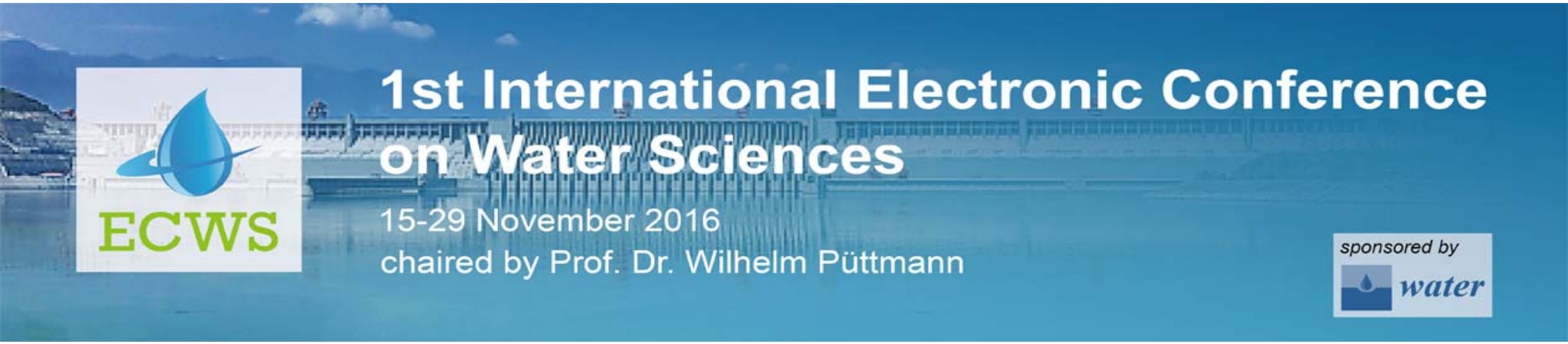

Evolution of Low Temperature Desalination Process

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Outline of the Presentation

1. Energy requirements for desalination
2. New desalination technology
3. Working principle
4. Phase I: Theoretical studies
5. Phase II: Pilot scale studies
6. Phase III: Field scale studies
7. Conclusions

Energy for Desalination

Minimum Theoretical Energy Requirement for Production of 1 kg of Freshwater is 2.5 kJ (Spiegler, 1977)

Process		Multi-Effect Solar Still (MESS)	Multi Stage Flash Distillation (MSF)	Multi Effect Distillation (MED)	MVC	MED-TVC	Reverse Osmosis	ED
Energy Requirements	Thermal energy (kJ/kg)	1500	250-300	150-220	_	220-240	_	_
	Electrical energy (kWh/m^3)	0	3.5-5	1.5-2.5	11-12	1.5-2	5-9	2.6-5.5
	Total electric equivalent (kWh/m^3)	0	15-25	8-20	11-12	21.5-22	5-9	2.6-5.5
GHG Emissions kg CO_2/m^3 H_2O	Maximum value	0	24	19.2	11.5	21	8.6	5.3

Research Goals and Objectives

Phase I: Theoretical Studies

• Study **New**, energy-efficient, self-sustainable, low temperature desalination (LTD) system

• Study and evaluate the performance of LTD system using low grade solar/waste energy (heat rejected by refrigeration system)

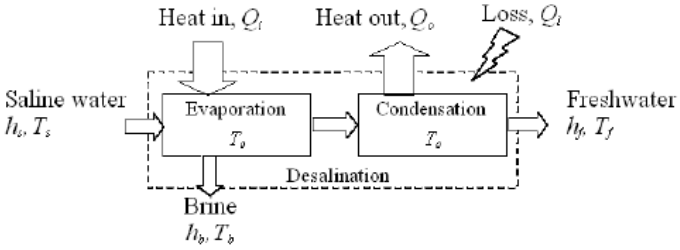
• Application of renewable energy sources such as solar collectors, Photovoltaics, PV/T collectors and Geothermal water sources

New, Low-Temperature Desalination System

- Continuous process (Energy-efficient, lower specific energy
- requirement)
- Near vacuum pressures (natural means of gravity & barometric
- pressure head- Natural Vacuum)
- Lower temperature (40-50 0C < Conventional)
- Renewable/Low Grade energy Source dependent
- No mechanical pumping
- No cooling

Thermodynamic Justification

Generic Phase-Change Desalination Process



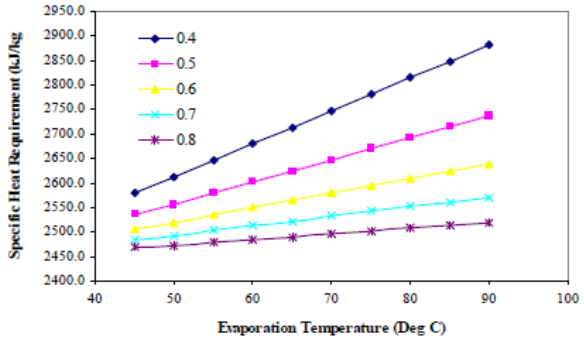
Thermodynamic Analysis (FLT)

$$Ein = Eout$$

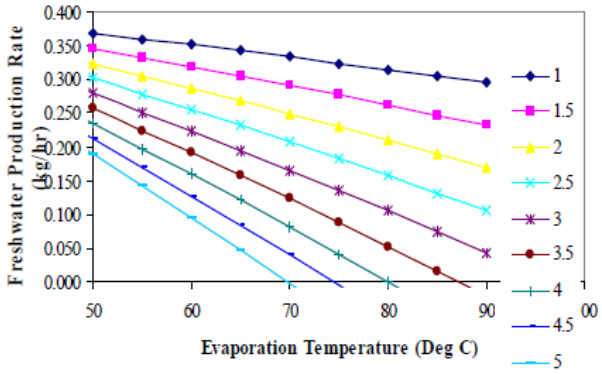
$$m_s h_s + Q_i = m_f h_f + (m_s - m_f)h_b + m_f h_L + Q_L$$

$$\frac{m_f}{m_s} = \frac{[\frac{(Q_i - Q_L)}{m_s} + (h_s - h_b)]}{(h_f - h_b + h_L)}$$

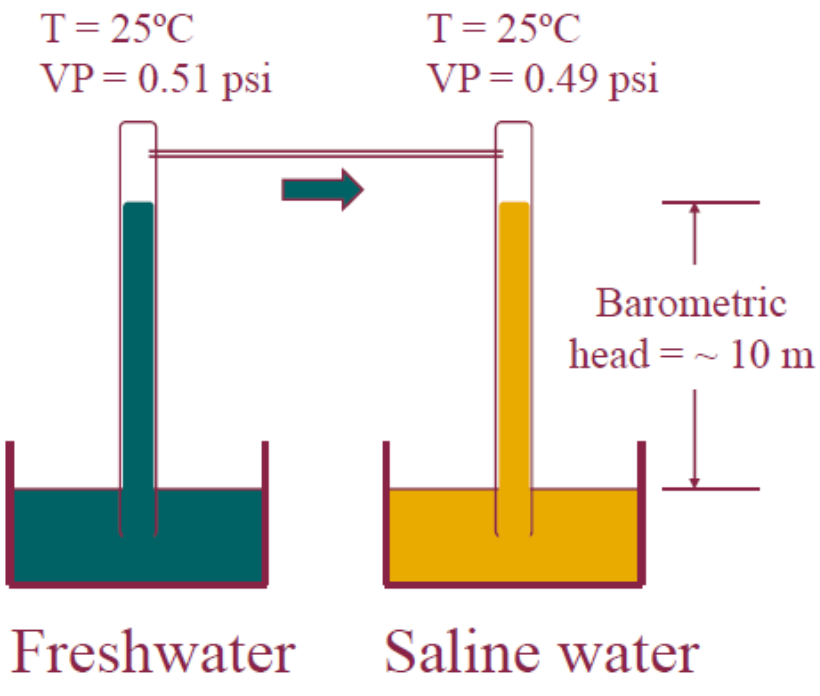
Q_i = variable kJ/hr, Fixed feed rate, 1 kg/hr

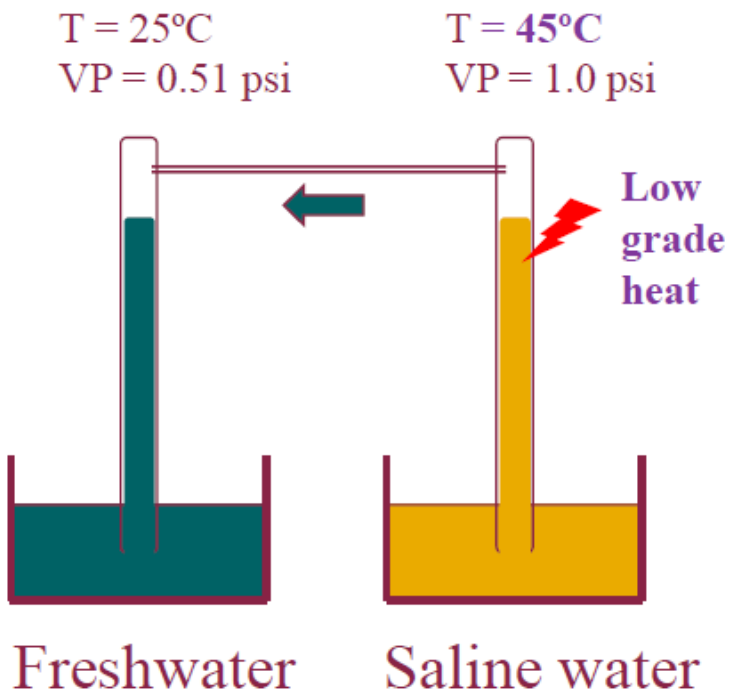


Q_i = 1000 kJ/hr, variable feed rate, kg/hr

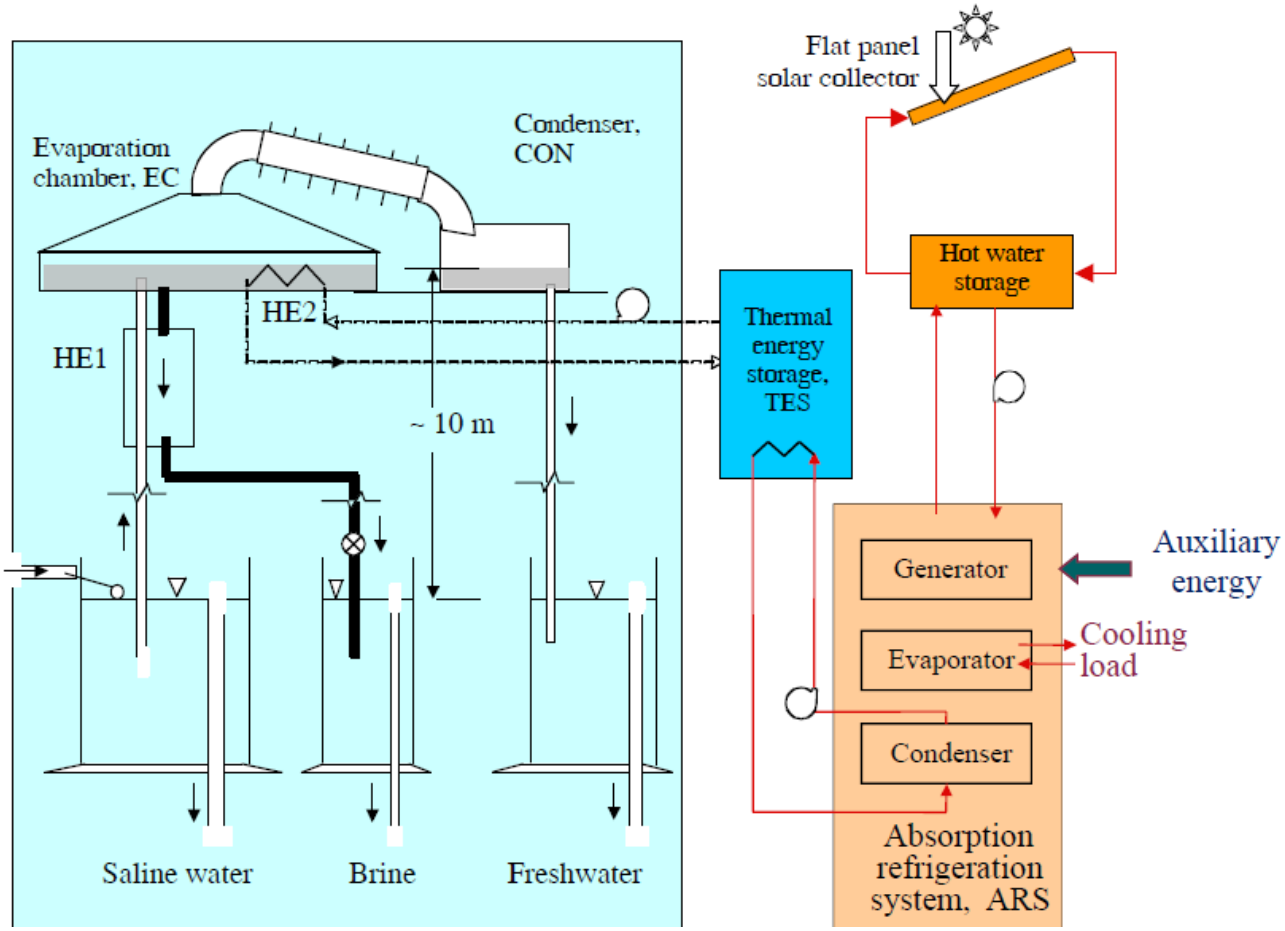


Physical Principle behind Natural Vacuum





Desalination Using Low Grade Waste Heat



Summary of Results (Theoretical Study)

Energy Source	Mode of operation	Heat energy required (kJ/kg freshwater)	Mechanical energy required (kJ/kg freshwater)	Total Energy required (kJ/kg freshwater)
ARS configuration	Continuous	194	14	208
Solar collectors	Batch	3118	4.1	3122.1
PV/T collectors	Batch	3118	4	3122
Geothermal source*	Continuous	2934	144	3078

Research Goals and Objectives

Phase II: Pilot Scale Studies

- Develop and Demonstrate the feasibility of low temperature desalination unit in continuous mode of operation using the power from electric grid

- Demonstrate the feasibility of low temperature desalination unit using renewable energy sources (direct solar and photovoltaic energy) through pilot scale study

- Feasibility study of reclaiming potable quality water from the effluent of wastewater treatment plant (City of Las Cruces, NM) by LTD system

Experimental Setup

LTD Process

Objectives:

- To demonstrate the feasibility of LTD system using Renewable energy
- To study use of Different Combinations of Energy

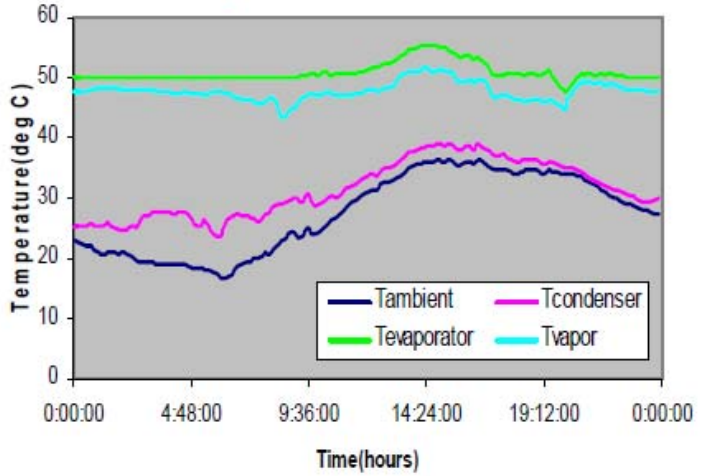
Method:

- Heat source: Solar/Photovoltaic Energy
- Withdrawal rate: 0.250 kg/hr
- Open top during Day time
- Evaporation temperatures: 45-60 ^{0}C
- Summer conditions

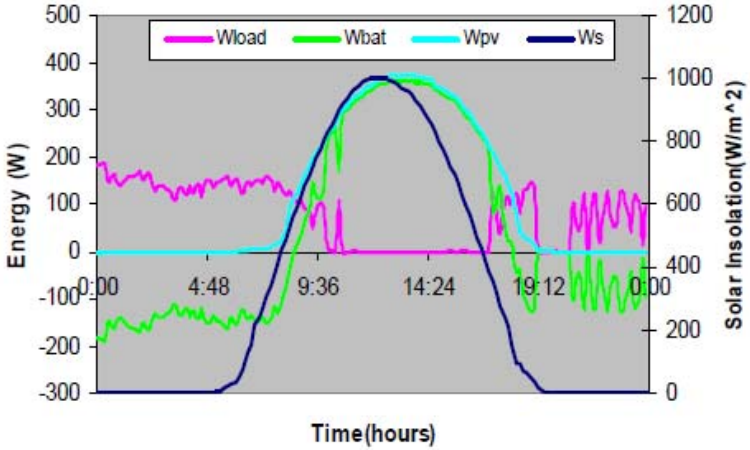
Experimental Results

Prototype Des@LT Unit powered by RES

Temperature Profiles

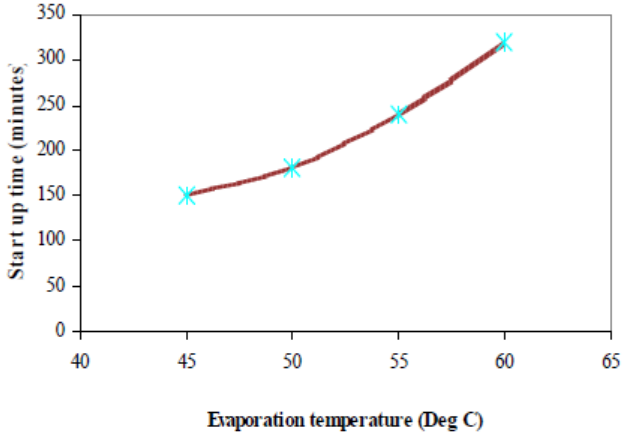


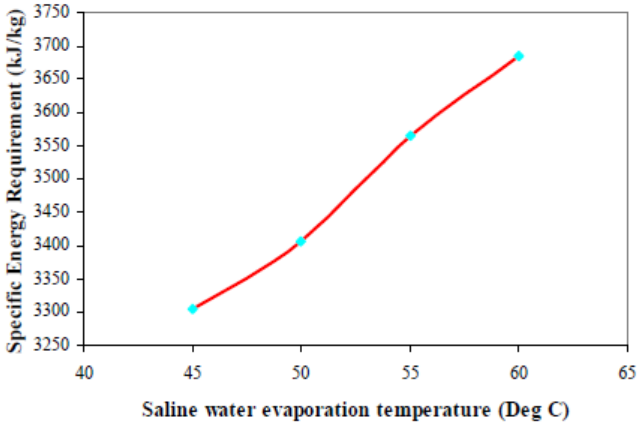
Energy Profiles



Experimental Study - Phase II: Summary

Thermodynamic Benefits





- **Reduced Start up time, Reduced response time for Freshwater demand**
- **Reduced Specific Energy Requirements by LTD systems**

Experiment	Description	Mode of Operation	Specific Energy Requirement (kJ/kg)
Case 1	Utilization of direct solar energy	Batch	4157
Case 2	Utilization of direct solar energy with a reflector	Batch	3118
Case 3	Solar energy during sunlight hours, photovoltaic energy during non-sunlight hours	Continuous	**2926**
Case 4	Solar and photovoltaic energy together	Batch	3325

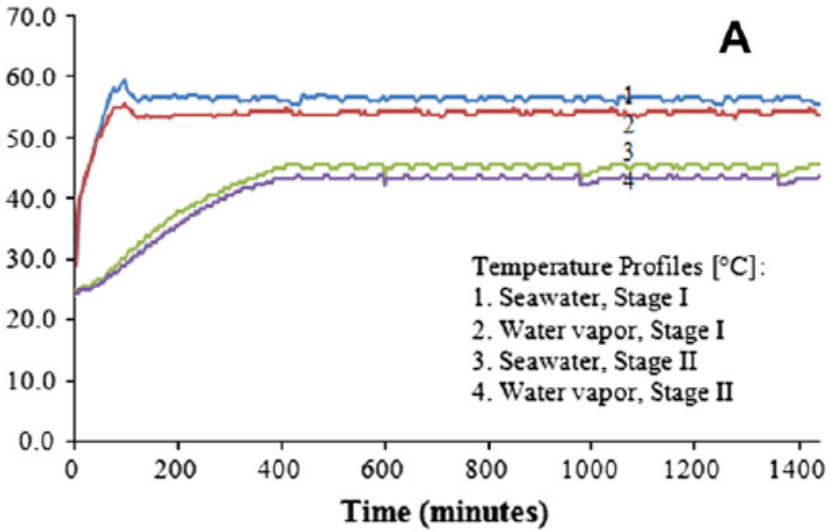
Wastewater Effluent Reclamation

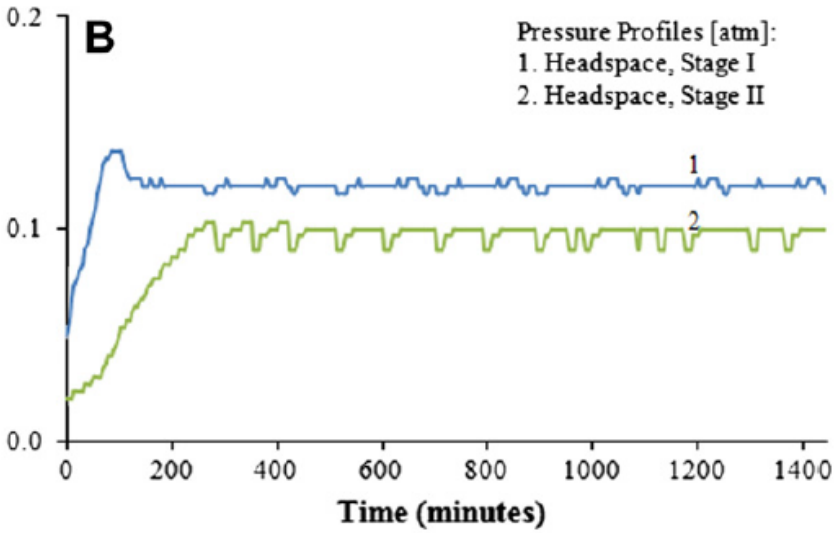
Water quality measure	WWTP effluent	Product water	US EPA Standards
BOD (mg/L)	9.7	-	
TSS (mg/L)	5.1	< 1	
TDS (mg/L)	727	21	500
Nitrates/nitrites(mg/L)	2.4	< 0.1	1
NH_3(mg/L)	23.2	< 0.5	
Chlorides (mg/L)	0	0	4
Coliform (cfu/100)	77	< 1	0
pH	7.1	7.1	6.5-8.5

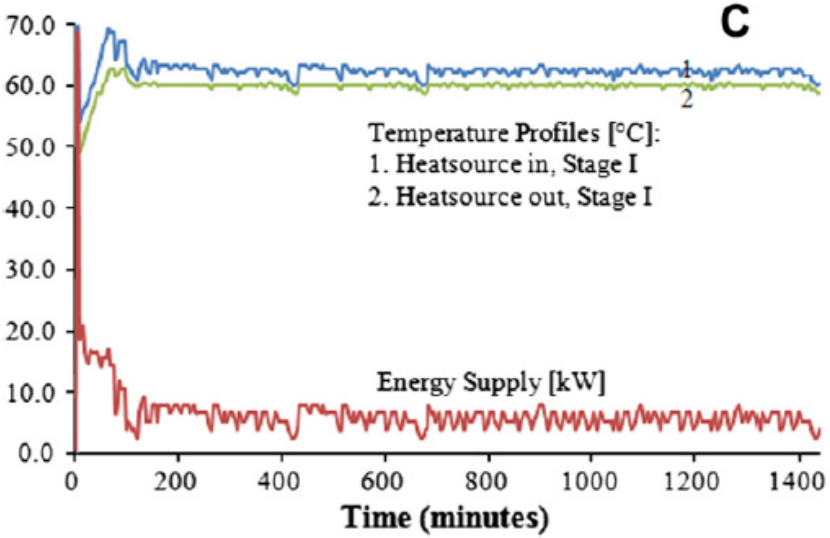
Phase III: Field Studies

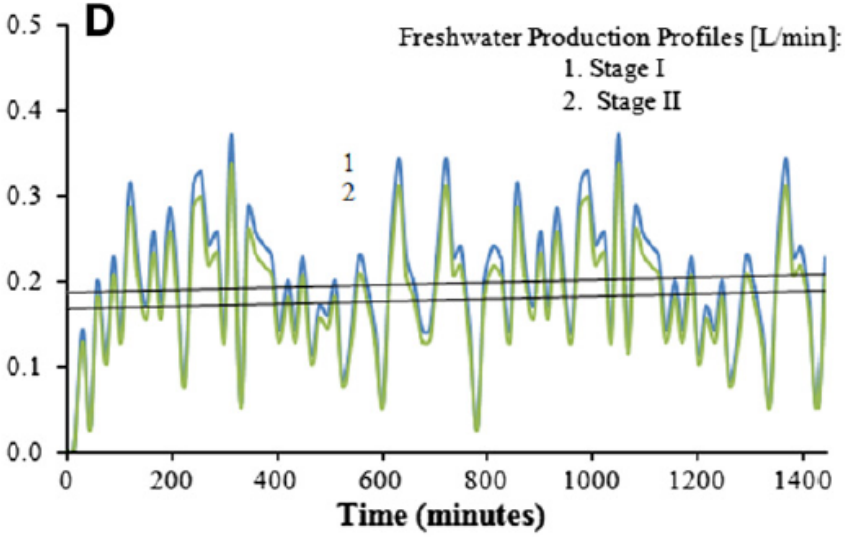
Objectives:

- To demonstrate low temperature desalination (LTD) unit at freshwater production rates (75-100 gal/d)
- To demonstrate two-stage low temperature desalination unit
- To study the process variables such as heat and mass transfer coefficients, areas, scaling and fouling issues
- To determine the specific energy requirements for a two-stage low temperature desalination (LTD) process


A
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
200
400
600
800
1000
1200
1400
Time (minutes)
1
2
3
4
Temperature Profiles [°C]:
1. Seawater, Stage I
2. Water vapor, Stage I
3. Seawater, Stage II
4. Water vapor, Stage II


B
0.2
0.1
0.0
0
200
400
600
800
1000
1200
1400
Time (minutes)
Pressure Profiles [atm]:
1. Headspace, Stage I
2. Headspace, Stage II
1
2


C
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0
200
400
600
800
1000
1200
1400
Time (minutes)
1
2
Temperature Profiles [°C]:
1. Heatsource in, Stage I
2. Heatsource out, Stage I
Energy Supply [kW]


D
0.5
0.4
0.3
0.2
0.1
0.0
0
200
400
600
800
1000
1200
1400
Time (minutes)
Freshwater Production Profiles [L/min]:
1. Stage I
2. Stage II
1
2

Advantages of Low Temperature Desalination

- Thermodynamic efficiency
  - lower heat fluxes/temperature differentials; better thermal efficiency, lower heat losses to the environment
- Low corrosion and scaling rate
  - safe to use plastic pipes & aluminum plates;
  - temperatures well below the saturation limits of problem scalants
- Flexibility and reliability
  - short start-up, less time for heating up, freshwater demand
  - solid construction, proven equipment, low maintenance

Low energy costs: enables use of low cost heat sources which would otherwise be lost to environment

ex: stack gases, cooling water streams and low pressure exhaust steam

Conclusions

- Experimental studies demonstrate the feasibility of using direct solar energy and photovoltaic energy
- Lower energy: Specific energy requirements for single effect is 2926 kJ/kg
- Two-stage LTD process successfully demonstrated
- Two-stage energy requirements about 1600 kJ/kg
- The system does not require any mechanical pumping except occasional removal of accumulated gases
- High quality distillate (TDS < 50 ppm)
- High exergy efficiency (quality of energy completely utilized)
- Multistage configuration can improve both energy and economic budget of the process