Project 07123-05 - Prototype Design and Demonstration of Produced Water Purification at Wellhead Using Co-Produced Energy Sources

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November 30, 2011

PRESENTATION OUTLINE

- ❑ **OVERVIEW**
- ❑ **HUMIDIFICATION DEHUMIDIFICATION PROCESS**
- ❑ **BENCH SCALE TESTS**
- ❑ **FIELD PROTOTYPE – DESIGN, FABRICATION & TESTING**
- ❑ **RESULTS AND DISCUSSION**
- ❑ **ECONOMICS OF DESALINATION / PROCESS COST**
- ❑ **CONCLUSION**

OVERVIEW

❖**Project Goal**

– Develop and demonstrate a thermal-based desalination process for produced water purification at the wellhead using co-produced energy and solar energy.

❖ **Timeline**

– Project start date: August, 2008
– Expected project end date: January, 2012

❖ **Budget/Total Project Funding**

– RPSEA: $409,506
– Cost share: $683,163
– Total budget: $1,103,706

❖**RPSEA Contract: #07123-05**

– RPSEA project manager: Charlotte Schroeder

SCOPE AND APPROACH

Project included two phases:

Phase 1 (FY08-09):	To develop a produced water purification technology that can be deployed at wellhead, including process design, equipment fabrication and equipment procurement. (COMPLETE)
Phase 2 (FY09-10):	Pilot Test of Produced Water Purification at Wellhead . (COMPLETE)

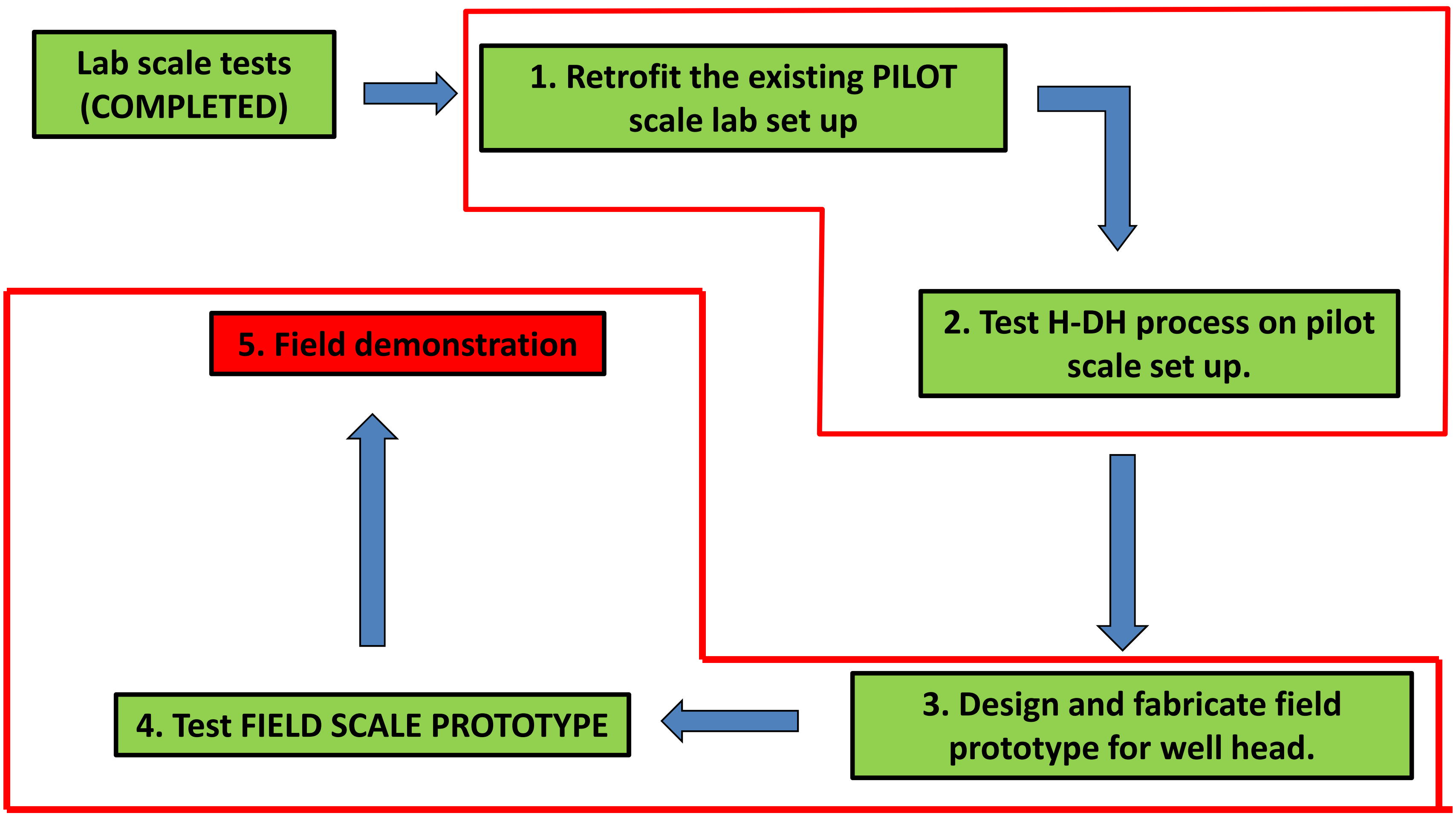
GANTT CHART

PROJECT Demonstration of Produced Water Purification at Wellhead by Using Co-Produced Energy Sources

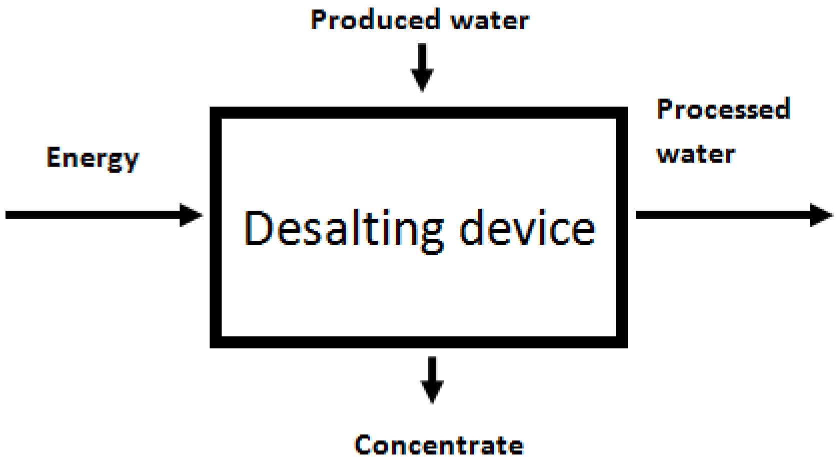
GANTT CHART- (PROJECT SCHEDULE AND PROGRESS STATUS)

PHASE	Sl No	ACTIVITY	STATUS	TIME SPAN OF PROJECT											
				2008				2009				2010			
				Q1(J-M)	Q2(A-J)	Q3(J-S)	Q4(O-D)	Q1(J-M)	Q2(A-J)	Q3(J-S)	Q4(O-D)	Q1(J-M)	Q2(A-J)	Q3(J-S)	Q4(O-D)
PHASE I (01 January 2008 - 31 December 2008)	1	**Project Management Plan** - Objectives of project. - Work beakdown structure, Planned expenditures. - Milestones.	Planned												
			Actual												
	2	**Technology Status Assessment.** - Summary report of proposed technology.	Planned												
			Actual												
	3	**Technology Transfer**	Planned												
			Actual												
	4	**Development of a Co-Sited Produced Water Purification Technology That Can Be Deployed at the Wellhead**	Planned												
			Actual												
	4.1	Low-temperature distillation process for produced water desalination to be designed and demonstrated	Planned												
			Actual												
	4.2	Enhance heat transfer and latent heat recovery.	Planned												
			Actual												
	4.3	Optimize operating parameters.	Planned												
			Actual												
	5	**Deployment of solar and coproduced energy sources.**	Planned												
			Actual												
	5.1	Quantitative analysis of solar & geothermal energies .	Actual												
			Planned												
	5.2	Procure equipment for deployment of solar and coproduced geothermal energies.	Actual												
			Planned												
	5.3	Prototype for pilot test	Actual												
			Planned												
PHASE 2 (01 January 2009 - 31 December 2009)	6	**Pilot Test of Produced Water Purification at Wellhead**	Planned												
			Actual												
	6.1	**Pilot tests at wellhead (site) for 1 year.** - Monitor parameters - Study scale deposition rates and implement periodic acid cleaing of equipment.	Planned												
			Actual												
	6.2	Managing the concentrate from produced water will be evaluated	Planned												
			Actual												
	6.3	Quality assessment of purified product and its other potential uses.	Planned												
			Actual												
	6.4	Technical feasibility and economic efficiency study	Planned												
			Actual												

➢ KEY DELIVERABLES OF THIS PROJECT



BACKGROUND



MEMBRANE PROCESSES

1) Reverse Osmosis
2) Electro dialysis

THERMAL PROCESSES

1) Multi-Stage Flash
2) Multiple Effect Distillation
3) Vapor Compression Distillation

Humidification Dehumidification process (H-DH)

➢ TYPICAL PRODUCED WATER CONCETRATIONS

Component	San Juan Basin (CBM) mg/L	Permian Basin (Oilfield), mg/L	Typical seawater, mg/L
Bicarbonate	5870.3	1538.1	107
Hydrogen Sulfide	65	22.5	N/A
Chloride	2389.5	130636	19352.9
Sulfate	24.1	4594.1	2412.4
Sodium	4169.3	80421.2	10783.8
Potassium	35	398.6	399.1
Magnesium	19	894.1	1283.7
Calcium	11	4395.5	412.1
Strontium	6.3	88.9	7.9
Iron	0.65	65.3	15.5
Total Dissolved Solids (TDS)	**12590.2**	**223054.3**	**34774.4**

Typical produced water concentrations compared with sea water

➢ BENIFICIAL USES OF TREATED PRODUCED WATER

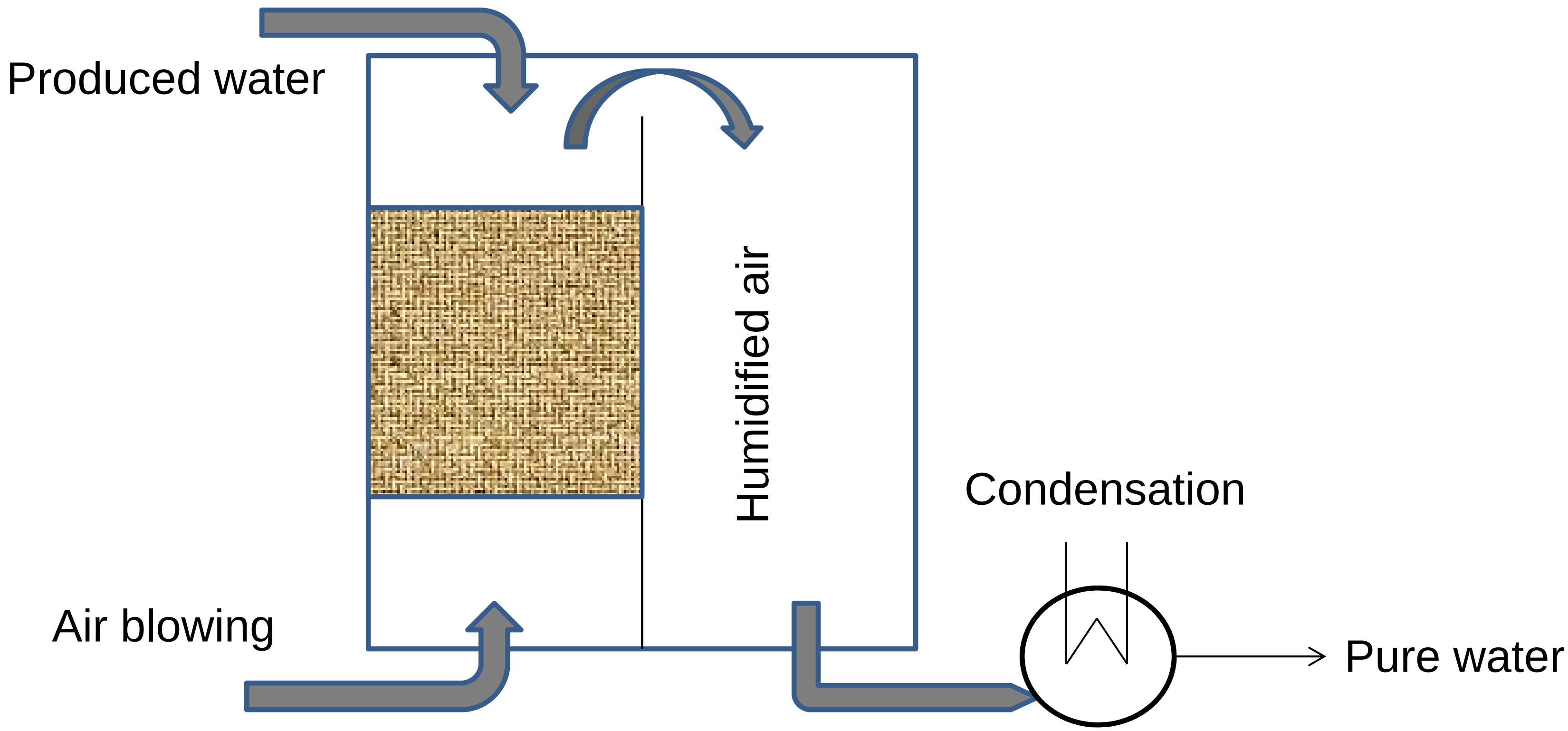
Beneficial uses	Water quality requirement		Main Concerns
	Suspensions	Dissolved components	
Offshore disposal	Solid < 10 mg/l Oil< 5 mg/l	No limitation	Environmental impact
Reinjection	Solid< 1 mg/L Oil< 5 mg/l	No limitation	Formation damage
Irrigation **(Rowe et al.,)1995)**	Oil & grease < 35 mg/l	TDS < 2000 mg/l	Salinity, trace elements, chlorine residues, and nutrient
Cooling water (EPA, 2004)	N/A	TDS < 2700 mg/l	Corrosion, biological growth, and scaling.
Chemical process **(EPA 2004)**	N/A	TDS < 1000 mg/l	Low turbidity, suspended solids and silica

Water quality requirements for various end uses

➢ HUMIDIFICATION DEHUMIDIFICATION PROCESS (H- DH PROCESS)

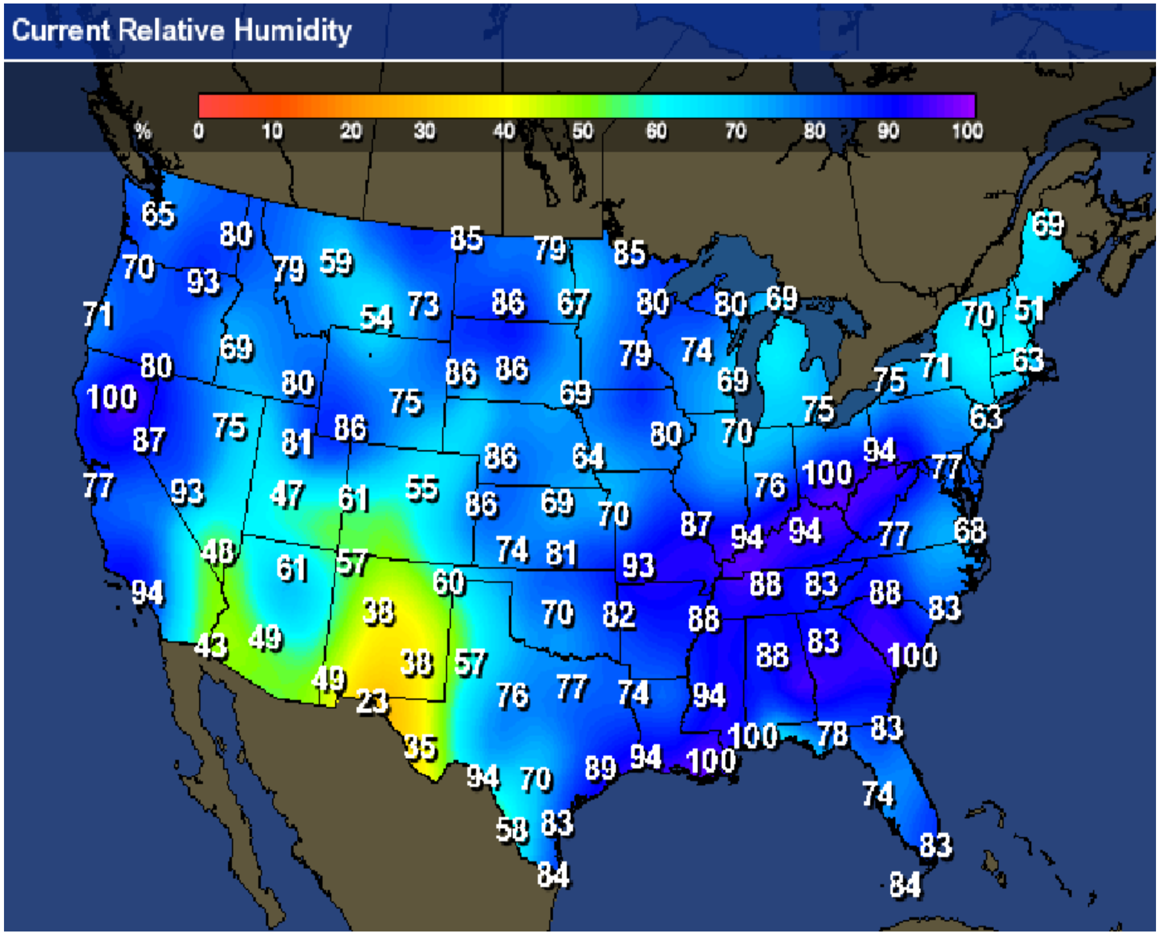
Produced water purification (Desalination) in this work is achieved by humidification and subsequent condensation/dehumidification

A simple schematic representing the process is shown below



RELATIVE HUMIDITY BY STATE

NEW MEXICO TECH

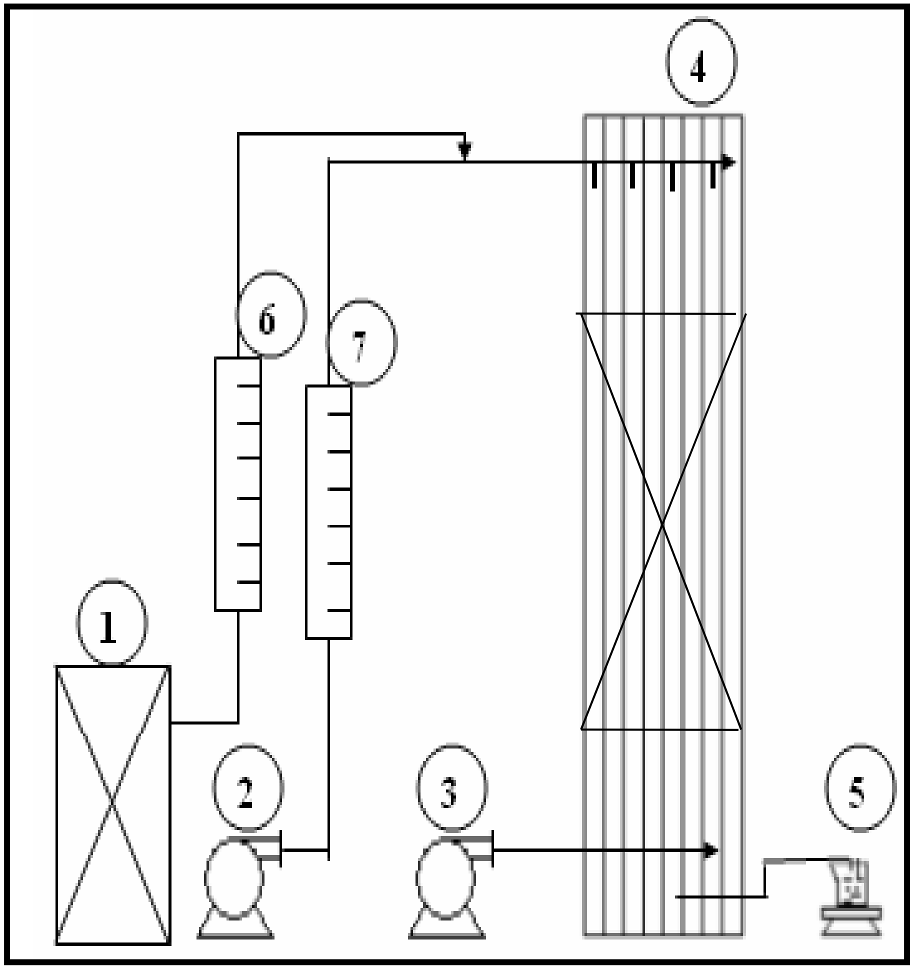


This map shows the relative humidity distribution across the United States with the lowest being in NM, TX and AZ. It can clearly be seen why this technology is promising in New Mexico, Western Texas and also Arizona due to the high relative humidity gradient available until saturation.

BENCH SCALE TESTS

RETROFIT EXISTING SETUP , TESTS

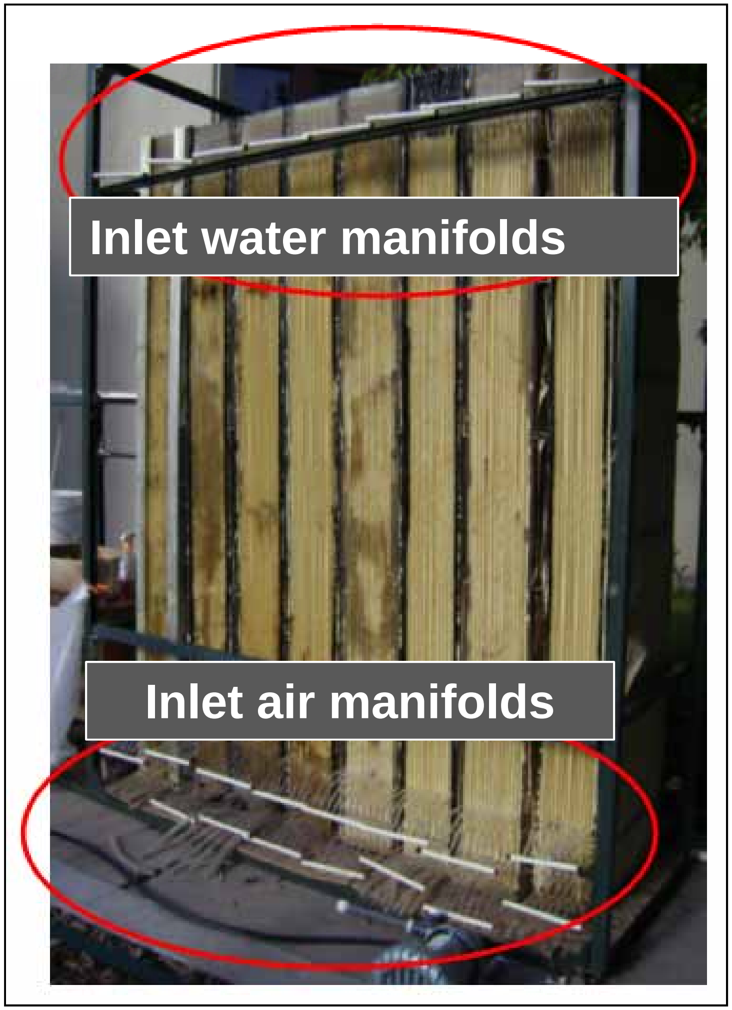
➢ BENCH SCALE TESTS – EXPERIMENTAL SET UP



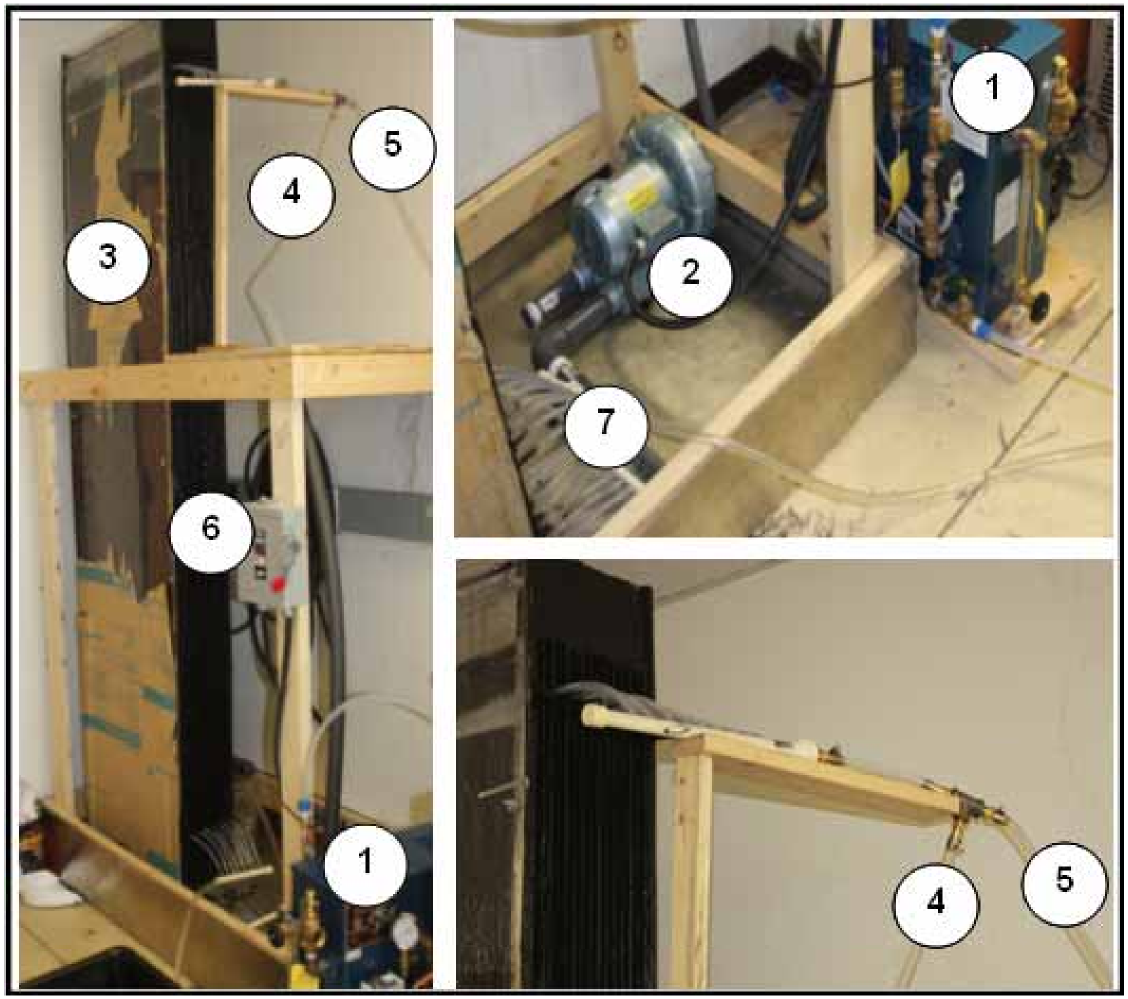
Schematic of the bench scale pilot set up.

1. Steam generator (25 lb/hr)
2. Produced water inlet pump
3. Air inlet pump
4. Water purification unit
5. Purified water collection
6. Inlet water flow meter
7. Inlet air flow meter

➢ BENCH SCALE TESTS – WATER PURIFICATION UNIT



➢ BENCH SCALE TESTS – EXPERIMENTAL SET UP



1. Steam generator (25 lb/hr)
2. Inlet air pump
3. Water purification unit
4. Inlet steam
5. Inlet water feed
6. Power supply
7. Purified water outlet

Experimental set up for the bench scale tests.

➢ **BENCH SCALE TESTS – OPERATING MODES**

Direct steam injection

CONTINUOUS PROCESS

Steam to heat inlet batch feed

BATCH PROCESS

❖ BENCH SCALE TESTS – OBSERVATIONS

- The bench scale tests provided a a good indication of the water quality, but not the yield.

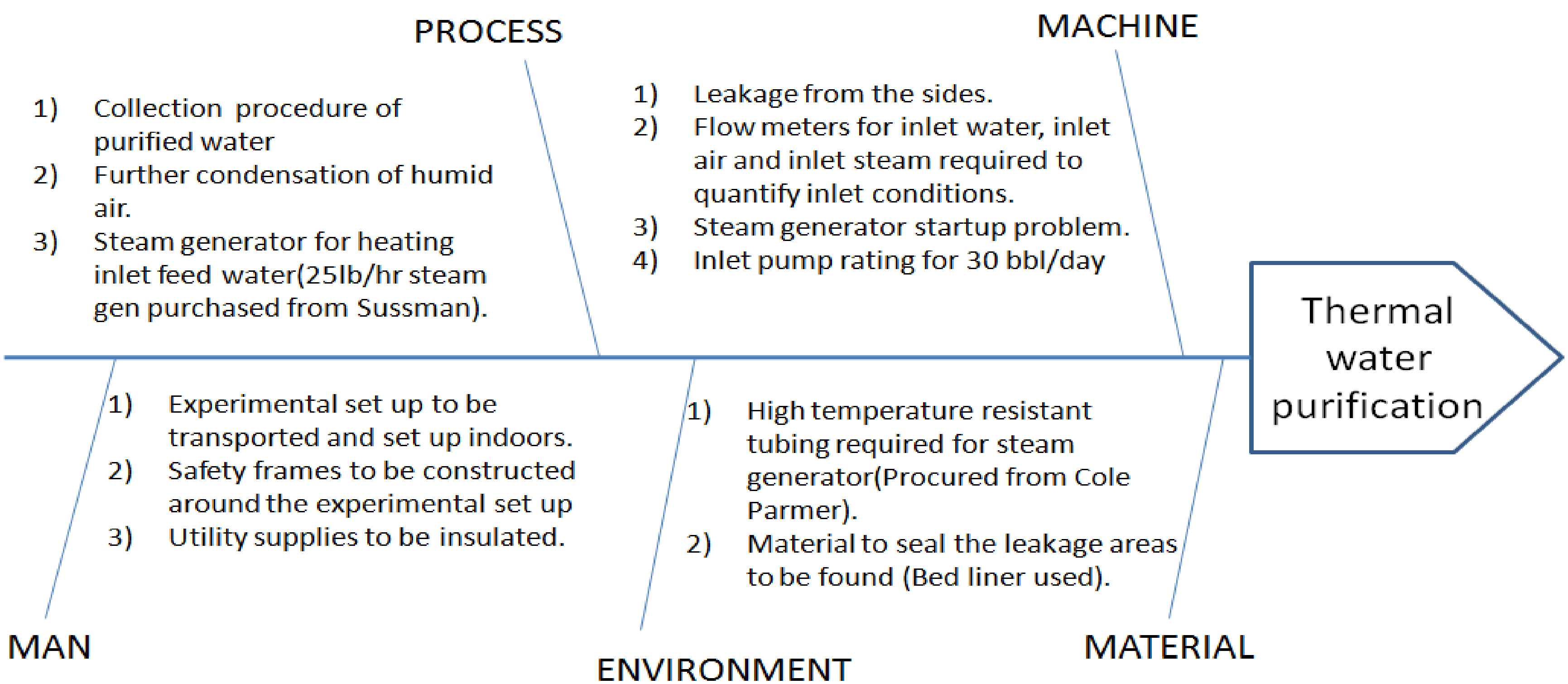
- However, it was necessary to establish the process yield as already established in the lab scale tests in the past.

- This was due to several reasons such as poor heat transfer due to the material of construction, leakage in the modules and possible intermixing as seen from the ion rejection results that decreased with time

- However, the ion rejection potential of the process was established and was well over 95%, as confirmed by the laboratory results.

❖ BENCH SCALE TESTS – TROUBLESHOOTING PROCESS

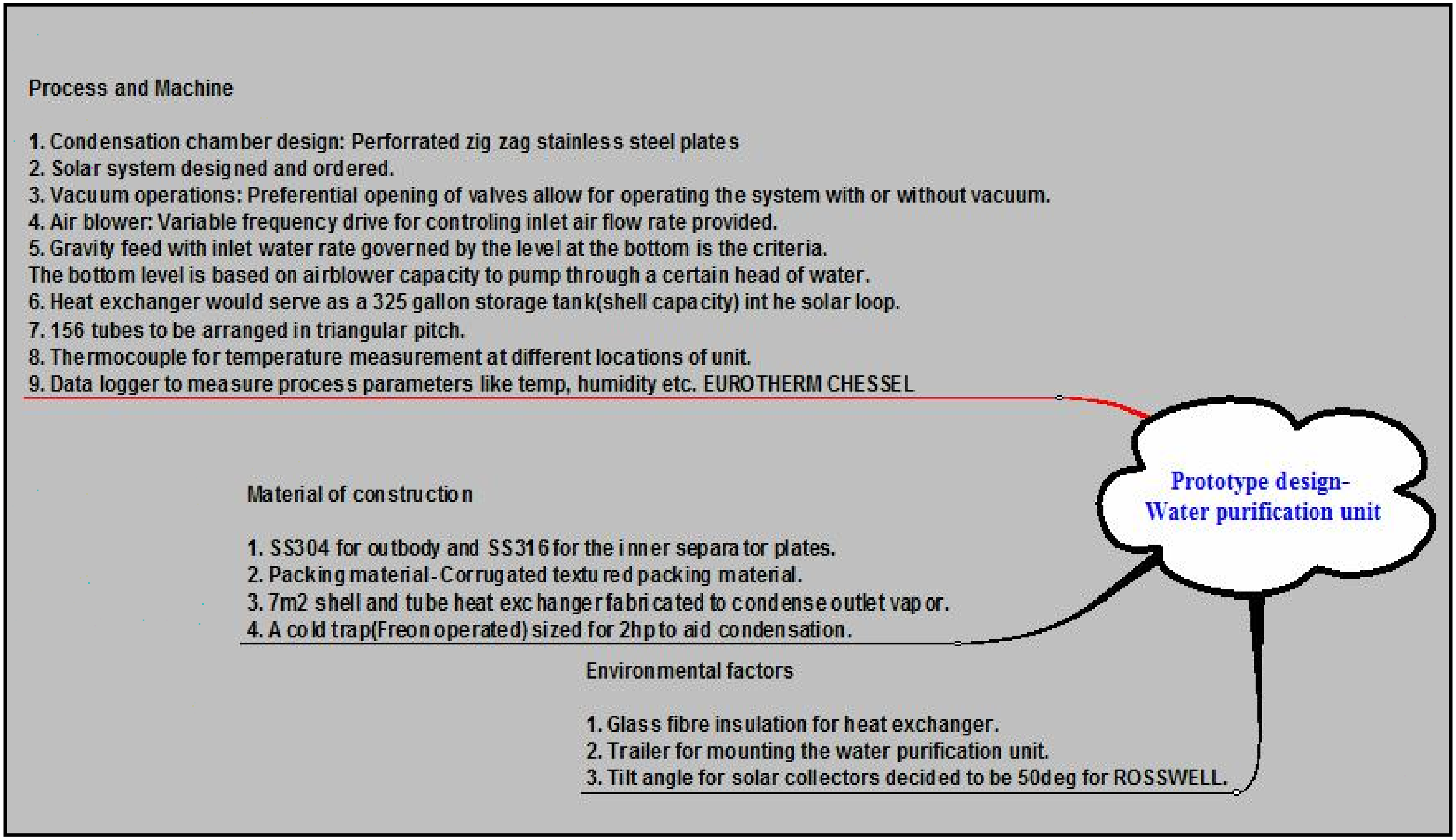
A fishbone diagram lists out and prioritizes the root causes of a problem, by looking at it from different perspectives- (Man, Machine, Material, Method and Environment)



Fishbone diagram troubleshooting the bench scale process

❖ FIELD PROTOTYPE– DESIGN, FABRICATION AND TESTING

A mind mapping carried out before design of the field prototype is shown below



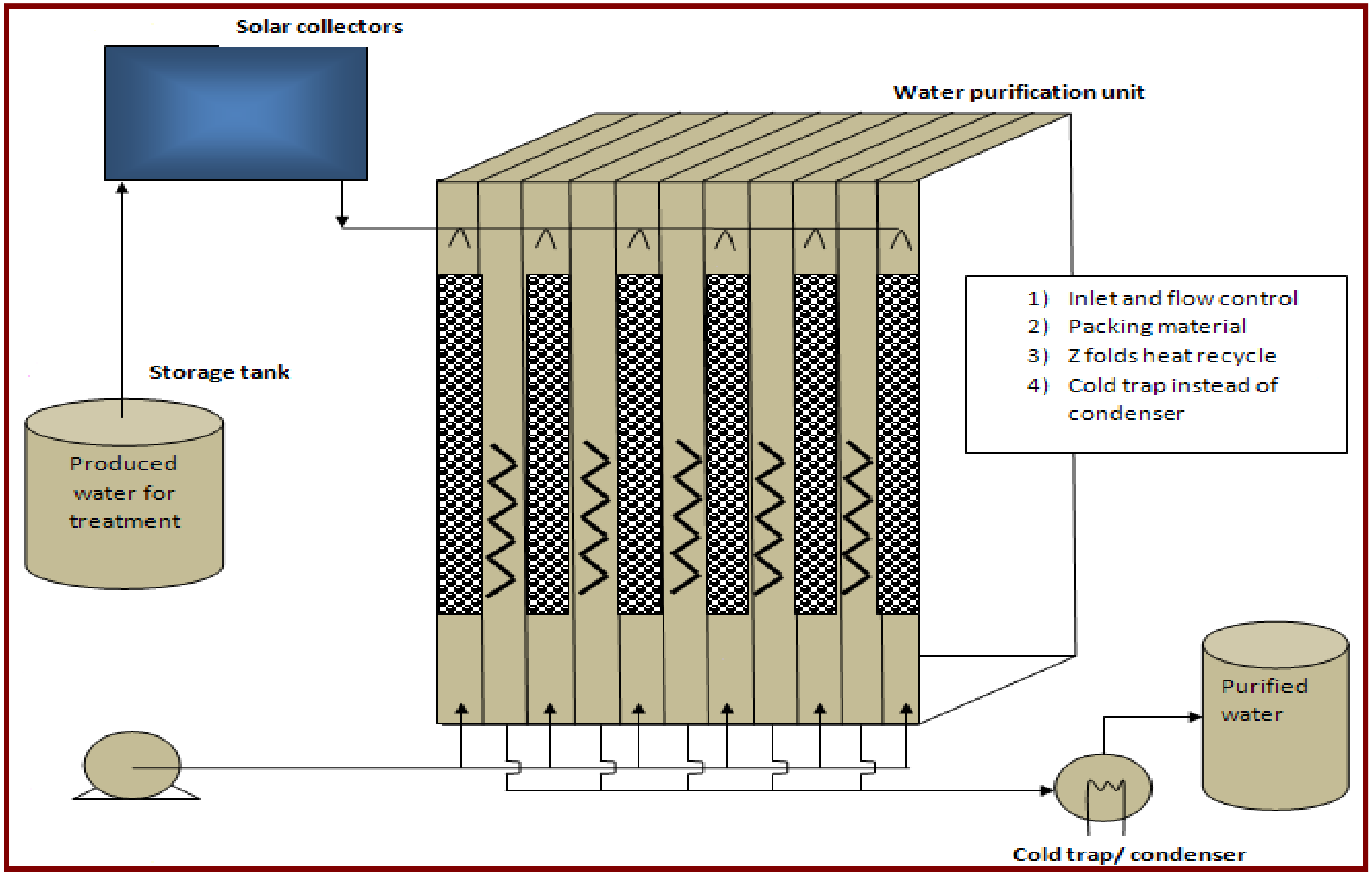
Mind mapping for design of the field prototype.

FIELD PROTOTYPE

DESIGN, FABRICATION AND TESTING

FIELD PROTOTYPE- SCHEMATIC

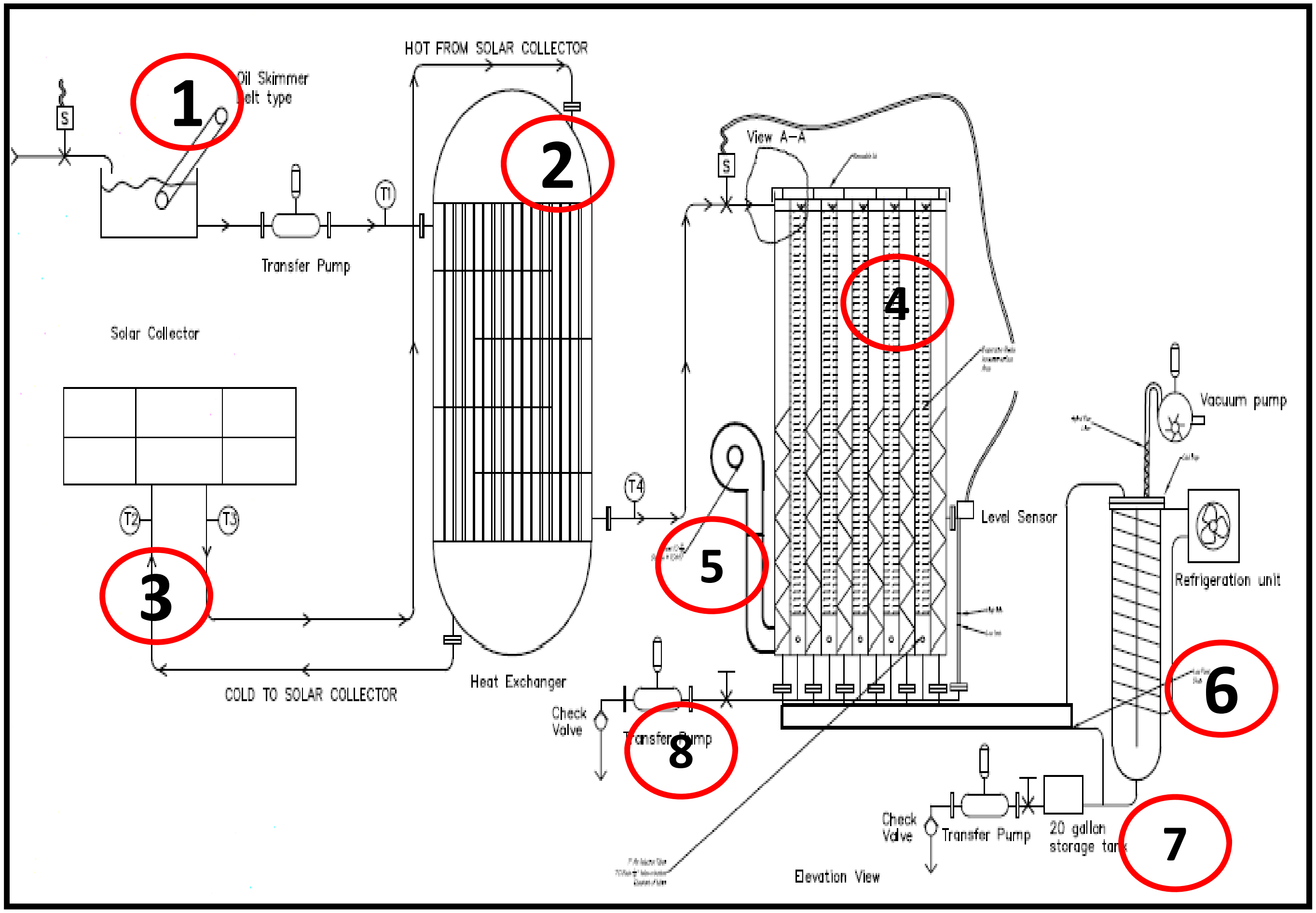
A schematic of the field prototype



Schematic representation of the field prototype.

➢ FIELD PROTOTYPE– DESIGN, FABRICATION AND TESTING

The P&ID(Piping and Instrumentation) diagram is as shown

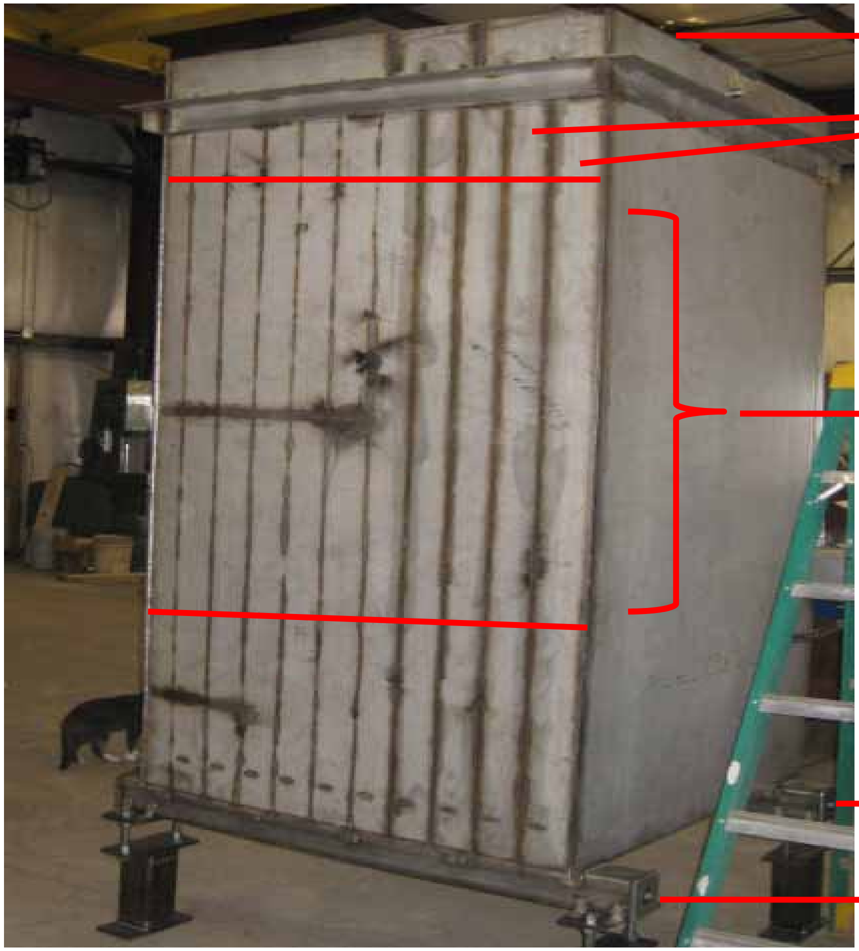


P&ID of the field prototype on site

1. Oil skimmer
2. Holding tank
3. Solar panels
4. Humidification dehumidification (HDH) unit
5. Air blower
6. Condenser
7. Discharge pump
8. Concentrate discharge pump

➢ FIELD PROTOTYPE– DESIGN, FABRICATION AND TESTING

The fabricated prototype is described below



Removable ceiling for replacing packing and maintenance.

Alternate hot and cold chambers

Packing

Outlet process stream to condenser

Concentrate brine drain

Fabricated water purification prototype

➢ FABRICATED FIELD PROTOTYPE

Trailer holding the water purification unit

➢ FABRICATED FIELD PROTOTYPE

Fabricated prototype inside the trailer

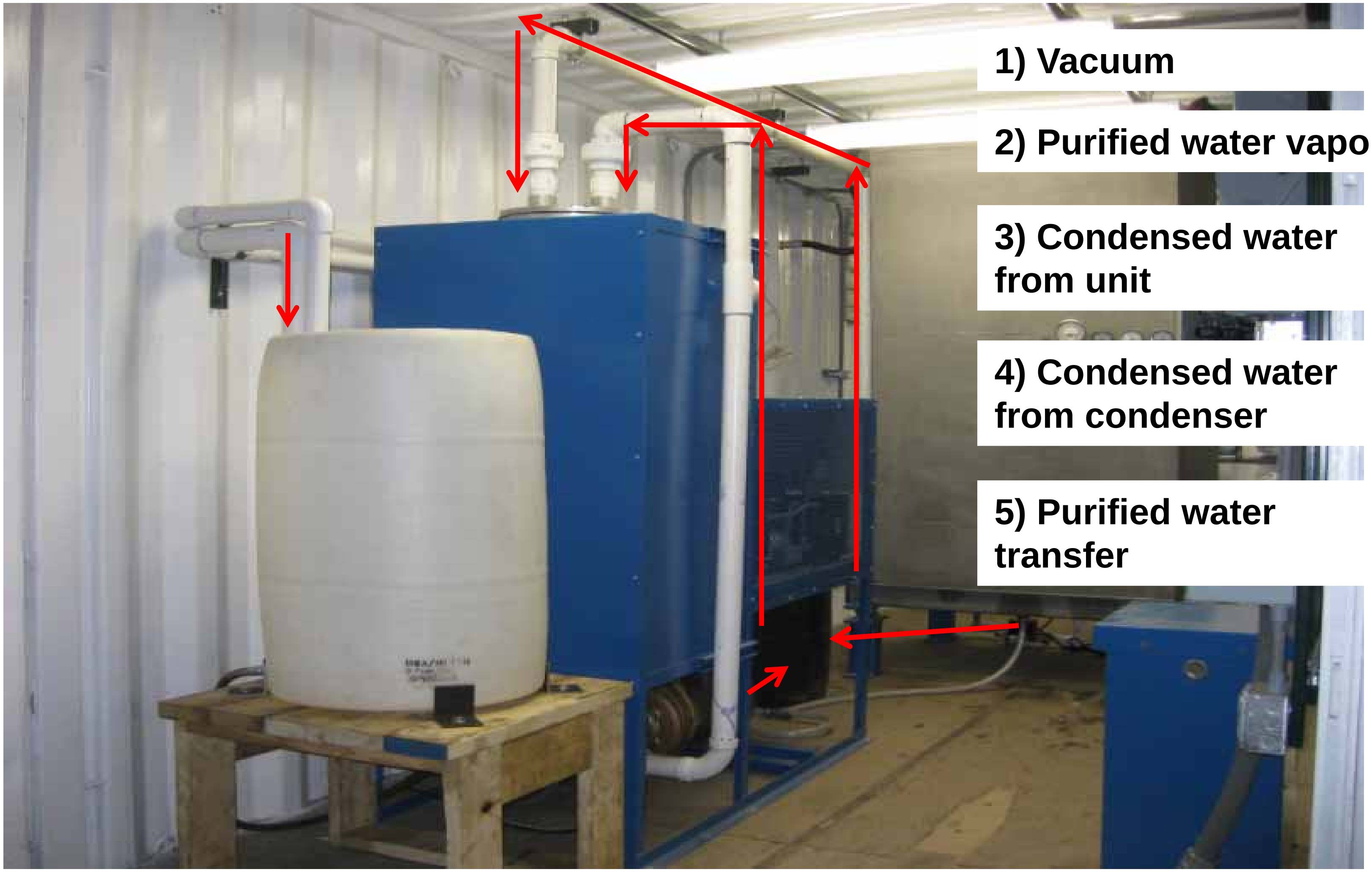
FIELD PROTOTYPE – OPERATING MODES

Air blowing with water condenser

Air blowing with cold trap

Vacuum with condenser

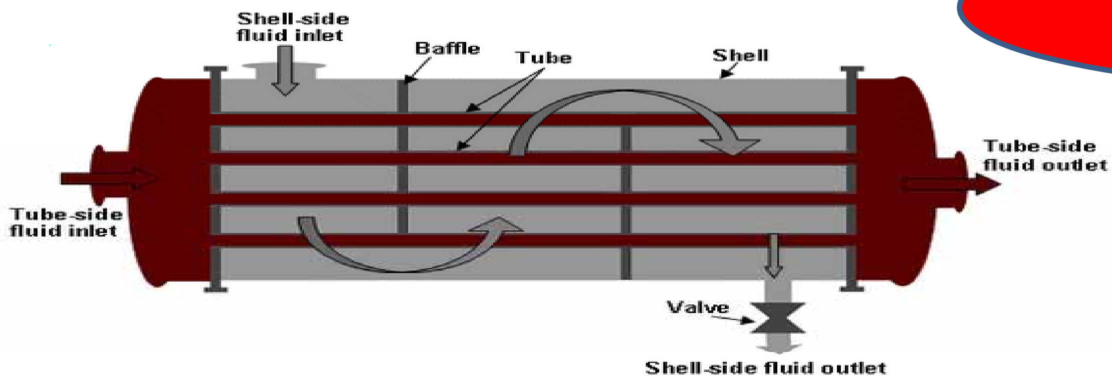
➢ FABRICATED FIELD PROTOTYPE



Fabricated prototype inside the trailer

CONDENSER SIZING

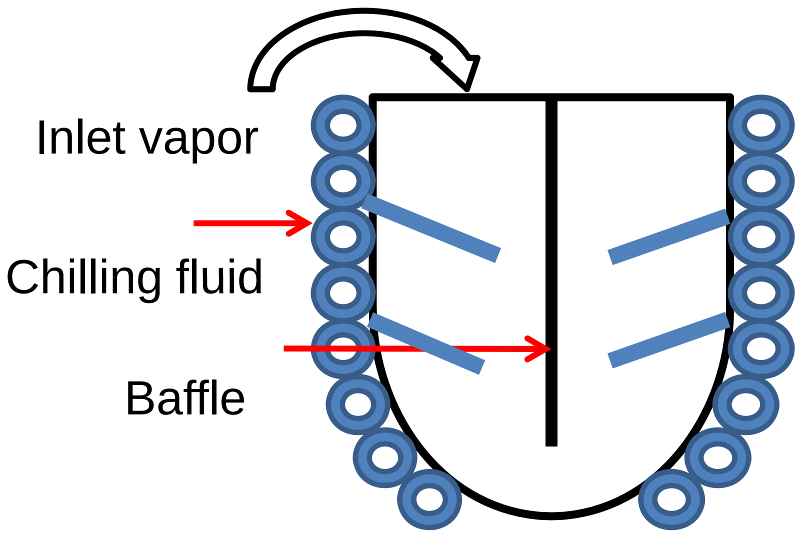
Theoretical requirement



SHELL AND TUBE HEAT EXCHANGER

Rating: 2.2 m²

- Tube side surface area
- (126 tubes, 5' long)
- Cost > 3x (Cost)cold trap



REFRIGERANT BASED COLD TRAP

Rating: 2.2 m²

- Shell side/ cylinder surface area
- (1' dia, 3.5' long)

CONDENSER

Rating: 4.5 m².
- **Tube side surface area**
- **(126 tubes, 5' long)**
- **Cost > 3x (Cost)cold trap**

Rating: 3 m².
- **Air cooled**
- **Capacity: 20 bbl/day**

WATER CONDENSER

AIR COOLED CONDENSER

SOLAR SYSTEM SIZING

➢ SOLAR HEATING OF PRODUCED WATER

Evacuated tubes and flat plate solar collectors were considered, however glycol based flat plate collectors were chosen due to budget constraints and as space wasn't a constraint.

HEAT INPUT REQUIRED FOR SOLAR HEATING

Q= m*Cp*delT

Q=	Heat transfer rate (KW or KJ/s)
m=	Quantity of fluid to be heated (kg)
Cp=	specific heat (kJ/kg°C)
t=	Time in sec
ΔT=	Temperature gradient (°C)

Q= 3108 * 3.2 * (71 – 15)

692876 KJoule

= 556 KBTU

HEAT INPUT REQUIRED FOR SOLAR HEATING- Solar company method

630 gallons/day or 15 bbls

(15 * 42 gallons) X 8.34 lbs/gallon X (75) degree change in fahrenheit divided by 78% (Efficiency)

= 500 KBTU

The above calculation is a rule of thumb method of calculating the heat required to size the solar collectors, which is about 23% off from the traditional calculation.

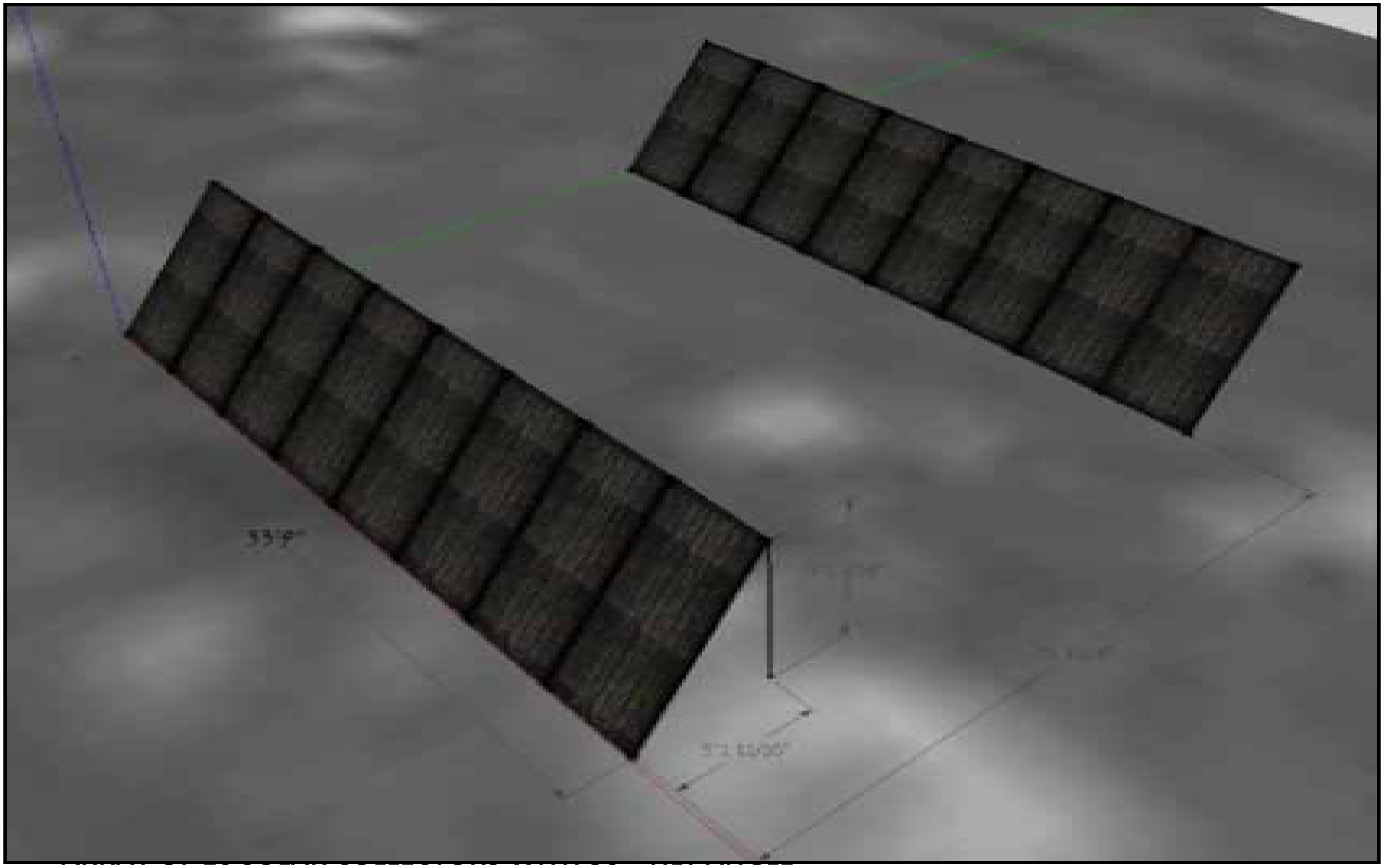
SIZING THE SOLAR PANELS [1]

1(8x4) 32 ft^2 solar collector = 32,000 BTU/day

500 KBTU / 32000 = 15.625 = 16 collectors

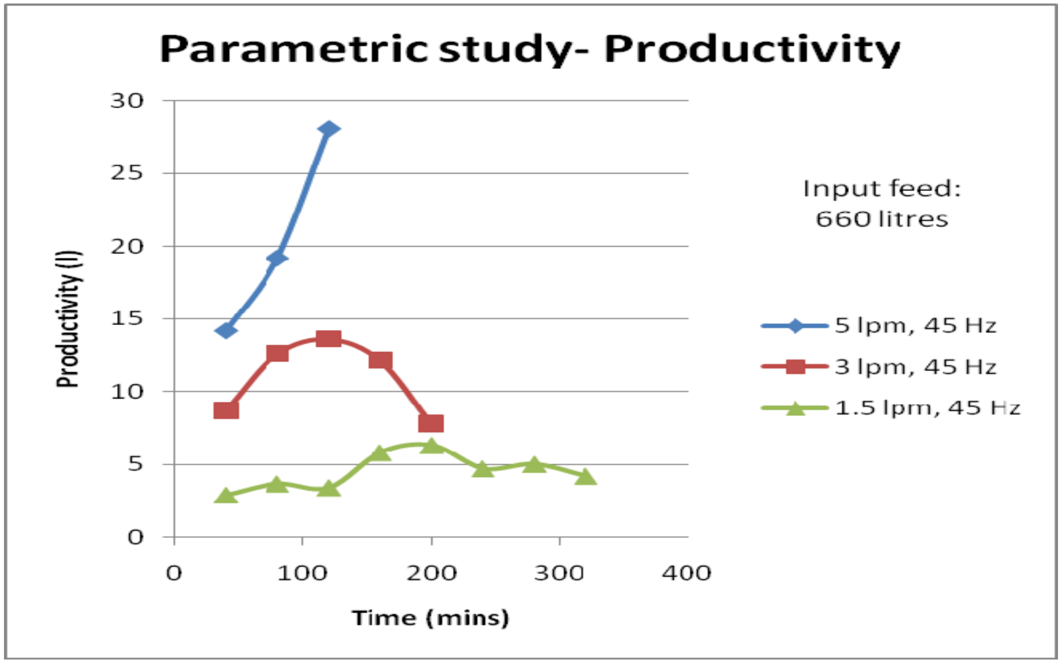
SOLAR PANEL ORIENTATION

➢ SOLAR HEATING OF PRODUCED WATER



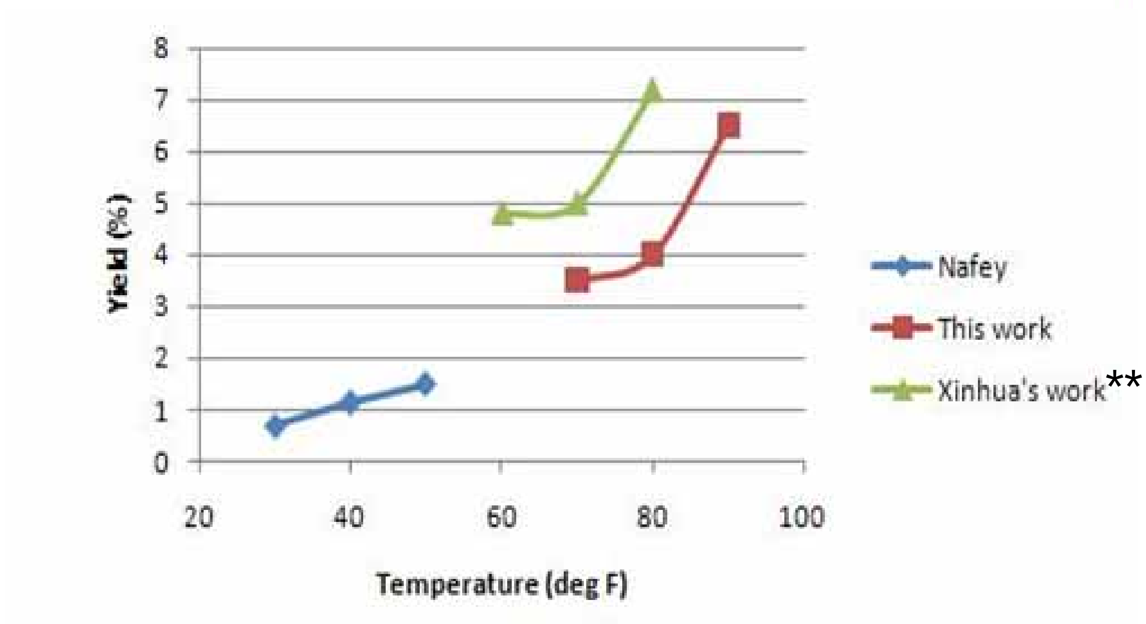
❖ PARAMETRIC STUDY OF THE SYSTEM

- A detailed parametric analysis of the humidification dehumidification process was carried out in the lab scale tests.



Effect of flow rate on productivity

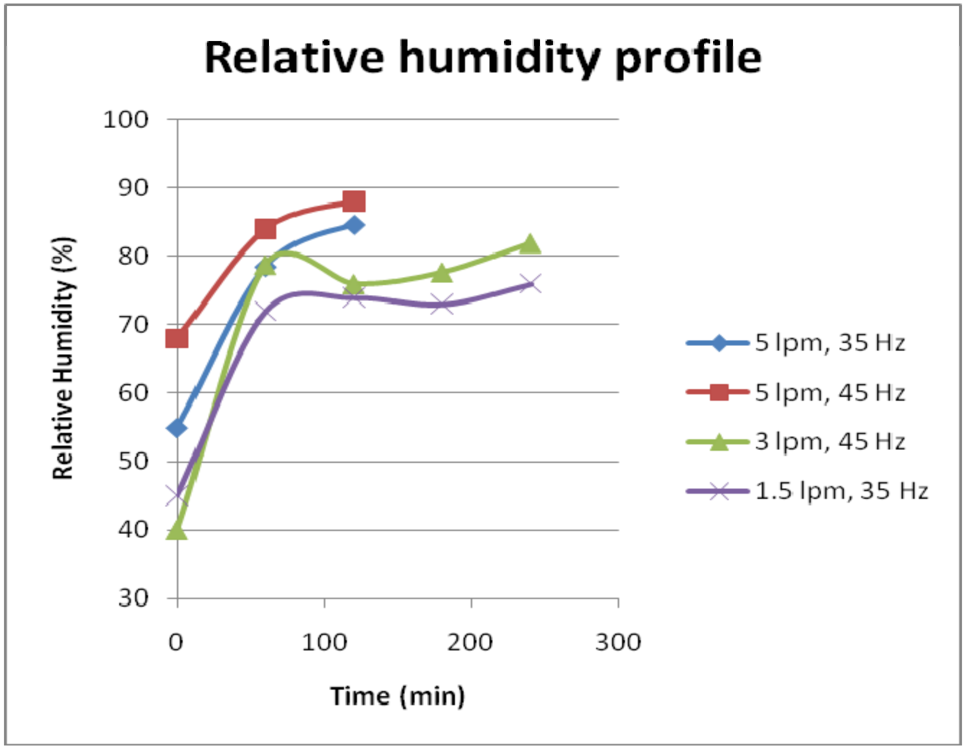
➢ EFFECT OF TEMPERATURE ON PRODUCTIVITY



Effect of inlet water temperature on productivity

** Xinhua Li, “Experimental analysis of produced water desalination by humidification-dehumidification process,” Masters thesis, New Mexico Tech, Nov 2009.

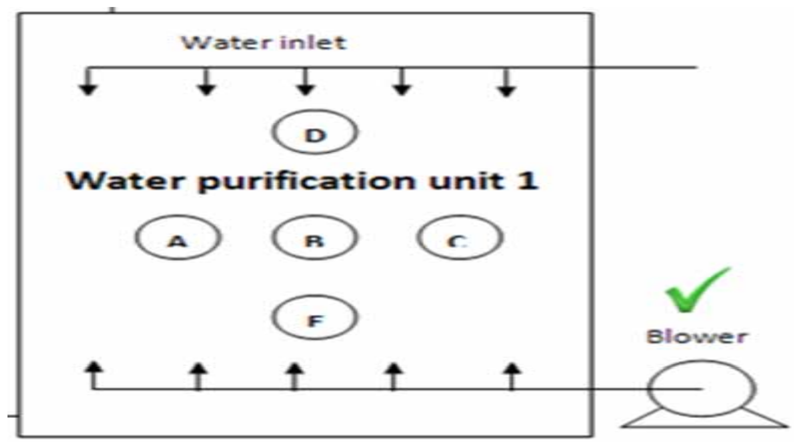
➢ RELATIVE HUMIDITY PROFILE WITHIN THE SYSTEM

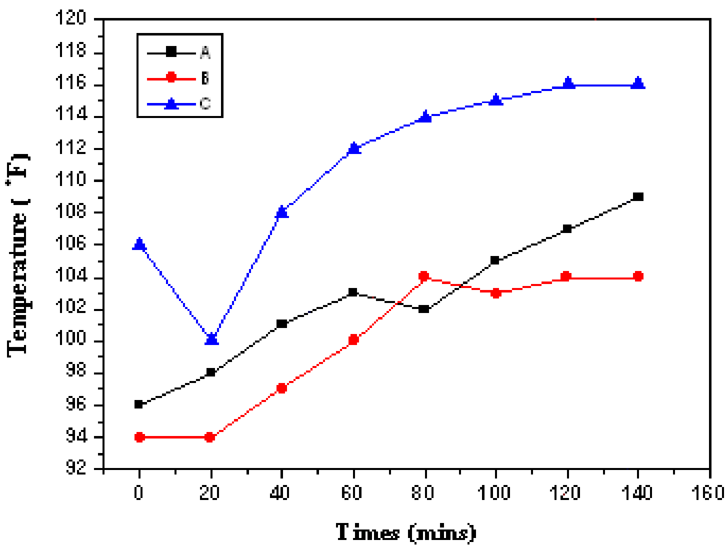


Relative humidity profile

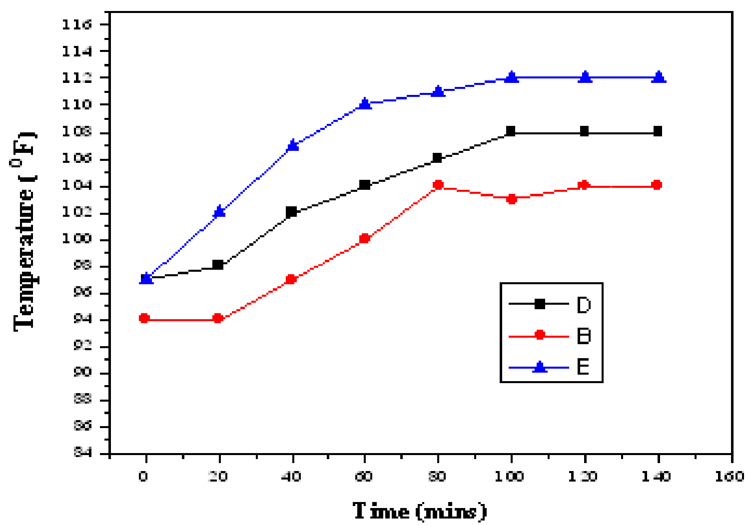
TEMPERATURE PROFILE

➢ TEMPERATURE PROFILE WITHIN THE PROCESS





Temp. change along horizontal direction



Temp. change along vertical direction

Tests on prototype – (Pre field tests)

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- Tests for ion rejection carried out with NaCl feed

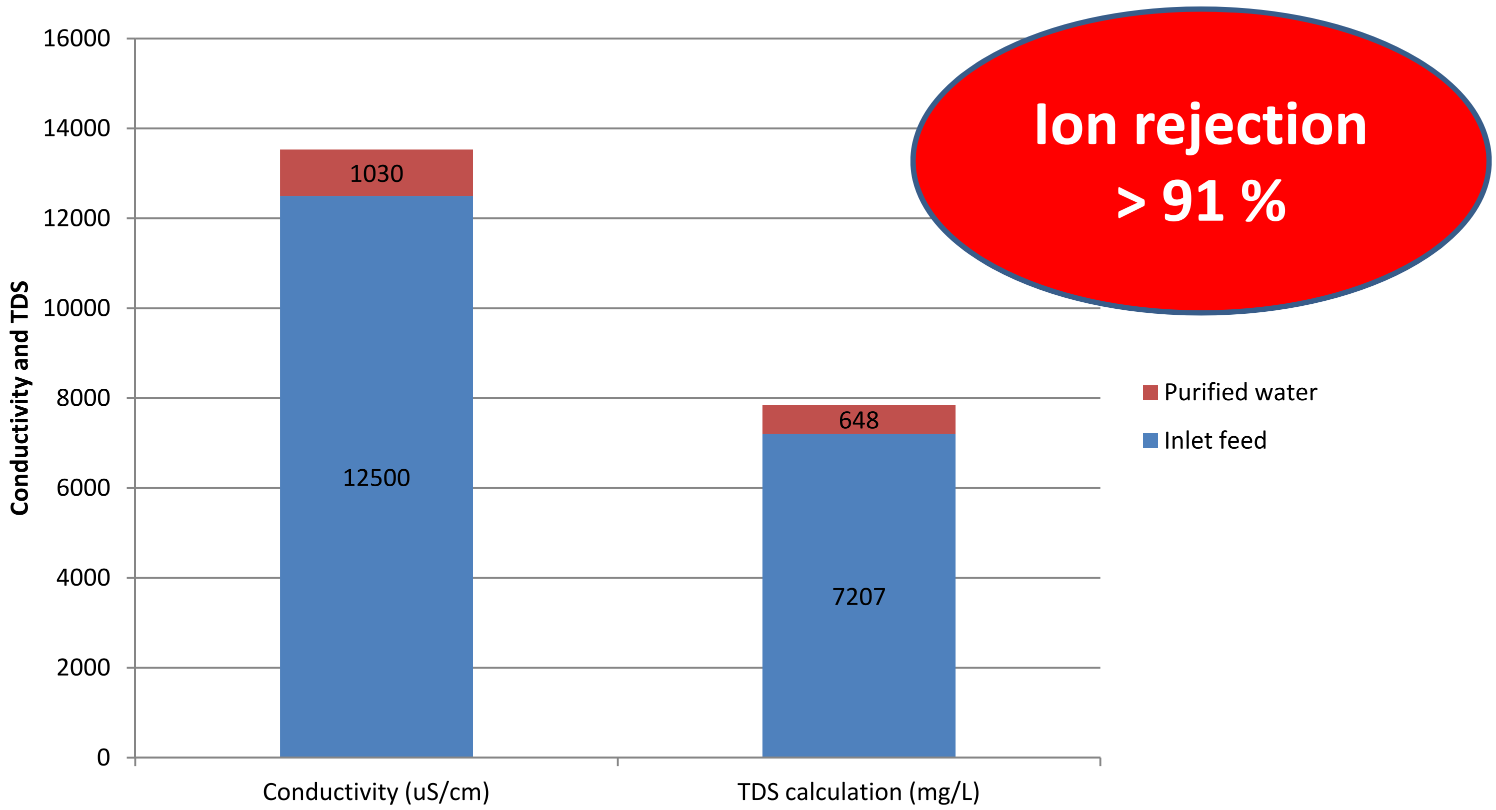
Quantity Measured	Inlet feed	Purified water
Sodium (Na) (mg/L)	2390	165
Chloride (mg/L)	3780	105
Fluoride (F-) (mg/L)	4	1.3
Phosphate (mg/L)	8	0.4
Potassium (K) (mg/L)	220	5.8
Magnesium (Mg) (mg/L)	22	12
Calcium (Ca) (mg/L)	145	39
Bromide (mg/L)	11	0.12
Total cations (meq/L)	118	10
Total anions (meq/L)	126	9.8
Percent difference	-3.3	1.7
Conductivity (uS/cm)	**12500**	**1030**
TDS calculation (mg/L)	**7207**	**648**

Ion rejection for NaCl feed

Tests on prototype – (Pre field tests)

❖ Tests for ion rejection carried out with NaCl feed

The TDS and Conductivity before and after the process are shown below



Ion rejection for produced water feed

Tests on prototype – (Pre field tests)

NEW MEXICO TECH

- Tests for ion rejection carried out with produced water feed

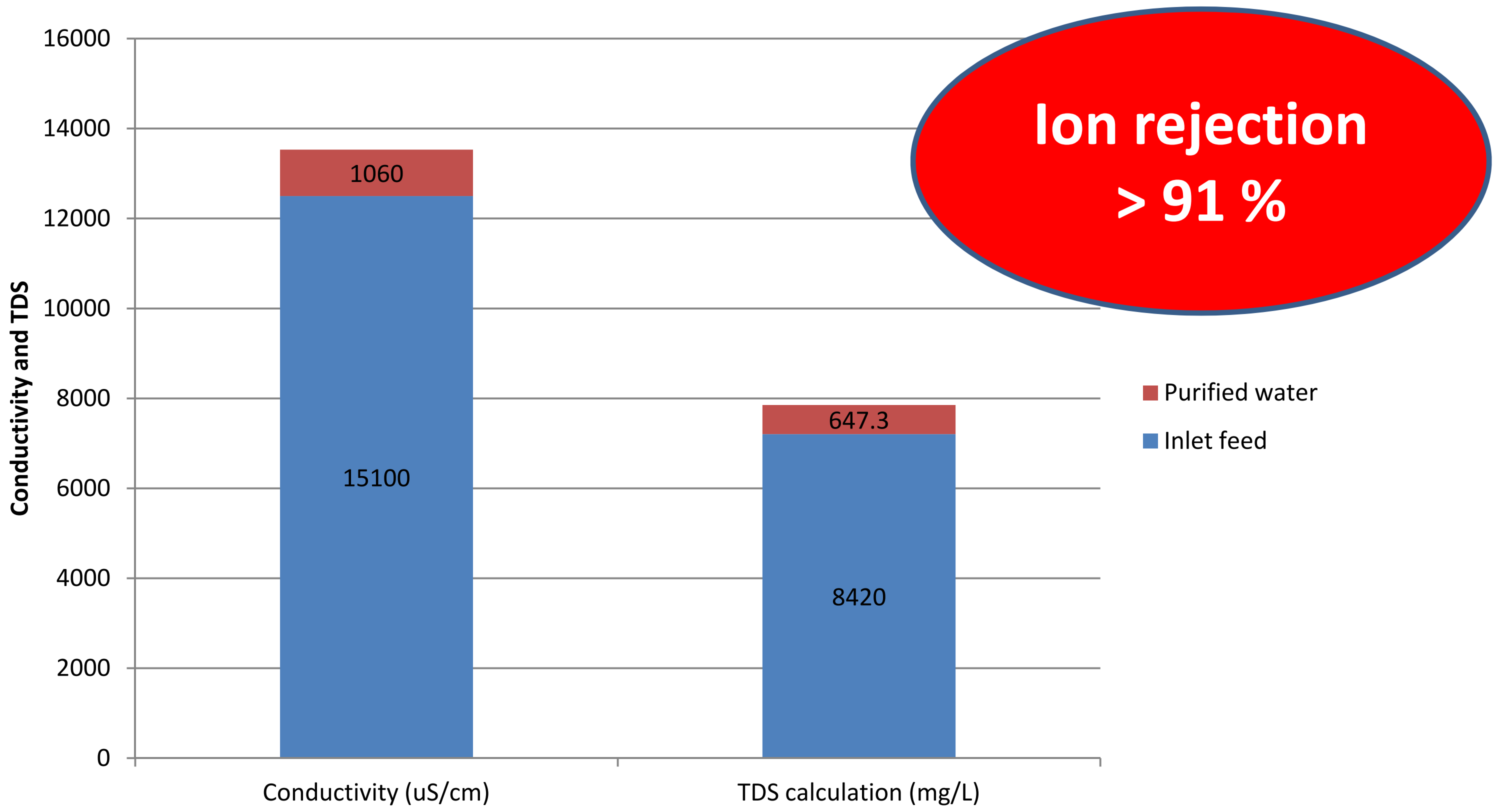
Quantity Measured	Inlet feed	Purified water
Sodium (Na) (mg/L)	3220	165
Chloride (mg/L)	4920	105
Fluoride (F-) (mg/L)	3	1.2
Phosphate (mg/L)	8.8	0.4
Potassium (K) (mg/L)	4.9	5.7
Magnesium (Mg) (mg/L)	6.5	11
Calcium (Ca) (mg/L)	23.7	37.0
Bromide (mg/L)	3	0.1
Total cations (meq/L)	142	10
Total anions (meq/L)	143.8	9.9
Percent difference	-0.6	0.5
Conductivity (uS/cm)	**15100**	**1060**
TDS calculation (mg/L)	**8420.7**	**647.3**

Ion rejection for produced water feed

Tests on prototype – (Pre field tests)

- Tests for ion rejection carried out with produced water feed

The TDS and Conductivity before and after the process are shown below



Ion rejection for produced water feed

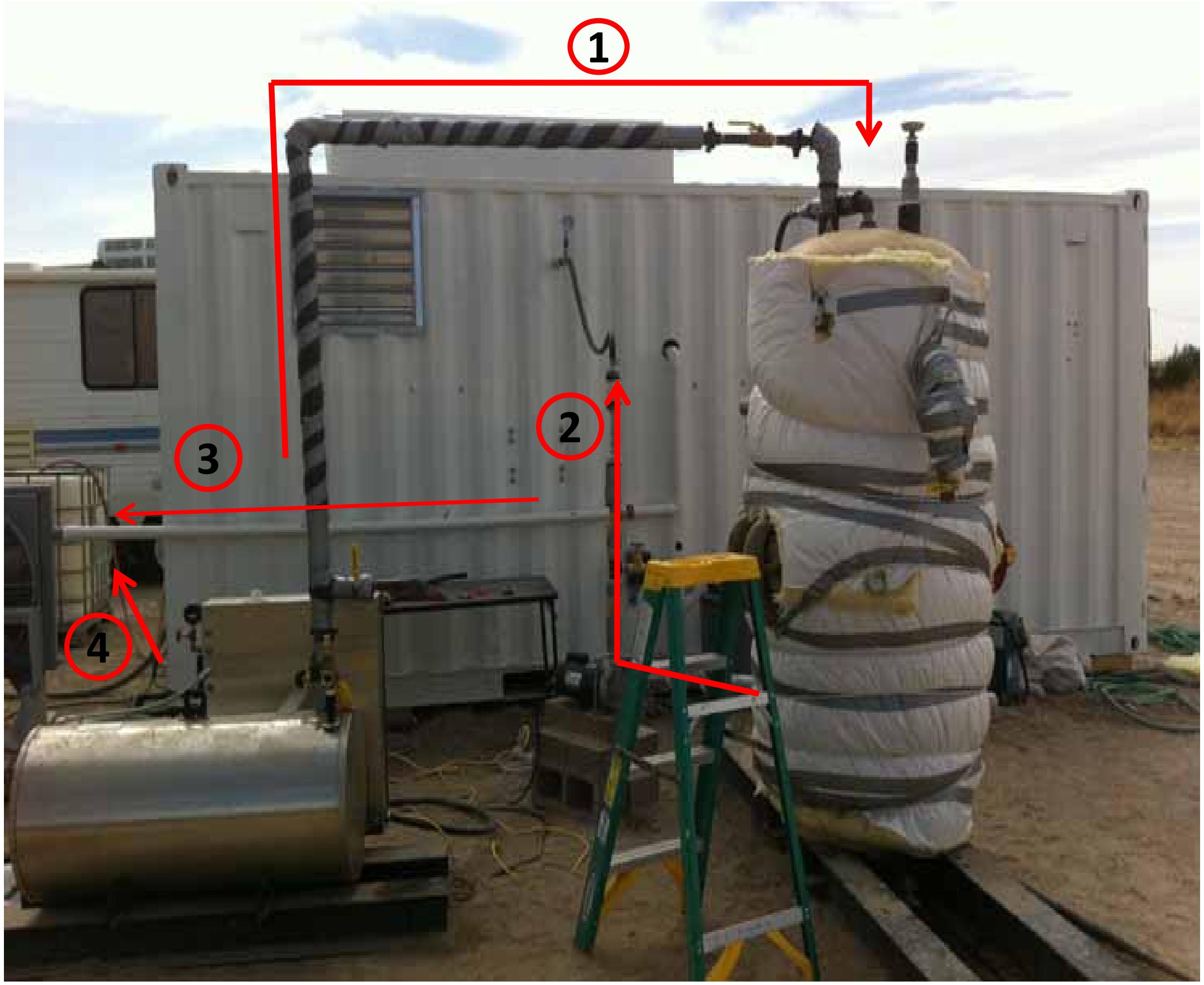
FIELD TESTS

FIELD PROTOTYPE – OPERATING MODES

Air blowing with air cooled condenser (HDH process)

HDH process + Latent heat

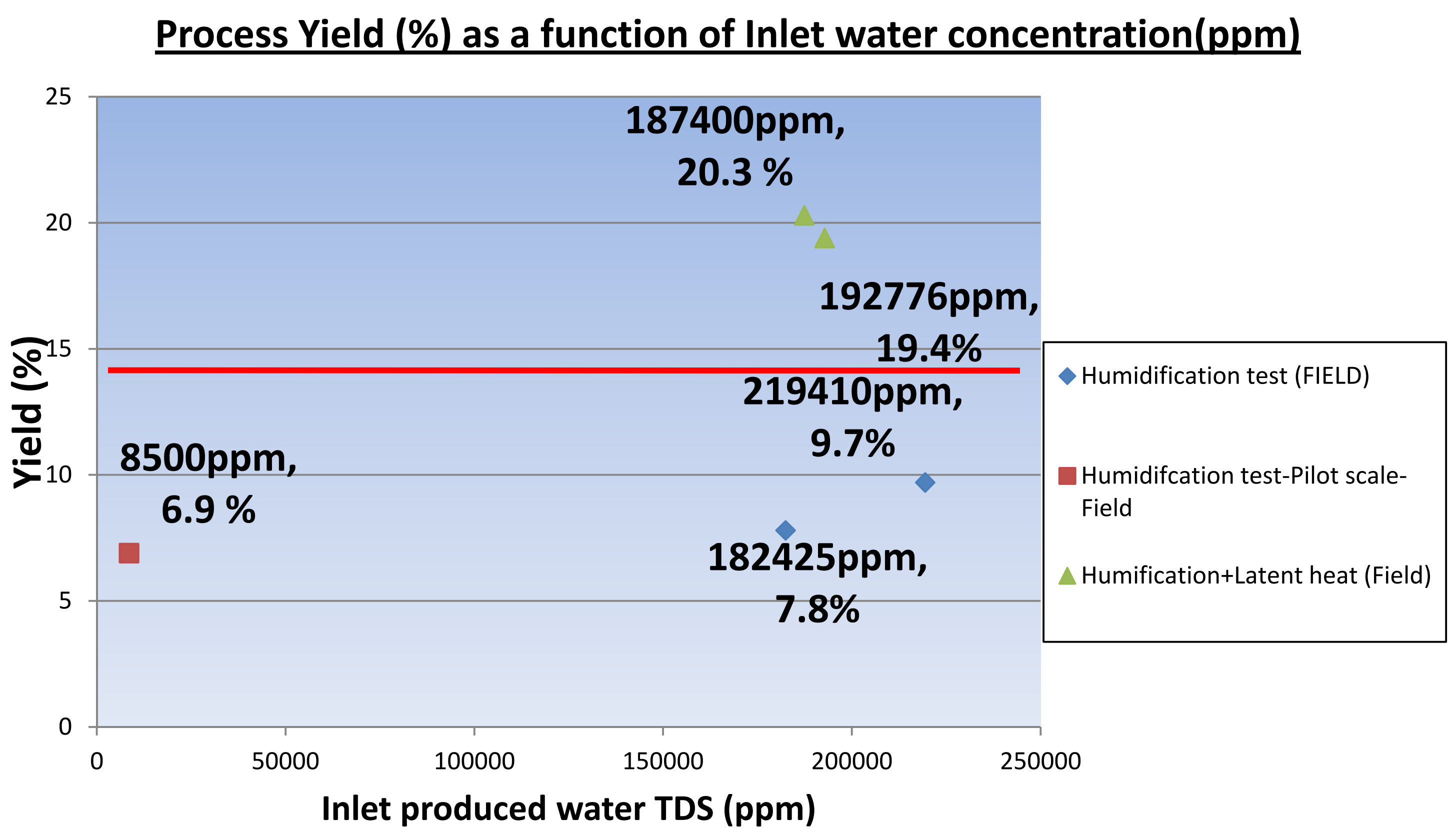
❖ FIELD TESTS



1. Process heating
2. Inlet water into the unit
3. Humidified vapor
4. Concentrate drain

❖ FIELD TESTS

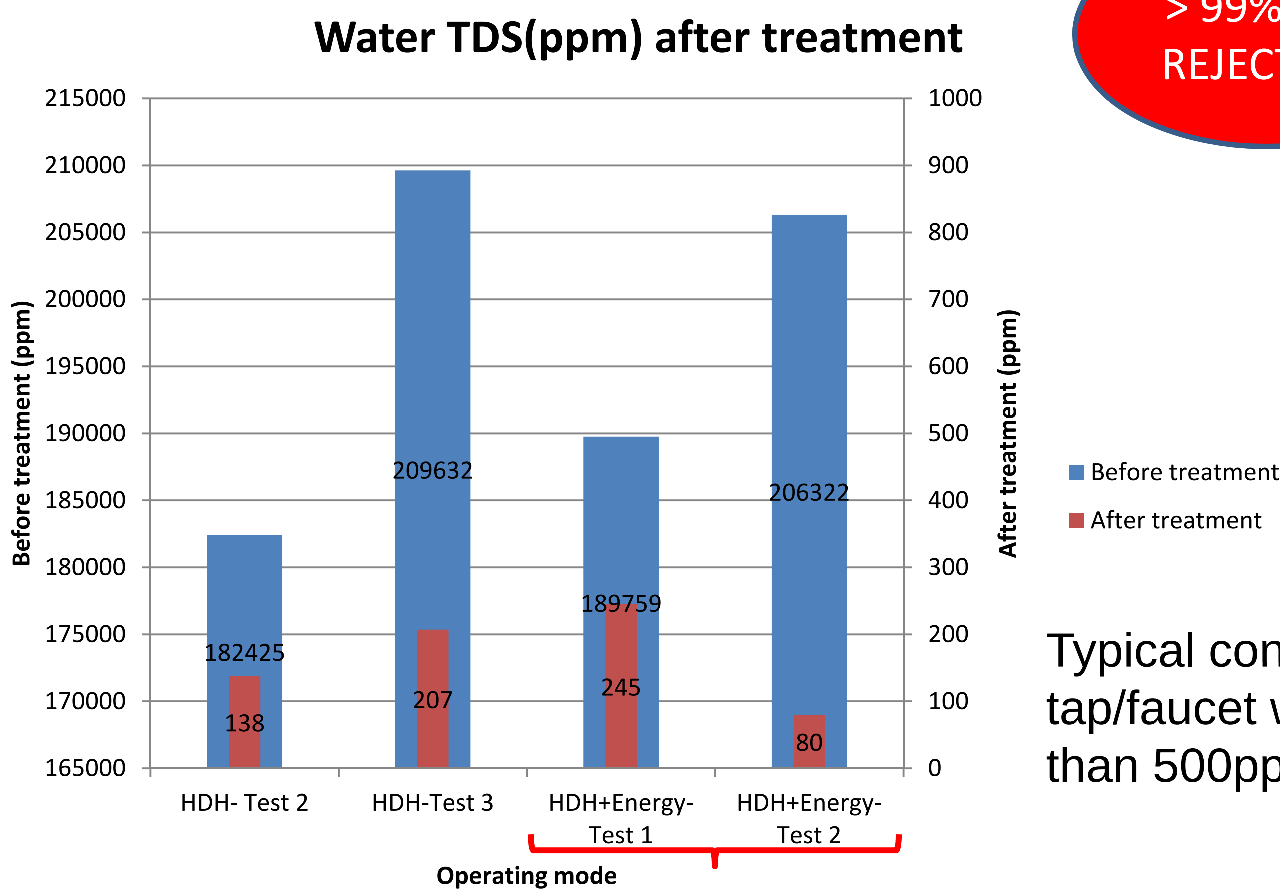
➢PROCESS YIELD AT VARIOUS INLET WATER CONCENTRATIONS



ION REJECTION

➤ **WATER TDS BEFORE AND AFTER TREATMENT**

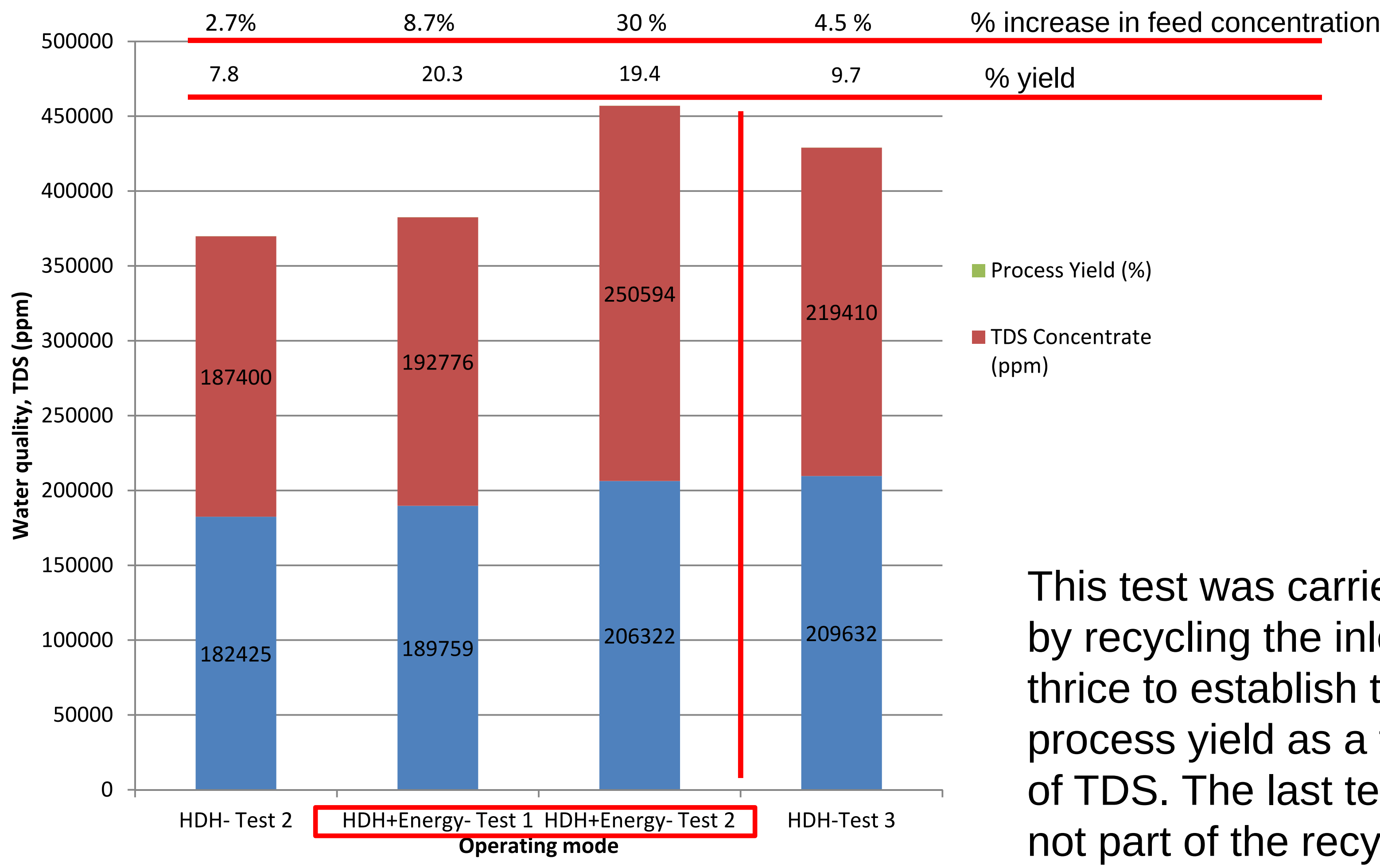
> 99% ION REJECTION



Typical concentration of tap/faucet water is less than 500ppm.

YIELD

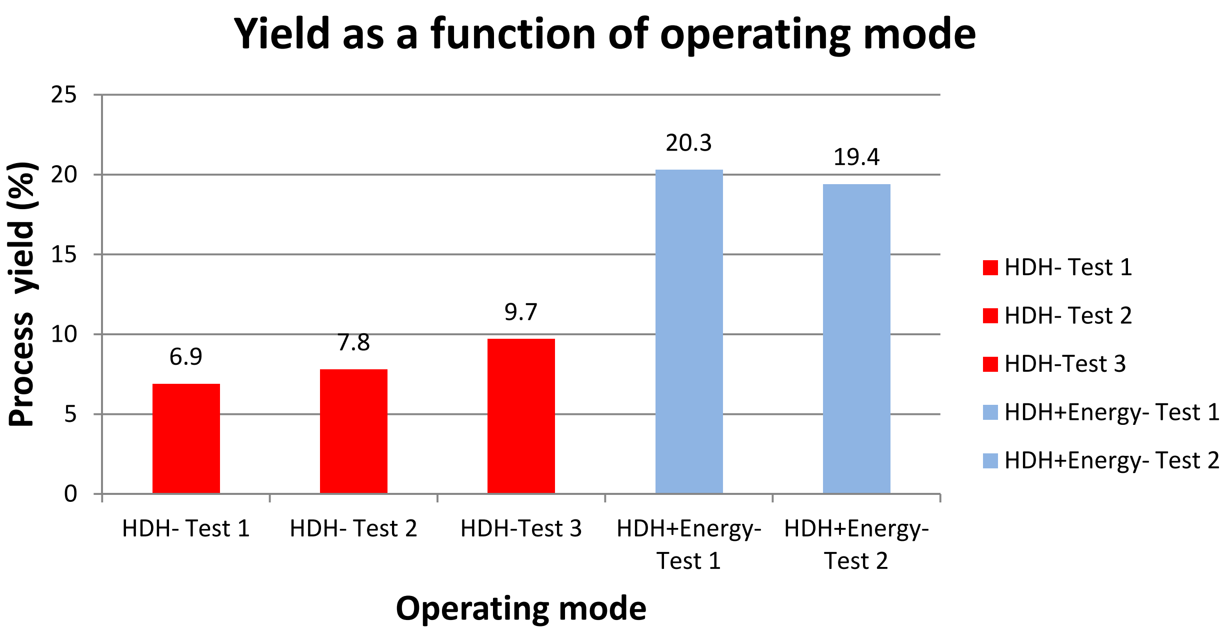
- WATER QUALITY (TDS, ppm) OF CONCENTRATE AFTER TREATMENT



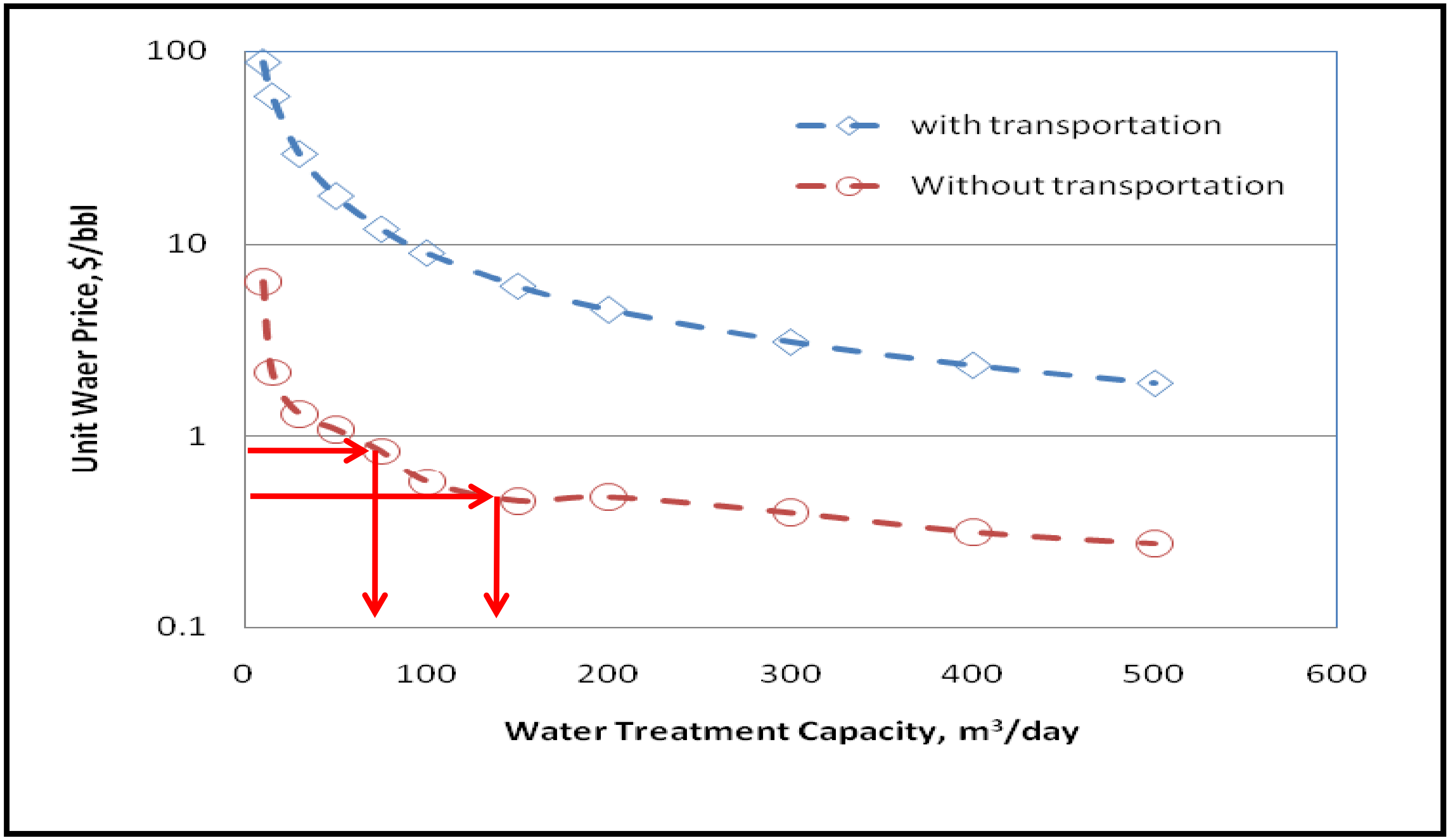
This test was carried out by recycling the inlet water thrice to establish the process yield as a function of TDS. The last test was not part of the recycle.

PROCESS YIELD – FIELD TESTS

- **YIELD COMPARISON OF VARIOUS OPERATING CONFIGURATIONS- FIELD TESTS**

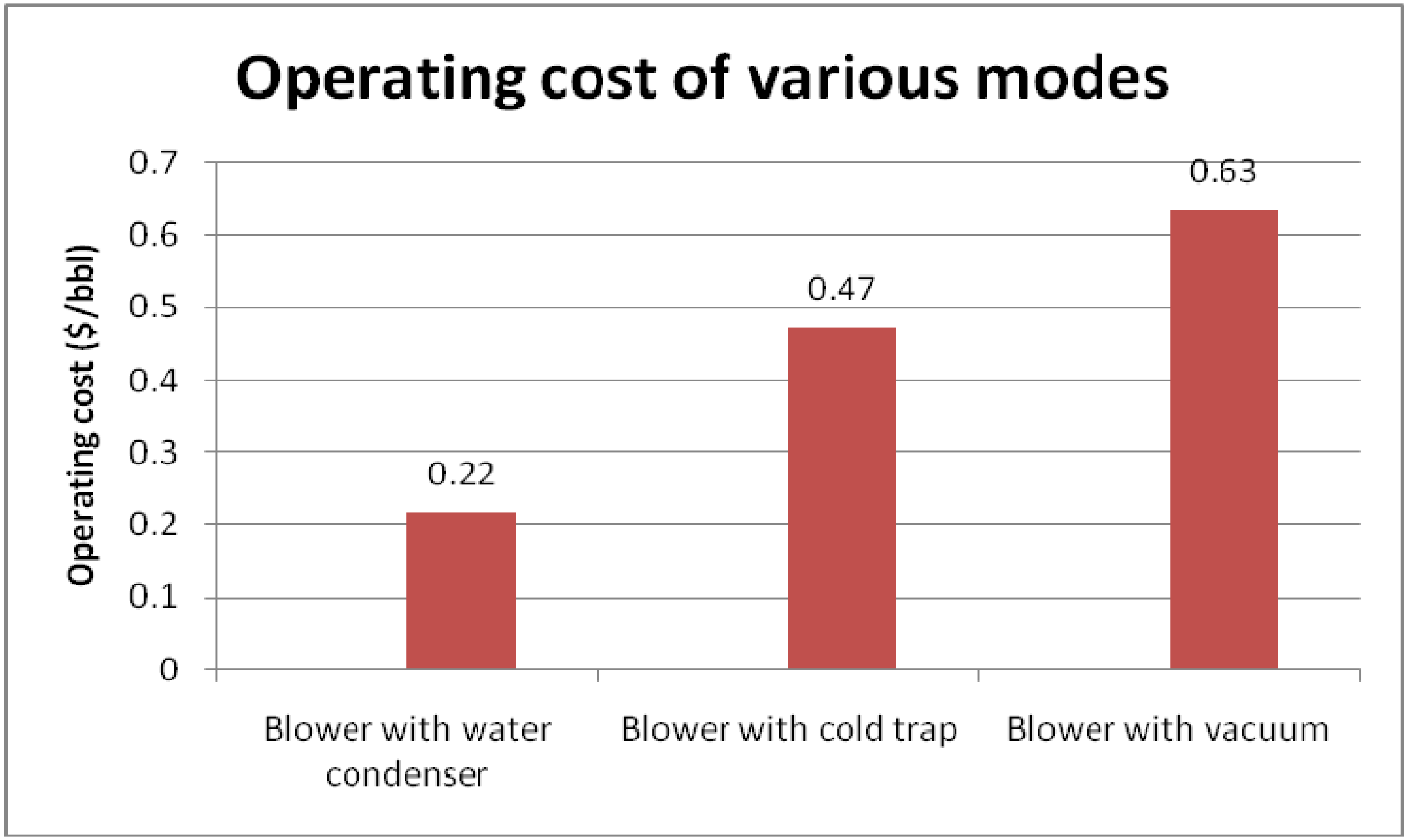


➢ ECONOMICS OF DESALINATION – REVERSE OSMOSIS



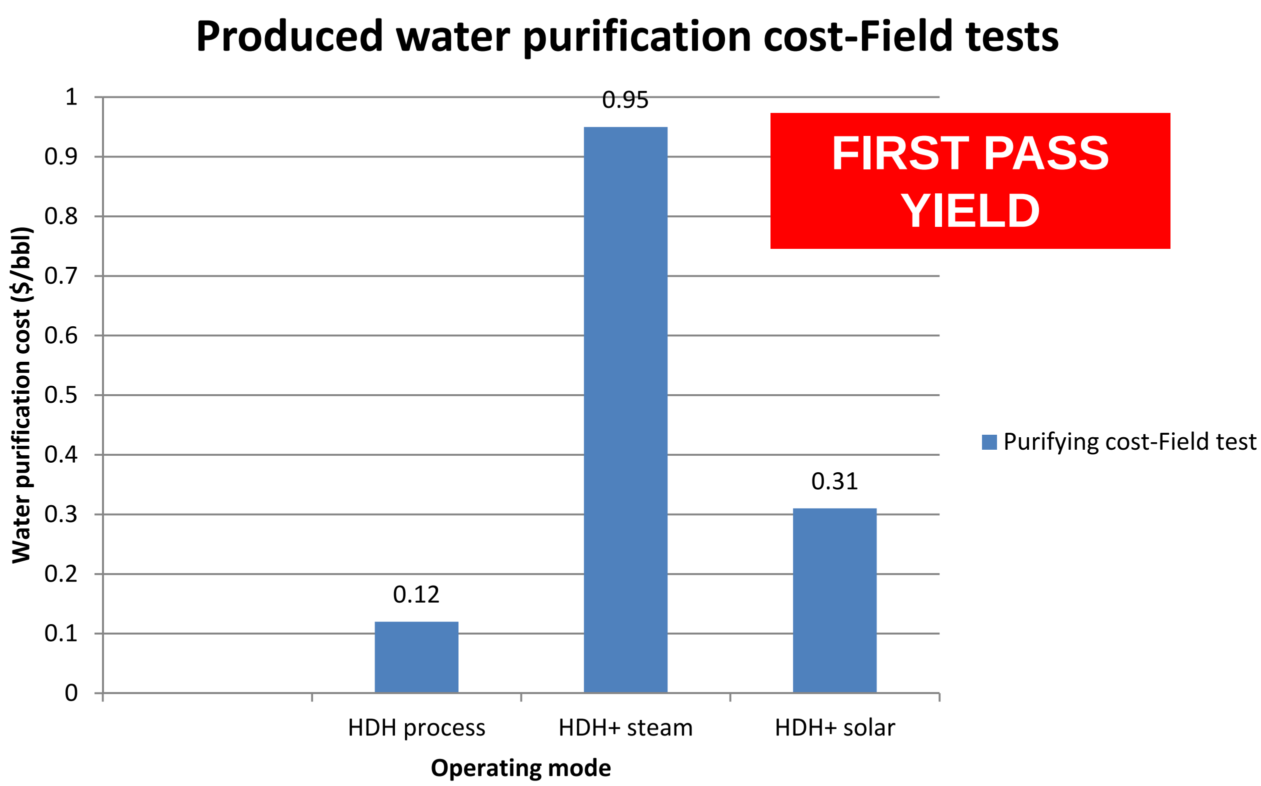
Economic analysis of RO process using DEEP (Desalination Economic Evaluation Program)

➢ **OPERATIONAL COST FOR VARIOUS MODES- Pilot scale tests**



PROCESS COST- FIELD TESTS

➢ **OPERATIONAL COST FOR VARIOUS MODES- Field scale tests**



➢ ECONOMICS OF DESALINATION

A comparison of the unit cost for desalination using various technologies is tabulated below

	MSF	MED	VC	RO	H-DH
Specific Investment Cost [$/m³/day]	1200 - 1500	900 – 1000	950 – 1000	700 – 900	NA
Total Cost Product [$/m³]	1.10 – 1.25	0.75 - 0.85	0.87 – 0.95	0.68 – 0.82	0.8
Hypothesis * Kaufler	Plant capacity Interest rate Project life Price electricity		30,000 m³/day 7% 20 years 0.065 $/kWh		Plant capacity: 36m³ /day or **20 bbl/day**

➢ CONCLUSIONS

✓ Produced water can be desalinated by the humidification dehumidification process. Specifically, the process can be operated at atmospheric pressure and relatively low temperature (60-80 °C) and thus low-temperature heat sources like coproduced geothermal energy could be deployed for the desalination process.

✓ In terms of economics and an overall appraisal of the various configurations, the configuration with the air blower and air condenser was found to be more efficient than vacuum distillation both in terms of yield and energy requirement.

✓Supplying additional latent heat increases the process yield. In these tests a steam generator was used to simulate the use of solar panels to provide the required latent heat to the process. Use of solar panels would further decrease process costs, with a corresponding increase in yield.

➢ CONCLUSIONS

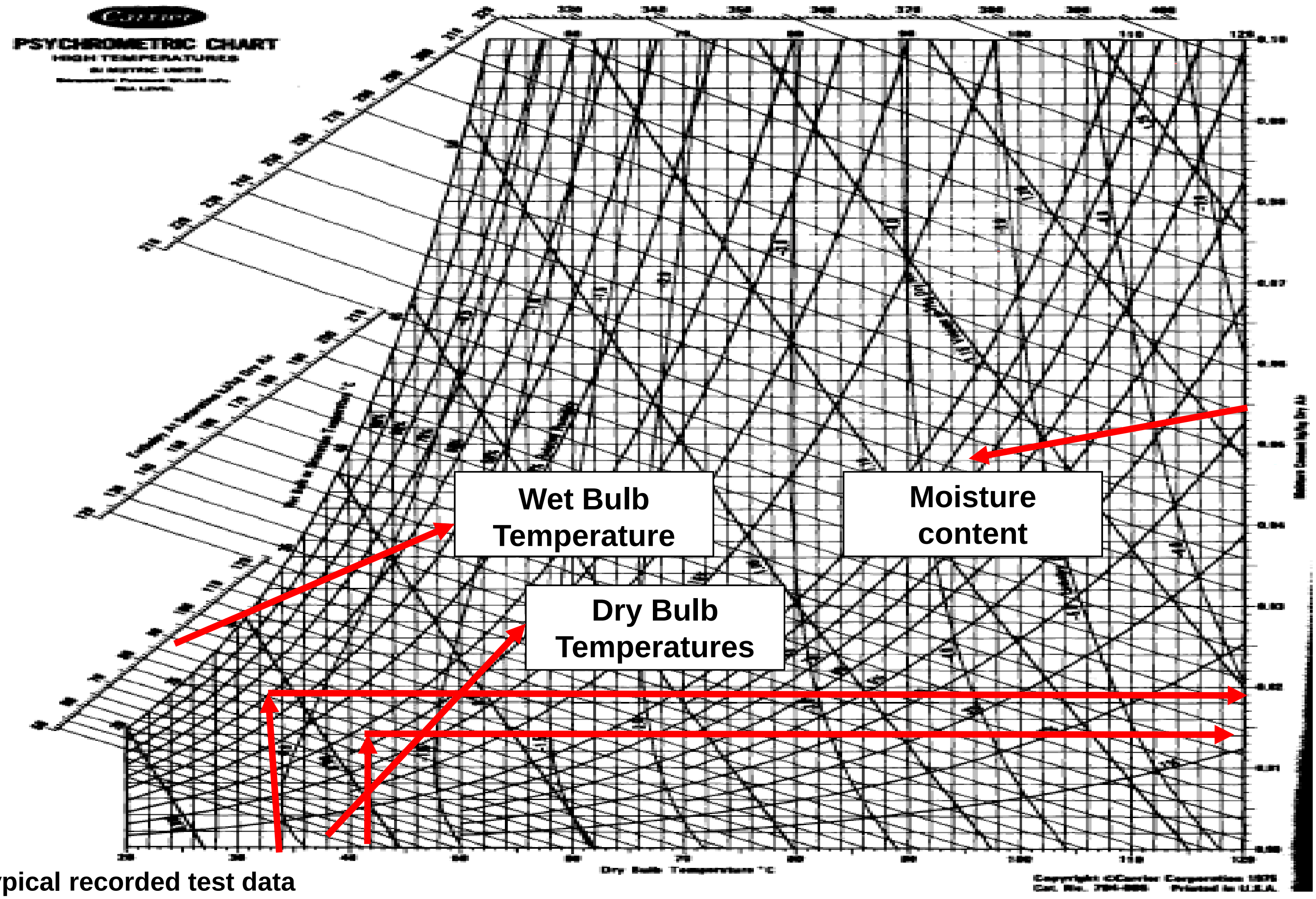
✓ The total productive yield defined as the total vapor generated, including water condensed and water vapor lost ranges from 10% to 20% depending on the system configuration.

✓ An ion rejection capacity of over 99% was observed for the lab tests, 93% was observed during the pilot scale tests, and over 99% for the field tests.

✓ The process is successful in terms of the expected water quality, however, the use of coproduced energy sources and solar energy can improve the process further from a yield perspective, with our focus being coproduced energy sources and solar energy.

THANK YOU !

HUMIDITY CHART



Typical recorded test data

- **OPERATIONAL COST CALCULATION FOR H- DH PROCESS**