Steady-state analysis of a desalination system based on the principle of NVD

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Overview

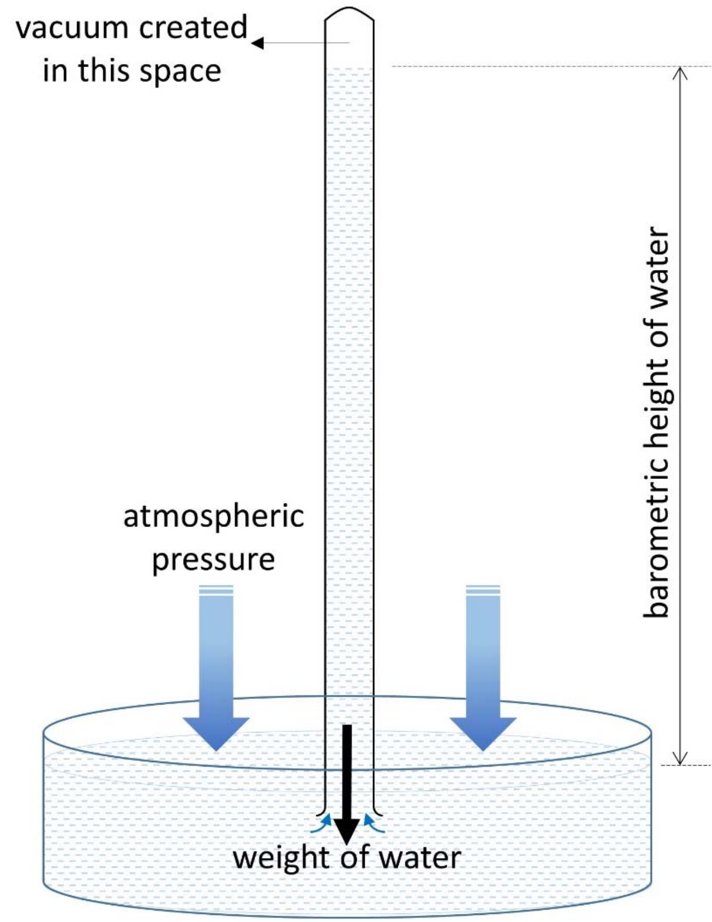
- Introduction
- Process Description
- Mathematical Model
- Results
- Conclusion

Introduction

- Freshwater shortage is an ever-growing problem especially in areas like the MENA region
- Desalination is the only viable solution
- Conventional desalination technologies are energy intensive
- Many environmental hazards are associated with desalination
- Renewable energy sources need to be explored

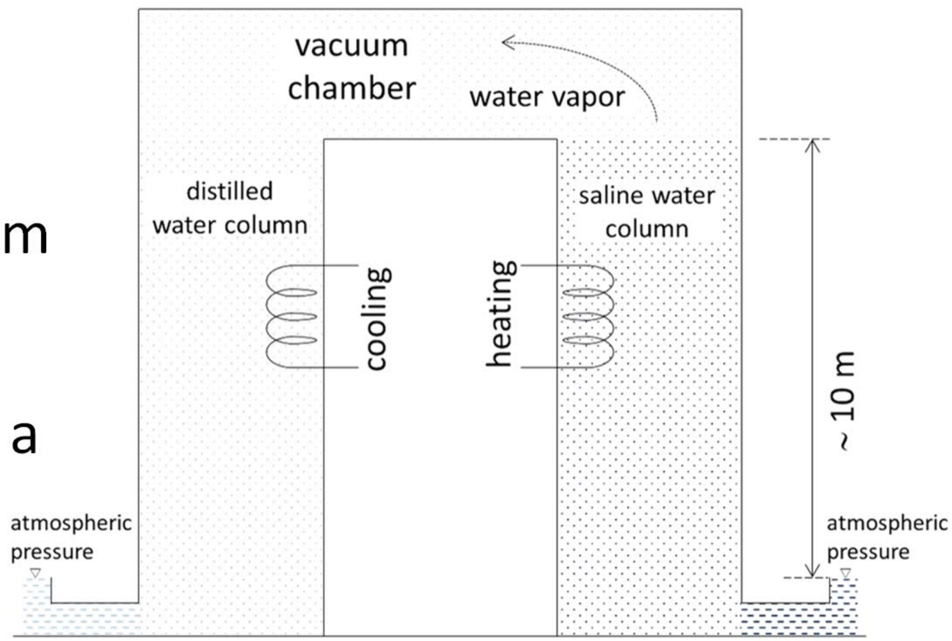
Natural Vacuum Distillation

- Water column with a sealed top drains into an open container of water
- Water column with a height of ~10.3 m can balance the atmospheric pressure
- The space above the water column has a “natural vacuum”



Natural Vacuum Distillation

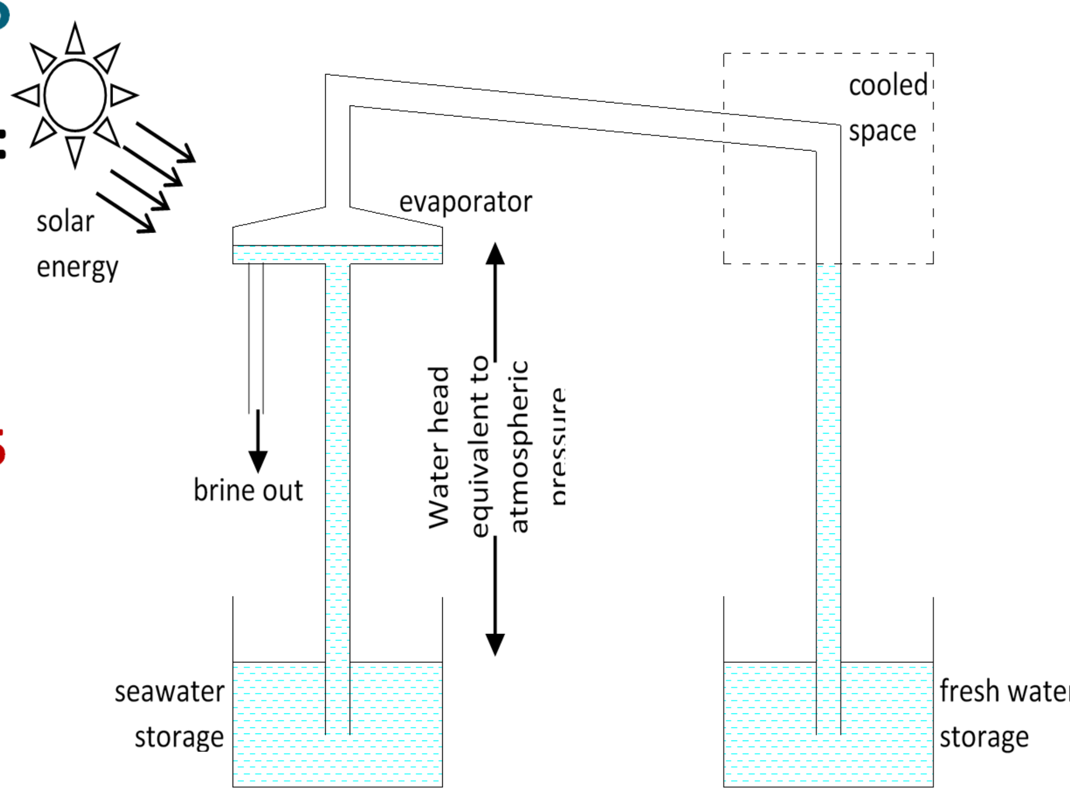
- Two water columns – saline water and distilled water
- Connected on top by a vacuum chamber
- Saline water is maintained at a temperature higher than distilled water
- Water vapor moves from saline water column to distilled water column



Previous Works

Production Rates (kg/day):

- Single Stage:
  - Bemporad, 1995: (**1.7**)
  - Alkharabsheh, 2003: **6.5**
  - Eames et al., 2007: **30**
  - Gude, 2008: **192**
  - Jitsuno, 2012: **10**
- Two-Stage:
  - Abutayeh (2008): **40**
  - Gude (2012): **500**



Major issue:

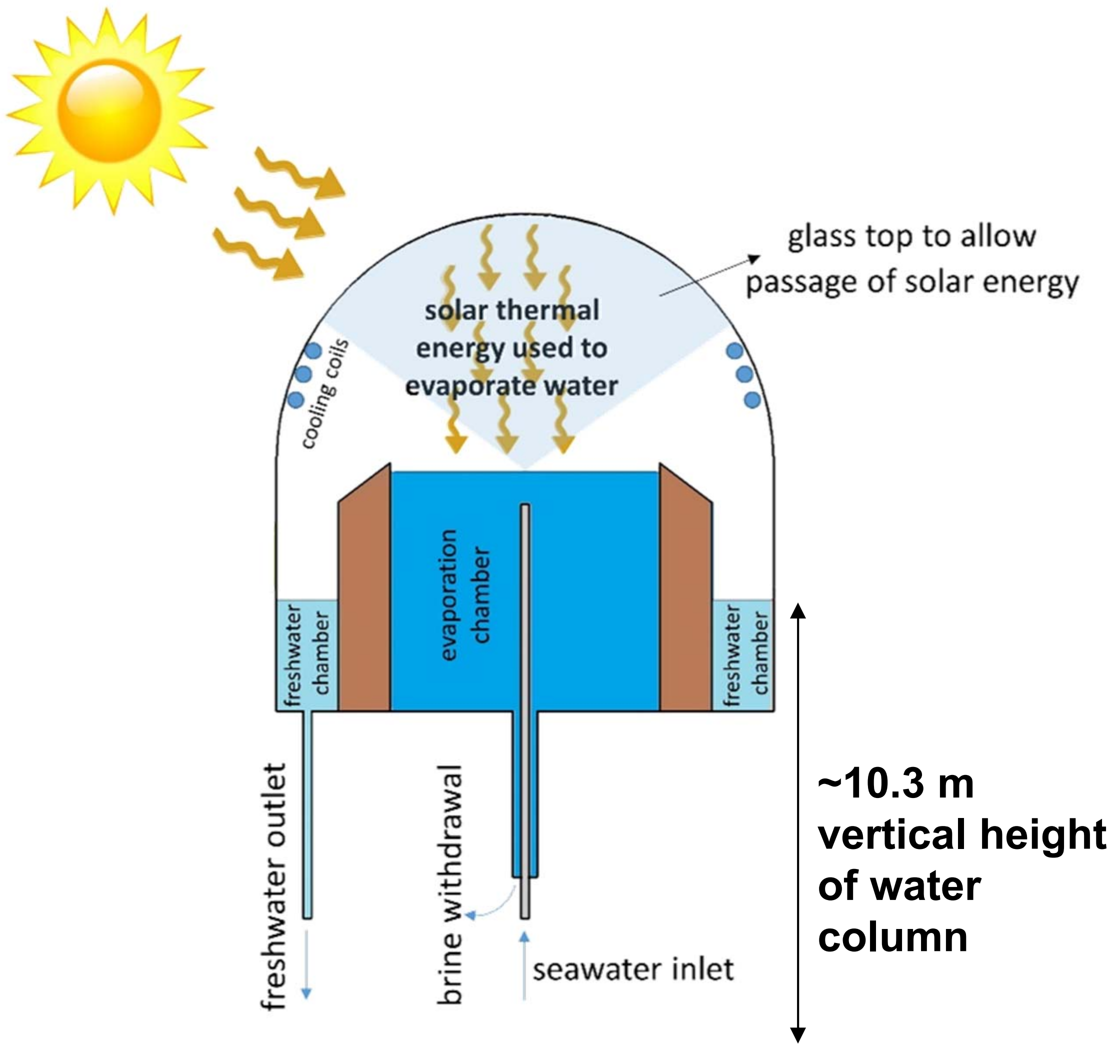
Vapor transport from salt water side to freshwater side

Proposed system

Spherical design with condenser space under same roof solves vapor transport issue

Uses solar energy for evaporation

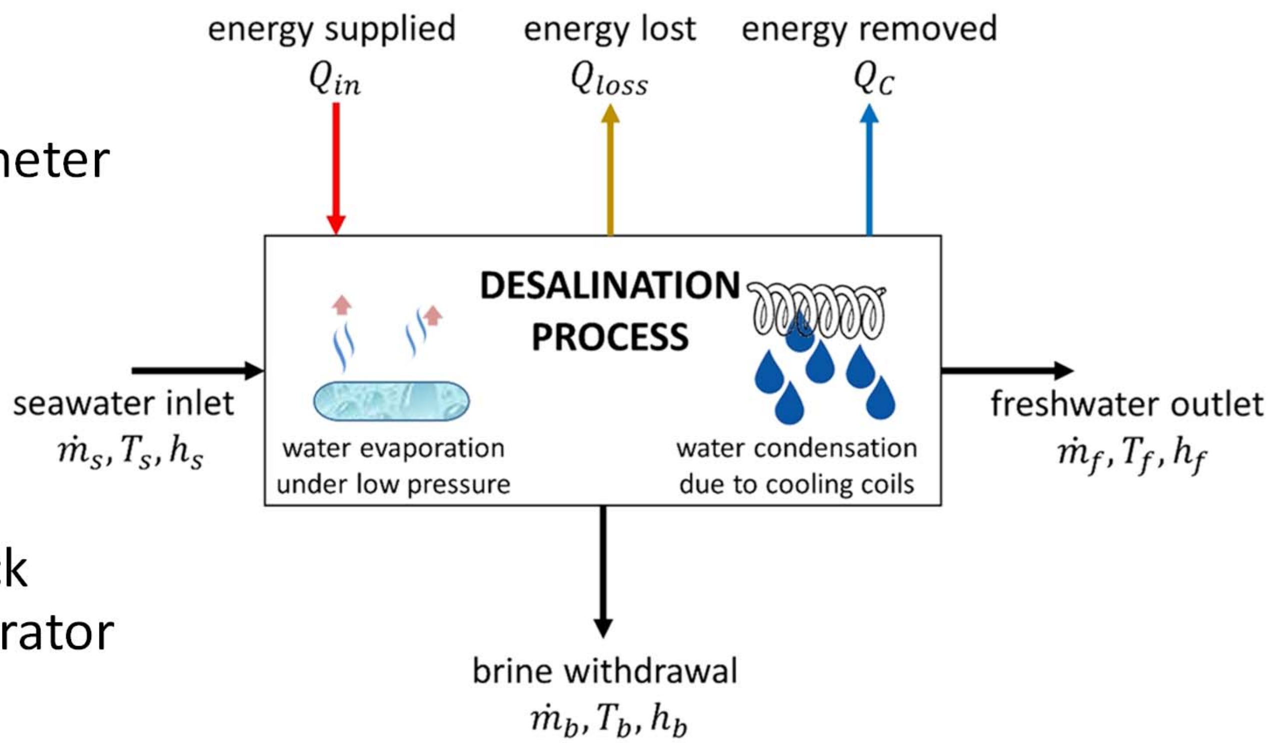
No mechanical pumping energy required for operation



Mathematical Model

Assumptions:

- Lumped parameter model
- All the vapor produced is condensed
- No vapor condenses back into the evaporator



Mathematical Model

- Mass balance

$$\dot{m}_s = \dot{m}_b + \dot{m}_f$$

- Energy balance

$$\dot{m}_s H_s + Q_{in} = \dot{m}_b H_b + \dot{m}_f H_f + Q_{loss}$$

- Solute balance

$$\dot{m}_s C_s = \dot{m}_b C_b$$

Mathematical Model

- Evaporation equation (Bemporad, 1995)

$$\dot{m}_f = A \times \alpha_m \times \left(f(C_b) \frac{p(T_s)}{\sqrt{T_s + 273}} - \frac{p(T_f)}{\sqrt{T_f + 273}} \right)$$

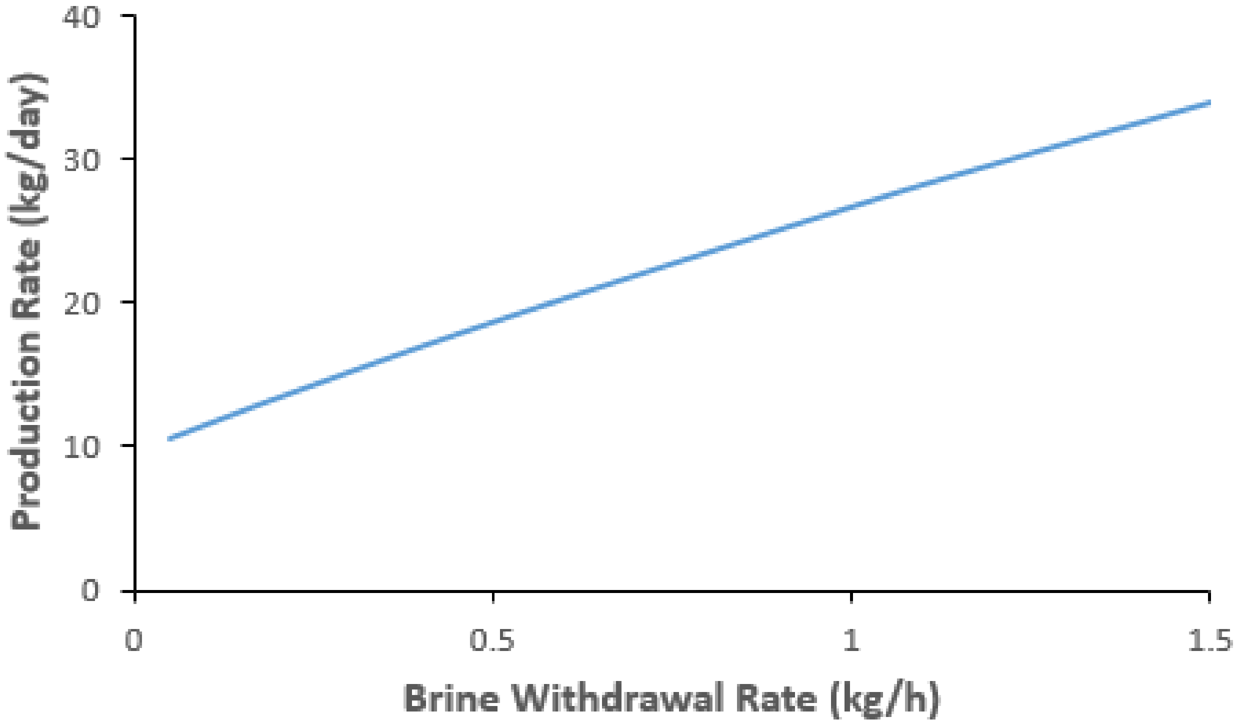
- Model was solved using a code written in MATLAB®

Results

- The effects of the following parameters were investigated:

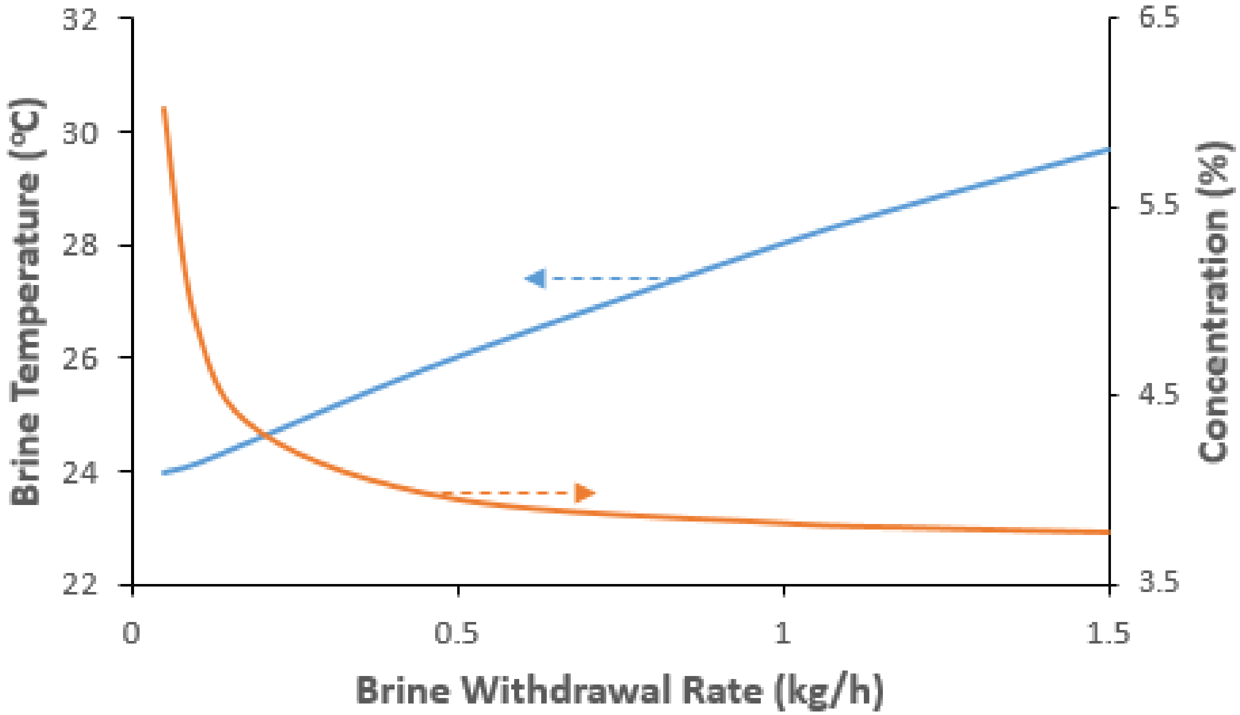
  - Brine Withdrawal Rate
  - The inlet temperature of heated seawater
  - Temperature of the cooled desalinated water
  - External heating load

Effect of changing the Brine Withdrawal Rate



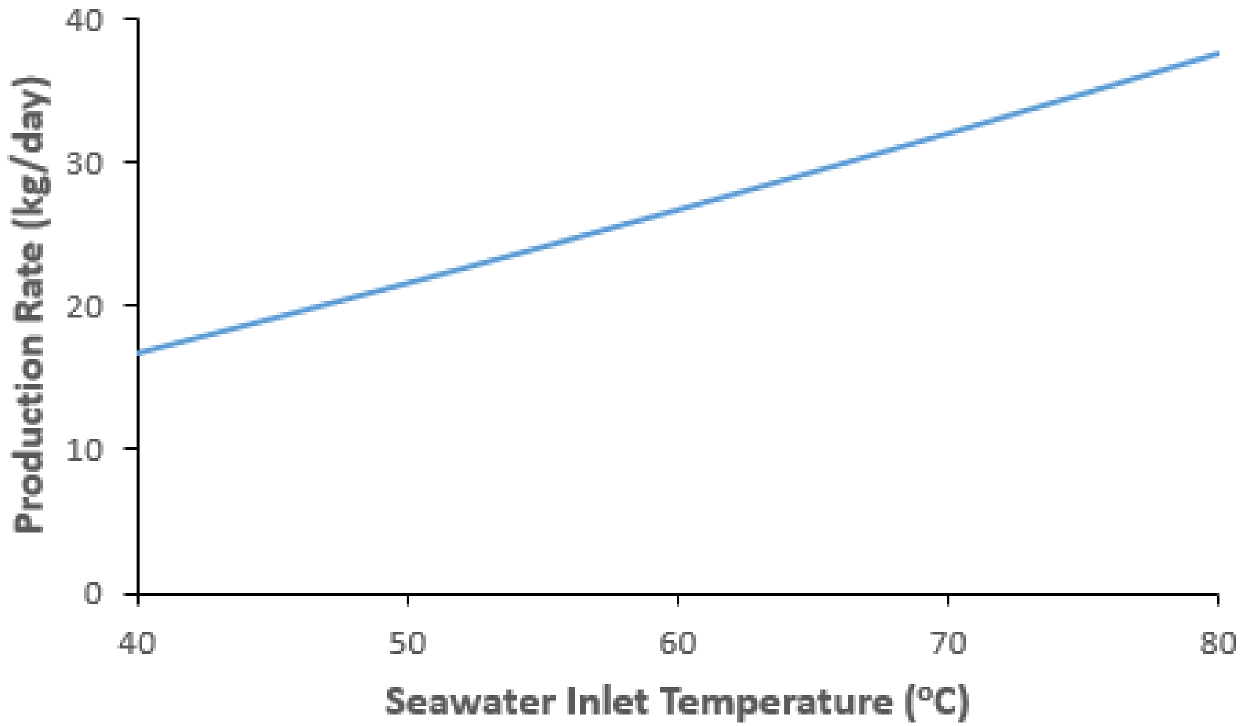
- Higher brine withdrawal rate gives higher production but it will require higher feed rate (i.e. more heating energy wasted)

Effect of changing the Brine Withdrawal Rate



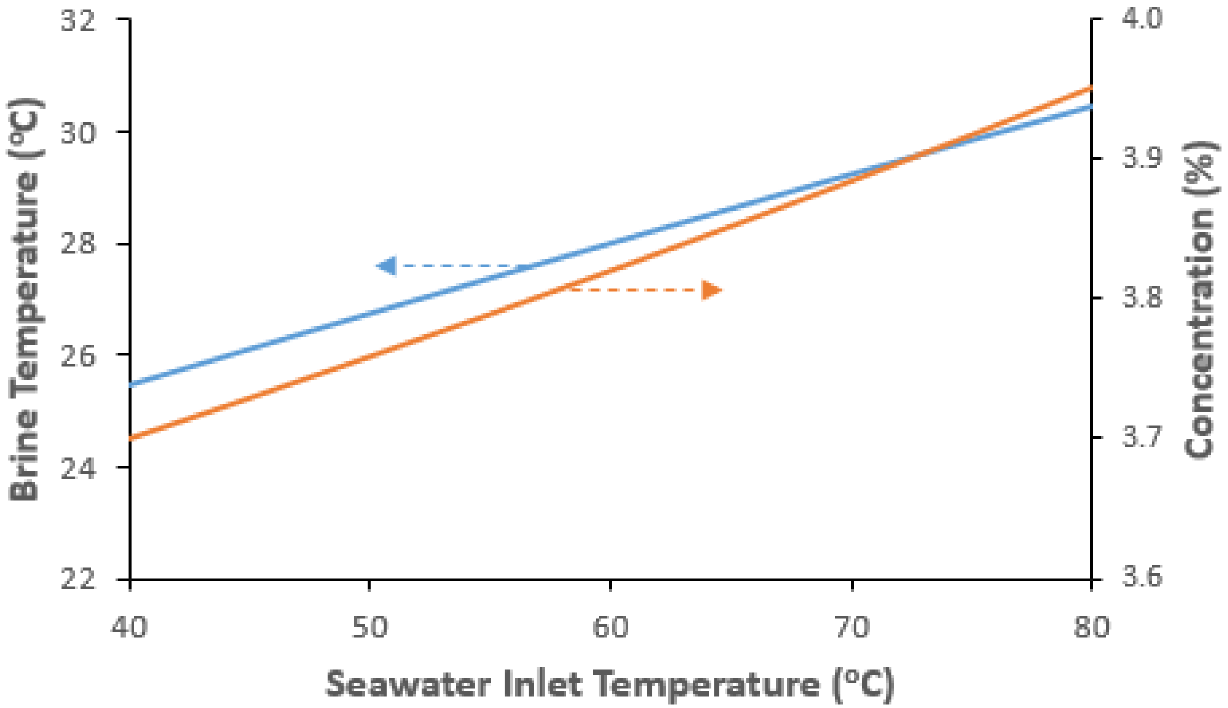
- Low brine rates cause higher concentrations increasing scaling hazards

Effect of changing the Seawater Inlet Temperature



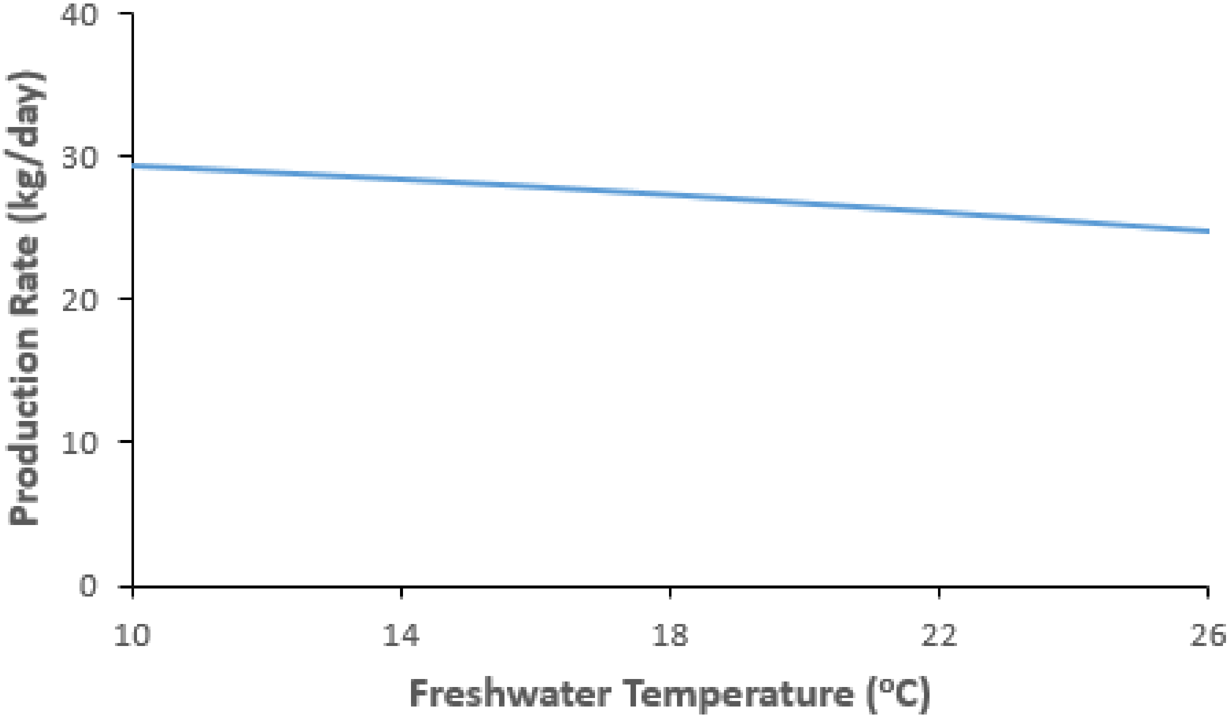
- Production rates of around 40 kg/day are calculated for inlet temperature of 80 ^{o}C

Effect of changing the Seawater Inlet Temperature



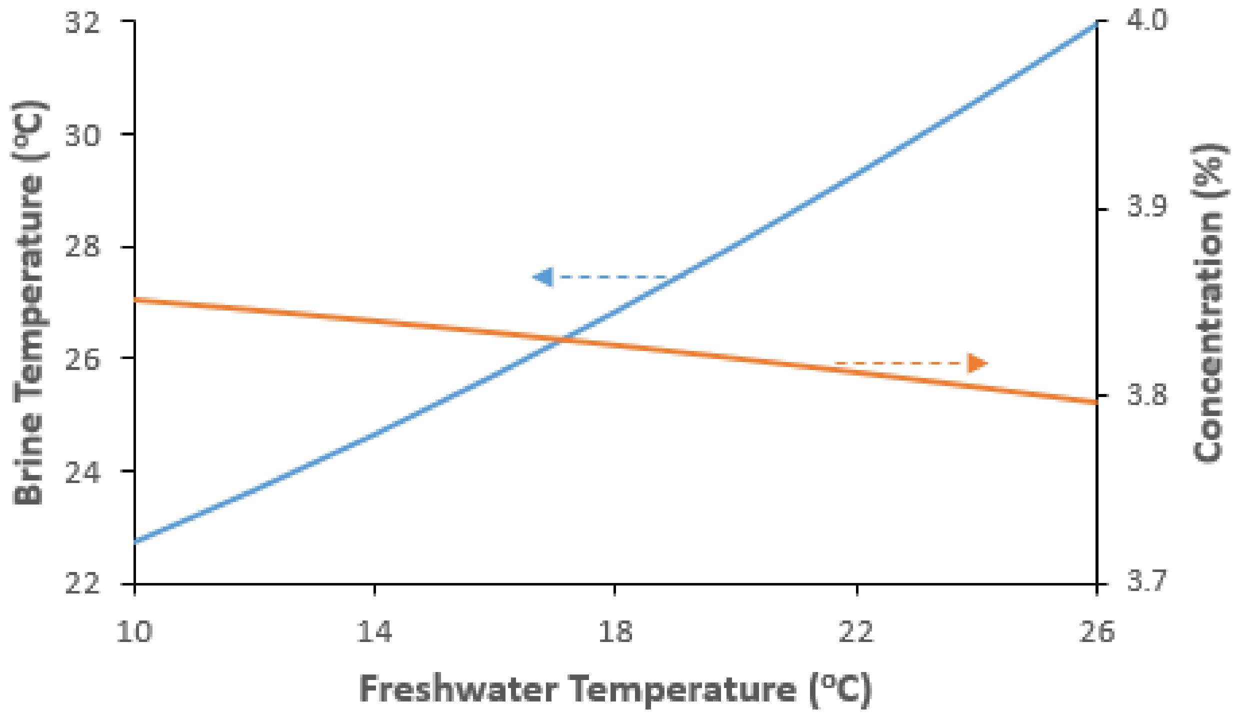
- Higher temperatures results in elevated brine temperature and concentration which are both environmental hazards

Effect of changing the Freshwater Temperature



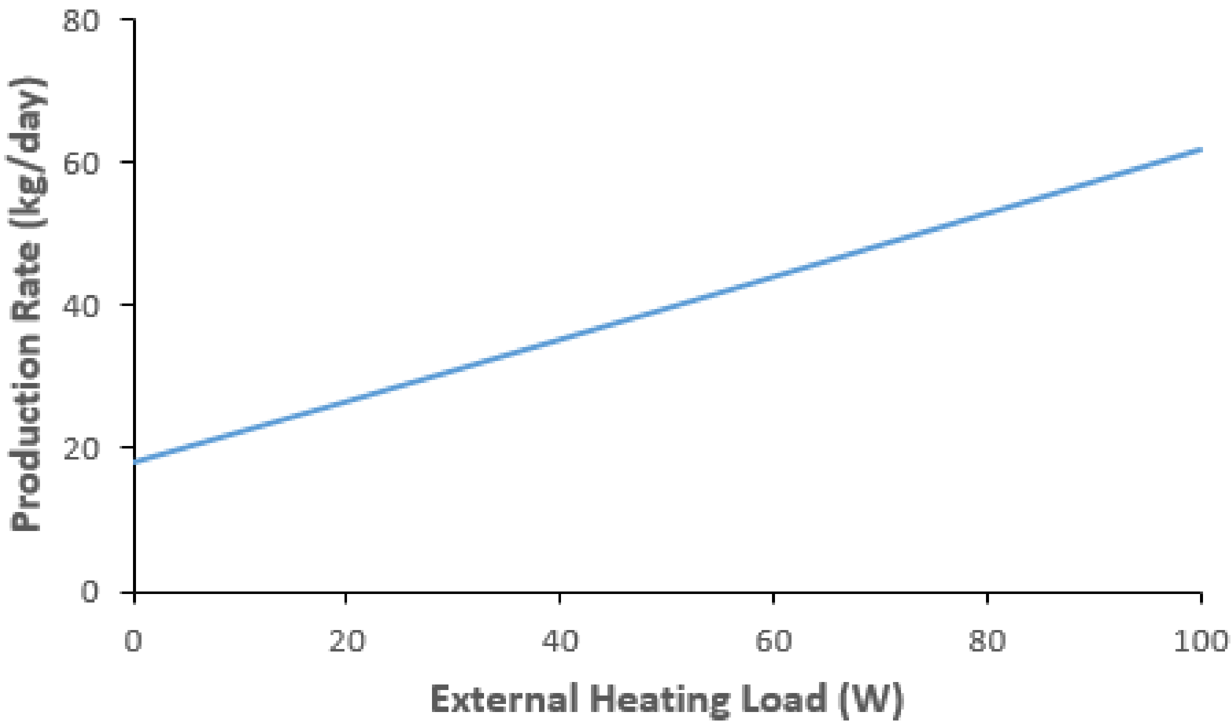
- Lower temperatures on the freshwater side enhance the production rate

Effect of changing the Freshwater Temperature



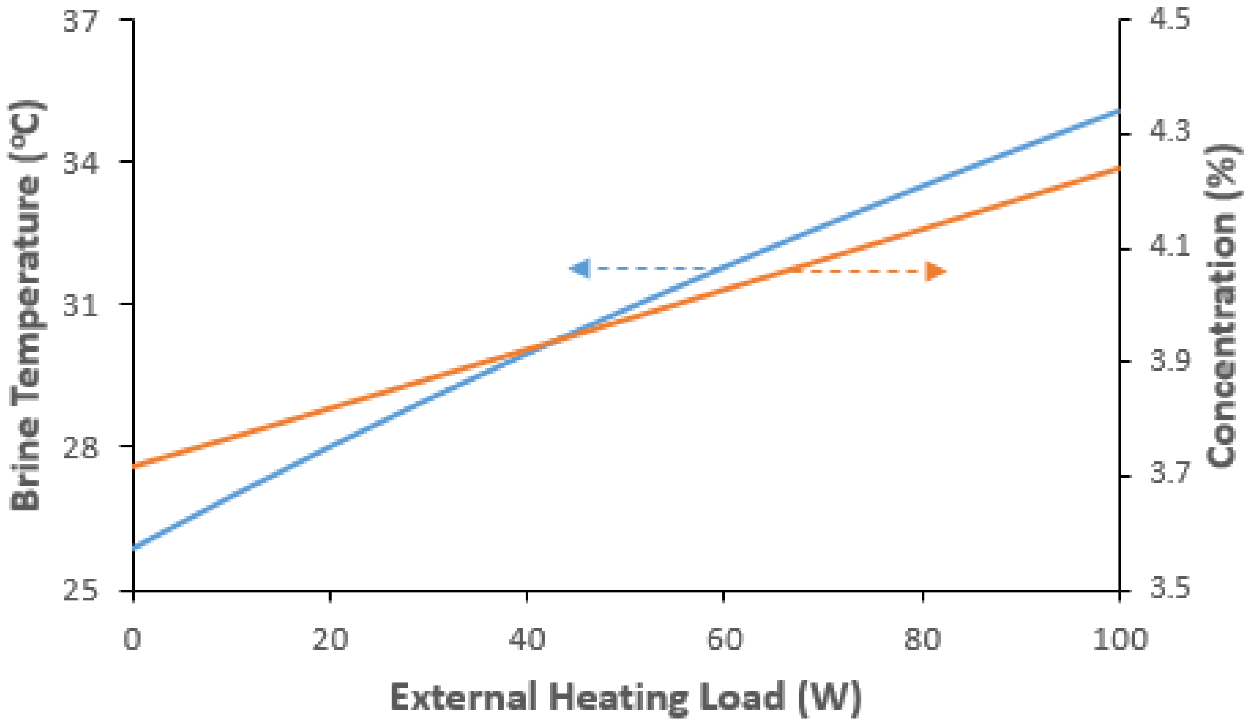
- For hot climatic regions, deep seawater can be used to condense the vapor

Effect of changing the External Heat Load



- Using 100 W of external heating load (other than the feed heating) provides up to 4 times better production rates

Effect of changing the External Heat Load



- Brine outlet temperature and concentration could be a concern

Comparison with conventional desalination technologies

- Ref: Karaghouli and Kazmerski (2012), Renew. Sust. Energy Rev. 24, 343-356

Process	Capacity (m^3/day)	Cost ($/$m^3$)
MSF	23,000 – 528,000	0.56 – 1.75
MED	91,000 – 320,000	0.52 – 1.01
	12,000 – 55,000	0.95 – 1.5
	< 100	2.0 – 8.0
RO	100,000 – 320,000	0.45 – 0.66
	15,000 – 60,000	0.48 – 1.62
	1,000 – 4,800	0.7 – 1.72
Low temperature NVD	**0.5**	**3.0 – 7.0**

Comparison with other renewable energy desalination technologies

- Ref: Gude et al. (2012), Energy Conv. Manage. 56, 192-198

Process	Capacity (m^3/day)	Cost (\$/m^3)
Solar still	0.5 – 1	12 – 12.5
MED (solar)	85	7 – 10
RO (PV)	1	12 – 15.6
Membrane Distillation (solar)	<1	13 – 18
Solar thermal desalination	<1	12.9
Low temperature NVD	**0.5**	**3.0 – 7.0**

Conclusion & Recommendations

- The effects of the changes of the parameters on the performance of the system were discussed.
- Higher brine withdrawal rates give better production rates but loss of energy
- Lower withdrawal rates could cause scaling hazards
- Higher inlet temperatures are preferred but cost of heating needs to be considered to obtain optimum temperature

Conclusion & Recommendations

- Lower temperatures are preferred on the freshwater side
- Renewable energy or waste heat source could be utilized for additional heating within the evaporation chamber
- Studies show NVD systems to achieve low production costs compared to other renewable energy based desalination technologies
- Medium to large scale water production plants could be possible using NVD