ASSESSMENT OF FREEZE MELTING TECHNOLOGY FOR BRINE CONCENTRATION

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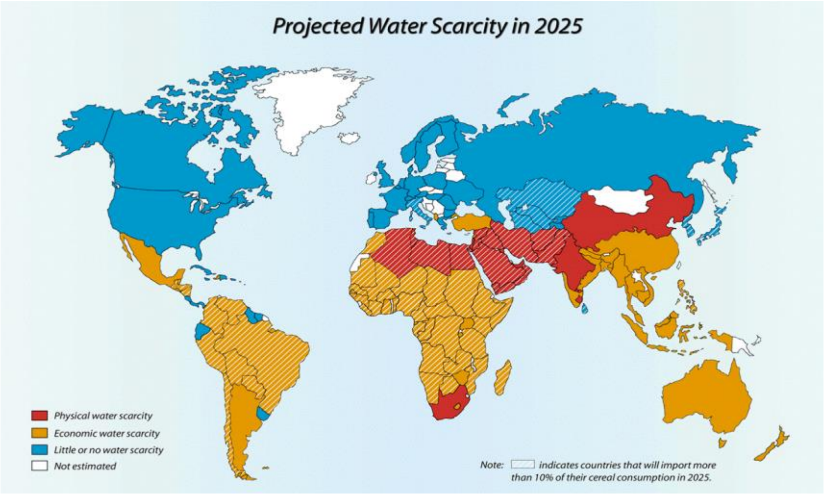
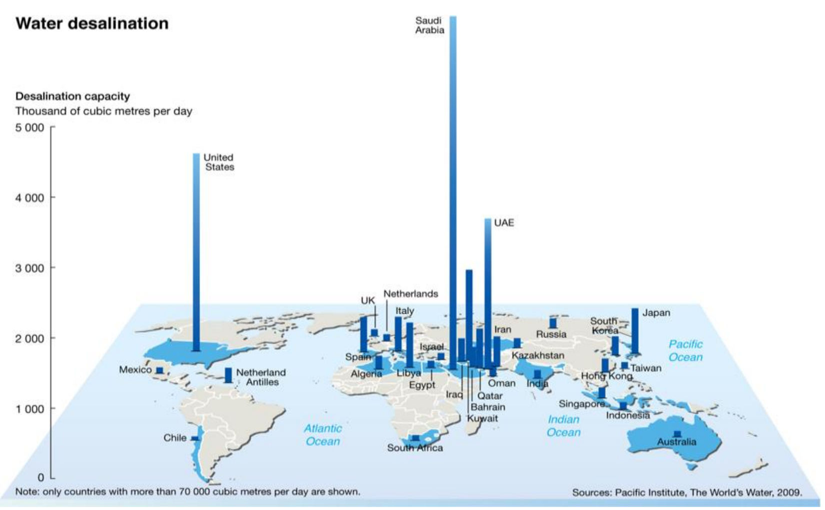
Overview

- Introduction
- Feed Characteristics & Experimental Setup
- Experimental Procedure
- Results
- General Observations
- Conceptual Design of Pilot-Scale System for Desalting High Saline Waters
- Conclusions & Recommendations

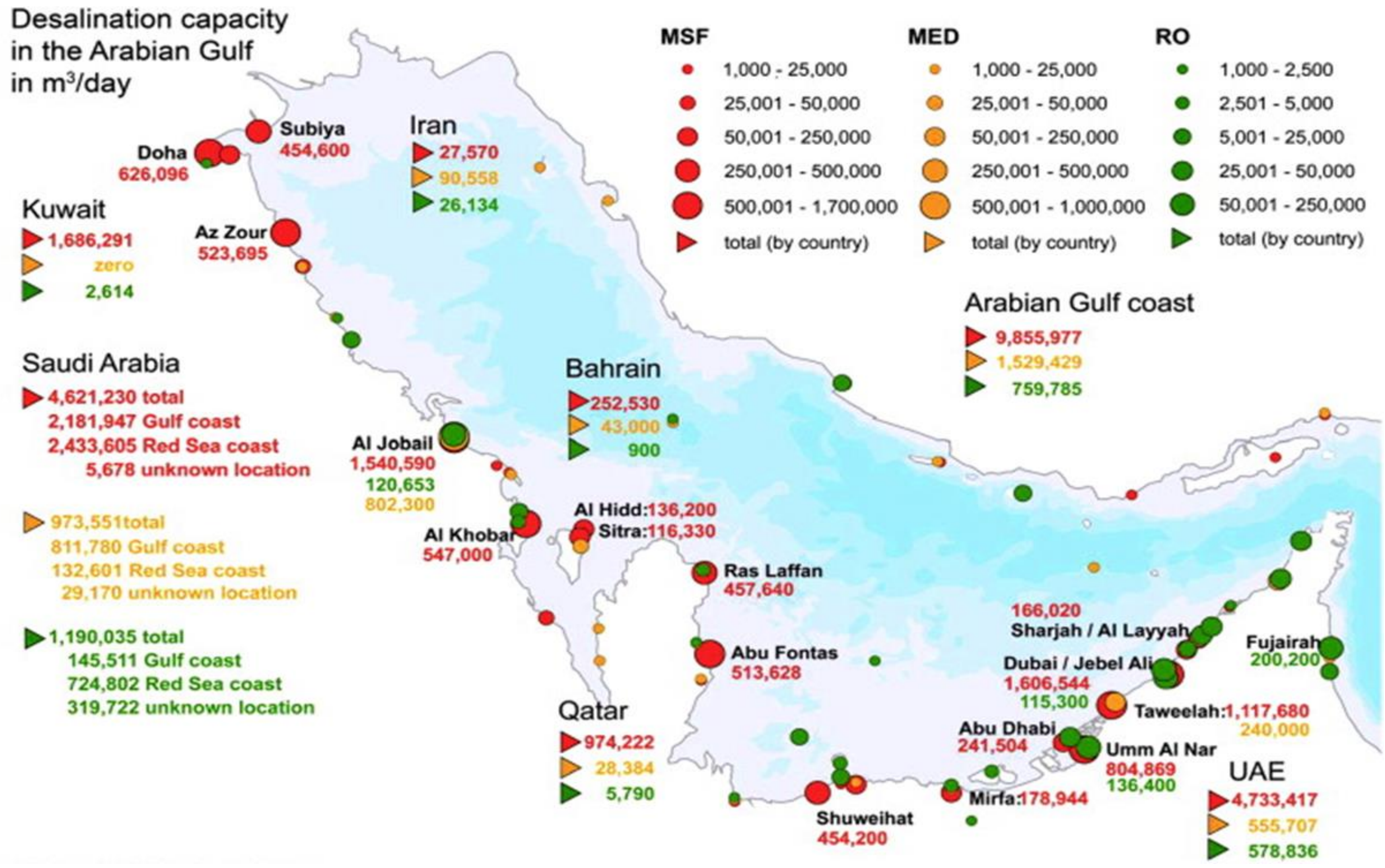
Introduction: Seawater Desalination in Kuwait





- Kuwait is situated in an arid region with
  - ✓ Extremely hot weather;
  - ✓ Very little rainfall; and
  - ✓ Very limited natural freshwater resources
- For the past six decades, Kuwait has fully depended on conventional seawater desalination technologies to meet its water needs.
- The desalinated water is produced by the following technologies:
  - ✓ Multistage Flash Distillation (MSF) (456.3 MIGPD);
  - ✓ Reverse Osmosis (RO) (120 MIGPD); and
  - ✓ Multi-Effect Distillation (MED) (107 MIGPD)
- On the global scale, Kuwait has the fourth largest seawater desalination capacity.

Seawater Desalination Plants in the Arabian Gulf



Introduction: Seawater Desalination Challenges

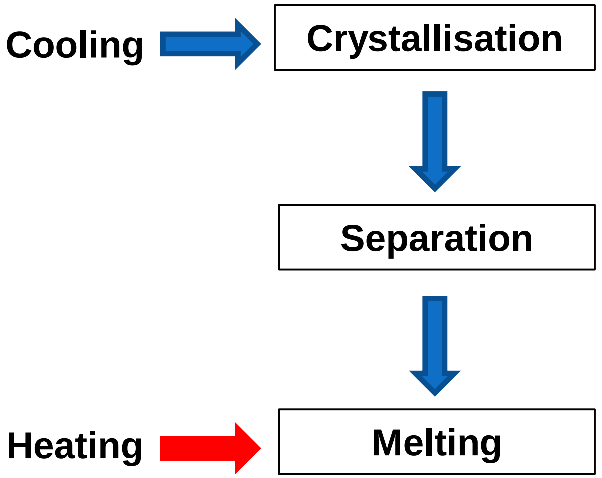
- Conventional seawater desalination technologies are prohibitively expensive and energy intensive processes, limited by:
  - ✓ Corrosion, Scaling, and fouling problems
  - ✓ High brine temperature (Thermal)
  - ✓ Limited water recovery
  - ✓ Osmotic pressure (RO membrane)
  - ✓ **Brine Challenges**
    - ❑ Large volumes
    - ❑ High TDS and degree of hardness
    - ❑ Contains chemical additives.
    - ❑ Temperature higher than feed water (Thermal)
    - ❑ Brine contains undesirably higher suspended substances compared to feed water (Thermal)

Major Components of Seawater and RO Brines

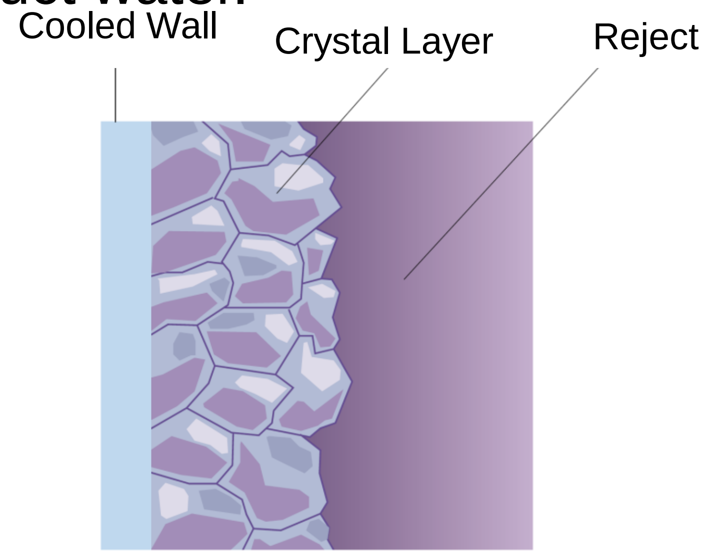
Parameter	Units	Arabian Gulf Seawater	Shuwaikh Desalination Plant
			RO Brine
pH	-	8.2	7.36
EC	mS/cm	68.4	98.09
Ca^{2+}	mg/l	648	904
Mg^{2+}	mg/l	1,676.7	2,736
$(SO_4)^{2-}$	mg/l	4,200	5,400
Cl^-	mg/l	26,100	44,000
Na^+	mg/l	16,925	24,950
TDS	mg/l	48,116	78,450

Introduction

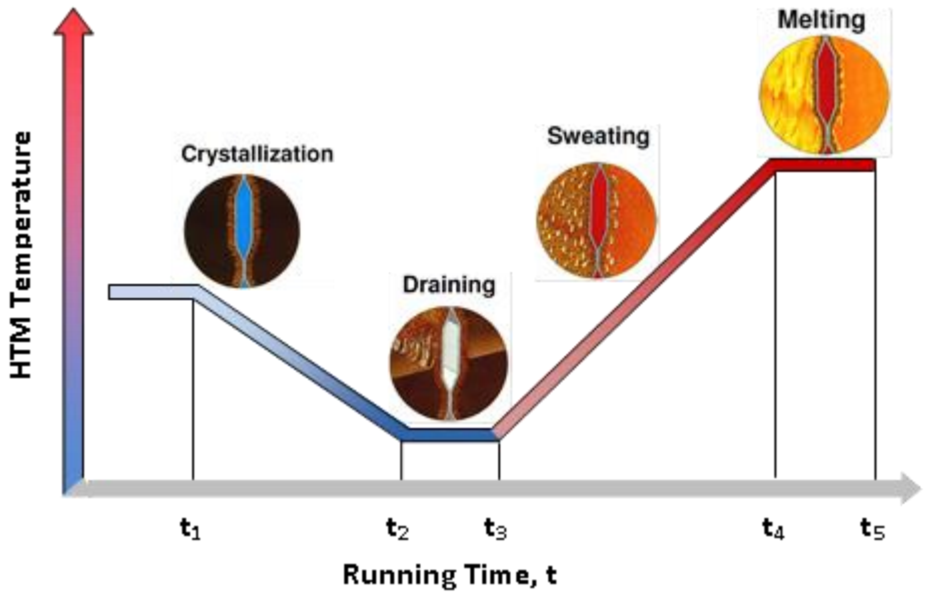
- To date, intensive research on innovative seawater desalination technologies is carried out by scientists all over the globe to determine the most feasible brine disposal process.
- Freeze-Melting (FM) technology could be feasible for such an application.
- FM is based on cooling, crystallisation, reject separation, ice melting and separation i.e. removing final product water.



Principle of FM



Layer Crystallisation



Temperature-Time Profile

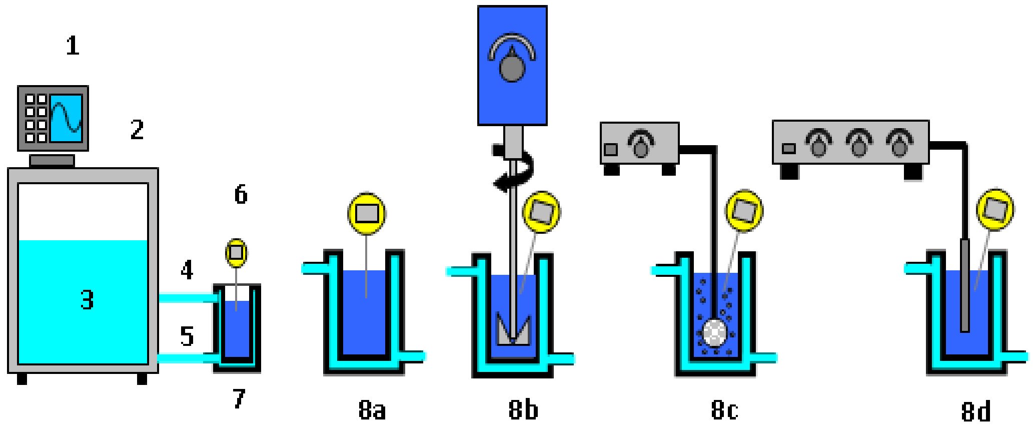
Introduction (cont'd)

- **Advantages of FM:**
  - Low energy requirement, low biological fouling challenges, very high separation factor, minimal scaling and corrosion problems, low-cost materials, absence of chemical pretreatment.
  - FM has advantages over conventional freezing desalination in terms of handling and separating ice slurries as well as:
    - Easily controllable crystal growth rates because FM depends on the refrigeration temperature.
    - No complicated ice separation and washing equipment.
    - No moving parts are involved in the process equipment.
    - Simple post-crystallisation treatments (i.e. washing and sweating).
- **Study Objective:** to assess the viability of a static and three dynamic FM processes to concentrate brines; compare experimental data; and propose a simple conceptual design of pilot-scale system for desalting and concentrating brines.

Feed Characteristics & Experimental Setup

The physical and chemical analysis of the tested feed

Feed	Feed Salinity (Wt%)	Electrical Conductivity (mS/cm)	Volume (ml)	Freezing Point (°C)
NaCl	7.0	84.8	500	-4.8



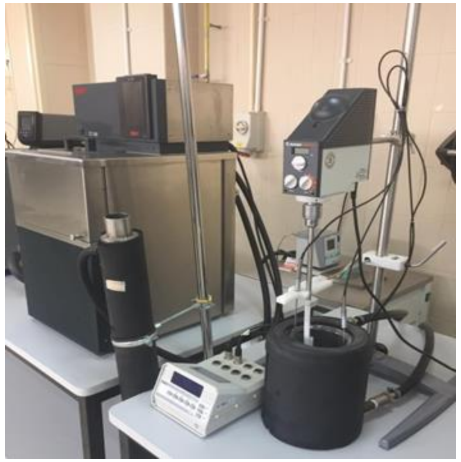
(1) Heating and cooling PID controller
(2) Heating and cooling bath thermostatic bath
(3) Heat transfer medium (HTM)
(4) and (5) Inlet and outlet HTM flexible tubes, respectively
(6) Digital thermometer
(7) Jacketed beaker
(8a) Static crystallizer
(8b) Mechanical stirring
(8c) Air-pump
(8d) Ultrasonic device.

Schematic of Experimental Setup

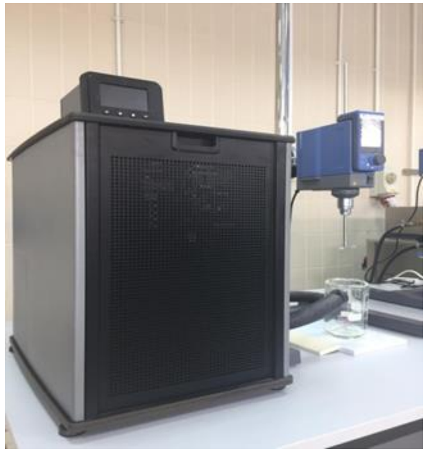
Experimental Setup (cont'd)

a. Static FM system

b. Dynamic FM system
Using
ultrasonic process (UP)



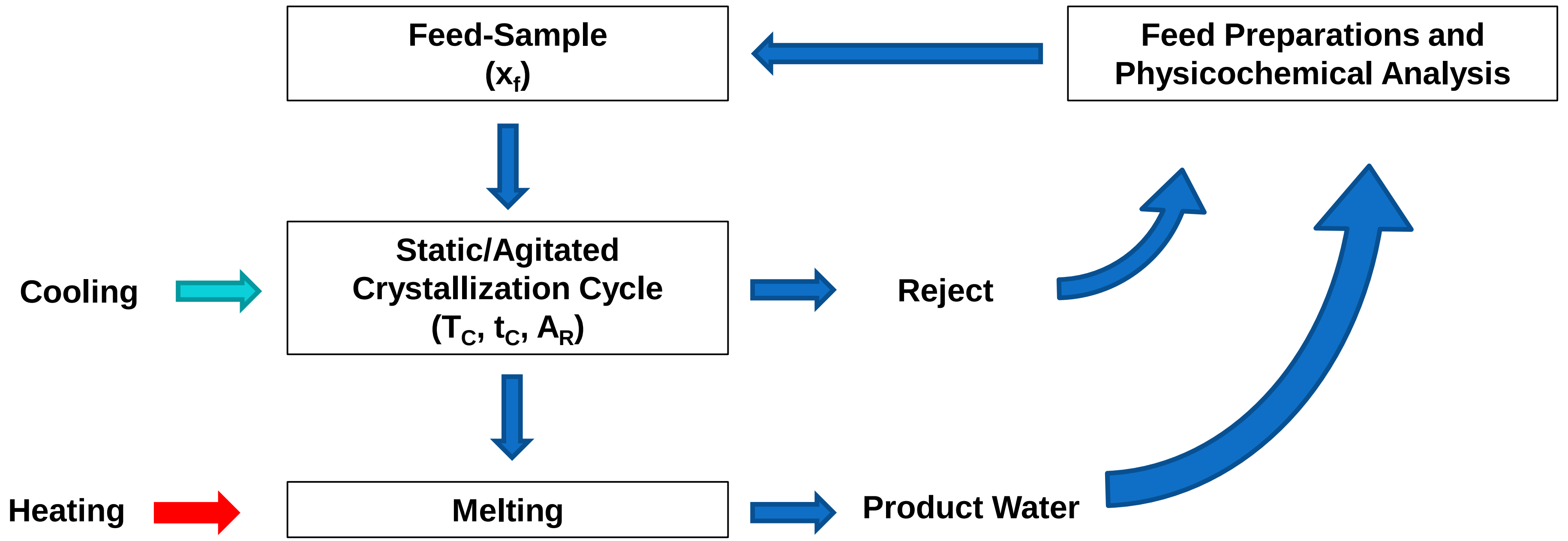
c. Dynamic FM system
Using
bubbling process (BP)



d. Dynamic FM system
Using
mechanically stirred system (MSS)

The Tested Static and Dynamic FM Crystallization Systems

Experimental Procedure



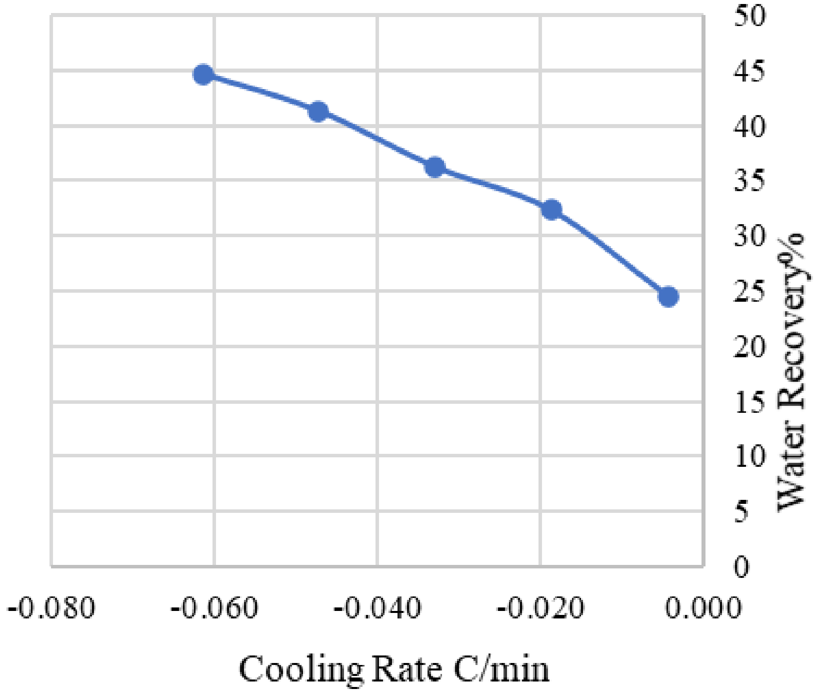
Simplified Block Diagram of the Experimental Procedure

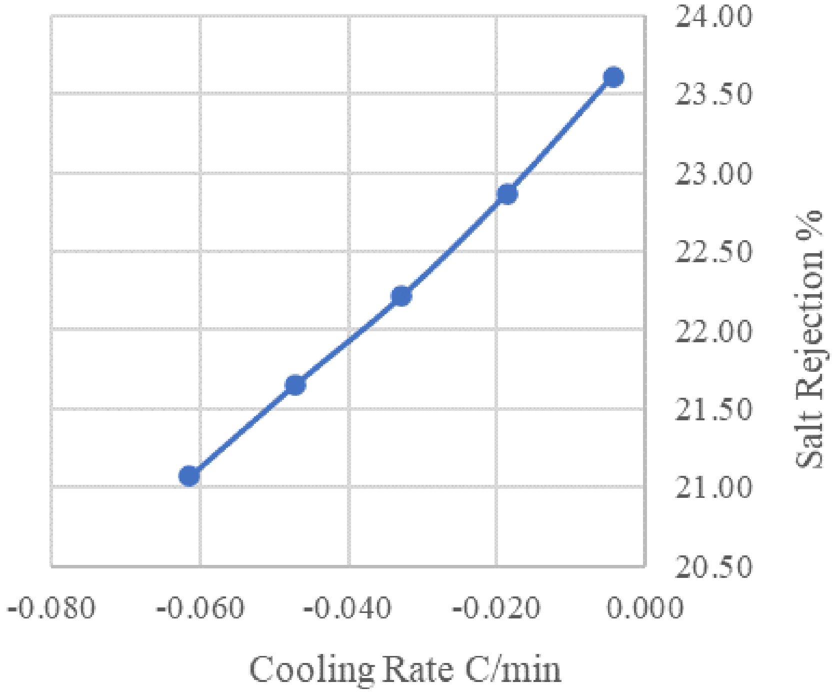
Experimental Procedure (cont'd)

Overview of the Logic of the Experimental Envelop

Parameter			Reasoning
Start-Point Temp. (T_{SPT}), ºC		25	Provide performance indicators at room temperature conditions.
End-Point Temp. (T_{EPT}), ºC		-4 – -30°C	Testing the effect of end-point temperature to the performance indicators of the crystallisation process.
Crystallisation Method	Static	Static Method	Testing the effect of static method upon the performance indicators of the crystallisation process.
	Stir Rate	200 – 800 rpm	Testing the effect of stir rate upon the performance indicators of the mechanically stirred crystallisation process.
	Flow-Rate	10 – 30 L/min	Testing the effect of air flow-rate upon the performance indicators of the crystallisation process with air-compressor.
	Amplitude	20 – 60	Testing the effect of amplitude rate upon the performance indicators of the crystallisation process with ultrasonic device.
Running Time, min		60 – 240 min	Testing the effect of cycle time upon the performance indicators.
Feed Concentration, ppm		70,000	Testing with NaCl to simulate brine produced from RO.

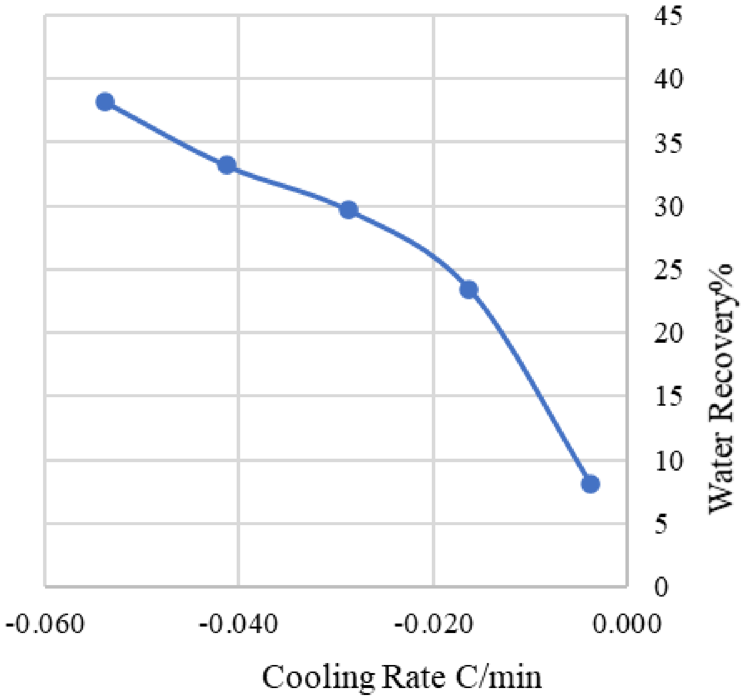
Results: Static Freeze Crystallization Process

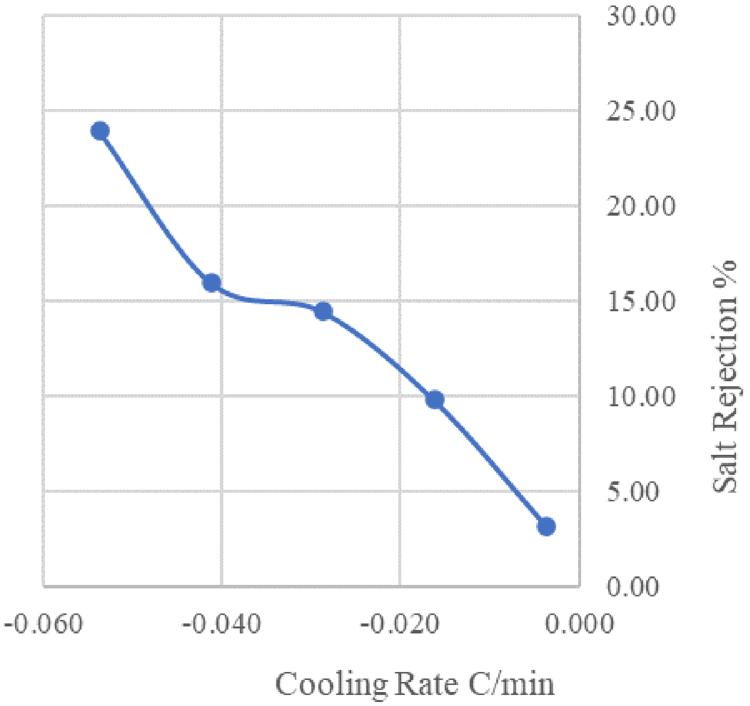




Water Recovery and Salt Rejection Versus Cooling Rate

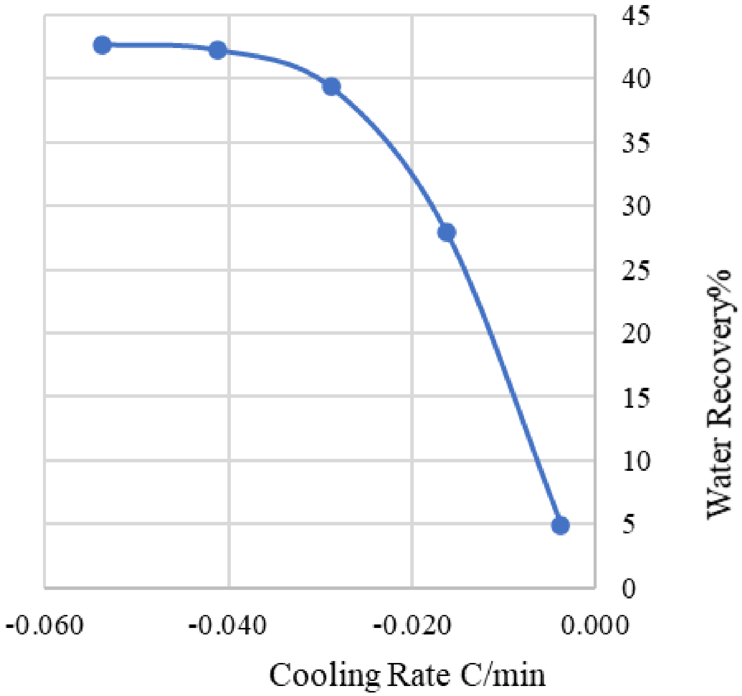
Results: Dynamic Crystallization Process using Ultrasonic Process

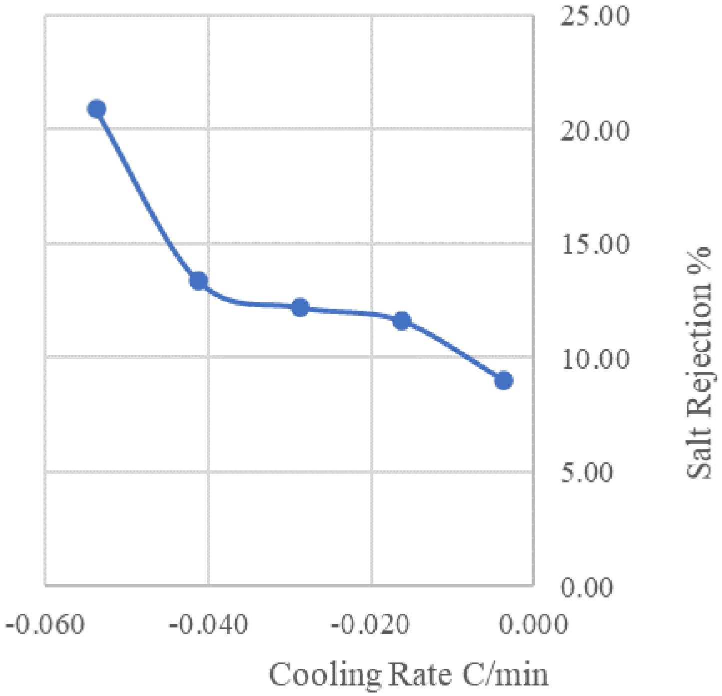




Water Recovery and Salt Rejection Versus Cooling Rate at Amplitude of 20

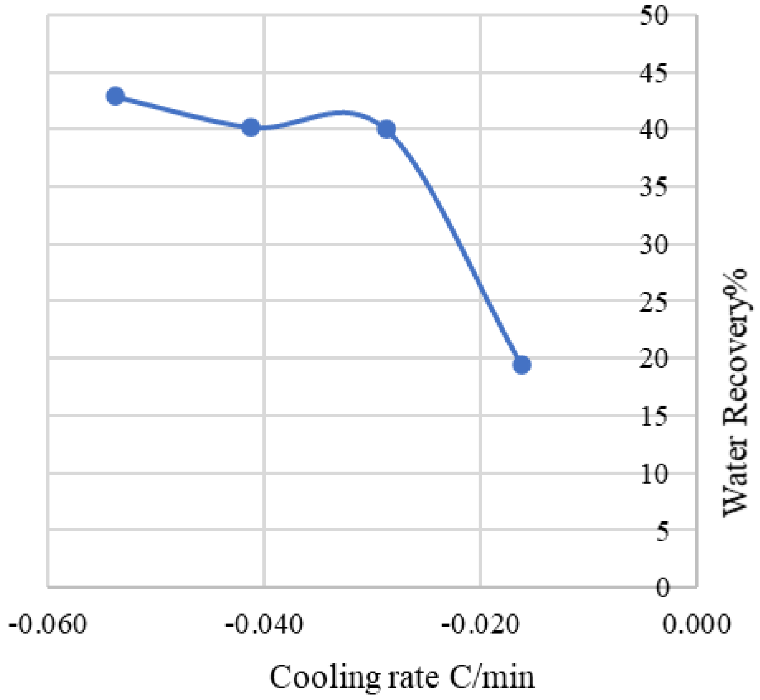
Results: Dynamic Crystallization Process using Ultrasonic Process (cont'd)

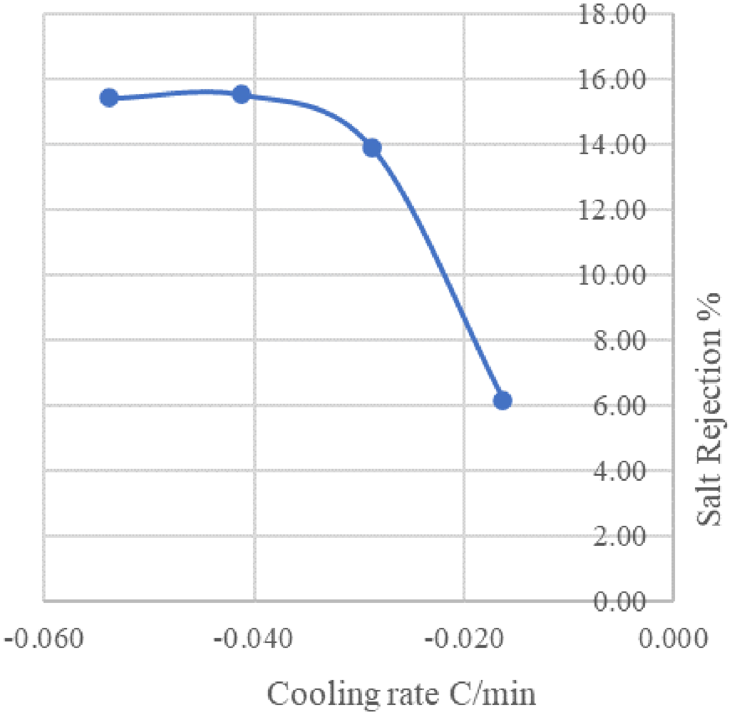




Water Recovery and Salt Rejection Versus Cooling Rate at Amplitude of 40

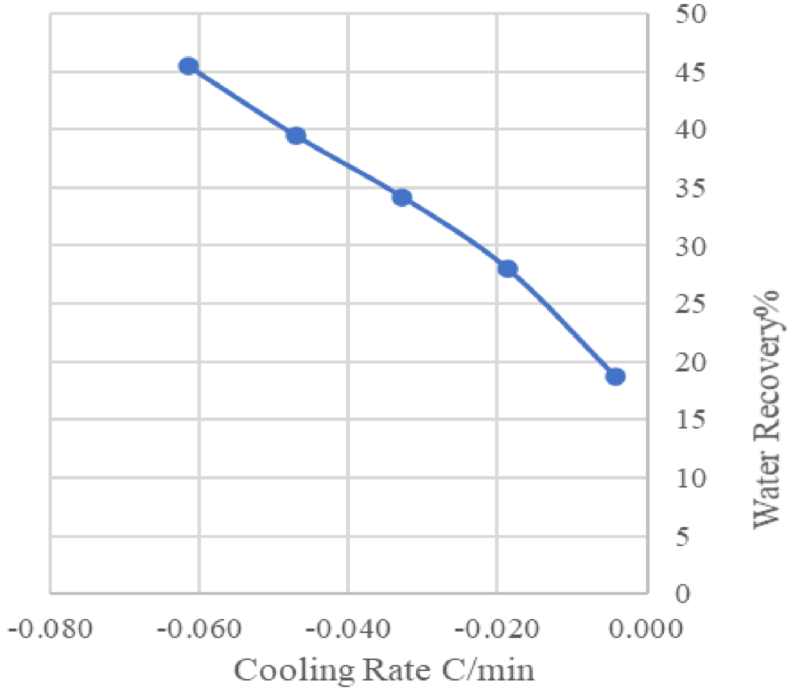
Results: Dynamic Crystallization Process using Ultrasonic Process (cont'd)

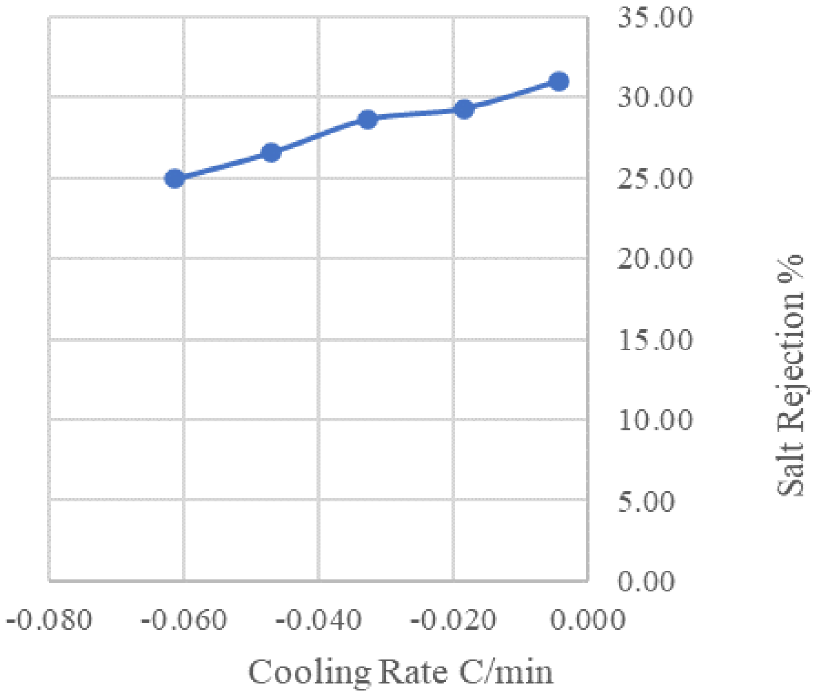




Water Recovery and Salt Rejection Versus Cooling Rate at Amplitude of 60

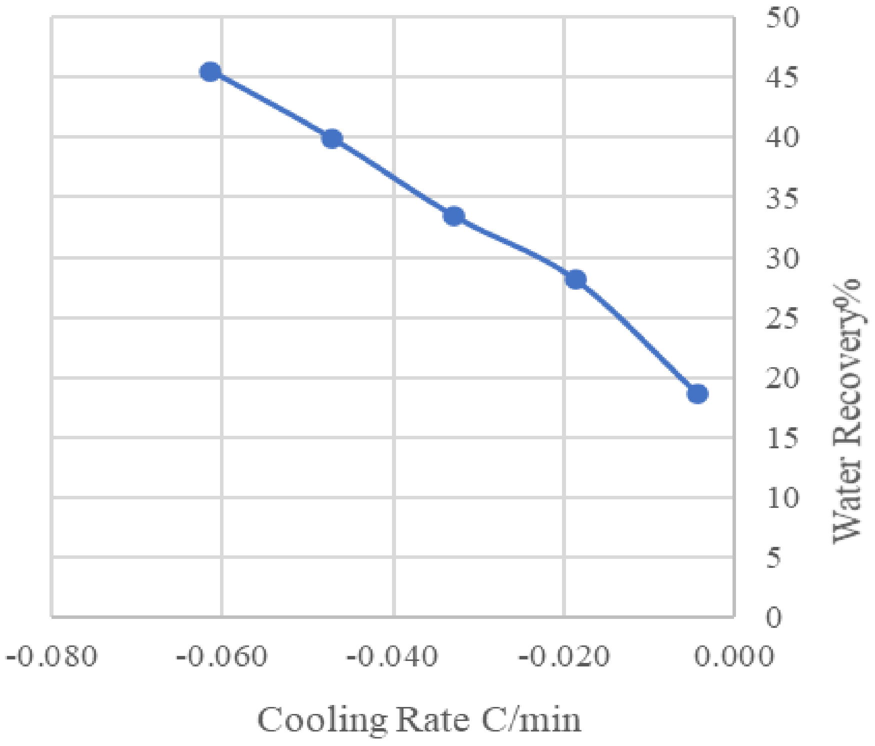
Results: Dynamic Crystallization Process using Bubbling Process

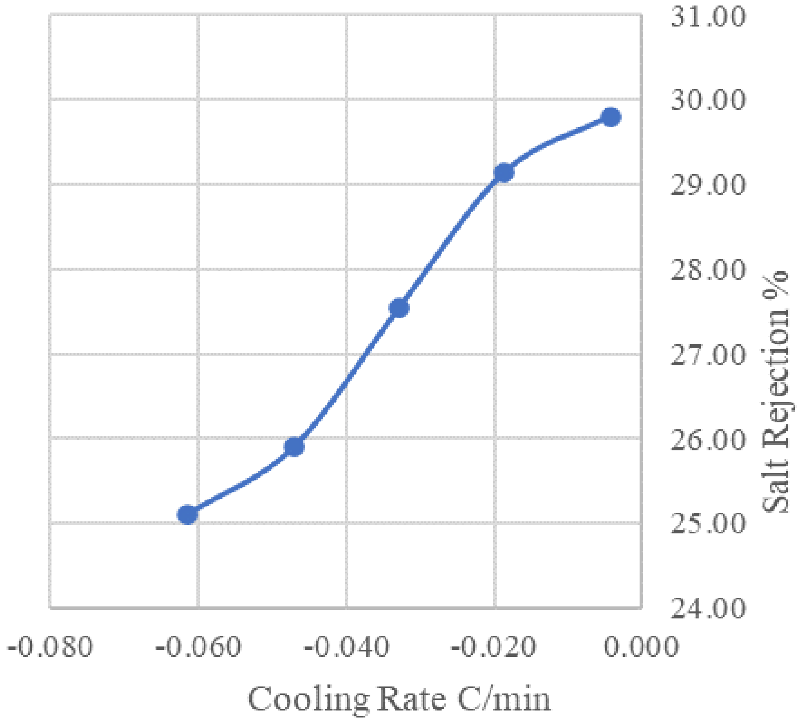




Water Recovery and Salt Rejection Versus Cooling Rate at Air-Flow Rate of 10 L/min

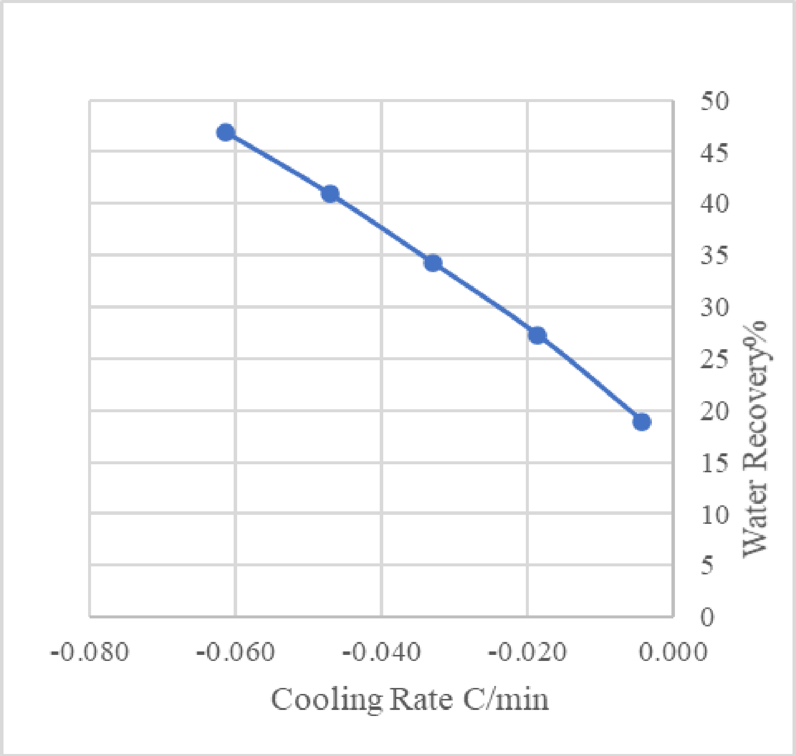
Results: Dynamic Crystallization Process using Bubbling Process (cont'd)

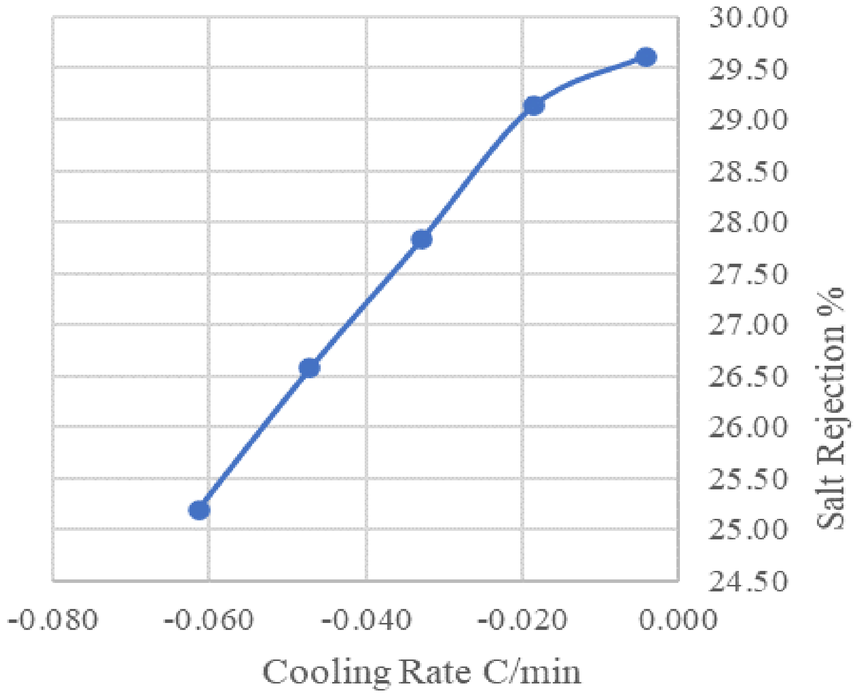




Water Recovery and Salt Rejection Versus Cooling Rate at Air-Flow Rate of 20 L/min

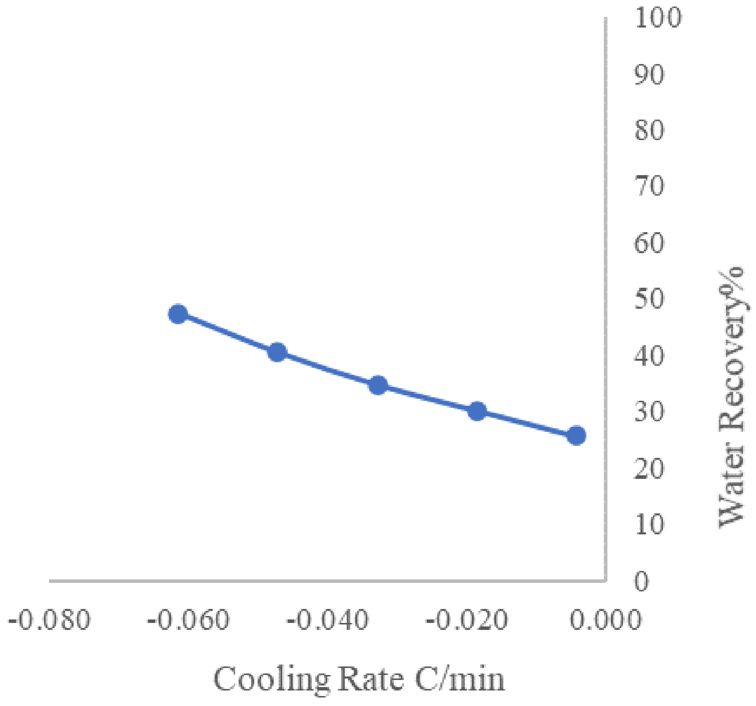
Results: Dynamic Crystallization Process using Bubbling Process (cont'd)

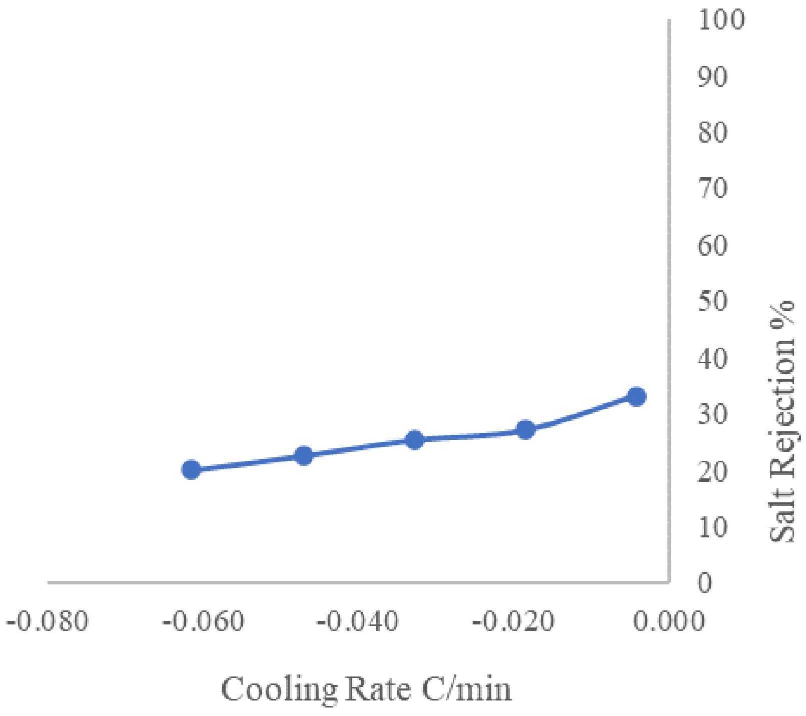




Water Recovery and Salt Rejection Versus Cooling Rate at Air-Flow Rate of 30 L/min

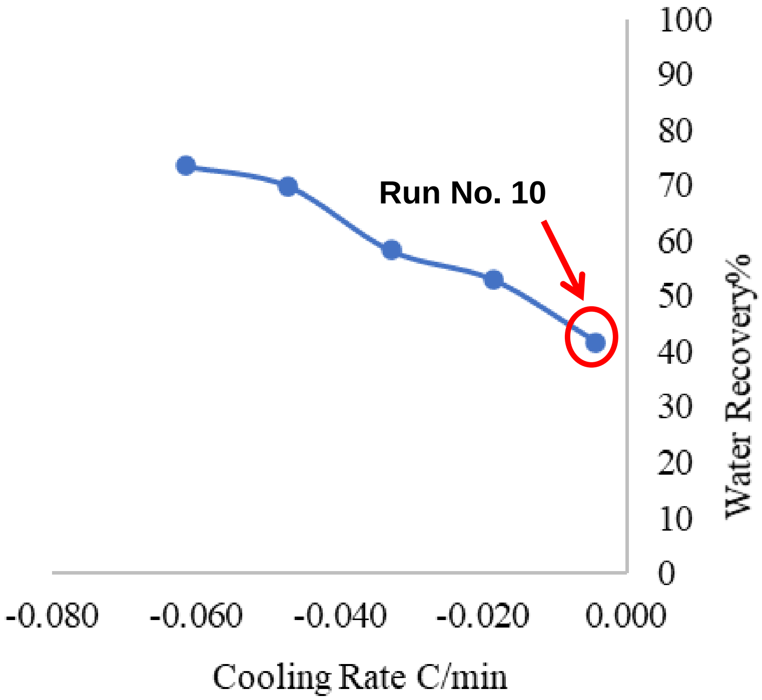
Results: Dynamic Crystallization Process using Mechanically Stirred System

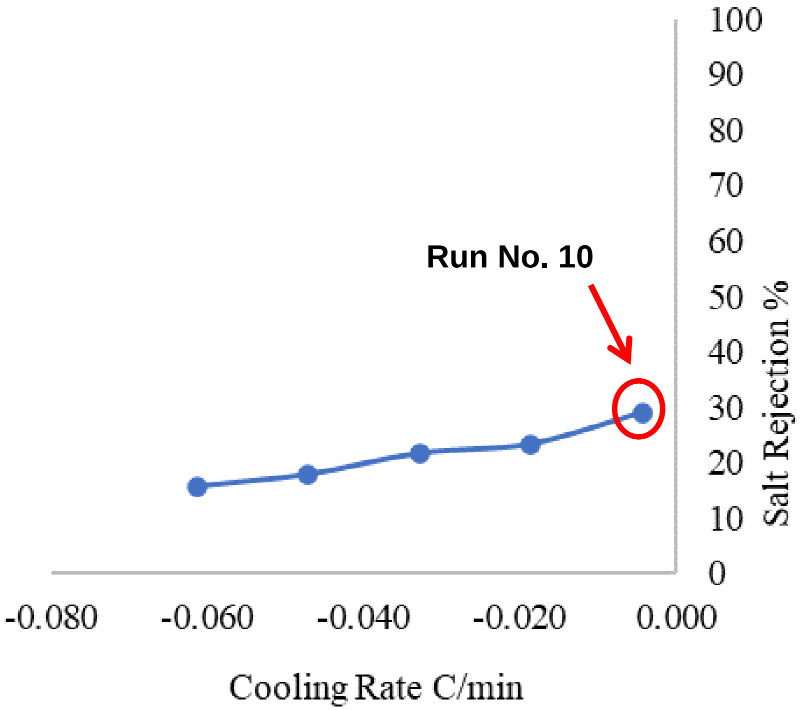




Water Recovery and Salt Rejection Versus Cooling Rate at Stir-Rate of 200 rpm

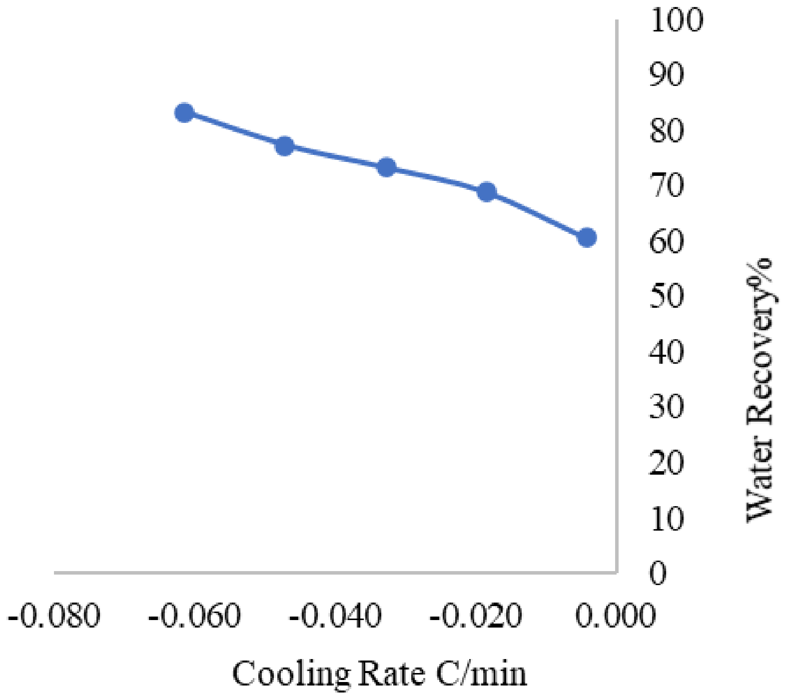
Results: Dynamic Crystallization Process using Mechanically Stirred System (cont'd)

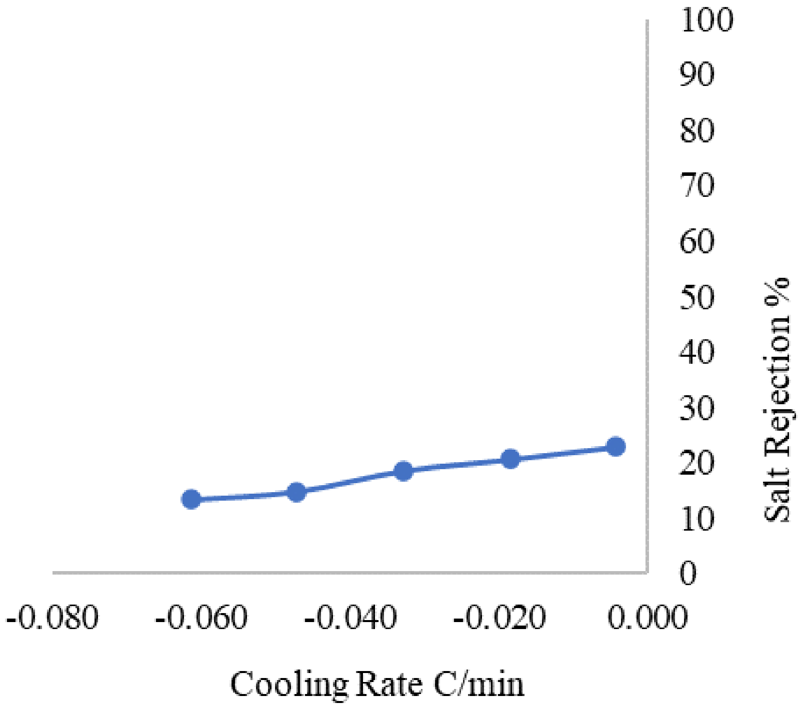




Water Recovery and Salt Rejection Versus Cooling Rate at Stir-Rate of 400 rpm

Results: Dynamic Crystallization Process using Mechanically Stirred System (cont'd)





Water Recovery and Salt Rejection Versus Cooling Rate at Stir-Rate of 600 rpm

General Observations

- Although the product water obtained by the tested FM systems was not comparable to RO, FM processes are still promising since the tested systems were operated as a single FM stage without the use of post-crystallization treatments i.e. washing and sweating process.
- According to optimal operating conditions, the tested FM influenced by the stirring process was capable of reducing the salinity values of feed with salt concentration of 70,000 ppm down to an average of 49,690 ppm with an average water recovery ratio of 41.1%.
- This means that the proposed FM technology is capable of producing final product water close to seawater quality that can be further desalted by RO membrane technology to produce potable water.

Conceptual Design of Pilot-Scale System for Desalting High Saline Waters

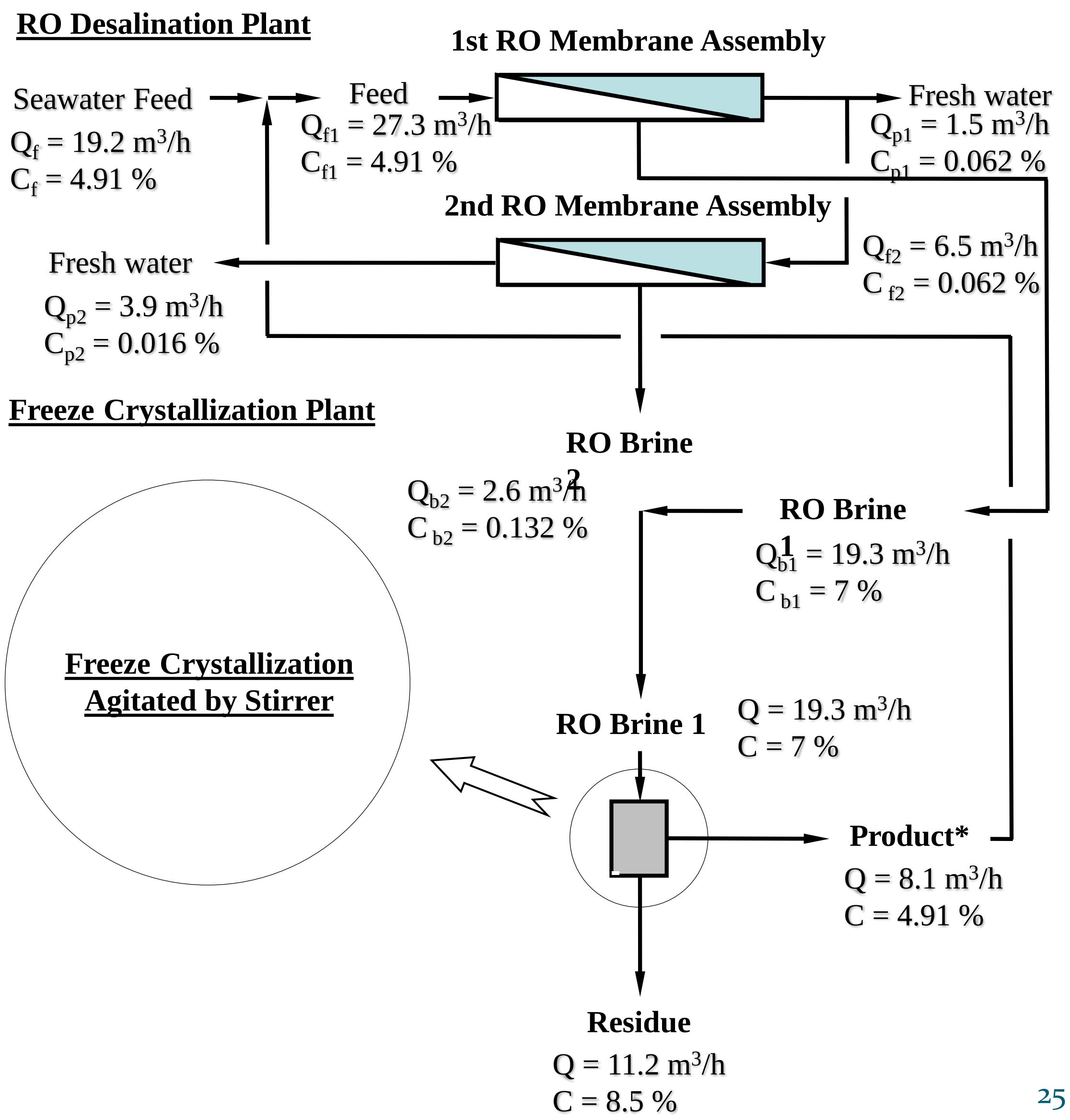
- Selected System: Dynamic Crystallization Process using Mechanically Stirred System.
- Operating conditions:
  - Optimal cooling rate and stirring rate are -0.004 and 400 rpm, respectively.
  - Feed and product concentration are 70,000 ppm and 49,690 ppm, respectively.
  - Water recovery ratio of 41.1%.

- The proposed FM process was designed with a single freezing stage without use of a sweating process.
- Kadhmah RO desalination plant was used for the integration with the proposed FM process under continuous operation.

Conceptual Design of Pilot-Scale System for Desalting High Saline Waters

Estimation of the annual rates of all water streams of the Kadhmah RO desalination, the freeze crystallisation plant, and the combined plants in tons per year.

Kadhmah RO Plant		
Feed[1] (t/y)	Product[2] (t/y)	Brine[3] (t/y)
239.15	34.17	191.84
Freeze Crystallization Plant		
Feed (t/y)	Product (t/y)	Residue (t/y)
169.07	70.96	98.11
Combined Plant		
Feed[1] (t/y)	Product[2] (t/y)	Residue (t/y)
168.19	34.17	98.11



Conclusions & Recommendations

Conclusions

- Various forms of FM were investigated for concentrating high saline water.
- Overall, the experimental results showed that the freeze crystallization influenced by the stirring process was effective in concentrating high salinity feed, while producing saline water that could subsequently be desalted using RO desalination technology.
- This gives a clear indication that the proposed FM process could be a feasible process for concentrating RO brines in order to minimize the volume of the waste streams of RO desalination plants, and more specifically, inland desalination plants.

Conclusions & Recommendations (cont'd)

Recommendations

- Increasing the crystallizer capacity to a suggested range of 50 to 100 L, taking into consideration the fact that the investigated agitation system might be changed to higher agitation rates corresponding to the crystallizer's capacity.
- Multistage FM and post-treatment processes should be further investigated and assessed.
- A jacketed tube with a discharge option at the bottom of the crystallizer could be used to remove the rejected brine from the crystallizer once the crystallization process is completed.
- Multistage FM and post-treatment processes should be subjected to further detailed technical-economic analysis and investigations for future applications.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