water-NaCl Phase Diagram

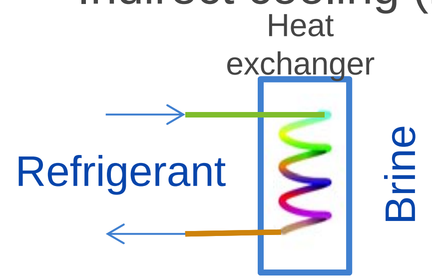


Potential advantages

- **Potential** for high energy efficiency (heat of ice fusion is 334 kJ/kg and that of water vaporization is 2,270 kJ/kg)
- Fewer corrosion problems due to low process temperatures

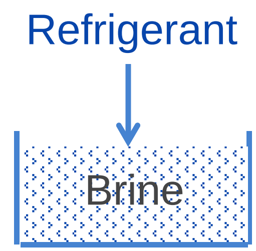
Existing Eutectic Technologies

- Indirect cooling (heat exchanger)



Features
- Ice formation on HX surfaces
- Limited water recovery

- Direct refrigerant injection into brine



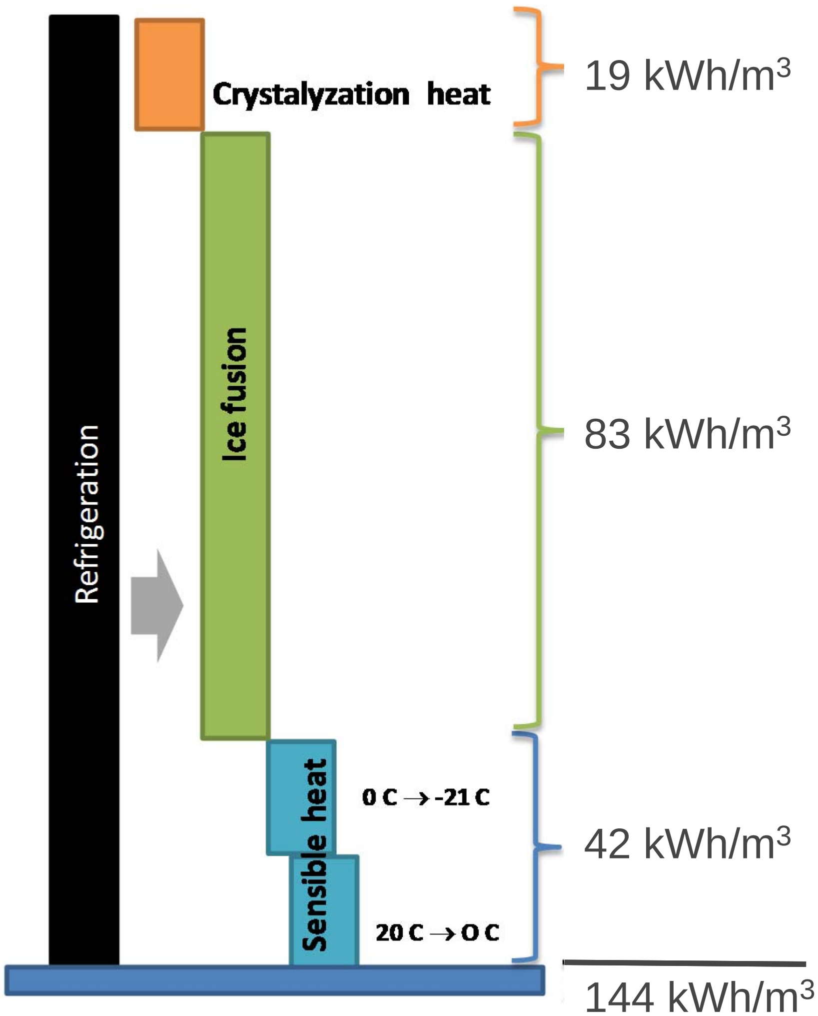
Features
- Improved efficiency of heat transfer
- Limited water recovery

Disadvantage of existing methods: low water recoveries

Differentiator: this technology targets 100% water recovery

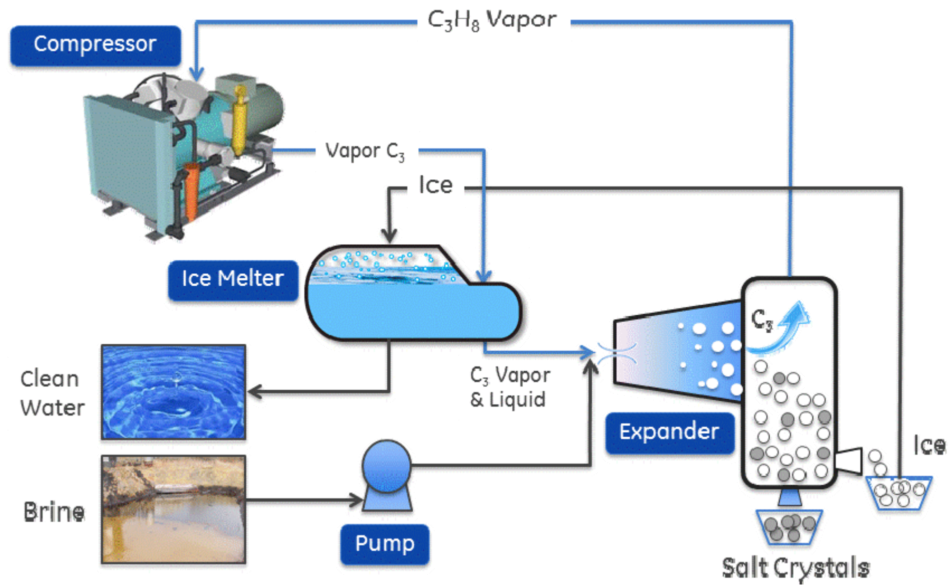
Refrigeration System - Process Energy Balance

Energy Balance



Energy recovery is critical to the process efficiency

Propane Refrigeration Based Process



Most energy invested in freezing brine can be recycled into refrigeration system by means of sensible and phase energy heats

- Energy requirements are low

Assumptions

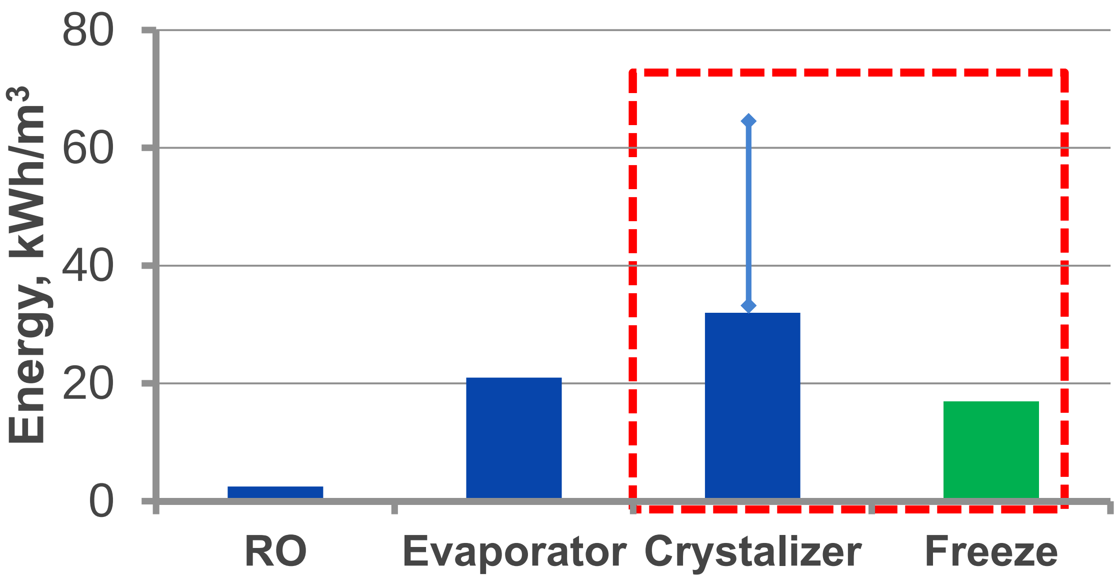
Main Assumption	Assumption impact	How assumption is addressed/validated
Energy invested in brine freeze can be recovered	Process efficiency, COW treatment	Aspen Plus modeling
100% brine freeze can be achieved	Water recovery, COW treatment	CFD modeling, testing
Ice and salt can be separated	Water quality, efficiency, CAPEX, COW treatment	Not directly addressed; literature review

Other assumptions:

- Presence of other than NaCl salts does not significantly impact performance
- Propane losses are not significant
- Nozzle performance does not degrade significantly with time
- Low requirements for brine pre-treatment

If all assumptions are validated, technology performance is promising →

Projected Performance



Targeted application – high salinity brine treatment

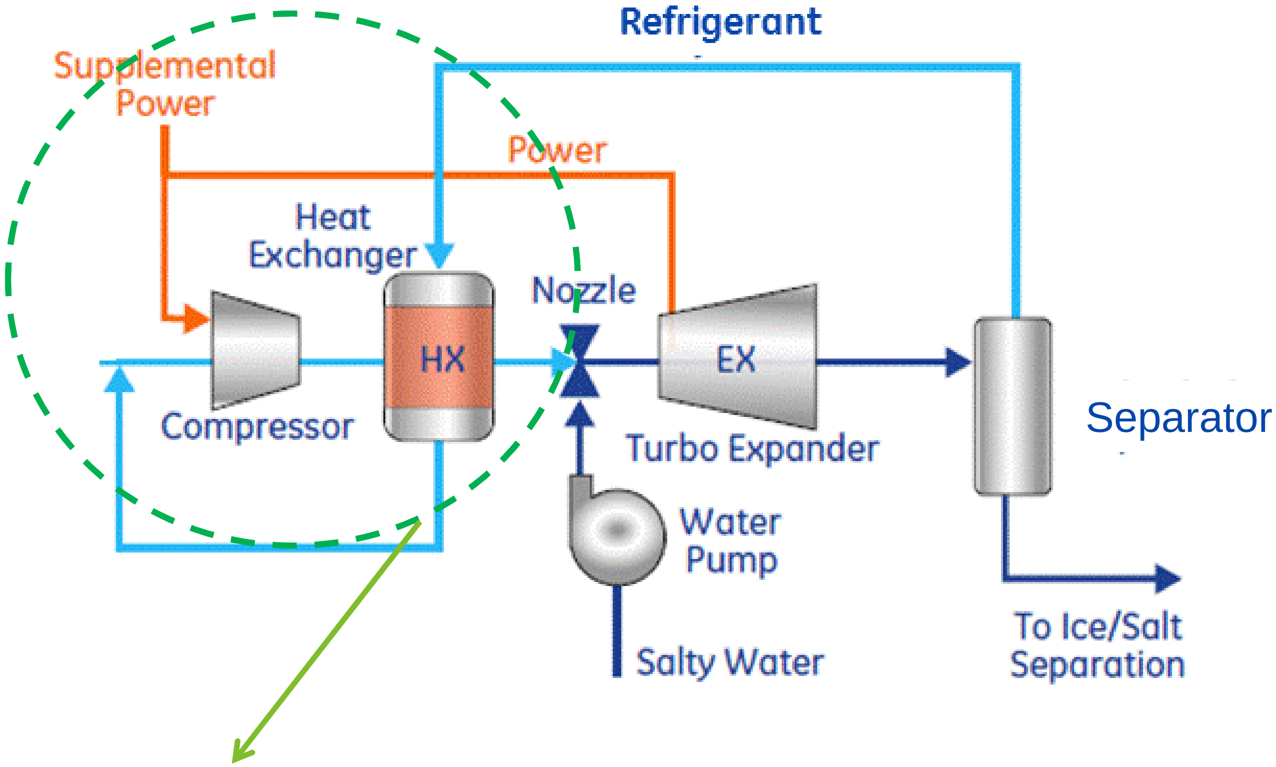
- Technology targets last step in ZLD treatment
- Improved energy efficiency of water recovery

Comparison with Thermal Crystalyzer

Performance Area	Thermal Crystallizer	TE Freeze
Water recovery, %	95%-99%	Up to 100%
Energy consumption, kWh/m3 gal	30-60	18
Water treatment cost, $/m^3$	15	9 (↓40%)
Construction material	Corrosion resistant metal alloys	cs, potentially plastic components
Chemicals consumption	Scale inhibitors and de-foaming agents	None expected
Product water quality	TDS ~ 10 mg/L.	TBD

Potential for significant cost savings for ZLD applications

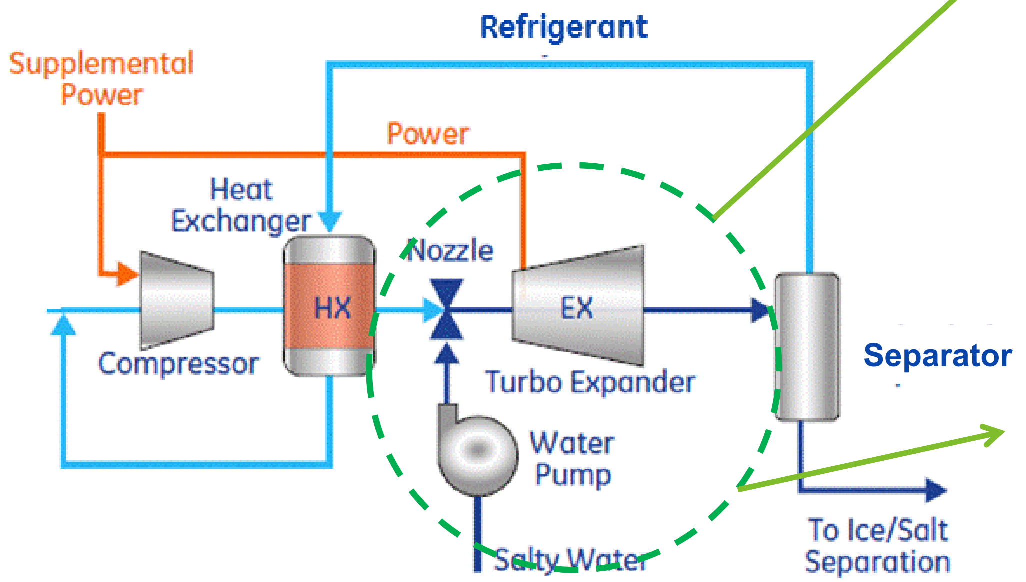
Water Desalination Using Freeze : Key Subsystem – Refrigeration System



- Reducing energy requirements
- Refrigeration fluid selection

One of the focus areas of the current project

Water Desalination Using Freeze: Brine Injection and Freeze System



Two options for brine injection are evaluated

Injection After Turbo-Expander

Advantages Simplicity, no impact on TE

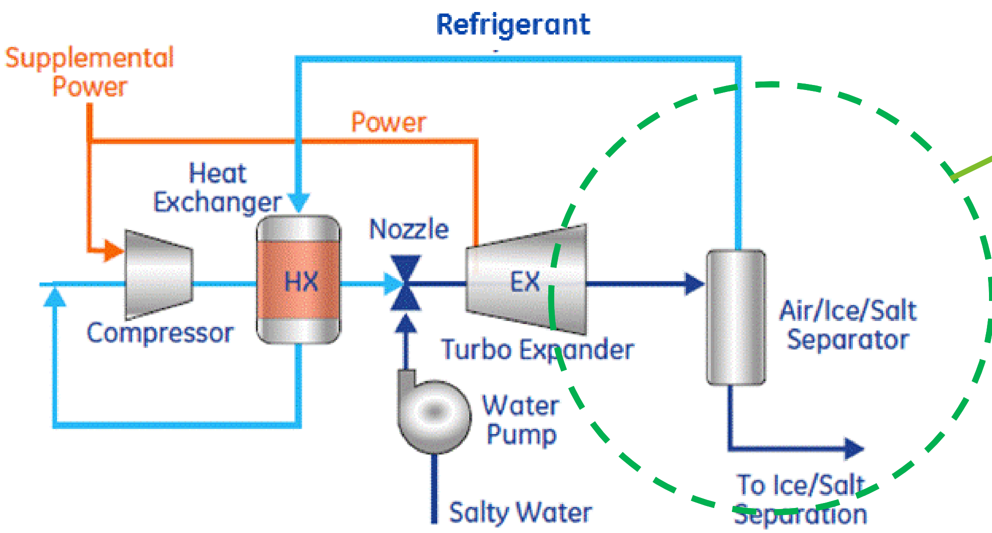
Disadvantages Longer droplet freeze time (larger footprint), smaller droplet sizes, nozzle performance risks

Injection Inside Turbo-Expander

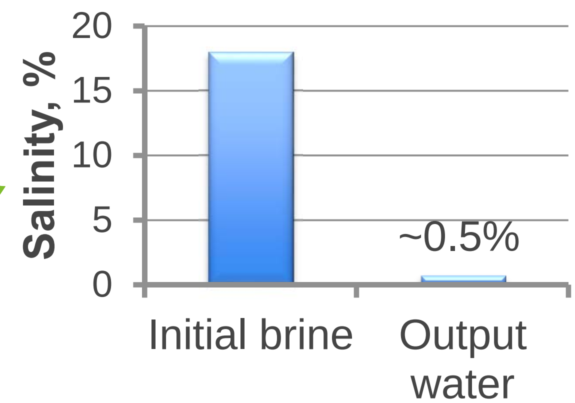
Advantages Reduced energy requirements, smaller footprint, more effective heat transfer, larger droplet sizes

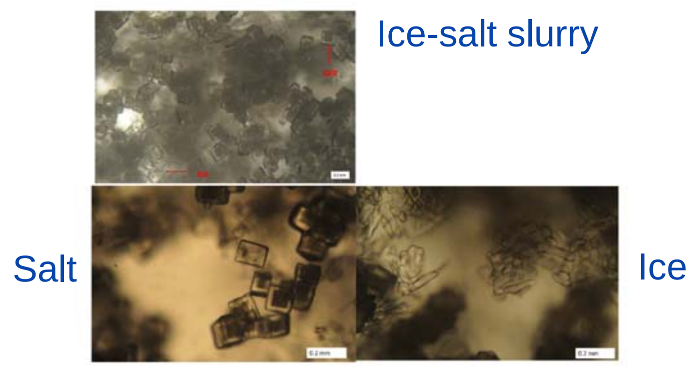
Disadvantages Potential for accretion and erosion

Water Desalination Using Freeze: Salt-Ice Separation system



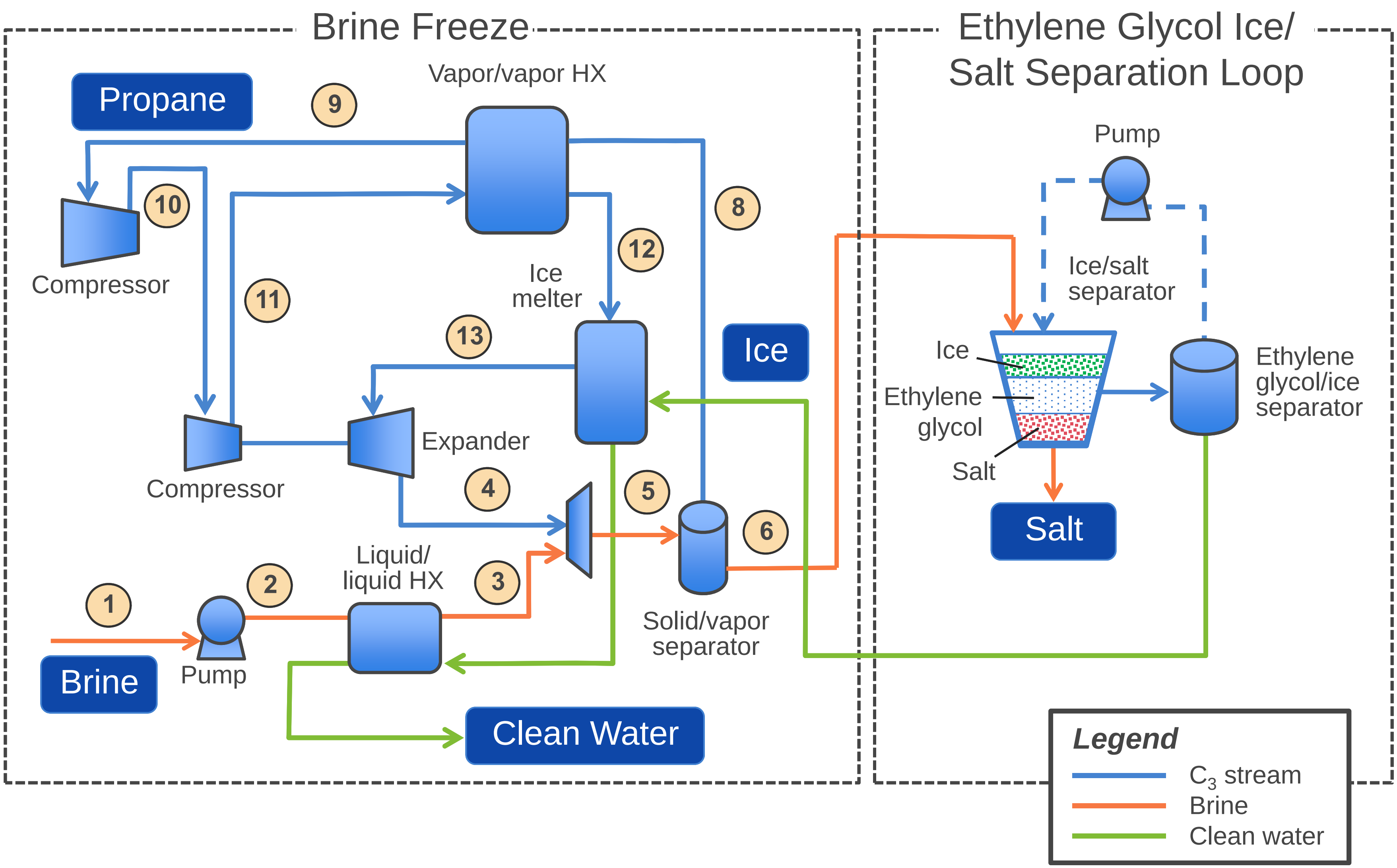
2012: Work performed at Delft University of Technology, The Netherlands





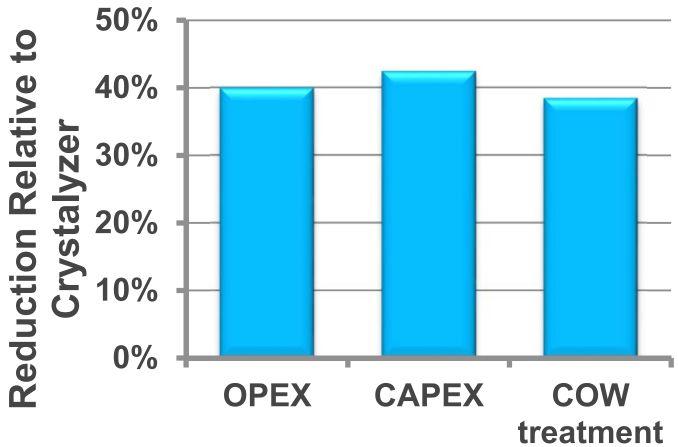
Based on publicly available data, ice/salt separation is possible
Not addressed in the current project

Process BFD

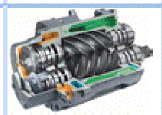
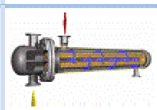
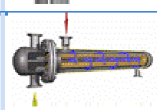


Aspen model was built to estimate energy requirements and equipment CAPEX

CAPEX Estimate



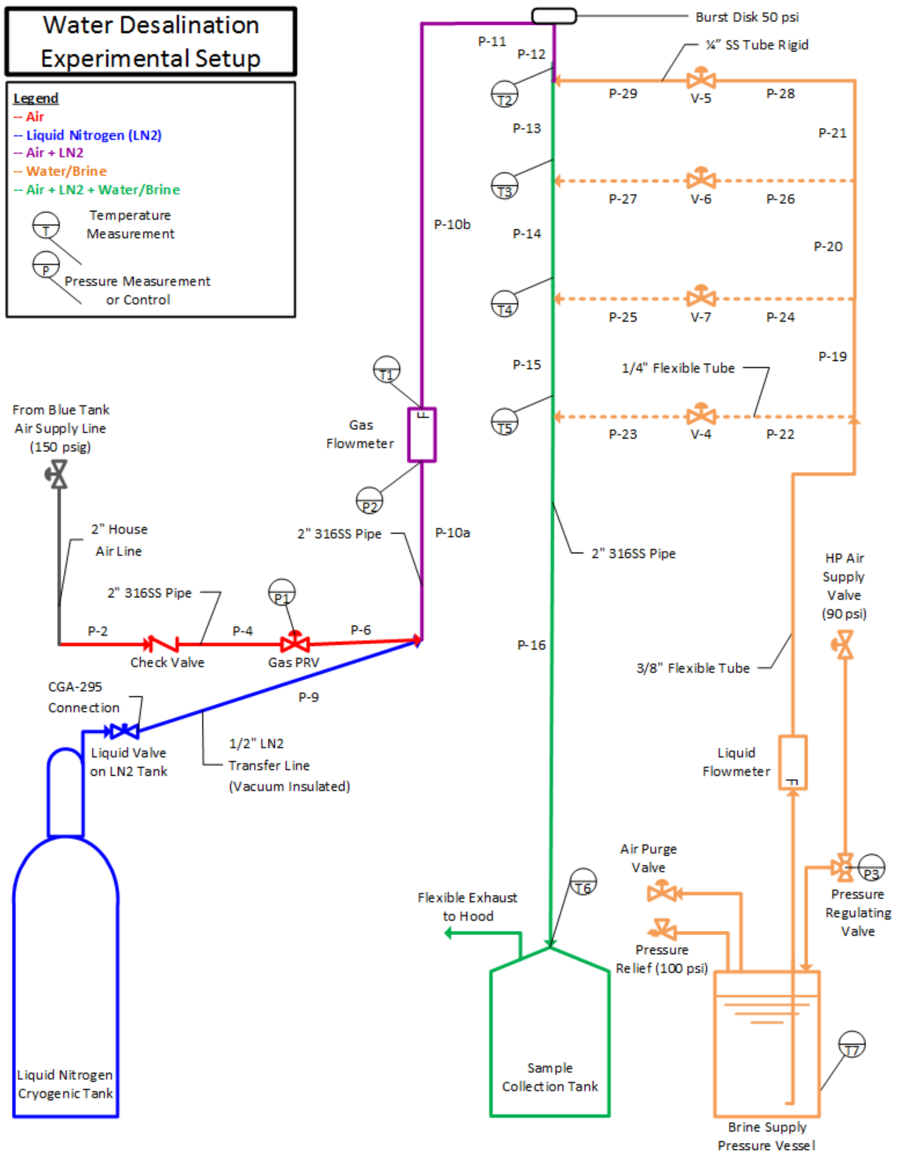
- 16 gpm brine flow rate
- 100% water recovery
- Assumed that flotation method is effective in separation of ice and salt

Equipment		Notes
Propane screw or reciprocating compressor		Commonly used in propane refrigeration systems
Air cooler		Available from many vendors including GE
Vapor/vapor HX		Shell & tube HX, available from many vendors
Ice melter		Kettle HX, available from many vendors
Liquid/liquid HX		Shell & tube HX, available from many vendors

Except for turbo-expander, all equipment is commonly used and is available from multiple vendors

Equipment		Notes
TE-compressor combination		Unique GE design
Brine pump		Available from many vendors
Nozzle		Available from many vendors
Separation vessel		Vertical vessel, easily manufactured
Rotary valve to handle solids		Available from many vendors
Water pump		Available from many vendors

Test Rig



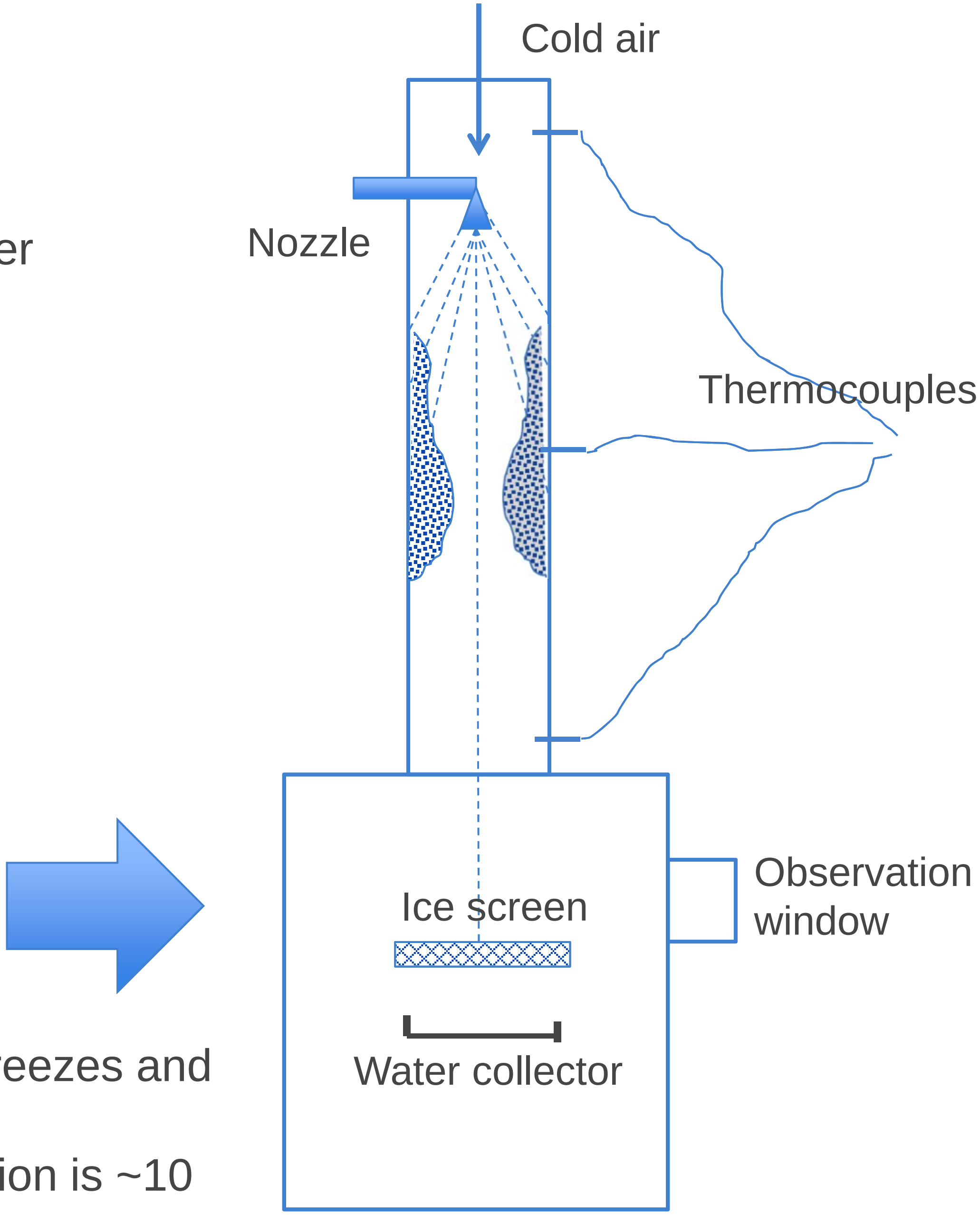
Primary objective: demonstrate at least 80% brine freeze

Secondary objective: characterize ice/salt structure

Sampling Section

Approach

- Collect ice on 40 µm particle screen
- Water is collected in a collector under the screen



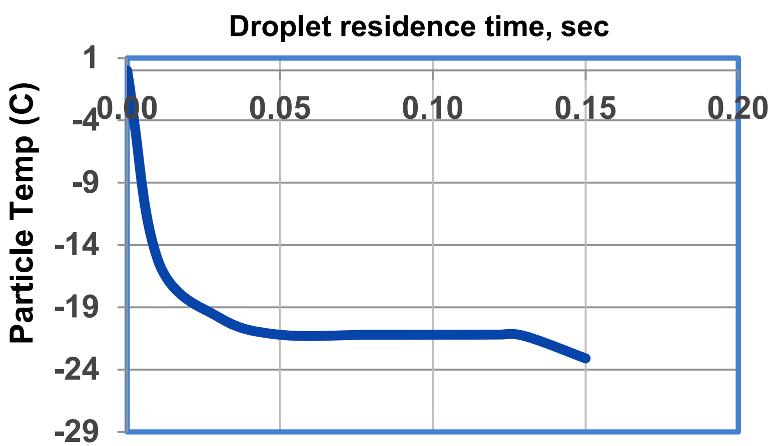
Initial observations

- Water sprayed on walls of the tube freezes and blocks the pipe
- Time available for the sample collection is ~10 min

Test Setup

Conditions	ΔT, C	Droplet Diameter, μm	Residence Time, ms	Brine Mass in air, %
Targeted	40	50-100	100-200	2-5
Actual	20	~130-170	125-230	5.2

Brine Droplet Freeze (CFD)



Droplet cooling to the freezing temperature is a minor contributor to the overall droplet freezing time

Initial results with water injection:

- 100% water freeze
- No water collected

Water freeze testing is good first indication of ability to achieve 100% brine freeze

Initial Test Results

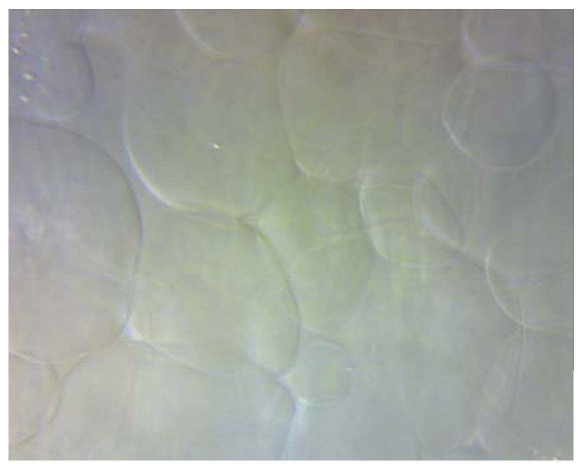
Sample collection

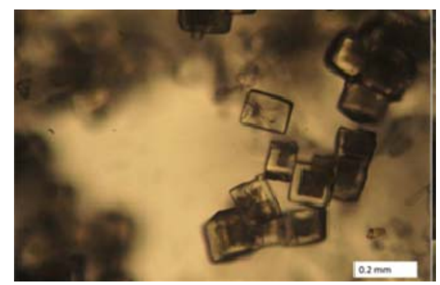
Test 3 29

Sample

100% water freeze

Sample characterization





Salt crystals separated from ice under slow freeze conditions

Take Away Points

- Technology described in this presentation based on brine freezing
- Potential for 100% water recovery
- Most promising technology application is Zero Liquid Discharge
- Potential for 40% cost of water treatment reduction in comparison with thermal crystalyzer
- Technology is in early stage of development (TRL3)