Low Temperature Desalination: An Option for Sustainability & Energy Savings

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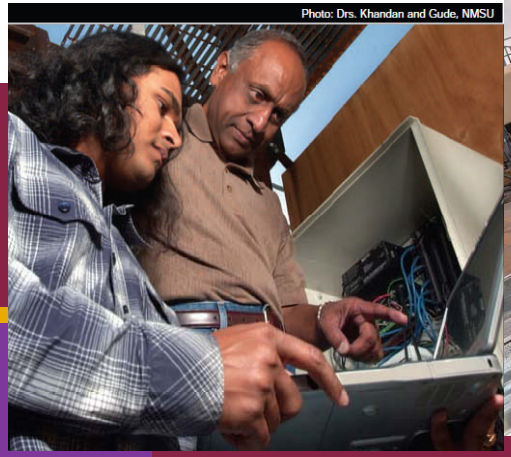
Photo: Drs. Khandan and Gude, NMSU

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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

- 45 % of the unit desalinated water cost is due to the energy requirements in the process

Research Goals and Objectives

Phase I: Theoretical Studies

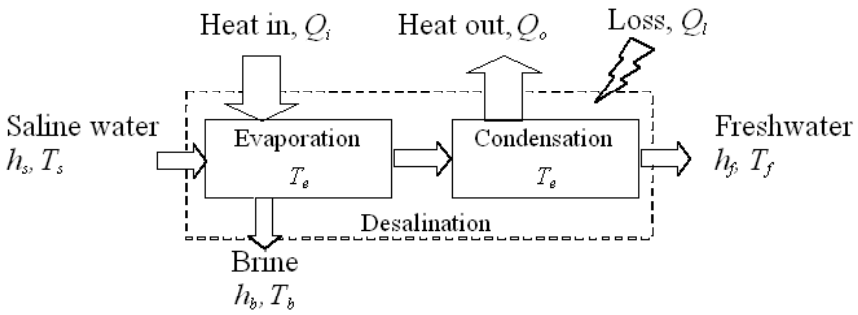
- Study **New**, energy-efficient, self-sustainable, low temperature desalination (LTD) system
- Study and evaluate the performance of LTD system using low grade solar/waste energy (heat rejected by refrigeration system)
- Application of renewable energy sources such as solar collectors, Photovoltaics, 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 ^{0}C < Conventional)
- Renewable/Low Grade energy Source dependent
- No mechanical pumping
- No cooling

Thermodynamic Justification

Generic Phase-Change Desalination Process



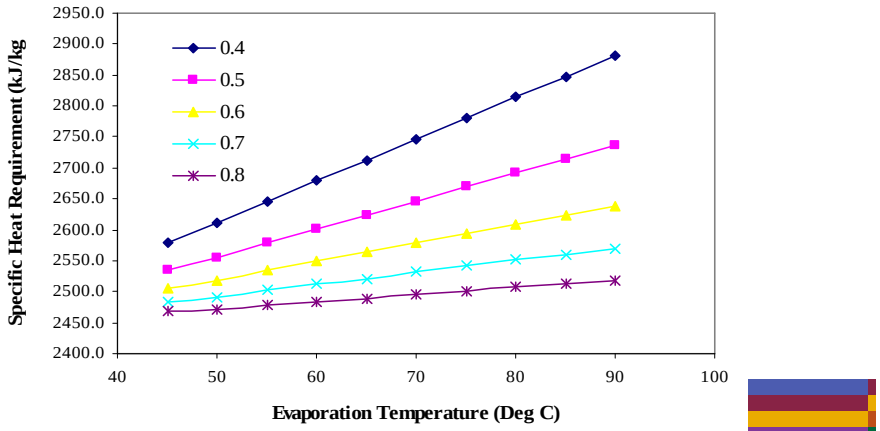
Thermodynamic Analysis (FLT)

$$Ein = Eout$$

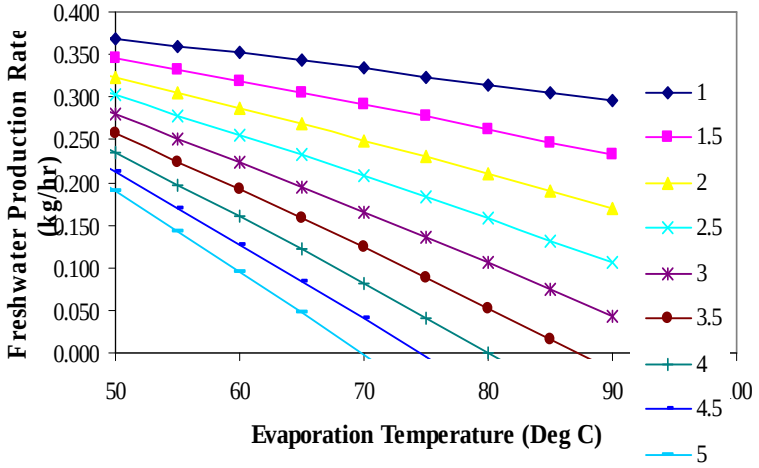
$$m_s h_s + Q_i = m_f h_f + (m_s - m_f) h_b + m_f h_L + Q_L$$

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

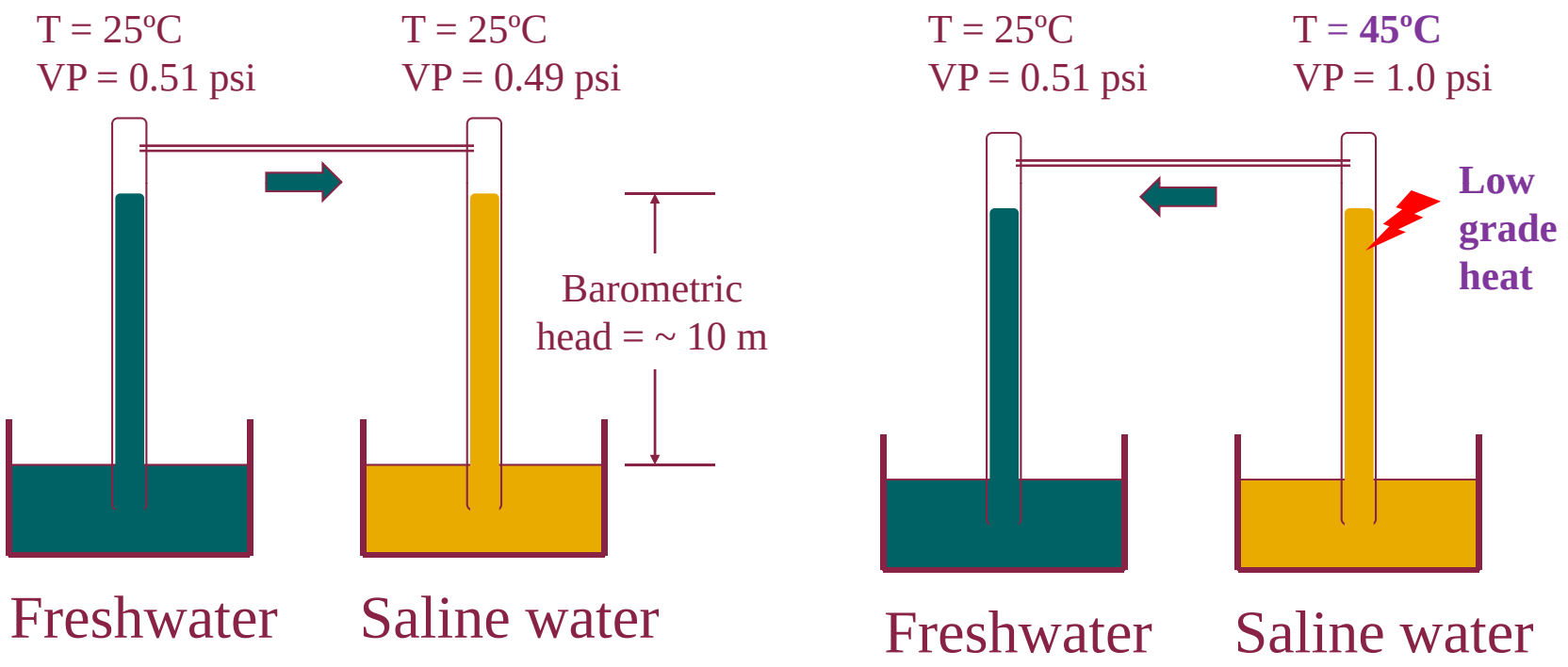
Q_i = variable kJ/hr, Fixed feed rate, 1 kg/hr



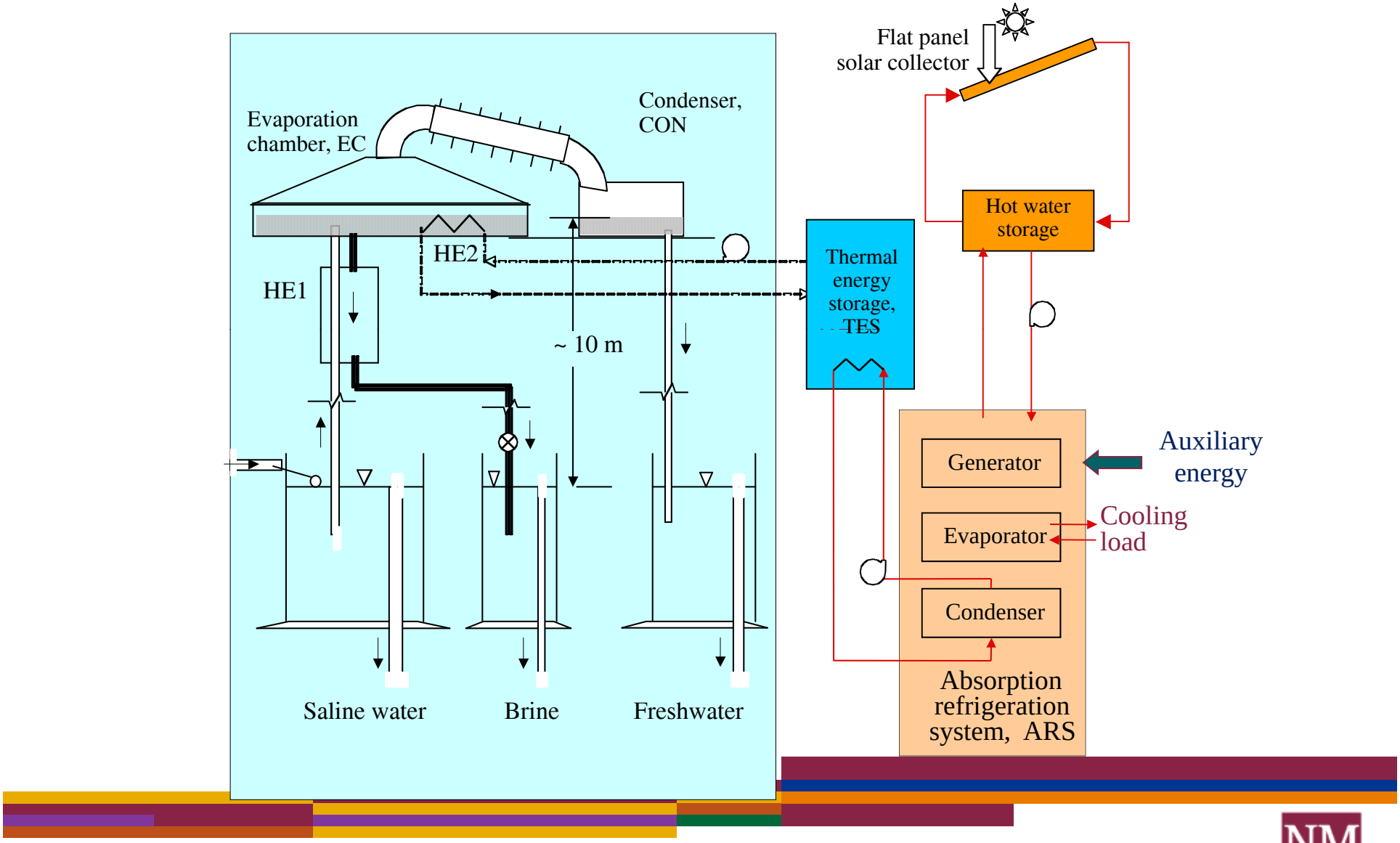
Q_i = 1000 kJ/hr, variable feed rate, kg/hr



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 at NMSU

Objectives:

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

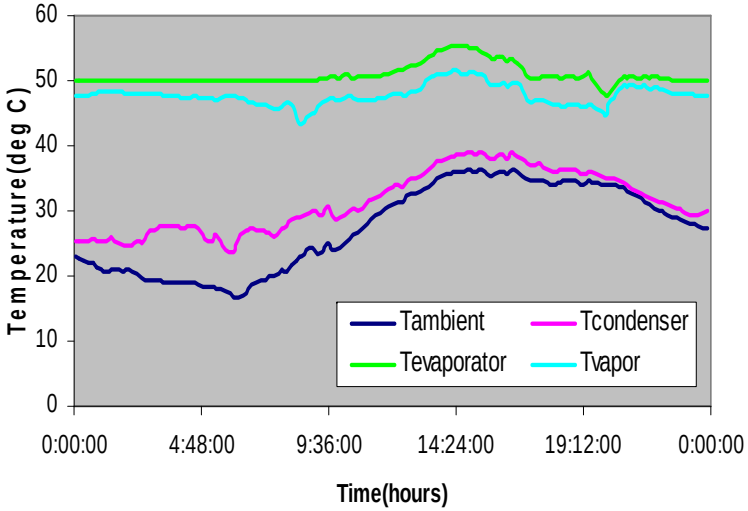
Method:

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

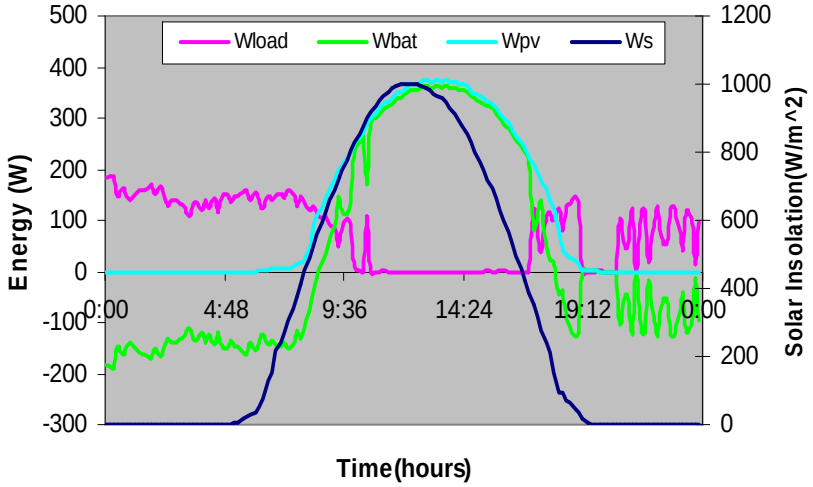
Experimental Results

Prototype Des@LT Unit powered by RES

Temperature Profiles



Energy Profiles



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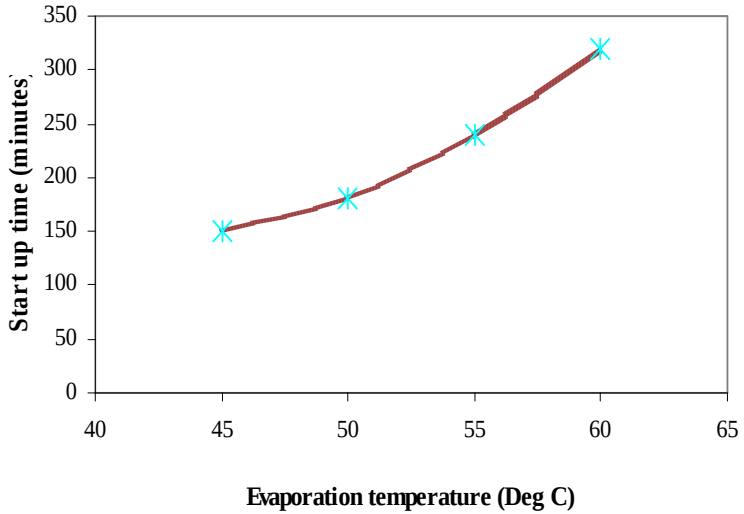
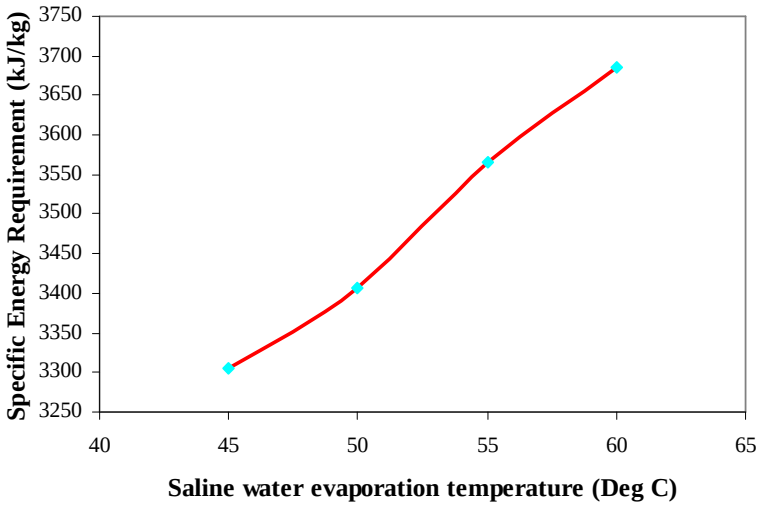
Experimental Study - Phase II: Summary

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

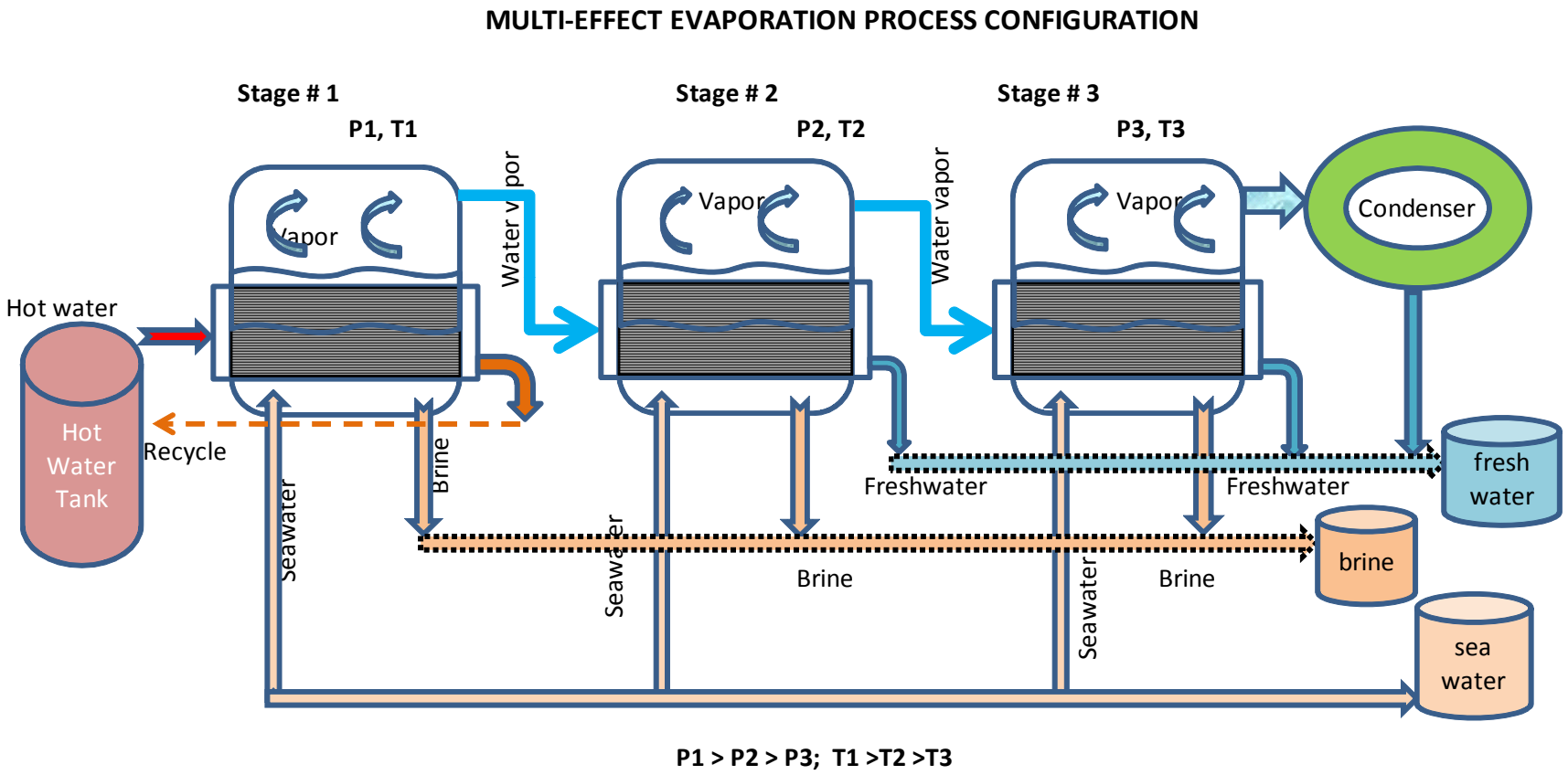
Parameter	Test 1			Test 2		
	Before	After	% Reduction	Before	After	% Reduction
BOD (mg/L)	11	7	36.4	10	6	40
TDS (mg/L)	935	68	92.7	783	54	93.1
TSS (mg/L)	5.1	0.5	90.2	8	1	87.5
Nitrate/Nitrite (as N-mg/L)	2.4	0.1	95.8	0.4	0.1	75.0
Ammonia (as N-mg/L)	26.13	0.5	98.1	22.68	3.27	85.6
pH	7.1	7.1	0.0	7.6	7.6	0
Coliform (cfu)	77	0	100	55	0	100

Phase III: Field Studies

Objectives:

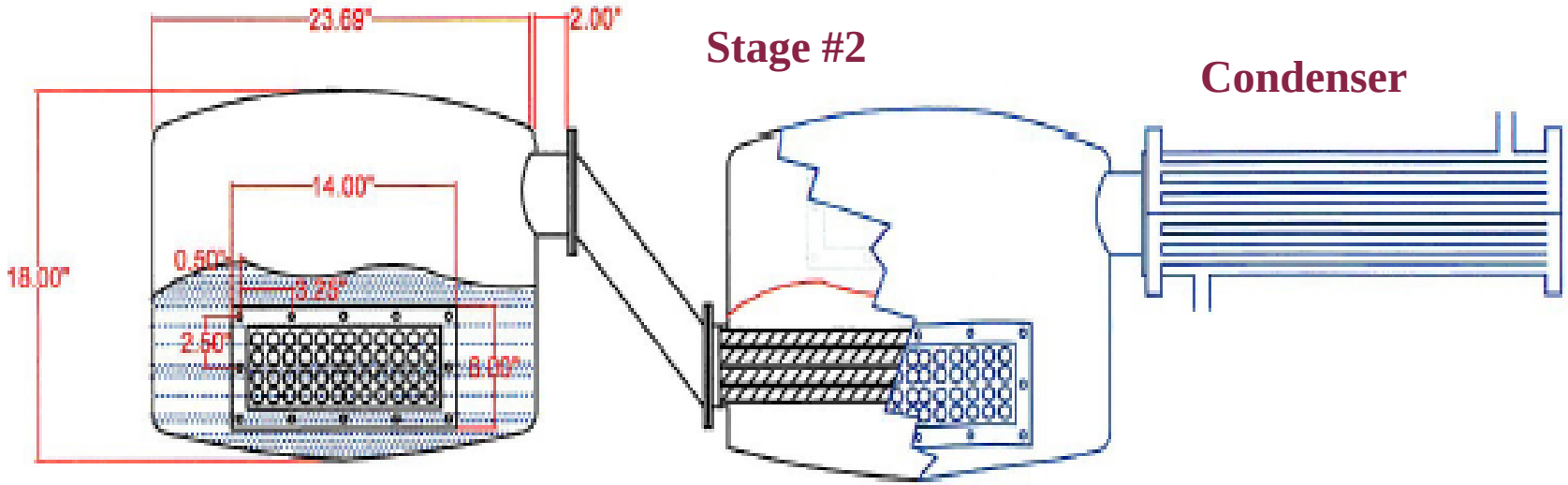
- To demonstrate low temperature desalination (LTD) unit at freshwater production rates (75-100 gal/d)
- To demonstrate two-stage low temperature desalination unit
- To study the process variables such as heat and mass transfer coefficients, areas, scaling and fouling issues
- To determine the specific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

Multi-effect LTD Process Configuration



Two-stage LTD Process

Stage #1



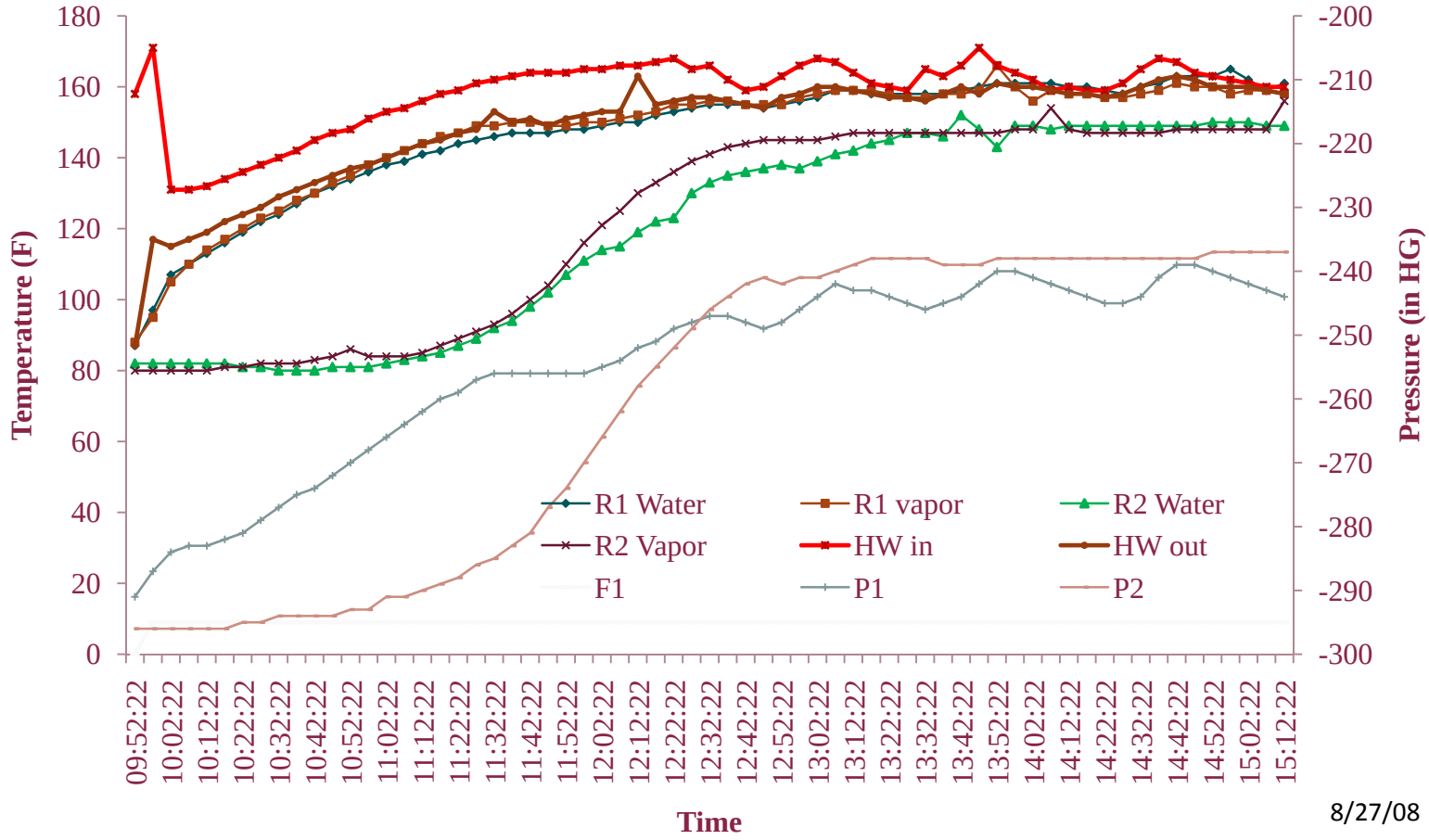
Stage #2

Condenser

Source Characteristics:

- Seawater direct from ocean
- TDS ~ 22000 ppm
- Temperature: 10-15 ^{0}C
- Hot water source: boiler powered by electric grid

Temperature and Pressure Profiles



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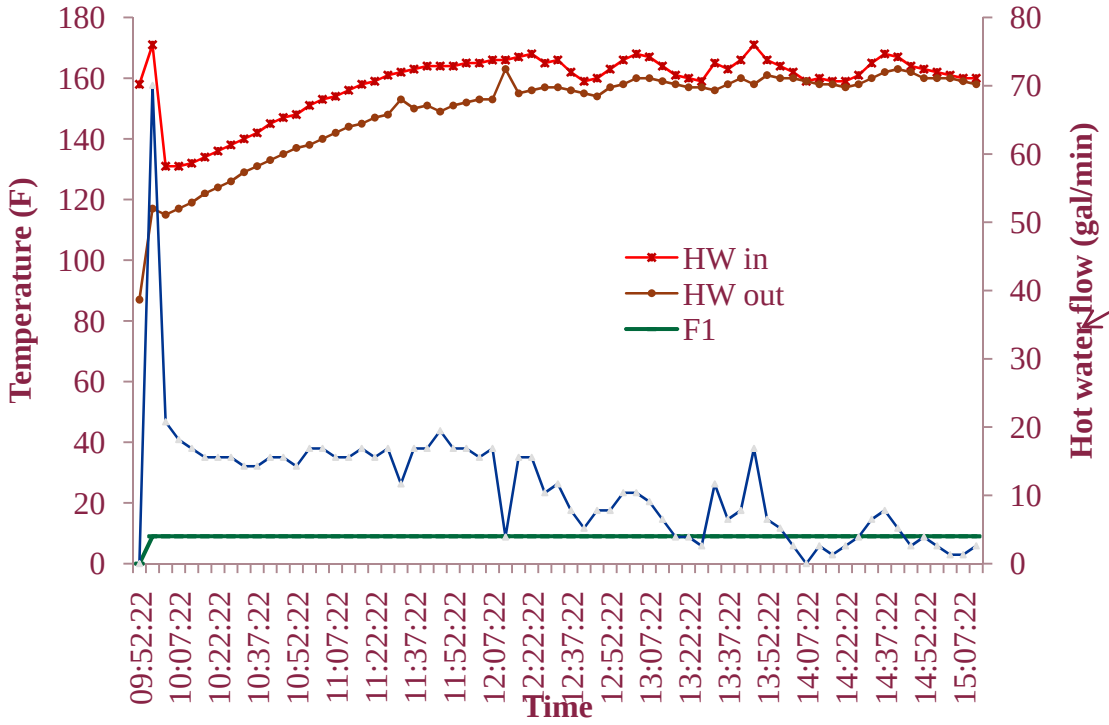
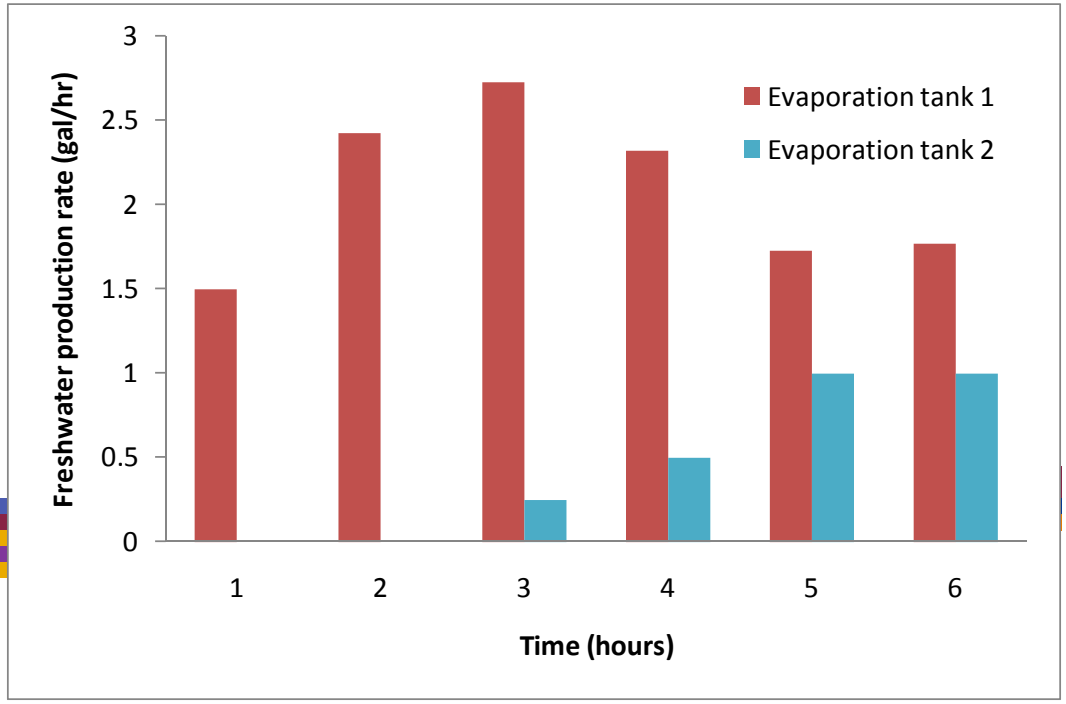


Temperature & Energy Profiles

2-Stage Freshwater Production Profiles (75-90 gal/d)



Product Water Quality

Sample	TDS (ppm)	Conductivity (µS)	pH
Feed water	22500	32150	7.8
Fresh water	155	185	7.6
USEPA standard	**< 500**		**6.5-8.5**
Feed water	22800	32600	7.8
Fresh water	71	145	7.5
USEPA standard	**< 500**		**6.5-8.5**
Feed water	22600	32200	7.8
Fresh water	54	113	7.5
USEPA standard	**< 500**		**6.5-8.5**
Feed water	22300	31800	7.8
Fresh water	45	82	7.4
USEPA standard	**< 500**		**6.5-8.5**

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

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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