Solar Thermal Assisted Vacuum Freezing Desalination of Seawater at the Triple Point

DE-SC0015824

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Overview

Project Title:

Timeline:

Project Start Date: 09/27/2017

Budget Period End Date: 07/30/2019

Project End Date: 07/30/2019

Barriers and Challenges:

- Both energy consumption and financial cost of desalination technologies are relatively high to produce clean water.
- Vacuum freezing desalination technology at the triple point can potentially minimize energy consumption and cost, but subcooling of water and ice handling are problematic.

AMO MYPP Connection:

- 3.2 Emerging and Crosscutting Areas
  - 3.2.1 Clean water technologies
    - Fundamental materials discovery
    - Unit operation optimization

Project Budget and Costs:

Budget	DOE Share	Cost Share
Overall Budget	$1,000,000	-
Approved Budget (BP-1&2)	$1,000,000	-
Costs as of 5/13/19	$869,105	-

Project Team and Roles:

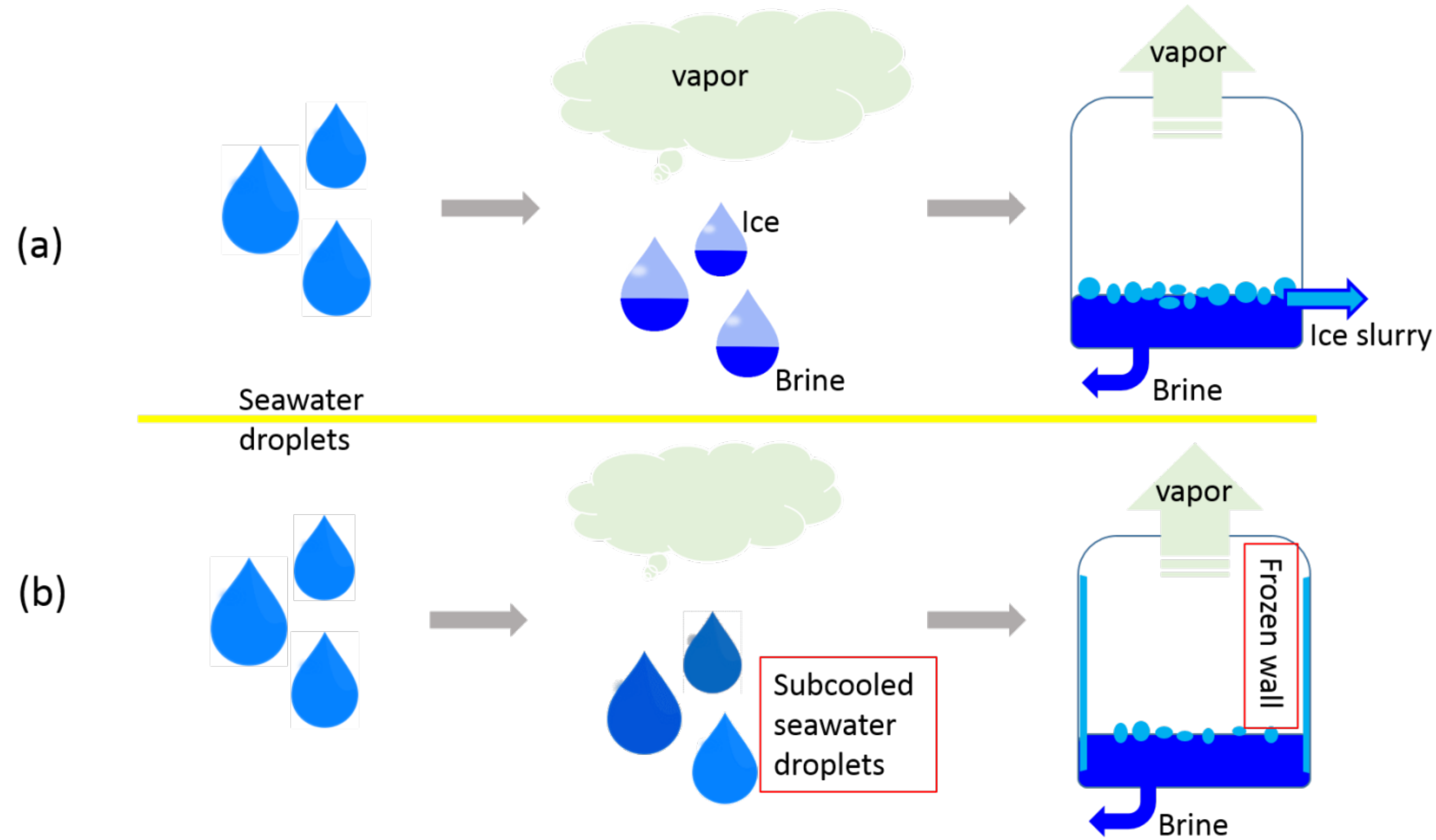
- Advanced Cooling Technologies, Inc.
  - Fangyu Cao, Ph.D., Principal Investigator
  - Jianjian Wang, Ph.D., Support Engineer
  - Raghavan Ranganathan, Ph.D., Support Engineer
- University of Maryland, College Park
  - Bao Yang, Ph.D., Professor, Academic Consultant
- Veolia Environnement
  - Jerome Leparc, Industrial Consultant

Project Objectives

- Problem
  - Cost of state-of-the-art clean water manufacturing (desalination) technologies is high.
  - AMO's target* for seawater desalination is <$0.5/m^3$, <1 kWh/m^3.
  - Vacuum Freezing Desalination can potentially exceed the target, if issues including freezing subcooling, ice handling, and effectiveness of water regeneration can be solved.
  - Current system provides little capability for subcooling suppression and material recycling.
- Objectives
  - Further develop the vacuum freezing desalination technology at <u>the triple point of seawater</u> with <u>minimized energy consumption</u> (18-29% lower than state-of-the-art RO technologies)
  - Challenge #1: <u>subcooling</u> of water prevents the triple point phase transition at "high" temperature
  - Challenge #2: <u>Ice</u> formation in the system that may block the operation
  - Challenge #3: <u>Water regeneration</u> from mixing ice and vapor

* **The AMO MYPP is available at: https://www.energy.gov/sites/prod/files/2017/01/f34/Draft%20Advanced%20Manufacturing%20Office%20MYPP_1.pdf**

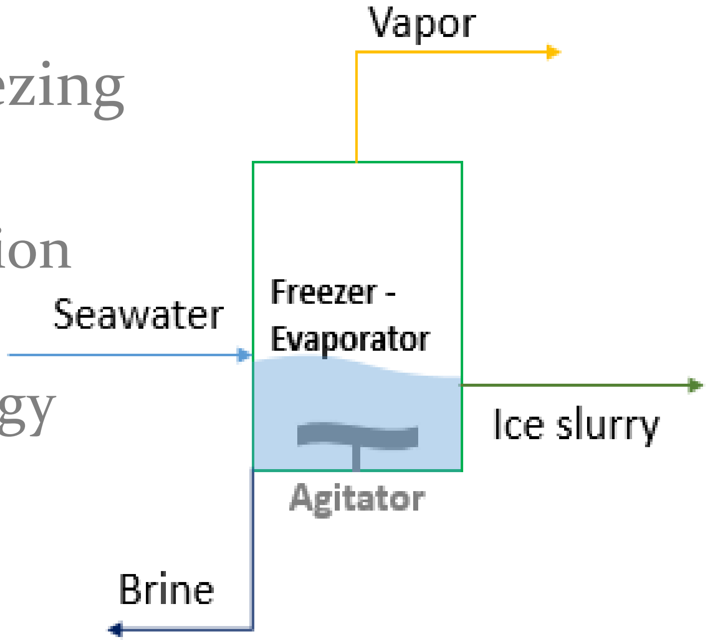
Major Technical Challenge



Vacuum freezing process at the triple point, in a) ideal condition without subcooling at freezing and b) reality with the existing of significant subcooling that prevents freezing in the droplets, therefore induces chamber temperature decrease, pressure drop, ice clogging, and energy consumption increase dramatically.

Technical Innovation

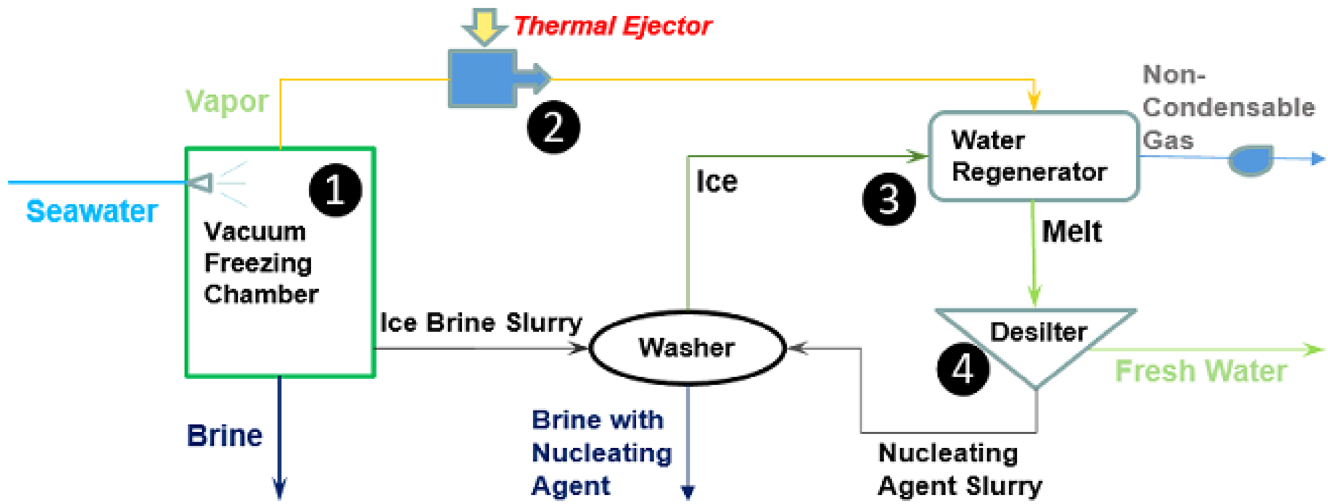
- Existing technology for vacuum freezing desalination
  - Small interface area of phase transition and heat transfer
  - Additional cooling source (and energy input) may need
  - Ice formation and handling issues



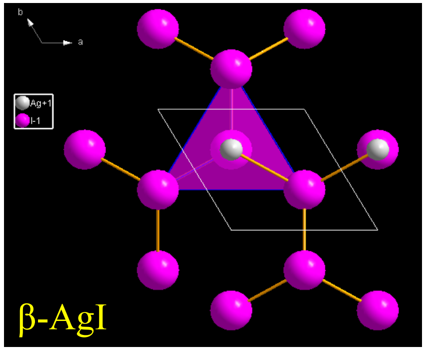
- Our approaches
  - Using spray freezing instead of bulk freezing for phase transition interface area increase and ice control
  - Suppressing subcooling of ice formation using modified nucleating agent (saves up to 69% energy consumption)
- Benefit
  - Less energy consumption, easier operation, lower cost of water

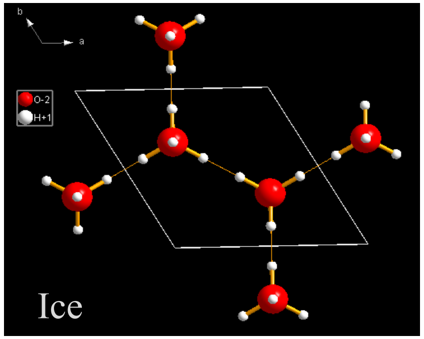
Technical Approach

- A novel vacuum freezing desalination process subcooling suppression and nucleating agent recycling



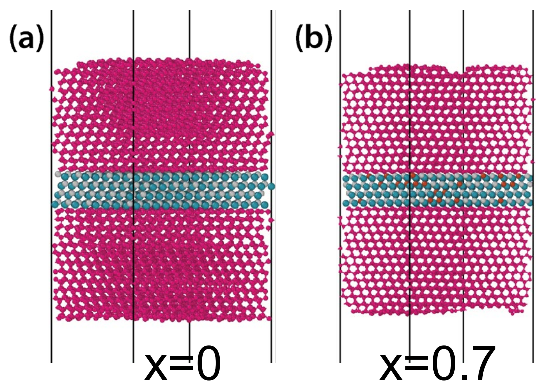
- Subcooling Suppression by epitaxial growth of ice on nucleating agents

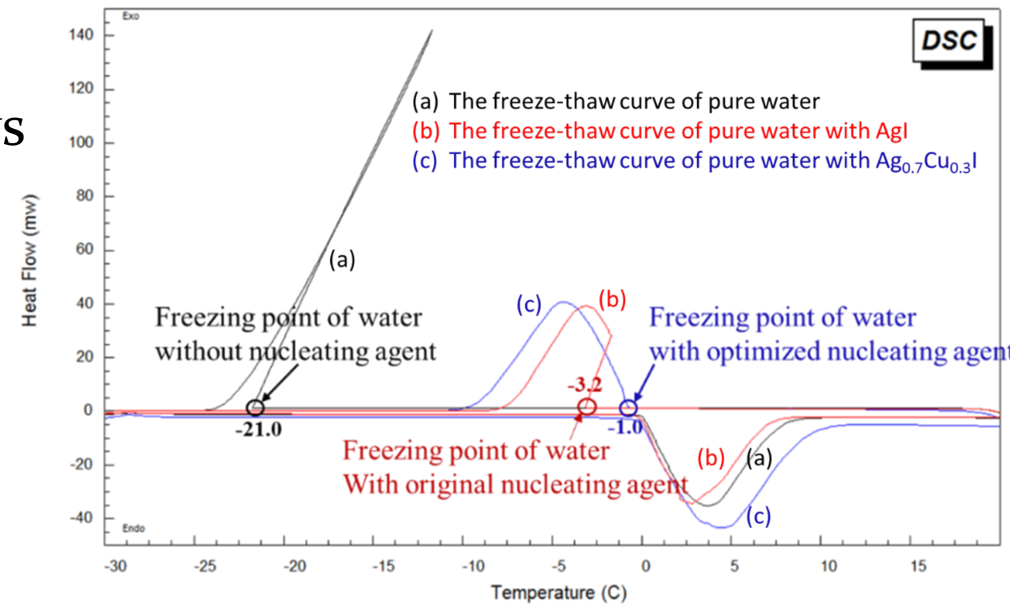




Results and Accomplishments

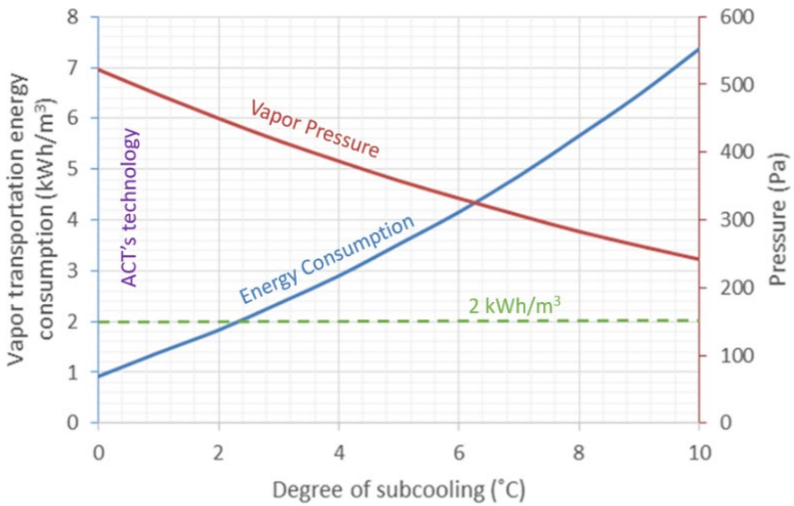
- Understanding the function of nucleating agents ($Ag_xCu_{1-x}I$) on ice formation
  - Experiments show that subcooling suppression by $Ag_xCu_{1-x}I$ provides optimum performance with x=0.7.
  - Meanwhile, Molecular dynamic simulation shows better epitaxial ice crystal growth with x=0.7.





Results and Accomplishments

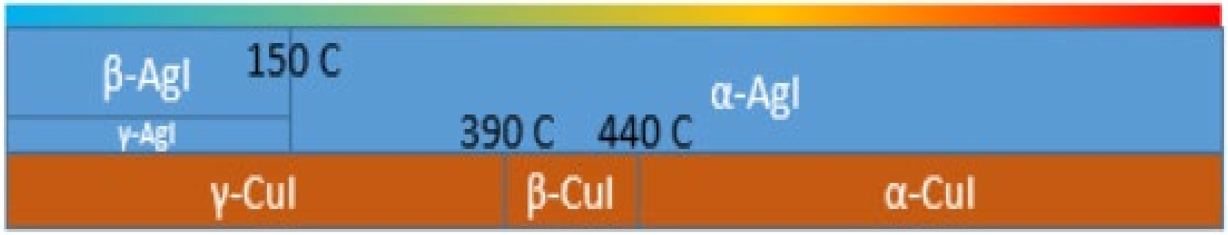
- Performance improvement of the vacuum freezing desalination system by subcooling suppression
  - The increase of subcooling of water at freezing induces the decrease of vapor pressure (red) in the vacuum freezing chamber and the increase of vapor pumping energy consumption per m^3 fresh water production (blue).



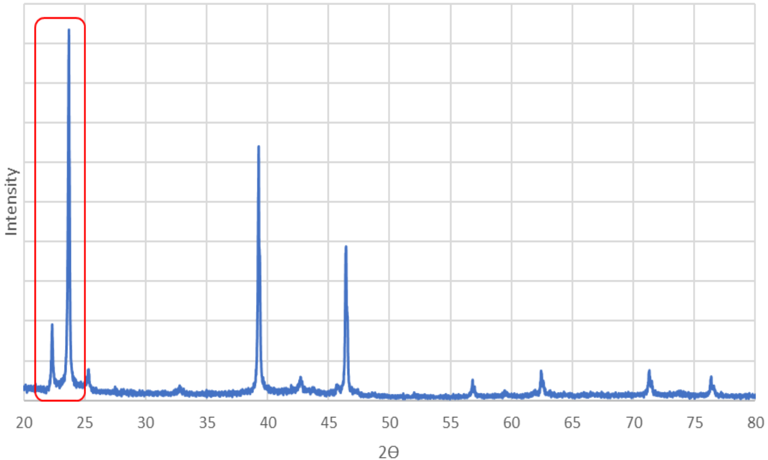
  - $0.34/$m^3$ cost of water is expected if the nucleating agents are developed and applied

Results and Accomplishments

- Nucleating agent synthesis
  - Different phases (β ,P63mc, wurtzite structure, iodargyrite; and γ F-43m, zinc blende structure, miersite) present different nucleating capability

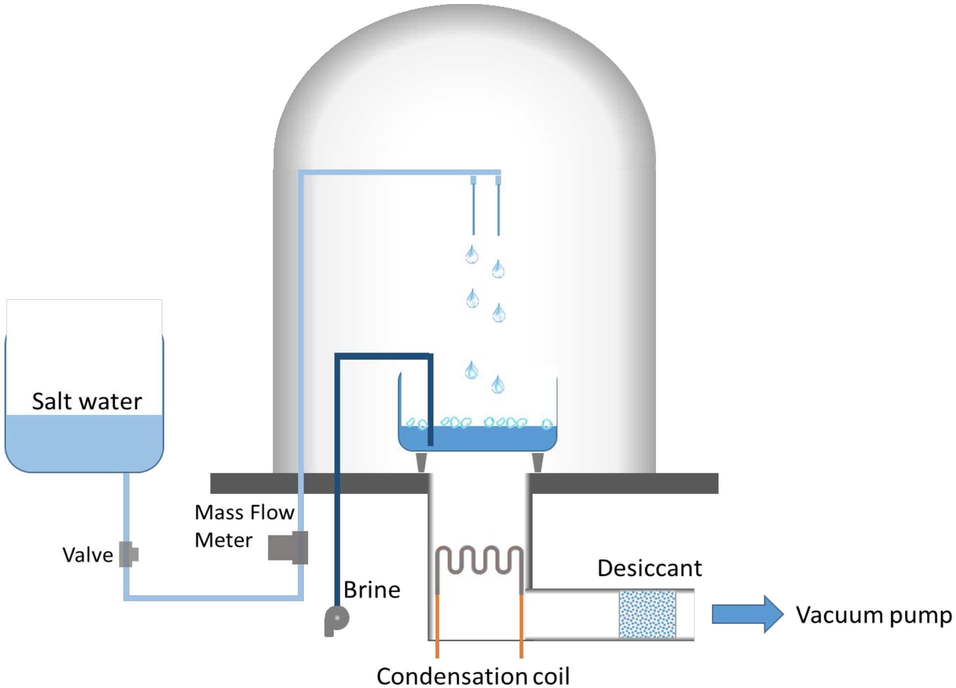


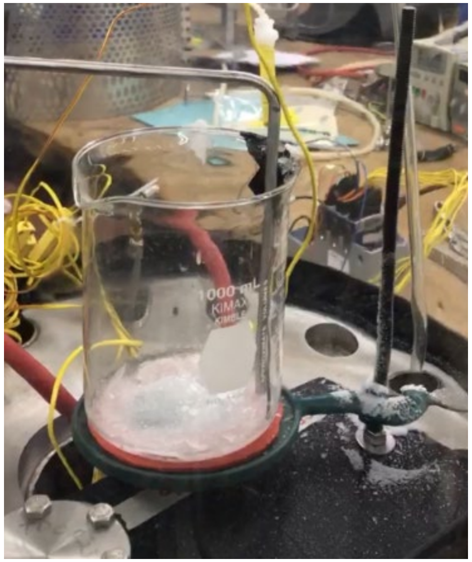
  - Experimental results show the ratio of β phase (preferred) is produced higher (>10%) at lower temperature (0 °C) and lower concentration.



Results and Accomplishments

- Vacuum freezing chamber
  - The vacuum freezing chamber has been scaled-up for 10 kg/day freshwater production.
  - Continuous ice formation was established under vacuum.

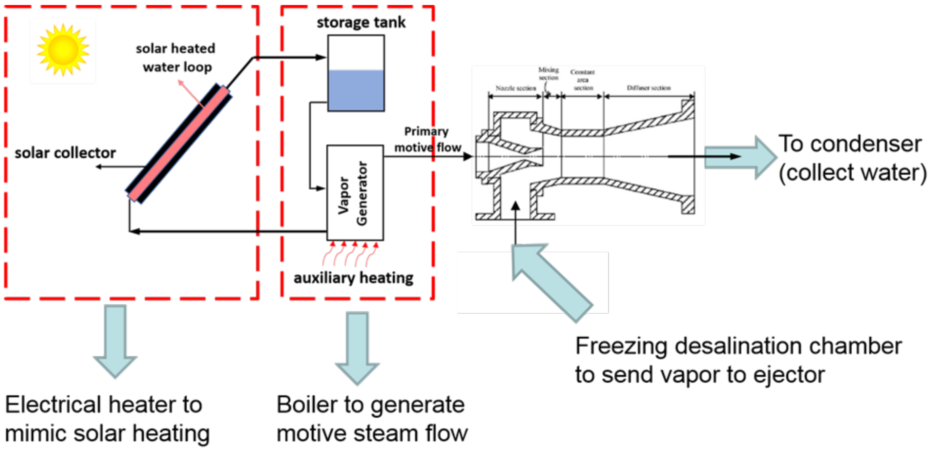


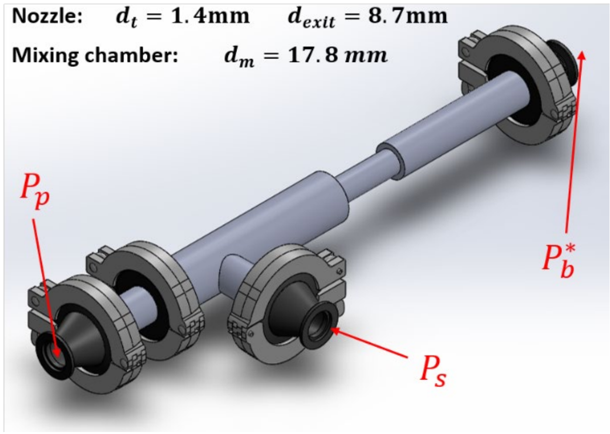


Ice/snow formation

Results and Accomplishments

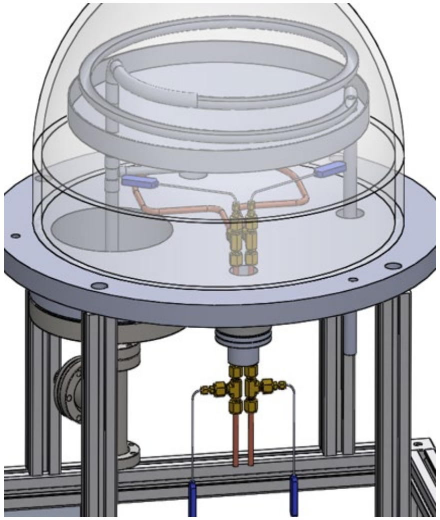
- Vapor compression / thermal ejector
  - ACT designed a vacuum ejector system to transport the water vapor from the vacuum freezing chamber to the condenser.
  - Auxiliary heating is supplied to the vapor generator to mimic solar heat for steam (as the driving flow) generation.

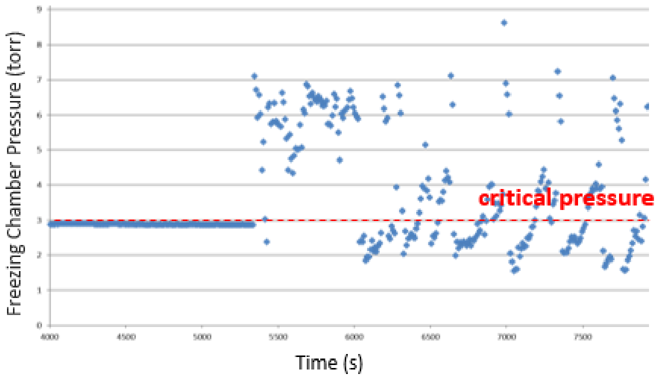




Results and Accomplishments

- Water Regeneration
  - A water regenerator is designed to condense compressed vapor on ice slurry for freshwater production.
  - Thermal ejector with steam generator is integrated to the water regenerator for testing. Refrigerant is used to mimic ice slurry.
  - Steady pressure can be maintained at designed pressure when steam generator temperature is 120 C.

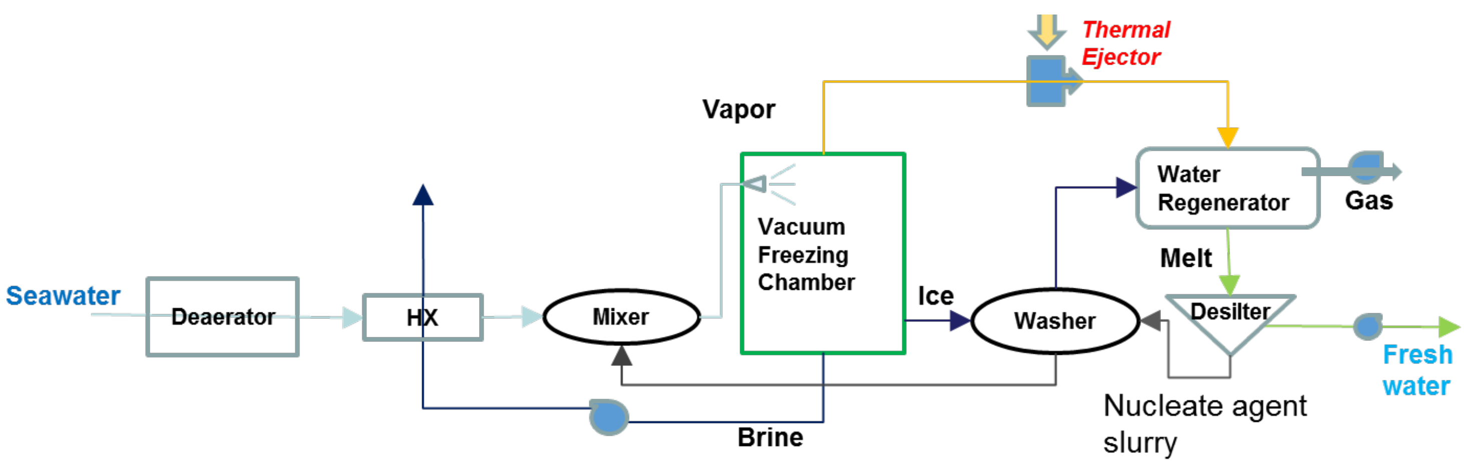




Pressure of freezing chamber. Steam generator temperature is at 120°C.

Results and Accomplishments

- Accomplishment and updated system design
  - Subcooling of water can be suppressed from 21 C to 1 C.
  - Vacuum freezing chamber is scaled up to 1 kg/h freshwater production.
  - Thermal ejector is used for vapor transportation, renewable and low-grade heat source can be used to drive the system.
  - Desilter (for solid-liquid separation) and ice washer (for brine removal from ice slurry) will be developed to complete the loop.



Transition (beyond DOE assistance)

- Further development strategy
  - ACT will continuously invest on technology development collaborating with Veolia and H2O Systems.
  - Subscale complete system by the end of this project.
  - Full scale demonstration by 2021, with the support of potential Phase IIA funding and upfront payment .
  - Technology will bring to market (by licensing) in 2021; revenue will be used for continuous development.
- Commercialization partner
  - Veolia Environnement S.A.
    - Engaging in technology review to fit industrial requirements
  - H2O Systems
    - Exploring niche market on water treatment for Oil & Gas industry
  - Larta Institute
    - Supporting on market information and commercialization advisory.