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Final Report

Membrane Technology for Produced Water in Lea County

Submitted by:
Lea County Government
100 N. Main
Lovington, NM 88260
And
New Mexico Institute of Mining and Technology
801 Leroy Place
Socorro, NM 87801

Report Authors:
Cecilia E. Nelson, Principal Investigator
Lea County Government
and
Ashok Kumar Ghosh, Ph.D., P.E.
Principal Researcher, New Mexico Institute of Mining and Technology

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DISCLAIMER

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1.0 Abstract

Southeastern New Mexico (SENM) is rich in mineral resources, including oil and gas. Produced water is a byproduct from oil and gas recovery operations. SENM generates approximately 400 million barrels per year of produced water with total dissolved solids (TDS) as high as ~ 200,000 ppm. Typically, produced water is disposed of by transporting it to injection wells or disposal ponds, costing around $1.2 billion per year with an estimated use of 0.3 million barrels of transportation fuel.

New Mexico ranks first among U.S. states in potash production. Nationally, more than 85% of all potash produced comes from the Carlsbad potash district in SENM. Potash manufacturing processes use large quantities of water, including fresh water, for solution mining. If the produced water from oilfield operations can be treated and used economically in the potash industry, it will provide a beneficial use for the produced water as well as preserve valuable water resources in an area where fresh water is scarce.

The goal of this current research was to develop a prototype desalination system that economically treats produced water from oil and/or natural gas operations for the beneficial use of industries located in southeastern New Mexico.

Up until now, most water cleaning technologies have been developed for treating water with much lower quantities of TDS. Seawater with TDS of around 30,000 ppm is the highest concentration that has been seriously studied by researchers. Reverse osmosis (RO) technology is widely used; however the cost remains high due to high-energy consumption [1]. Higher water fluxes and recoveries are possible with a properly designed Forward Osmosis (FO) process as large driving forces can be induced with properly chosen membranes and draw solution. Membrane fouling and breakdown is a frequent and costly problem that drives the cost of desalination very high.

The technology developed by New Mexico Tech (NMT) researchers not only protects the membrane, but has also proven to generate higher water flux, based on the series of

experiments conducted. Laboratory tests at NMT demonstrated that an unprecedented water flux of 1300 $l/m^2/hr$ (where typical flux is on the order of 0-3 $l/m^2/hr$ [1]) can be achieved from a properly designed membrane module. The patent pending NMT system, which was designed and developed at NMT was successful in reducing the possibility for concentration polarization and thereby increasing the permeate water flux, while still maintaining a high salt rejection rate of 96% or greater.

For feed solutions having a dissolved contaminant concentration greater than 10,000 ppm, preliminary economic analysis demonstrates that a well-designed FO process will outperform an RO process. Most produced water generated in SENM has TDS higher than 10,000 ppm. Therefore, it is logical to use FO to desalinate the water. Since the issues associated with concentration polarization has only recently been solved by our mechanically enhanced membrane module, the level of system maturity is not at the same level as that for RO. Our efforts going forward will be directed at taking the technology to a higher level of system maturity.

With the superior cost effectiveness for FO, it is imperative that this technology reach a point that is competitive with RO in order to meet the expanding need for water for industries in SENM. NMT seeks to demonstrate the greater cost effectiveness by proving the process through a scaled up model. To ensure success, NMT feels it is important to demonstrate this technology in a larger system, (~ 100,000 GPD), before venturing to the commercial scale. This will build confidence in the process with the commercial sector.

In addition, it will be possible to develop some of the operational processes around renewable energy sources for the scaled up model. This will further lower the operating costs and enhance the environmentally clean aspect of the process.

2.0 Introduction

Water is a very valuable resource in the U.S southwest. Natural sources of fresh water are insufficient to support economic growth in the region. Lea County in southeast New Mexico (SENM) as well as other municipalities in the region, who are on the front line when it comes to water needs, is proactive in searching for unconventional water sources. New Mexico Tech (NMT) recognizing the value of their Mechanically Enhanced Forward Osmosis System (MEFOS) with the water needs in the region has teamed with Lea County to demonstrate a scaled system to clean produced water. There is an abundance of produced water generated during oil and gas operations which, if cleaned sufficiently and cost-effectively, could be provided to offset water use in other areas, e.g., agriculture, mining, livestock watering to name a few. Table 1 gives a list of such applications with the qualitative requirements.

Table 1: List of applications for cleaned produced water with the qualitative requirements

Comparison of requirement (PPM)									
	Applications								
Chemicals	Produced Water	Potash Industry	Reinjection	Municipal disposal	Human Health	Crop Irrigation	Road dust control	Power Generation	Wildlife watering
Dissolve solids	**212909**	15000	**10000**		**1000**	1000			
Oil and grease		None	**42**	3.7				Deionized water Quality	
Hardness	**28,676**	maximum 800	**None**						**no effect**
Organics		None to minimum	**None**						
BOD				12					
Suspended solids	**140000**	None	**None**	10.1					
Ammonia as N		Ok to have some Nitrogen		1.27					
COD				60.3					
Chromium				0.2	**0.05**				**0.1**
Calcium	**9060**		**4400**						
Magnesium	**1470**		**895**						
Iron	**na**		**65**			1	**Heavy metal =50**		**2**
Sodium	**58800**		**80,420**						
Strontium	**410**		**90**						
Chloride	**110000**		**130,635**			250	**20,000**		
Sulfate	**1560**		**4595**			600			
Bicarbonate	**367**		**1540**						
Potasium	**nd**		**400**						
H2S	**none**		**23**						
Others									
	na - not tested	nd - not detected							

COD - Chemical Oxygen Demand = Determines amount of organic pollutant; BOD - Biological Oxygen Demand = How fast biological agents use up oxygen; TDS - Total dissolve solids. Hardness - Sum of calcium and magnecium (reported equivalent of CaCO3; Empty cel

SENM is rich in mineral resources, including oil and gas, and fresh water is necessary in the refinement process. Produced water is a byproduct from oil and gas recovery operations. SENM generates approximately 400 million barrels per year of produced water with total dissolved solids (TDS) as high as ~ 200,000 ppm. Typically, produced water is disposed of by transporting it to injection wells or disposal ponds, costing around $1.2 billion per year with an estimated use of 0.3 million barrels of transportation fuel.

New Mexico ranks first among U.S. states in potash production. Nationally, more than 85% of all potash produced comes from the Carlsbad potash district in SENM. Potash manufacturing processes also use large quantities of water – as much as 3.4 million gallons per day – including fresh water, for solution mining. If the produced water from oilfield operations can be treated and used economically in the potash industry, valuable water resources would be preserved for a region where fresh water is scarce and industry could continue to thrive. Table 2 illustrates the water quality requirement for the treated water in order to be acceptable to the potash mining process.

Table 2: Requirements of water quality to be acceptable to the potash industries

Chemical Salts	Acceptable concentration
Chloride content	1 ½ % or 15,000 ppm
Hardness (Maximum)	800 ppm (reported as equivalent concentration of $CaCO_{3)}$
Oil	None
Organics	None to minimum so that it may not cause any foaming problem in the potash process

2.1 Research Goal

The goal of this research project was to develop a prototype desalination system that economically treats produced water from oil and/or natural gas operations to benefit industries located in southeastern New Mexico. NMT's strategy was to incorporate a system that would constitute both a pretreatment and a treatment sub-system as shown in Figure 1.

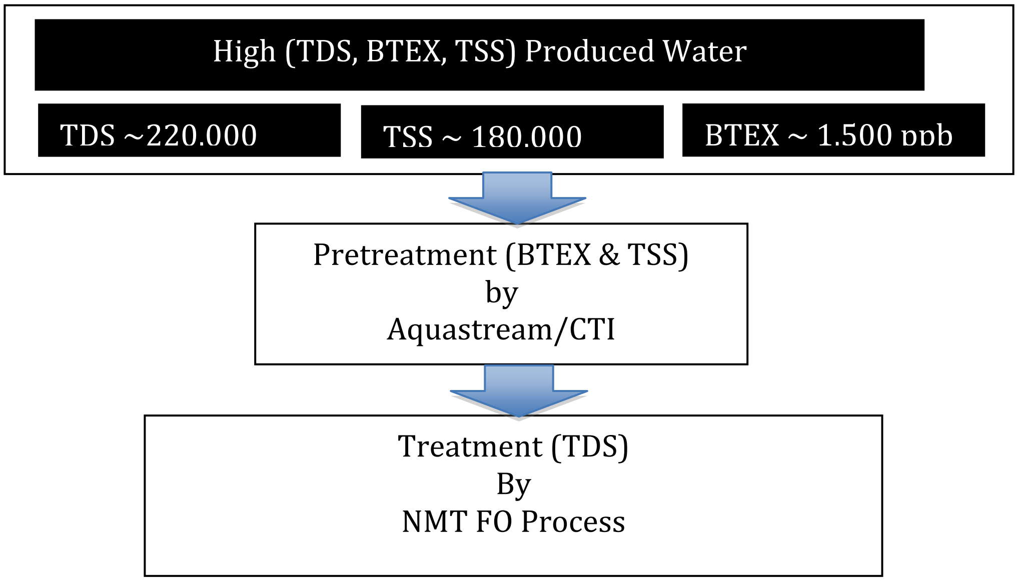


Figure 1: NMT's strategy towards solution to this problem

The objective of pretreatment is to remove the suspended solids and organics/ hydrocarbons/microorganisms to reduce the chances of membrane fouling. Depending on source water quality, one or both may be required. This pretreatment, which incorporates a micro dispersed flocculation process, will be followed by a NMT treatment process using forward osmosis (FO).

The goal of this project was achieved through investigation in the following three parts:

Part 1: Technical Investigation

Up until now, most water cleaning technologies have been developed for treating water with much lower quantities of Total Dissolved Solids (TDS). Seawater with TDS of around 30,000 ppm, is the highest concentration seriously studied by researchers. Reverse osmosis (RO) technology is widely used; however the cost remains high due to high-energy consumption. Higher water fluxes and recoveries are possible with a well designed FO process as large driving forces can be induced with properly chosen membranes and draw solution. Membrane fouling and breakdown is a frequent and costly problem that significantly drives up the cost of desalination [1]. Thus, NMT's technical investigation was aimed at finding an acceptable solution based on laboratory tests for desalinating produced water.

Part 2: Field Demonstration

The technology developed in the laboratory was demonstrated in a 1,000 gallons per day (GPD) desalination pilot plant. This part will also discuss how NMT sub-system was integrated with the Aquastream/CTI pretreatment sub-system to demonstrate the complete system.

Part 3: Economic Analysis and Commercialization Plan

A preliminary economic analysis was performed using the data generated from the pilot scale demonstration process. NMT’s FO process has obvious commercial value, but it is necessary first to demonstrate this technology in a larger system (on the order of 100,000 gallons/day) before venturing on to a commercial scale. It is also possible to develop some of the processes around renewable energy sources to keep the operating cost low and environmentally clean.

3.0 PART 1 - Technical Investigation

3.1 Produced Water

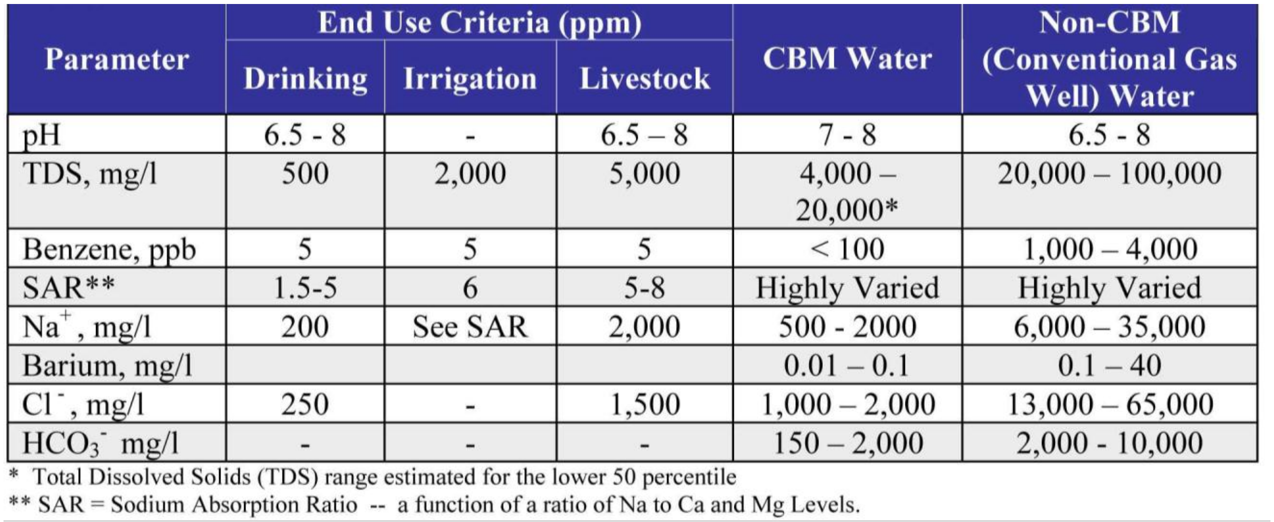
Performing a detailed chemical analysis of the produced water was the first step to this part of the investigation. Table 3 gives the chemical constituents of produced water collected on two different occasions from disposal pond “C” of Controlled Recovery, Inc. located in Lea County. Table 3 gives the chemical constituents of typical produced water collected from disposal ponds at two different times. Water is classified according to its salinity based on dissolved salts in parts per million (ppm) as: fresh water (< 500); brackish water (500-30,000); saline water (30,000-50,000) and brine (> 50,000).

Table 3: Chemical constituents of typical produced water

Chemicals	**Fall 2006 (ppm)**	**Fall 2008 (ppm)**	**Typical Sea water (ppm)**
Total dissolved solids (TDS)	212,909	145,000	~ 30,000
Hardness	28,676	nc	
Total Suspended Solids (TSS)	140,000	130,000	
Calcium	9,060	3,930	411
Magnesium	1,470	1,170	1295
Iron	nd	nd	0.0034
Sodium	58,800	47,330	10,750
Strontium	410	nd	13
Chloride	110,000	73,667	19,345
Sulfate	1,560	3,760	2,700
Bicarbonate	367	360	145
Benzene	np	560 ppb	
Toluene	np	600 ppb	
Ethylbenzene	np	110 ppb	
Xylene	np	180 ppb	
1,2,4 - Trimethylbenzene	np	27 ppb	
Bromide	np	197 ppm	
Potassium	np	5,670 ppm	390

nd – not detected; np – not performed; nc – not calculated; ppm – parts per million; ppb – parts per billion

Table 3 clearly indicates that produced water is contaminated with a broad range of inorganic and organic substances, which can vary widely from time to time and from one location to another. Appendix A gives the plots of the concentration of various chemical constituents present in produced water generated from wells located in SENM. Table 4 gives the typical values for produced water quality compared to specific criteria.



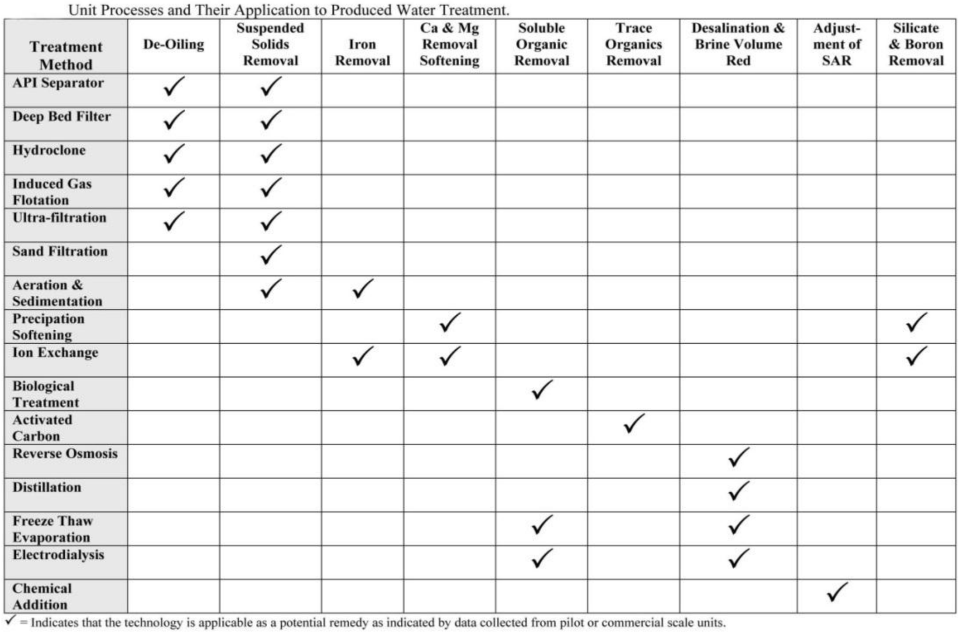
Parameter	End Use Criteria (ppm)			CBM Water	Non-CBM (Conventional Gas Well) Water
	Drinking	Irrigation	Livestock		
pH	6.5 - 8	-	6.5 – 8	7 - 8	6.5 - 8
TDS, mg/l	500	2,000	5,000	4,000 – 20,000*	20,000 – 100,000
Benzene, ppb	5	5	5	< 100	1,000 – 4,000
SAR**	1.5-5	6	5-8	Highly Varied	Highly Varied
Na^+, mg/l	200	See SAR	2,000	500 - 2000	6,000 – 35,000
Barium, mg/l				0.01 – 0.1	0.1 – 40
Cl^-, mg/l	250	-	1,500	1,000 – 2,000	13,000 – 65,000
HCO_3^- mg/l	-	-	-	150 – 2,000	2,000 - 10,000

* Total Dissolved Solids (TDS) range estimated for the lower 50 percentile

** SAR = Sodium Absorption Ratio -- a function of a ratio of Na to Ca and Mg Levels.

Table 4: Typical values for produced water quality compared to specific criteria

Typically, this produced water has been re-injected back into the ground using disposal wells. There has been much work in the last decade trying to find ways to clean this produced water both from a standpoint of reducing the volume of water that has to be re-injected and to sufficiently cleaning it for reuse. Figure 2 lists some of the more established technologies for cleaning produced water.



Unit Processes and Their Application to Produced Water Treatment.

Treatment Method	De-Oiling	Suspended Solids Removal	Iron Removal	Ca & Mg Removal Softening	Soluble Organic Removal	Trace Organics Removal	Desalination & Brine Volume Red	Adjust-ment of SAR	Silicate & Boron Removal
API Separator	✓	✓							
Deep Bed Filter	✓	✓							
Hydroclone	✓	✓							
Induced Gas Flotation	✓	✓							
Ultra-filtration	✓	✓							
Sand Filtration		✓							
Aeration & Sedimentation		✓	✓						
Precipitation Softening				✓					✓
Ion Exchange			✓	✓					✓
Biological Treatment					✓				
Activated Carbon						✓			
Reverse Osmosis							✓		
Distillation							✓		
Freeze Thaw Evaporation					✓		✓		
Electrodialysis					✓		✓		
Chemical Addition								✓	

✓ = Indicates that the technology is applicable as a potential remedy as indicated by data collected from pilot or commercial scale units.

Figure 2: Table of accepted processes for cleaning produced water

In an RO process, the amount of water that passes through the membrane relies on external pressure to drive water across a much stronger membrane. As the amount of TDS increases, a disproportionate increase in the requirement of pressure makes the system very expensive to operate [1]. The percent cost contribution of energy consumption to total cost increases exponentially for a typical RO process. A properly designed RO process can yield desirable high water fluxes (around 75 liter/square meter of membrane /hour) for low TDS water.

FO, unlike RO, utilizes the osmotic gradient for water transfer [2]. Biological fouling, caused by microorganisms sticking to the membrane producing a gel like layer, is a serious problem to operation in a commercial plant and has to be prevented.

3.2 Forward Osmosis (FO)

FO is a direct membrane osmosis process in which an osmotic driving force produces flow of water from the feed solution of low concentration into the draw solution of a comparatively higher concentration across a semi permeable membrane (Figure 3). The unequal solute concentration on both sides of the membrane is responsible for providing the required force to pull the water from the feed solution to the draw solution. Issues such as draw solutions and their selection; membranes and their characteristics along with screening concepts; membrane fouling and concentration polarization; the solute rejection process; membrane modules and packing densities; and cost aspects and energy requirements associated with FO are discussed in the following sub-sections.

In FO, water diffuses through a semi-permeable membrane from a feed solution toward a draw solution until achieving system equilibrium, where the solution concentration is equal on both sides of the membrane (Figure 3). The osmotic pressure can be calculated by using the following equation:

$$J_w = A(\Delta\pi - \Delta P)$$ Equation 1

Where,

J_w= the water flux
A = the hydraulic permeability of the membrane, varies by membrane type and pore size
$\Delta\pi$ = osmotic pressure gradient
ΔP = hydrostatic pressure gradient

The sign of J_w determines the theoretical water flux direction; positive J_w means forward osmotic flow and negative equaling reverse flow.

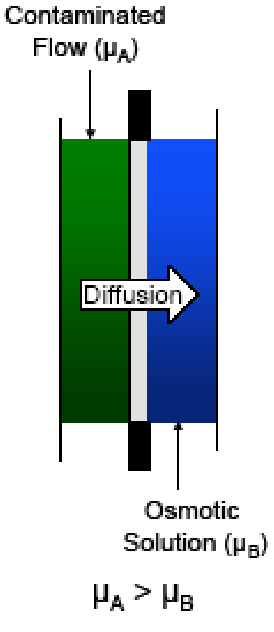


Figure 3: Flow of water across a semi-permeable membrane from a solution with high chemical potential (low salt concentration) to low chemical potential (high salt concentration)

The osmotic pressure is measured according to Equation 1 and is roughly proportional to the molar concentration of the dissolved salts in an ideal situation.

Ideally,

$$\pi = nRT$$

Equation 2

Where,

n = Sum of all ions in solution
R = Ideal gas constant
T = Temperature

The rate of water crossing through the membrane is defined using the following equation:

$$Q = K_{@20^{\circ}C} * 1.02^{(T-20^{\circ}C)} * A * (\pi_D - \pi_F)$$

Equation 3

Where,

Q = Rate of water crossing the membrane
K= Mass transfer coefficient
T = Temperature (°C)
A= Surface area of the membrane
$\pi_D - \pi_F$ = Difference in concentration of feed and draw solutions

Ideally, the osmotic pressure gradient is attained at no energy cost. This is assuming no thermal energy is introduced to the system and no pumping is required. Theoretically, the semi-permeable membranes allow water to flow at a reasonably fast rate, and the draw solution can be recycled repeatedly, eliminating some of the cost associated with draw solution concentration. A simplified view of the process is given in Figure 4.

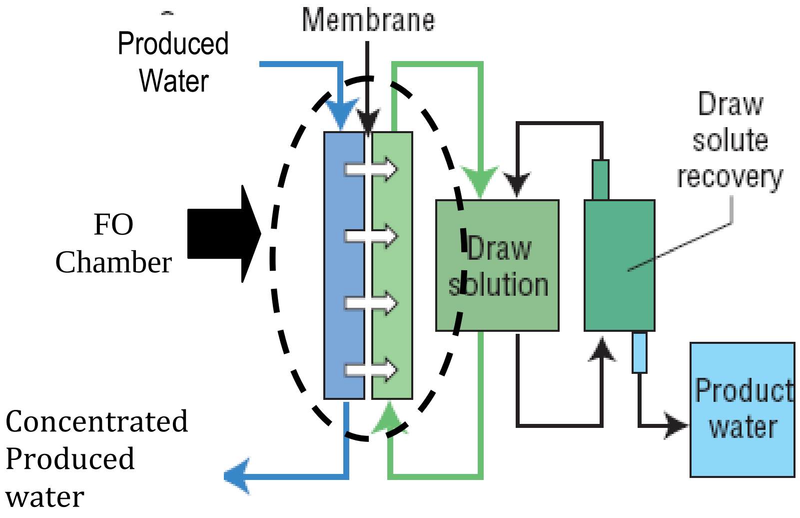


Figure 4: Forward Osmosis Desalination Process Schematic Diagram

The draw solute recovery process requires energy to separate the product water from the diluted draw solution.

3.2.1 Draw Solution

An ideal draw solution would be inexpensive, easily available, economical, and completely recoverable after permeation. Osmotic pressure as a function of solution concentration at 25˚C for various potential draw solutions is given in Figure 5.

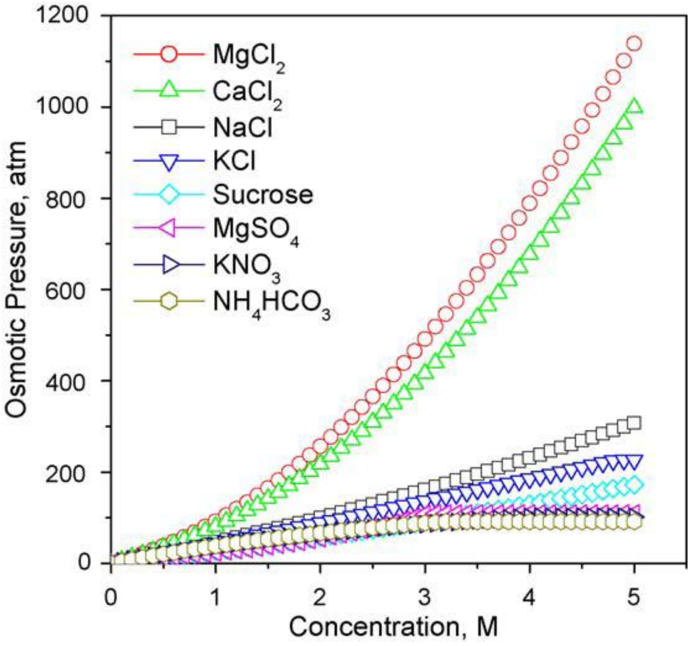


Figure 5: Osmotic pressure as a function of solution concentration at 25˚C for various potential draw solutions

In the FO process, the concentration of the draw solution continuously changes due to the movement of permeate from the feed side to the draw side. Ammonium Bicarbonate (NH_4HCO_3) is an effective draw solution because it has the characteristics of uniform osmotic pressure in a wide range of concentration [2]. NH_4HCO_3 can be easily converted to NH_3, CO_2 and H_2O and reconstructed into ammonium bicarbonate. Thus, NH_4HCO_3 satisfies most of the draw solution requirements.

Ammonium bicarbonate is highly soluble in water at room temperature and lower molarity as shown in Figure 6 [4]. For molarities above 3M, a higher temperature is required for dissolution. Hence, for molarities above 2M, a minimum amount of heat

(30^{o}C) was applied to aid in the dissolution process. NH_4HCO_3 has a pH of 7.8 and a solubility of 17.8 g/kg at 15^{o}C in water equivalent to a 2.5M draw solution. NH_4HCO_3, however, starts to decompose at 30^{o}C and completely decomposes to ammonia (NH_3) and carbon dioxide (CO_2) at temperatures above 60^{o}C. The concentration of draw solution considered in this batch study ranged from 3M (237.2 g in 1L of DI water) to 6M (474.4 in 1L of DI water) NH_4HCO_3. The draw solution was prepared by dissolving the required amount of NH_4HCO_3 crystals in deionized (DI) water.

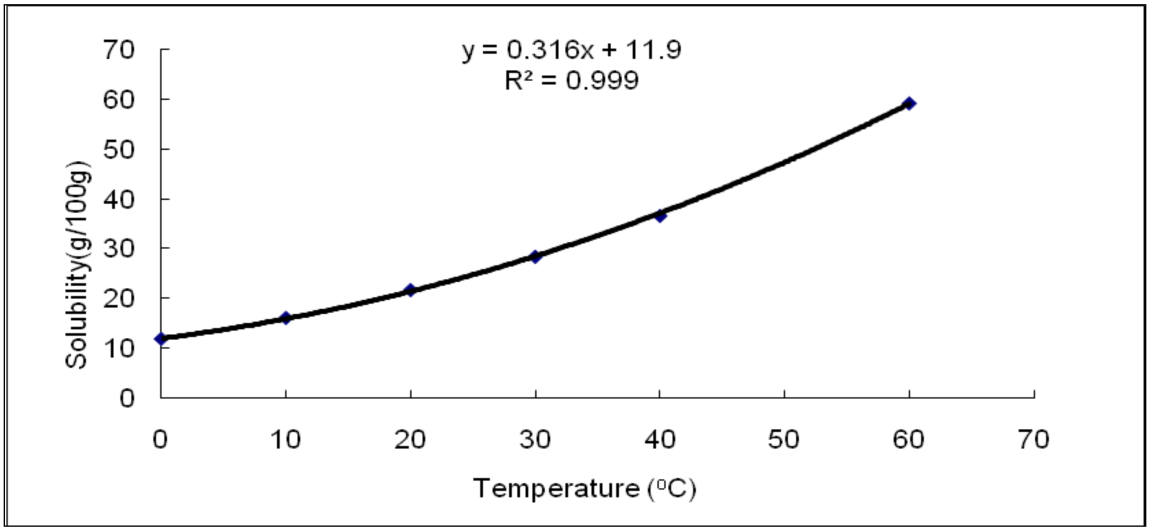


Figure 6: Solubility of ammonium bicarbonate at various temperatures.

3.2.2 FO Membrane (Cellulose Triacetate)

Modern FO membranes have anisotropic morphologies. These membranes have a very thin and dense layer, called the skin layer. The skin layer is supported by a thicker and more porous layer, which has negligible resistance to mass transfer. Current tests used a membrane made by Hydration Technology Inc. (HTI), (http://www.hydrationtech.com /low/hydration_contact.html) based on cellulose triacetate surrounding a polyester screen mesh. This membrane can tolerate high salt concentrations. A cross-sectional SEM image of HTI's FO membrane is shown in Figure 7. A polyester mesh is embedded within the polymer material for mechanical support. The membrane thickness is less than 50 μ.

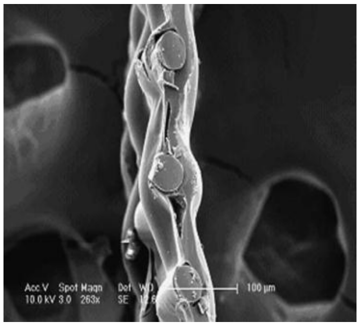


Figure 7: Cross section of a HTI CTA membrane

3.2.3 Concentration Polarization

Dissolved and particulate matters rejected by the membrane tend to accumulate on the face of the membrane causing concentration polarization (CP). CP occurs on both sides of the membrane. The draw solution in contact with the permeate side of the membrane is diluted at the permeate–membrane interface by the permeating water. This is called dilutive external CP.

The HTI membrane used in the NMT process has a thin active layer supported on a porous layer making it an asymmetric membrane. When the membrane is asymmetric and water along with solute propagates through the porous layer, a polarized layer occurs within the support layer of the membrane. This phenomenon is referred as internal concentration polarization (ICP).

Both internal and external CP have the potential to reduce the transport significantly. NMT developed a Mechanically Enhanced Circular Raceway (MECR) that overcomes most of the fouling issues related to concentration polarization. The raceway incorporates a system of paddles that sweeps the membrane surface thereby overcoming the tendency of fouling. Figure 8 shows the perspective view of the MECR (feed and draw chamber Volume = 5.5 liter; membrane area = 264 sq. cm).

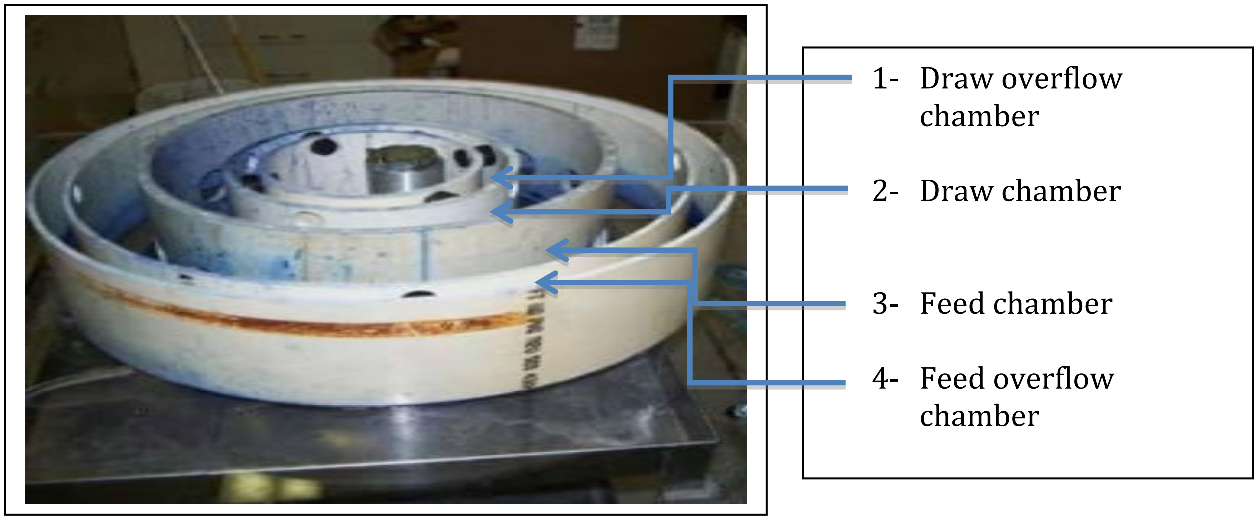


Figure 8: Mechanically Enhanced Circular Raceway (MECR) with four chambers: Feed side and Draw side and their corresponding overflow chambers

3.2.4 Flux Estimation

The laboratory tests performed using the MECR show the distribution of the water flux with osmotic pressure differences for the replicate runs of 2 Molar (M) /4 M and 2M/6M test matrices. The NMT developed technology (i.e. MECR) not only protects the membrane but has also proven to generate higher water flux based on a series of experiments conducted. Laboratory tests at NMT have demonstrated that an unprecedented water flux of 1,300 $l/m^2/hr$ (where typical flux is on the order of 0-3 $l/m^2/hr$ [1]) can be achieved from a properly designed membrane module. The patent pending MECR system, which was designed and developed at NMT, was successful in reducing the possibility for concentration polarization and thereby increasing the permeate water flux, while still maintaining a high salt rejection rate of 96% or greater.

The permeate flux was determined by measuring the increase in weight of the draw solution over the run duration as water permeates from the feed chamber into the draw chamber across a semi-permeable membrane. Knowing the ratio of the exposed membrane surface area to the feed solution, the water flux was estimated according to Equation 4.

$$F_w = \frac{V_f - V_i}{At\rho}$$ Equation 4

Where,

F_w = Water flux (g/m^2/hr)
V_f = Final draw volume (Liter, L)
V_i = Initial draw volume (L)
A = Membrane surface area (m^2)
t = FO run time (hr)
ρ = Density of water (g/m^3)

Chloride analysis was also performed to determine the salt flux through the membrane. The moles of chloride determined by the Mohr titration (Standard Method 4500-Cl-B) were used to determine the salt flux across the semi-permeable membrane as per Equation 5.

$$F_s = \frac{M_{cl}}{At}$$ Equation 5

Where

F_s = Salt flux (g/m^2/hr)
M_{cl} = Mass of chloride (g)
A = Membrane surface area (m^2)
t = FO run time (hr)

The percent of salt rejection after a four-hour FO run was determined for each experimental setup using Equation 6 and Equation 7. The amount of chloride salts that permeated through the membrane and the original feed concentration (C_f) were considered. The concentration of chloride in the draw solution (C_d) was determined by chloride analysis.

$$C_d = \frac{M_{cl}}{V}$$ Equation 6

Where,

C_d = Concentration of chloride in the draw solution (moles/L)
M_{cl} = Moles of chloride (moles)
V = Volume of sample (L).

$$R = \left(1 - \frac{C_d}{C_f}\right) \times 100$$ Equation 7

Where,

R = Salt rejection (%)
C_f = Original concentration of the feed solution (moles/L).

3.2.5 Observations

3.2.5.1 Water and Salt Flux

The preliminary results obtained from the raceway study are shown in Table 5 [4]. Figure 9 [4] shows the distribution of the water flux with osmotic pressure difference for the replicate runs of 2M/4M and 2M/6M test matrices. 2M/4M signifies a test case when the feed solution has 2M concentration (NaCl) and draw solution has 4M concentration of ammonium bicarbonate (NH_4HCO_3). This technology does not only protect the membrane but is also proven to generate higher water flux, based on the series of experiments conducted. The solid line is again an empirical logarithmic regression through the data and does not represent any fundamental relationship between water flux and osmotic pressure difference. Theoretically, water flux should be linear with osmotic pressure difference.

Table 5: Results of raceway FO test for 2M/6M and 2M/4M test matrices.

Matrices	Water Flux ($g/m^2/hr$)	Water flux ($gal/ft^2/d$)	Salt Flux ($g/m^2/hr$)	Osmotic Pressure Difference (atm)	Ln (π_d/π_f)	Salt Rejection (%)
2\6	1305358	660.8	544.1	100	1.12	96.9
2\6	1305604	660.9	633.6	103	1.13	96.4
2\6	1304126	660.1	546.7	103	1.13	96.9
2\6	1301909	659.0	531.6	98	1.10	97.0
2\6	1297969	657.0	519.7	100	1.12	97.0
2\4	1007789	510.1	547.9	50	0.71	96.9
2\4	1020079	516.4	538.8	51	0.72	96.9

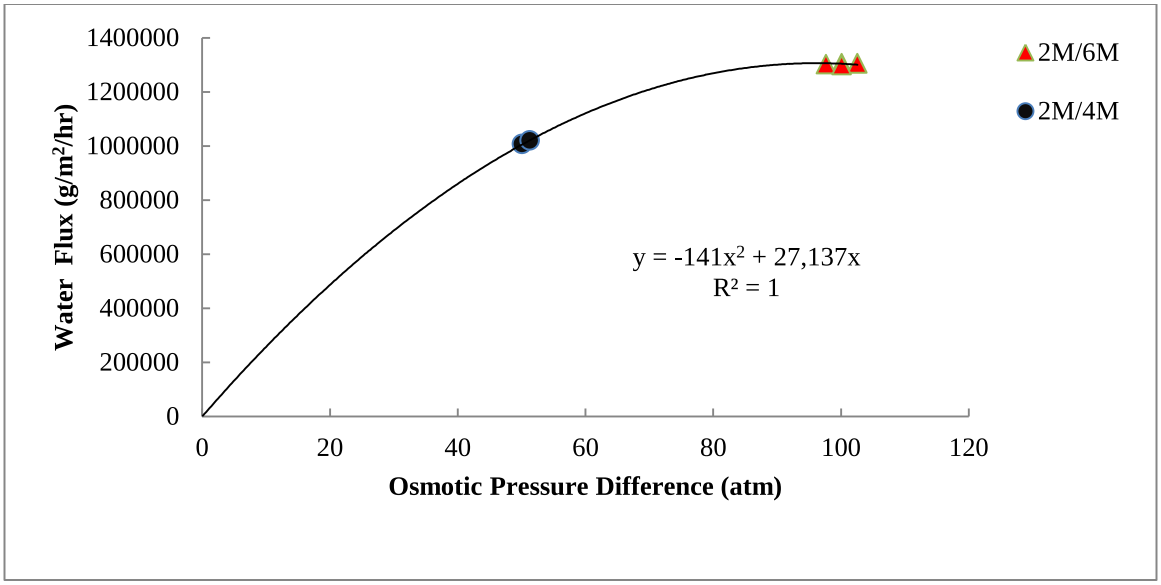


Figure 9: Water flux distribution for the raceway test with paddle

Table 6 and Figure 10 demonstrate the effectiveness of the paddle in the system as developed at NMT.

Table 6: Test results for the raceway without a paddle in place.

Matrices	**Water Flux ($g/m^2/hr$)**	**Water Flux ($gal/ft^2/d$)**	**Salt Flux ($g/m^2/hr$)**	**Osmotic Pressure Difference (atm)**	**$Ln(\pi_d/\pi_f)$**	**Salt Rejection (%)**
2\6	340707	172.5	176.6	104	1.14	97.0
2\6	341528	172.9	175.8	105	1.15	97.0
2\6	341938	173.1	174.0	103	1.13	97.0
2\4	295553	149.6	147.6	51	0.72	97.5
2\4	303762	153.8	157.7	50	0.71	97.3

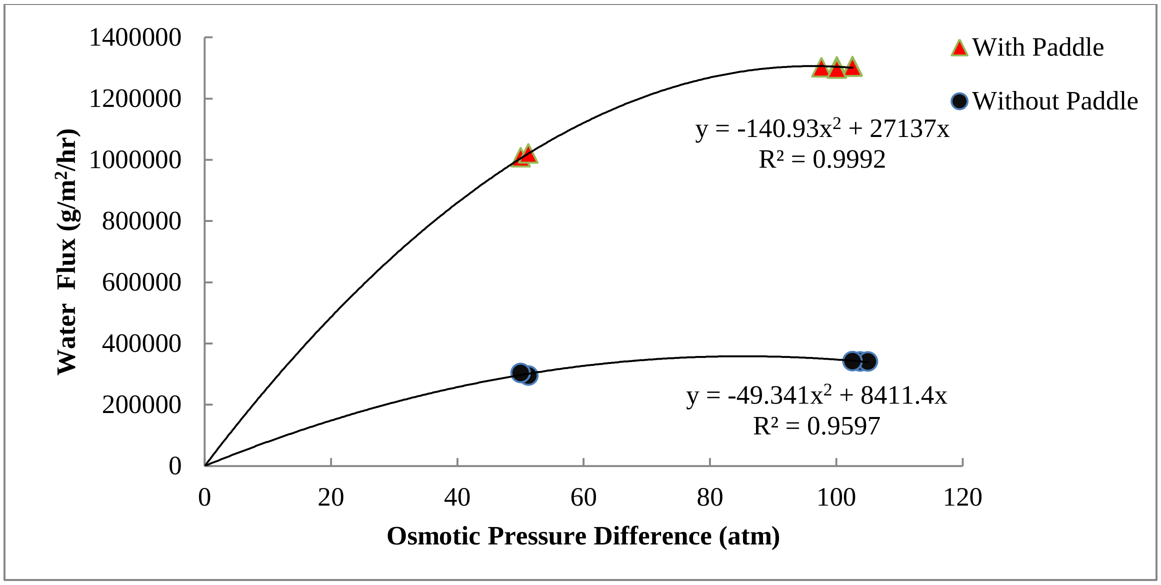


Figure 10: Comparing water flux of the raceway study with and without a paddle.

Figure 11 plots the test observation of salt flux across the membrane. It is clear that the amount of salt flux is independent of the osmotic pressure difference.

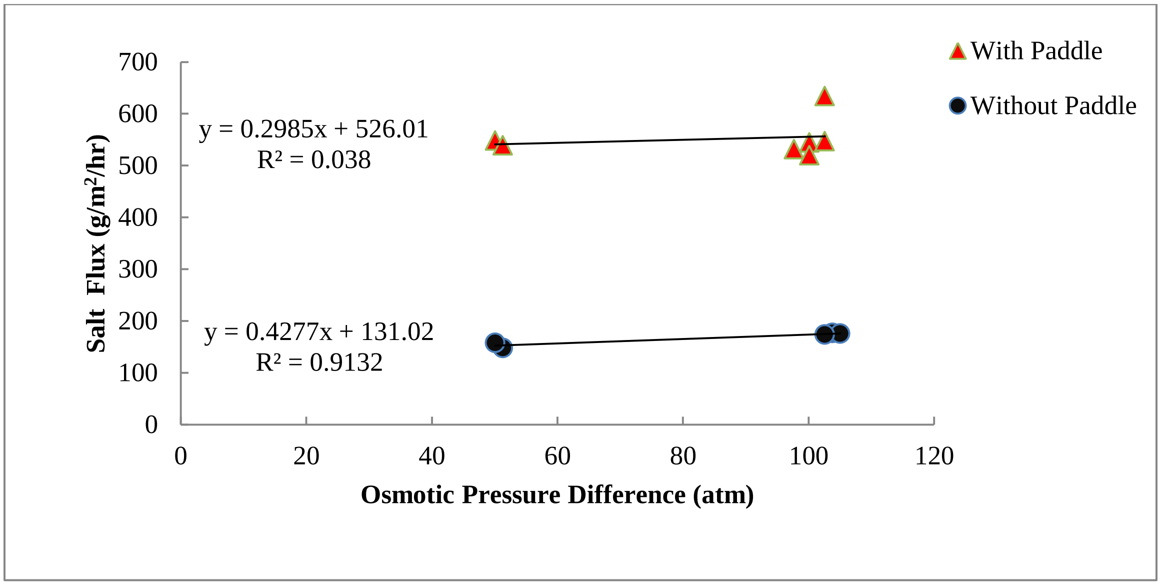


Figure 11: Comparing salt flux of the raceway study with and without a paddle.

Table 7: Water flux of the NMT FO sub-system compared to that obtained by Yale [5]

Osmotic Pressure Difference (atm)	**McCutcheon et al at Yale University**	**NMT (without paddles)**	**NMT (with paddles)**
	Water flux (gallon/square ft of membrane area/day)		
25	5		
40	6		
50	7		510
60	8		
70	9		
96	10		
100	10.2	172	660
102	1.4	Not measured	661

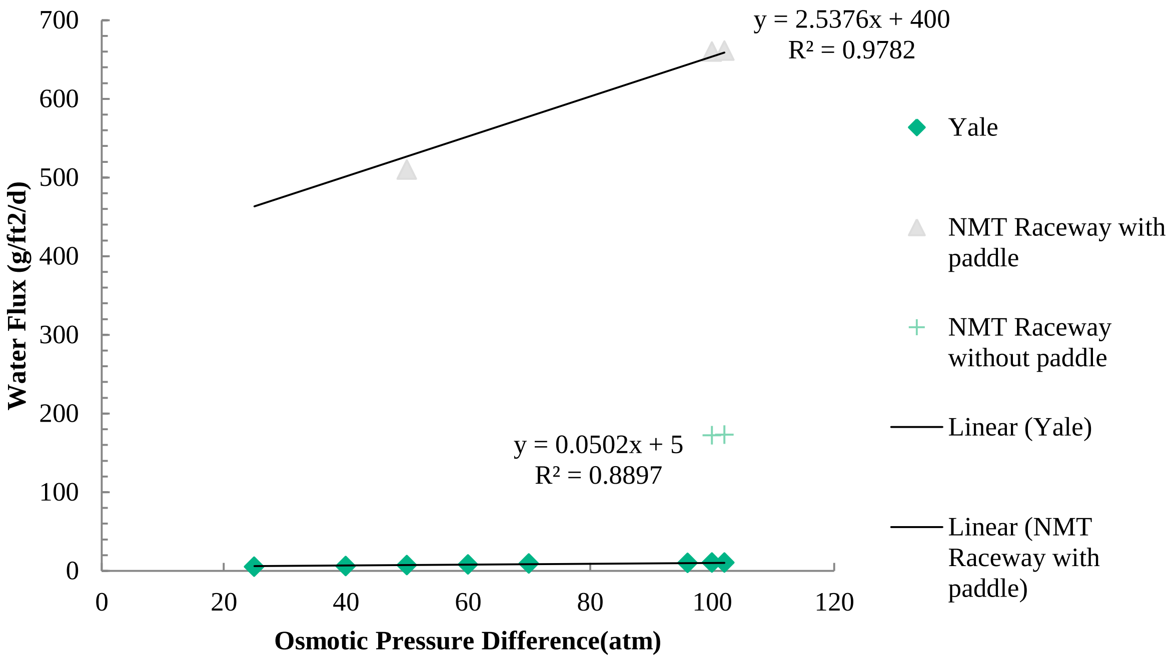


Figure 12: Water flux through the membrane at different osmotic pressures

From this observation, it can be concluded that a properly designed process can yield more than 600 gallons per square foot of membrane in one day.

3.2.5.2 Membrane Degradability Experiments

The results of tests performed using a 2M/5M matrix to determine the degree of membrane degradation are represented in the Figure 13. During five successive cycles of FO runs each of four hours, water flux increased slightly, remained steady, and decreased slightly for all the tests performed. The average water flux and salt flux was 8,346 g/m^2/hr and 81.4 g/m^2/hr, respectively.

A non-parametric statistical analysis was performed on the membrane degradation water flux and salt flux results using the Mann-Kendall two-tailed test for trend analysis at an α of 0.1. The analysis tested the null hypothesis, H_o, of no trend against the alternative hypothesis, H_A, of an upward or downward trend. For both water flux and salt flux, there was no significant trend upward or downward in five cycles of operation.

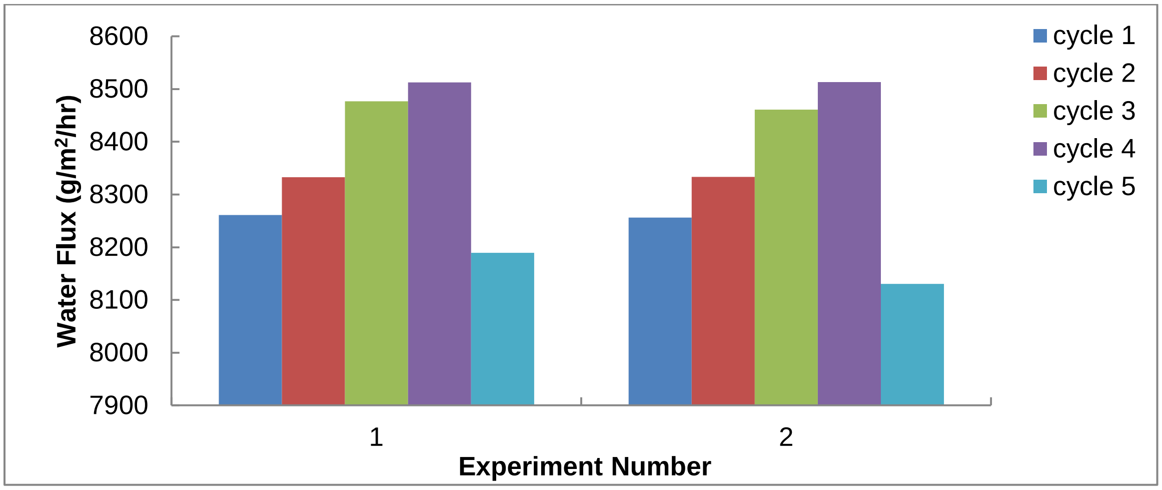


Figure 13: Membrane degradation using 2M/5M test matrix.

3.2.5.3 Recapture of Draw Solute

Under ideal conditions, a NH_4HCO_3 draw solution upon decomposition should have a mole ratio of NH_3 to CO_2 of 1:1 represented by the following reaction:

$$\underset{\text{1 mole}}{NH_4HCO_3} \rightarrow \underset{\text{1 mole}}{NH_3} + \underset{\text{1 mole}}{CO_2} + \underset{\text{1 mole}}{H_2O}$$

3.2.5.3.1 Recapture Test

Several batch mode recapture experiments were performed to determine the suitable conditions required for use in the Forward Osmosis experiment. The recapture experiment follows the basic principle of distillation and condensation. A 2M ammonium bicarbonate solution was used for the setup at different operating temperatures. Figure 14 shows the schematic diagram of the recapture experiment [6]. The 2M solution was first transferred into the round bottom flask that was placed on a heating bowl. This chamber was connected to a recovery flask and an outlet of a nitrogen gas cylinder. The recovery flask, which contained glass beads and 20ml of DI water, was embedded into a beaker filled with ice to help maintain the temperature of the flask content below 20^{o}C to enhance dissolution of gases in solution. It was also connected to a gas chamber outlet. A heating tape was coiled around the outlet that linked the two chambers to avoid re-crystallization of the ammonium salt.

The contents of the round bottom flask were heated to various temperatures, varying from 45^{o}C to 85^{o}C, for 2.5 hours. After each experiment, the amount of ammonia and carbon dioxide recaptured was estimated by using an ammonia probe and alkalinity titration, respectively.

After completion of the recapture experiment, it was observed that recapture is a function of temperature, time, and sparging flow rate. However, recapture is not a function of concentration. Also, the results showed that simultaneous absorption of ammonia and carbon dioxide in water is 1:1. In addition, the results showed that the use of air as a sparging gas produced the same results as nitrogen.

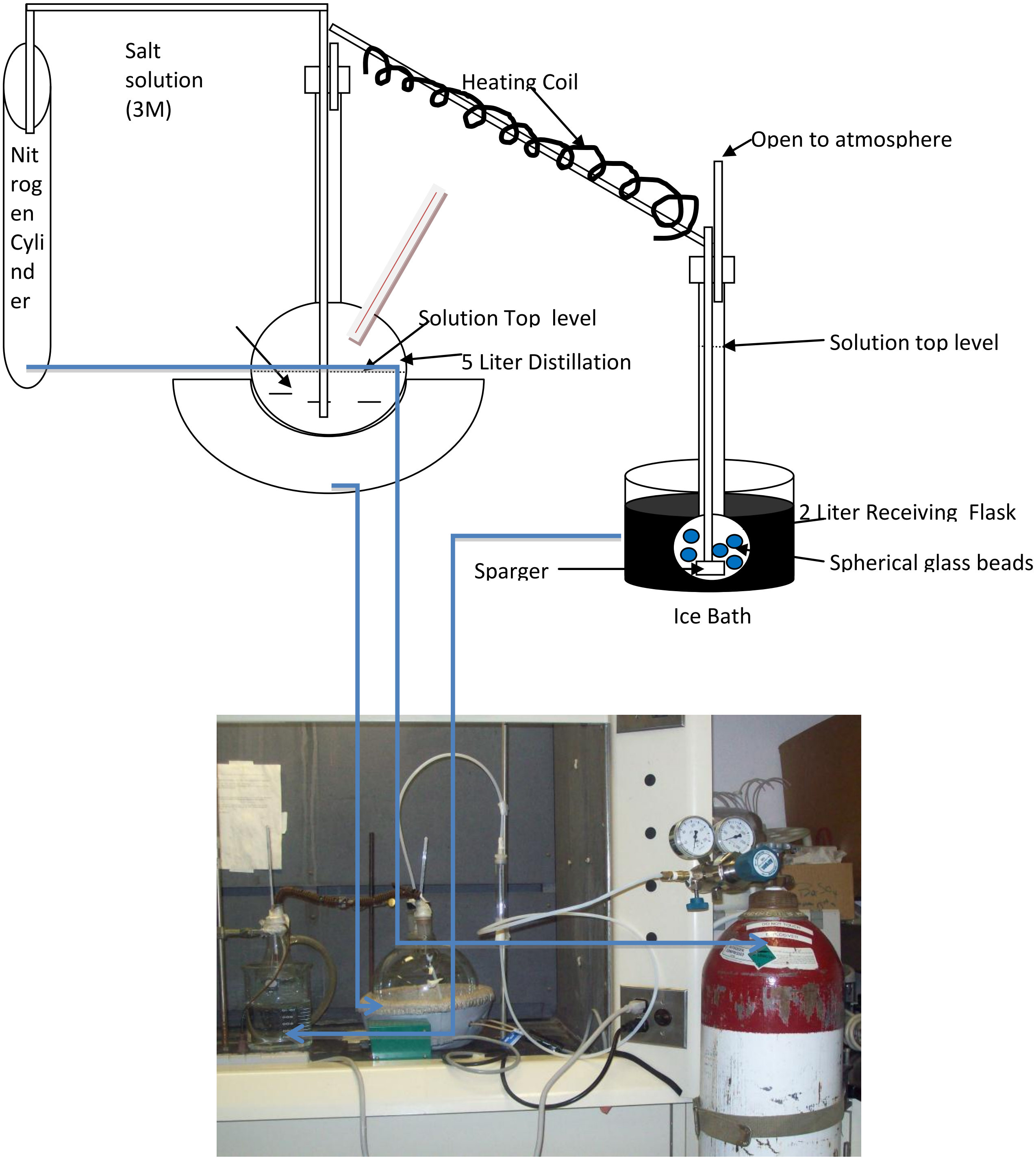


Figure 14: Laboratory test setup for recapture test

3.2.5.3.2 Observations

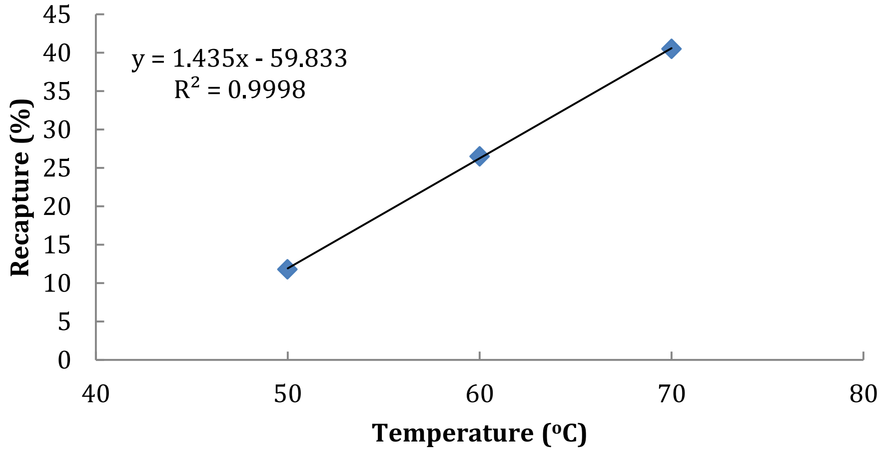


Figure 15: Overall effect of temperature on recover for 1 hr with N_2 of 5 Liter per minute (Lpm) at different concentrations

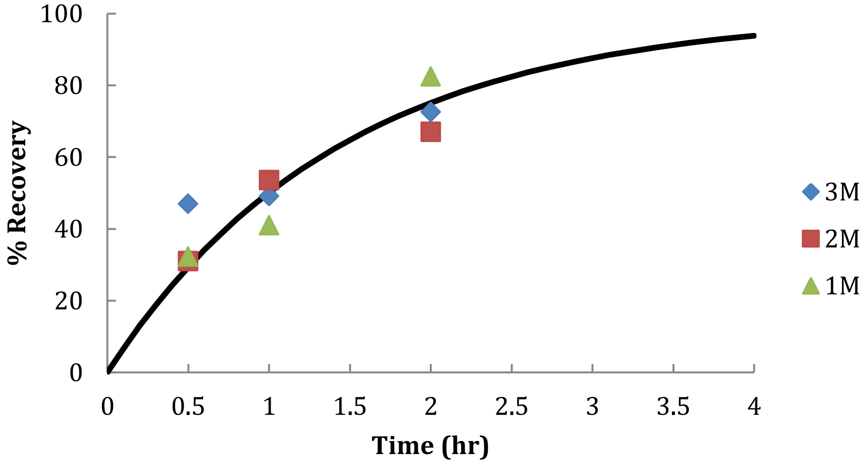


Figure 16: The overall effect of time on recovery at different concentrations with N_2 of 5 Lpm at 70°C

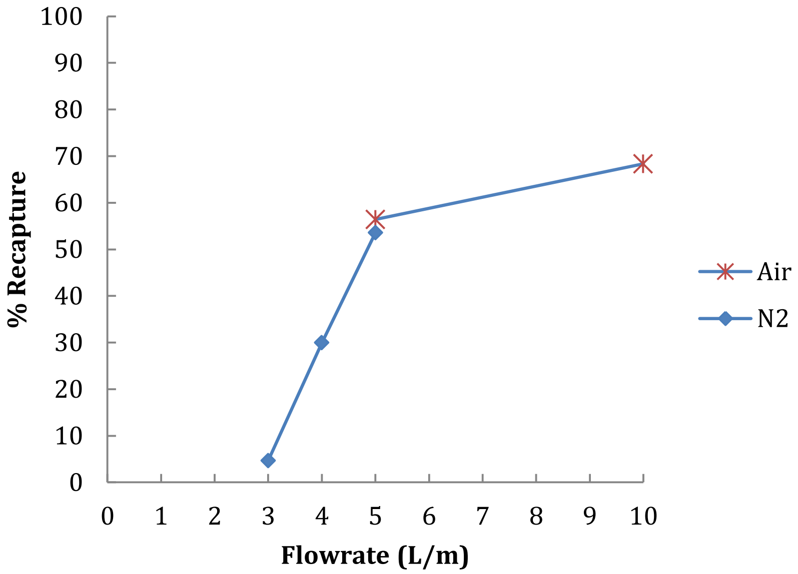


Figure 17: Effect of flow rate on recovery of CO_2 for 2M, 1 hr at 70^{o}C

3.2.5.4 Results

Extensive tests were performed using simulated feed. Actual draw solutions ranged from 2M (molar) to 4M NaCl and a 3M to 6M NH_4HCO_3 respectively. Using a commercially available Cellulose Tri-Acetate membrane, permeate water fluxes ranged from approximately 2,988 to 8,620 g/m^2/hr (1.4 to 4.4 gal/ft^2/day) for a wide range of test matrices, with a corresponding salt flux ranging from 36.7 to 51.5 g/m^2/hr. Salt rejection was observed to be 98% to 99%. Membrane degradation experiments over 5 cycles of testing using the same membrane show no statistical upward or downward trend in permeate flux. Thus, laboratory tests demonstrate that it is possible to desalinate produced water with TDS as high as 200,000 ppm or even more.

4.0 Part 2 - Field Demonstration

In order to make a complete system, the NMT FO process has to be augmented with a pretreatment process primarily to remove organic content and suspended solids from the produced water before the water goes to the NMT FO process. Aquastream/CTI provided the pretreatment during the field tests conducted in Jal located in southeastern New Mexico as shown in Figure 18. This pretreatment process is described in Section 4.2.

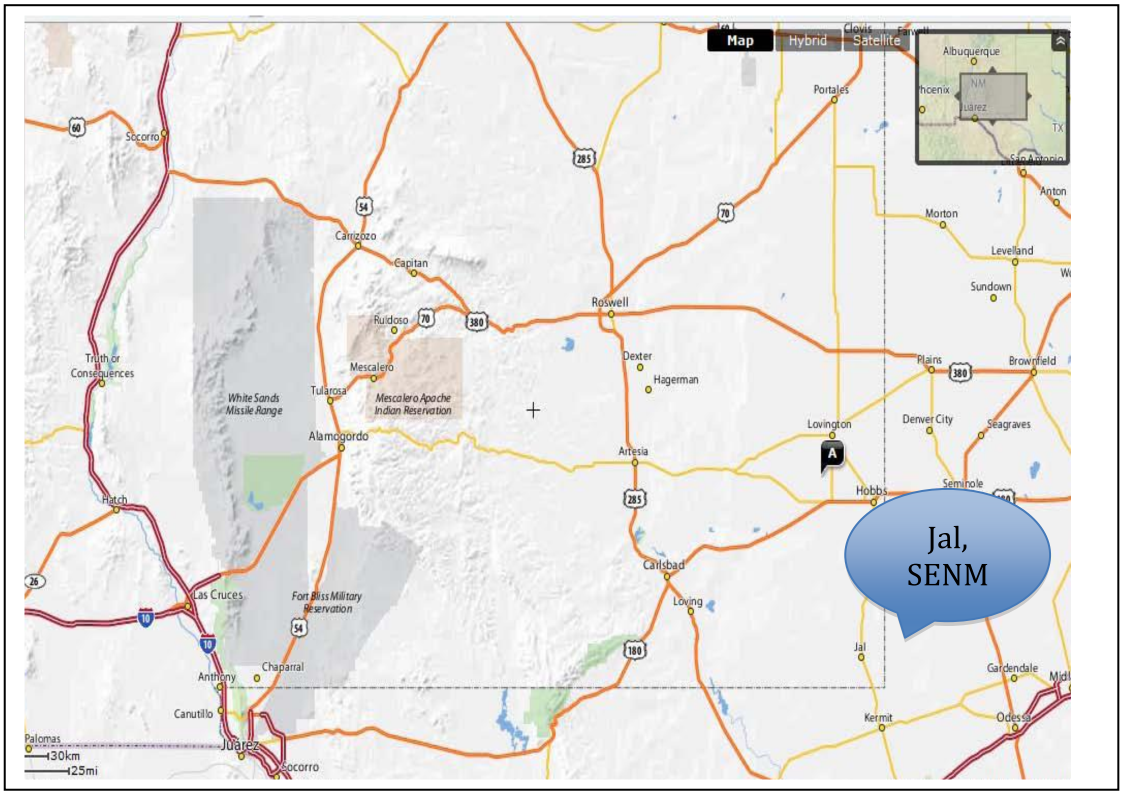


Figure 18: Field demonstration site at Jal, New Mexico

4.1 NMT FO Process

A 1,000 Gallons per day (GPD) pilot scale desalination process based on Forward Osmosis was designed and assembled to remove total dissolved solids. The plan view of the trailer consisting of following four components is given in Figure 19.

- Feed or produced water unit
- Membrane modules
- Draw solution unit
- Recovery unit.

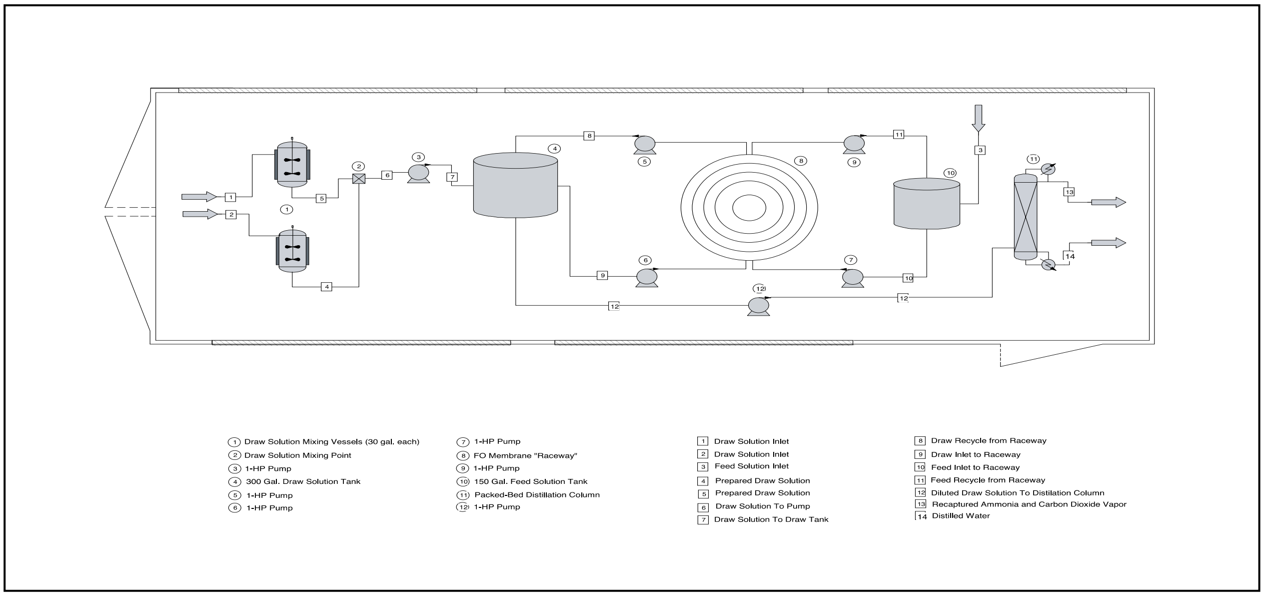


Figure 19: Forward osmosis pilot scale process flow diagram

4.1.1 Mixing Unit

The mixing unit consists of both feed and draw solution tanks, which are each 150 gallon water tanks and made from stainless steel. These stainless steel tanks were placed inside the mixing drums to capture heat for solution preparation and to avoid direct contact of solution with the epoxy lining from mixing drums. The heated water inside the mixing drum conducted the necessary heat to the solution through the wall of the stainless steel tank. A small pump was used to circulate the water inside the mixing drum for uniform heat supply to the stainless steel tanks (Figure 20).

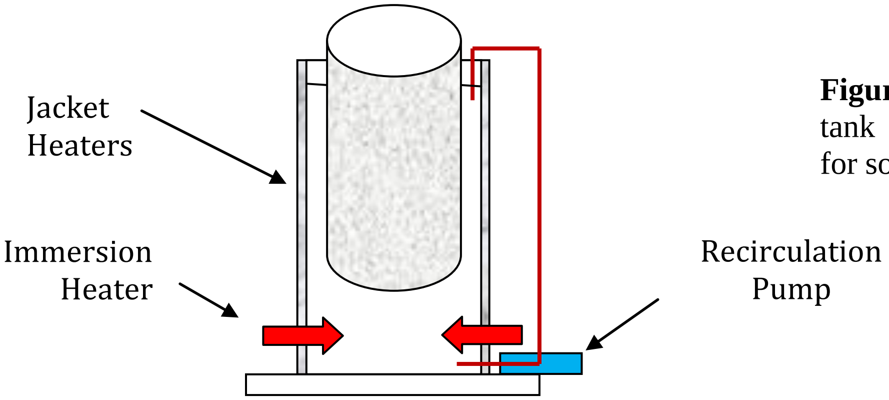


Figure 20: Stainless steel tank inside mixing drum for solution preparation.

Figure 21: Placement of the mixing tanks in the trailer

Figure 21 shows the mixing drum wrapped with heating jackets and the supporting mixers on top. These tanks are also provided with immersion heaters when more heating is needed.

4.1.2 Membrane Modules

A Mechanically Enhanced Circular Raceway (MECR) was developed that overcomes most of the fouling issues related to concentration polarization. Figure 22 shows the perspective view of the MECR. At the time of this report NMT was in the process of filing a patent application for this design, therefore details could not be provided here.

Figure 22: Isometric view of the NMT MECR

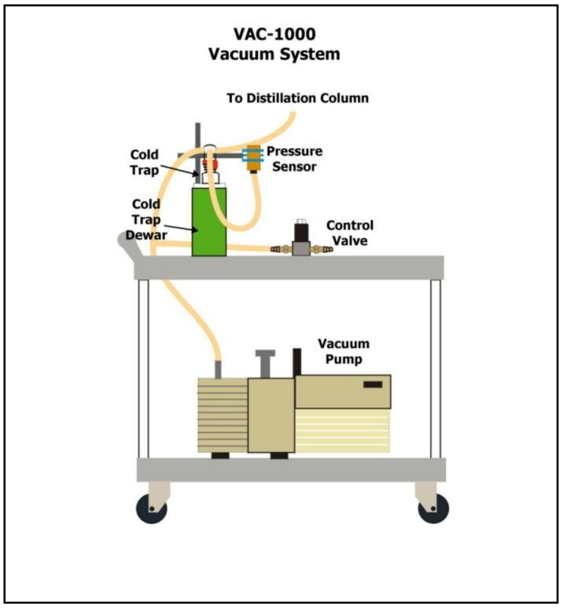
4.1.3 Draw Solute Recapture Unit

The pilot scale recapture system was designed in consideration of the results and the experience gained from the laboratory scale tests. The current objective is to process 50 liters of diluted ammonium bicarbonate (NH_4HCO_3) salt solution (~2M) on the distillation side using a distillation column and to recapture the escaping gases in concentrated solution using a condensation process. The whole process will not vaporize the water. Only gases will escape and will be recaptured on the receiving side. As a trial, a single column packed distillation system was used to capture the ammonia–carbon dioxide gases at about 60 degree Celsius leaving behind the product water with almost pure quality. On the receiving, end a gas absorption system was used to capture the escaping gases and to re-concentrate the draw solution to the desired concentration. The preliminary sketch of the system is provided at Figures 23 (a, b) (manufacturer's diagram). The manually operated packed column distillation system includes the following items:

a. Packed column and tube with heating tape for column head
b. Mounting rack for column and controls with containment pan and hydraulics for lifting the column from the pot flask
c. 50 liter heating mantle and insulating hood

d. 50 liter stainless steel pot flask with thermo well for temperature probe and nitrogen port for bubbling nitrogen through the diluted salt solution
e. Stainless steel pan to hold 25 liter receiver and ice for ice bath
f. 25 liter glass jug receiver with glass tube and vent

Figures 23a: Packed column distillation system



23b: The vacuum regulation system

Also, a vacuum regulated system (Figure 24) was attached to the distillation column to conduct experiments at sub-atmospheric temperatures for the possibility of increasing the whole recapture system efficiency. The vacuum regulation system is composed of the following components:

- Vacuum pump
- Cold trap
- Pressure sensor
- Manually operated vacuum control valve
- Cart

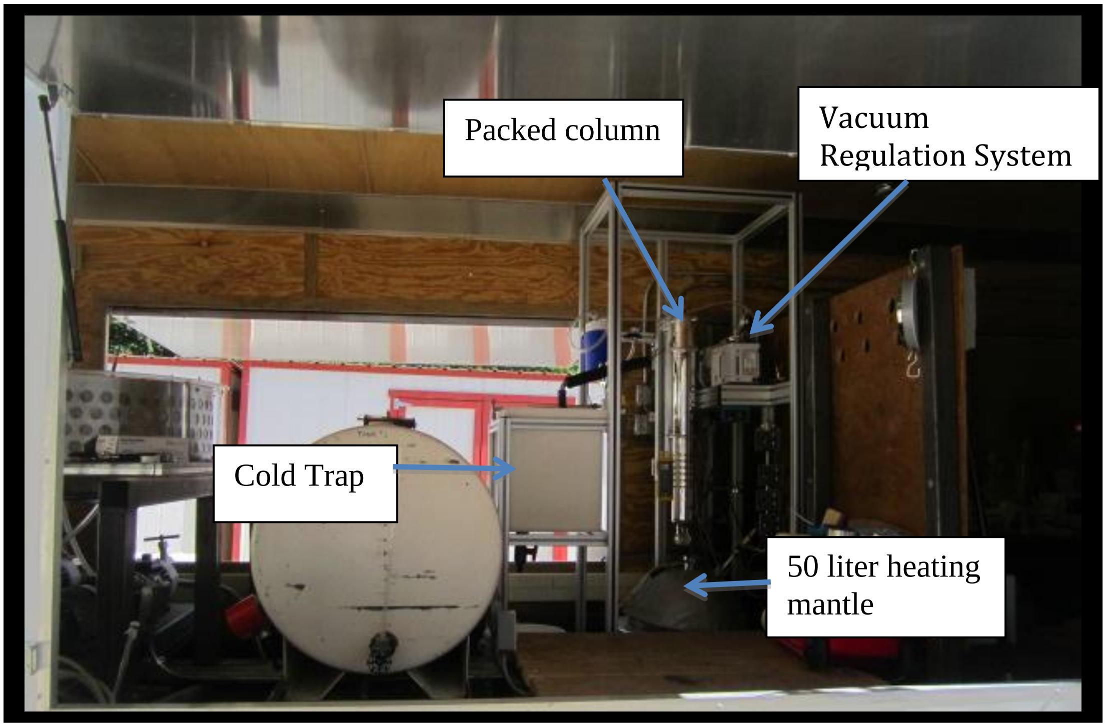


Figure 24: Different components of the packed-bed distillation column

4.2 Aquastream/CTI Subsystem (This portion of this report is taken from Aquastream/CTI's final report to the Lea County.)

The Aquastream/CTI micro-encapsulating flocculating dispersion (MFD) nanopolymer process combined with walnut shell filters successfully removed the oil and gas and total suspended solids from produced water to very low levels during the August 2010 trial. The removal of salt was done by the project team from NMT. Since no separation process can achieve "zero" residuals, a finite (on order of a few ppm TOG) amount of potential foulant remained in the stream. It was up to the NMT forward osmosis process to handle practical levels of oil and grease foulant through periodic back flushing or other such techniques common in the oil industry. Specifically, in the August 2010 trial, the untreated produced water had 32 ppm total oil and grease (TOG) and 110 ppm of total suspended solids (TSS). Following application of the MFD, which targets oil removal and the water-floc separator unit, the TOG fell to 7.1 ppm and 120 ppm of TSS. The water was subsequently run through a walnut shell filter to remove the TSS, after this state the TOG was 3.4 ppm and the TSS was below the detection limit of 50 ppm. The water was finally polished by running it through a 50 mm polypropylene ("sock") filter.

Following this stage, the TOG was below the 13 ppm detection limit and the TSS was 56 ppm (using a lower 10 ppm detection limit technique). Furthermore, the final water had less than 0.24 ppm of BTEX in it.

In the September trials the sample identified as "Bobcat" was treated with TOG reduced from 55.2 ppm to 13.0 ppm and TSS reduced to 3.00 ppm. The TOG level of the sample referenced as "Hannigan" was reduced from 60.0 ppm to 9.88 ppm and TSS was less than the 2.00 ppm reporting limit.

Aquastream/CTI provided the de-oiling technology and equipment for the field pilot demonstration activities. In this technology, low-concentration chemical additives are used to remove oil and grease (O&G), typically producing treated water containing <10 mg/L O&G. Specifically, MFD is a proprietary polymer solution that when combined with an activator is intended to remove oil from process water waste streams. Typical process water streams contain oil anywhere between 50-2,000 ppm. To compete with existing technologies, the process must be able to get the oil content below 30 ppm, the limit of most physical separations. Ideally, it would be able to get the oil content below 5 vppm. This allows the water to be discharged into a wider variety of locations and be used as feed for desalination and have beneficial use. Complete details, such as components and formulation details are proprietary and remain the exclusive property of Aquastream/CTI.

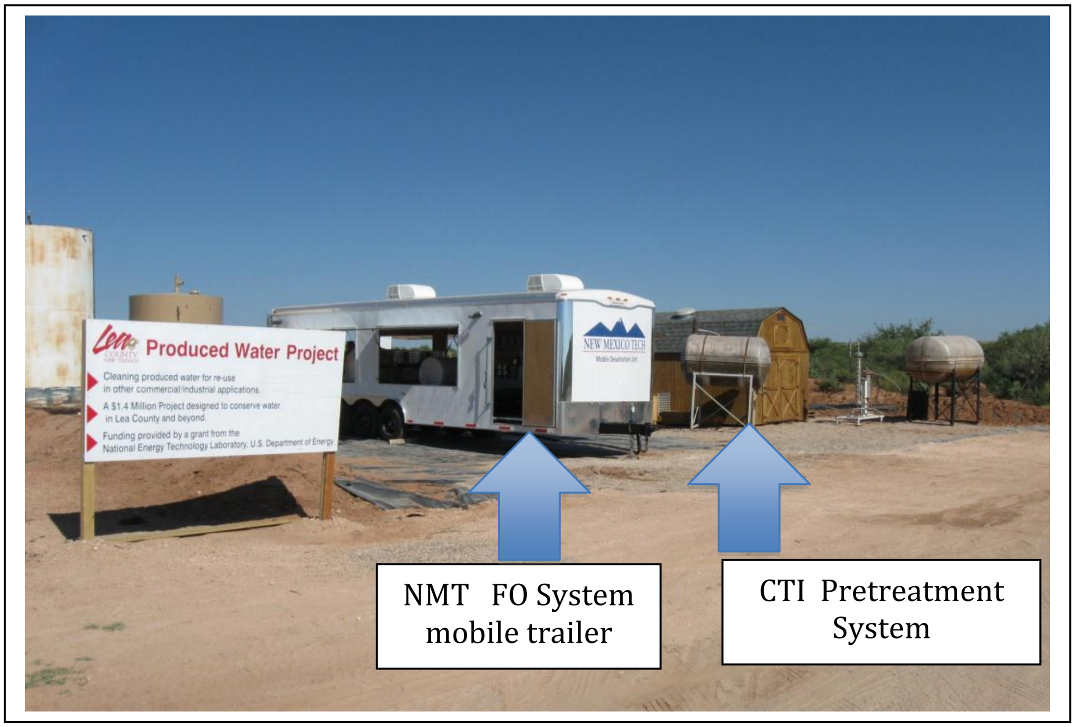


Figure 25: Field demonstration of the integrated NMT-CTI system at Jal, New Mexico

4.3 Demonstration Test Observations

4.3.1 At the NMT Site

Several tests were conducted at NMT site to understand what to expect at the Jal site demonstration. These tests were done using 60 gallons of both feed and draw solutions. It took about 12 hours to make 60 gallons of ammonium bicarbonate draw (6M) solution at 55°C, while it took only 2.5 hours to make sodium chloride (2M) solution.

4.3.2 JAL Demonstration

4.3.2.1 Aquastream/CTI Demonstration

Before putting the Aquastream/CTI treated water through the NMT FO process, water chemistry was determined for all four water samples provided to NMT. Test analysis was done at Cardinal Laboratories in Hobbs and Hall Environmental Analysis Lab, in Albuquerque, NM. Test results show that both the test houses yielded similar test data.

Table 8: The water quality of the CTI pretreated produced water

Source location	Oil and Grease	Total Suspended Solids (TSS)	Total Dissolved Solids (TDS)
Bobcat	< 10 ppm	< 2 ppm	57,000 ppm
Joyner	44.2 ppm	6.0 ppm	5,000 ppm
Hannigan	9.08 ppm	< 2 ppm	7,300 ppm
Brown #2	21.8 ppm	4.0 ppm	4,400 ppm

Bobcat water was tested to determine the effectiveness of the Aquastream/CTI process. Test observations are given in Table 9.

Table 9: Effectiveness of the Aquastream/CTI pretreatment process

Source location	Oil and Grease	TSS	Benzene	Toluene	Ethylbenzene	Xylene
Before the CTI	55.2	28	282 ppb	436	46	188
After the CTI	13	3	ND	ND	ND	ND

4.3.2.2 NMT Demonstration

The Bobcat feed water, once processed through the CTI pretreatment, was passed through the NMT system. When tested with NMT TDS meter, it was found to have dissolved salt concentration of around 61,875 ppm (~ 1.041 Molar). The NMT process removed approximately 2 gallons of water from the feed solution in 1 hour. This is equivalent to a flux of 27.5 liters per meter square of the membrane area in 1 hour. This number is twice that reported by the membrane manufacturer's highest value. Both the Joyner and Brown #2 water had high amounts of oil and grease and so were never processed through the NMT system.

Table 10: Some of the process parameters for Jal Site Pilot Test Demonstration

Variables	Draw Side	Feed Side
Initial Volume	45 Gallons	32 Gallons
Initial Molarity	5.098 OsmoM	1.041OsmoM
Initial TDS	318.880 of ppt NaCl	61.875 ppt of NaCl
Initial Chloride Level	1700 ppm	-
Final Chloride Level	1500 ppm	-
Final Molarity	4.818 OsmoM	1.180 OsmoM
Final TDS	305.105 of PPT NaCl	66.717 ppt of NaCl

Based on the NMT demonstration outcome, a preliminary economic analysis was performed to determine the cost effectiveness of the process developed and is provided in section 5.1.

5.0 Part 3 – Economic Analysis and Commercialization Plan

Forward Osmosis (FO) and Reverse Osmosis (RO) both have been known to have the potential to clean water containing high levels of dissolved minerals. In the last decade, RO has developed into a more mature technology and large-scale RO systems are presently installed around the world converting seawater and other brine water into drinking water. FO, on the other hand has not seen this level of system development due primarily to the fact that a draw solution is required to extract the water and then the draw must be removed from the 'cleaned' water. The identification of more effective draw solutions that are easier to separate has led to renewed interest in FO. NMT's proprietary and patent pending mechanically enhanced FO process developed under this program is a significant leap forward in FO technology and FO is now in a position where operational systems are possible for commercial application. This new advancement in FO technology is now being considered for cleaning produced water in a cost effective manner, something that until now has not been possible with membrane technology.

RO has been unsuccessful in cleaning these high TDS level waters due to the high pressure (and excessive energy) required to overcome the osmotic potential. There has been work devoted to trying to optimize this energy use for RO in general. The recent work of Zhu, Christofides, and Cohen found that there was an optimization of the product water recovery from RO at pressures that approach the osmotic pressure of the exit brine stream. A figure of merit based on the specific energy consumption (SEC), which has units of pressure in their analysis is given by Zhu et. al. [7],

$$SEC = \frac{\dot{W}_{pump}}{Q_p}$$

Where,

$W_{pump} = \Delta P \; x \; Q_f$ is the pump rate, $\Delta P = P_f - P_0$ is the difference in water pressure at the entrance of the membrane (P_f) to the pressure of the raw water (permeate pressure,P_0). Q_f and Q_p are the volumetric feed flow rate and the permeate flow rate, respectively. Energy cost optimization for a single RO without any energy recovery mechanism is given by

$$SEC \geq \frac{\pi_0}{Y(1-Y)}$$

Where,

$\pi_0 = f_{os}C_f$ is the feed osmotic pressure, f_{os} is the osmotic pressure coefficient, C_f is the salt concentration of the feed to the membrane and $Y$is a measure of the process productivity and is given by

$$Y = \frac{Q_p}{Q_f}$$

What this analysis for the specific energy consumption figure of merit (which is quadratic in Y) is telling us is that there is an optimum value for applied pressure to the RO membrane, which will be dependent on feed salt concentration and membrane properties. Any increase in the pumping will result in a non-optimal use of energy. The use of energy recovery processes will also change the value of this minimum.

Under the current program, we have been focusing on what the real FO system costs are and how they compare with other methods of water cleanup, in particular RO. Since FO is much less dependent on pumping pressure, the figure of merit will be different from that of RO. McGinnis and Elimelech used specific work equivalent as the figure of merit to compare RO and FO. They found that despite the fact that energy is the driving factor in all desalination processes, when comparing desalination of seawater using FO, the equivalent work (kW-hr/m^3) can be 72% less than that for RO [8].

A detailed cost comparison with RO has shown that the NMT FO method is the most cost effective method of water desalination and cleaning produced water. For seawater, the cost for a one million gallon a day (1 MGD) system is about $10 per 1,000 gallons and $14 per 1,000 gallons for FO and RO, respectively. It is anticipated that the FO energy costs can be further reduced through the use of alternative energy sources. We have looked at solar, wind, and fuel cells to accomplish this. One of these, fuel cells, is discussed in the following section.

We have also focused on how to commercialize the present method, and we are in the process of completing a business plan and preparing a plan for approaching investors. Several private investors have been identified and will be approached once the business plan and negotiations with NMT on the licensing rights of the process have been completed.

5.1 Preliminary Economic Analysis

Using the data from this FO desalination pilot process, attempts were made to calculate the cost of treated water [9]. This preliminary cost estimate compares a typical RO and FO process. Three different process volumes considered: 1 MGD, 10 MGD and 100 MGD. TDS is varied from 1,000ppm to 120,000ppm. Total cost includes initial, energy, operating, and maintenance costs.

5.1.1 Assumptions

(a) The desalination system is a closed system;
(b) Membrane packing density will be increased to produce 46.33 gallons of product water per hour from raceway;
(c) Plant life is 25 years;
(d) Interest rate is 6.5%;
(e) Ambient temperature = 30^{o}C;
(f) Draw solution of 4.5 M and above will be prepared above 30^{o}C. So, to keep the cost to minimum, more NH_4OH has been used for draw solution at 4.5 M and above; and
(g) Chemical cost will be reduced to 50 %, if a 10 year contract with minimum 10 ton order will be agreed.

5.1.2 Cost of Product Water

5.1.2.1 CAPACITY = 1MGD (COST in $/1.000 Gallons)

Table 11: Cost comparison between RO & FO for a 1 MGD system

	RO				FO			
TDS (ppm)	**Initial Cost**	**Energy Cost**	**O & M**	**Total Cost**	**Initial Cost**	**Energy Cost**	**O & M**	**Total Cost**
1000	1.41	1.68	0.73	3.82	1.81	7.07	2.77	11.65
2000	1.44	1.70	0.76	3.90	Na	Na	Na	Na
5000	1.57	1.81	0.88	4.26	Na	Na	Na	Na
10000	1.87	2.03	1.32	5.22	1.81	7.07	3.02	11.90
30000	4.07	2.99	2.33	9.39	1.81	7.07	3.56	12.45
35000	4.74	3.46	3.24	11.44	Na	Na	Na	Na
50000	6.45	4.73	4.41	15.59	Na	Na	Na	Na
60000	Na	Na	Na	17.73	1.81	7.07	4.51	13.39
90000	Na	Na	Na	21.45	1.81	7.70	7.44	16.95
100000	10.77	5.14	7.58	23.49	Na	Na	Na	Na
120000	16.18	6.61	11.61	34.42	1.81	7.70	8.99	18.50

Na – Not available

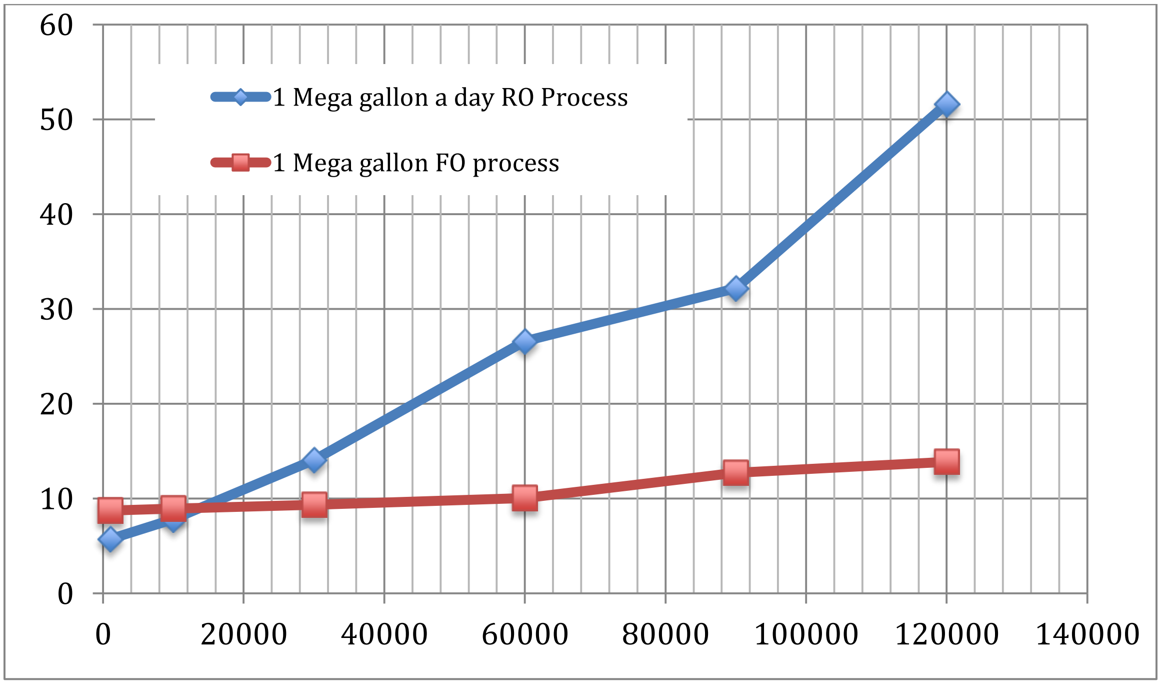


Figure 26: Cost comparison between RO & FO for a 1 MGD system

x – axis : TDS of the feed solution
y – axis : Total cost in dollar for producing 1000 gallons of water.
Total cost includes initial, energy, operating, and maintenance costs

5.1.2.2 CAPACITY = 10MGD (COST in $/1000 Gallons)

Table 12: Cost comparison between RO & FO for a 10 MGD system

	RO				**FO**			
TDS (ppm)	**Initial Cost**	**Energy Cost**	**O & M**	**Total Cost**	**Initial Cost**	**Energy Cost**	**O & M**	**Total Cost**
1000	0.54	0.66	0.29	1.49	0.69	2.81	1.02	4.52
2000								
5000								
10000	0.73	0.80	0.51	2.04	0.68	2.82	1.09	4.59
30000					0.70	2.81	1.31	4.82
35000	1.85	1.36	1.26	4.47				
50000								
60000					0.69	2.79	1.68	5.16
90000					0.69	3.01	2.91	6.61
100000	4.20	2.02	2.95	9.17				
120000	5.94	2.45	4.26	12.65	0.70	3.01	3.51	7.22
150000								

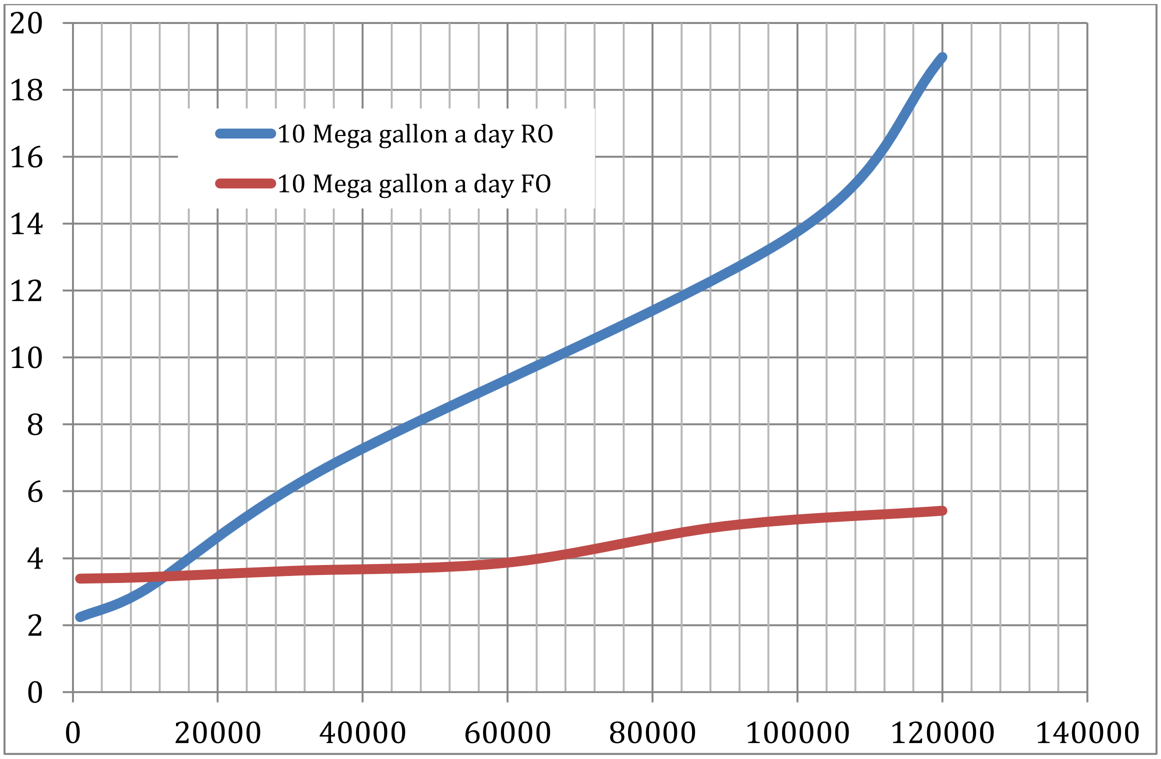


Figure 27: Cost comparison between RO & FO for a 10 MGD system

5.1.2.3 CAPACITY = 100MGD (COST in $/1000 Gallons)

Table 13: Cost comparison between RO & FO for a 100 MGD system

	RO				**FO**			
TDS (ppm)	**Initial Cost**	**Energy Cost**	**O & M**	**Total Cost**	**Initial Cost**	**Energy Cost**	**O & M**	**Total Cost**
1000	0.28	0.37	0.15	0.80	0.35	1.57	0.51	2.43
2000								
5000								
10000	0.39	0.42	0.27	1.09	0.35	1.54	0.61	2.50
30000					0.35	1.51	0.72	2.58
35000	0.98	0.73	0.67	2.38				
50000								
60000					0.35	1.56	1.01	2.92
90000					0.36	1.64	1.57	3.57
100000	2.23	1.09	1.56	4.88				
120000	3.16	1.31	2.26	6.73	0.36	1.64	1.91	3.91
150000								

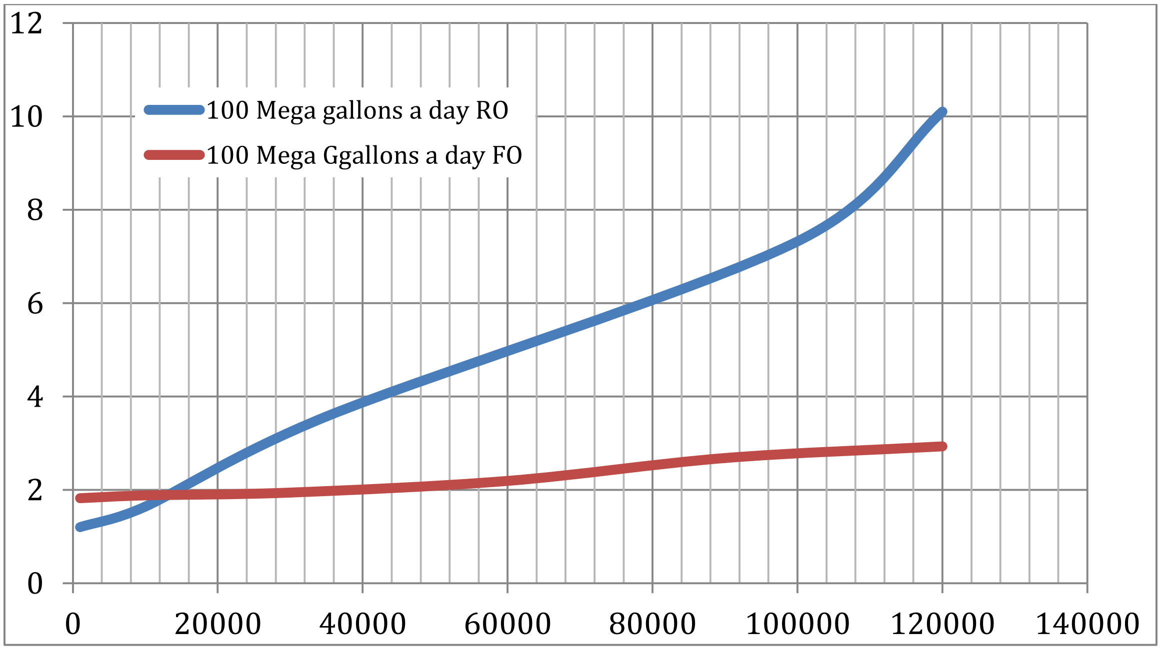


Figure 28: Cost comparison between RO & FO for a 100 MGD system

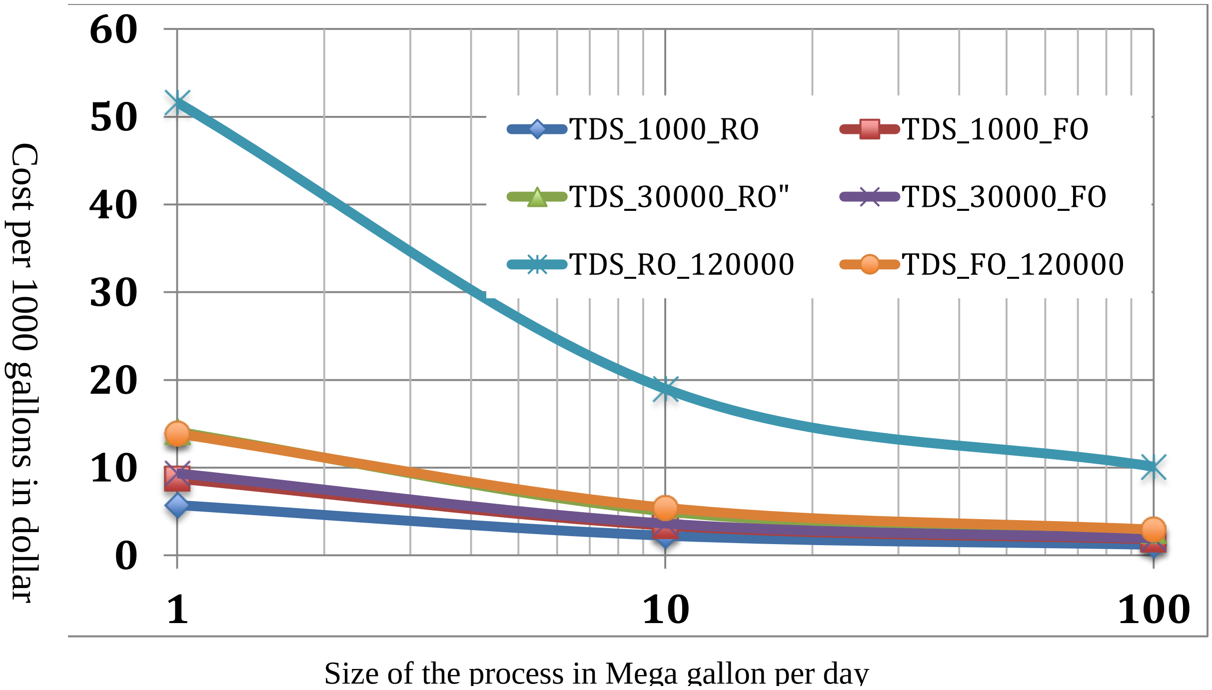


Figure 29: Cost versus process

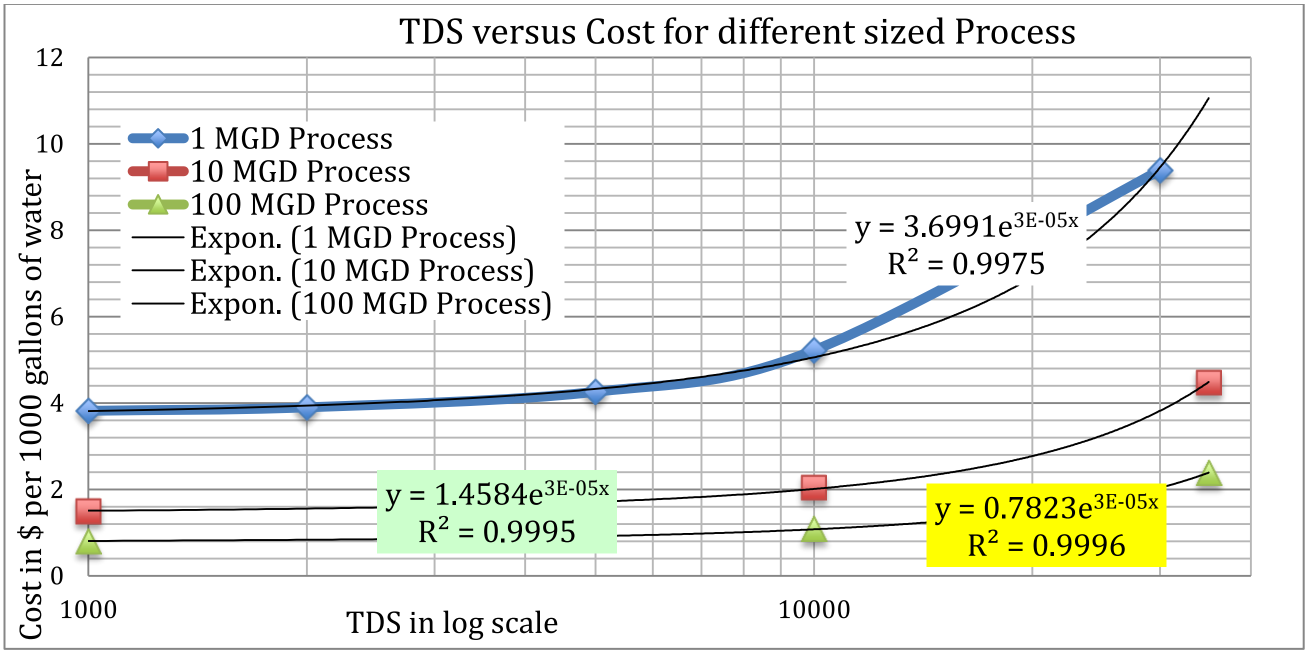


Figure 30: Cost versus TDS

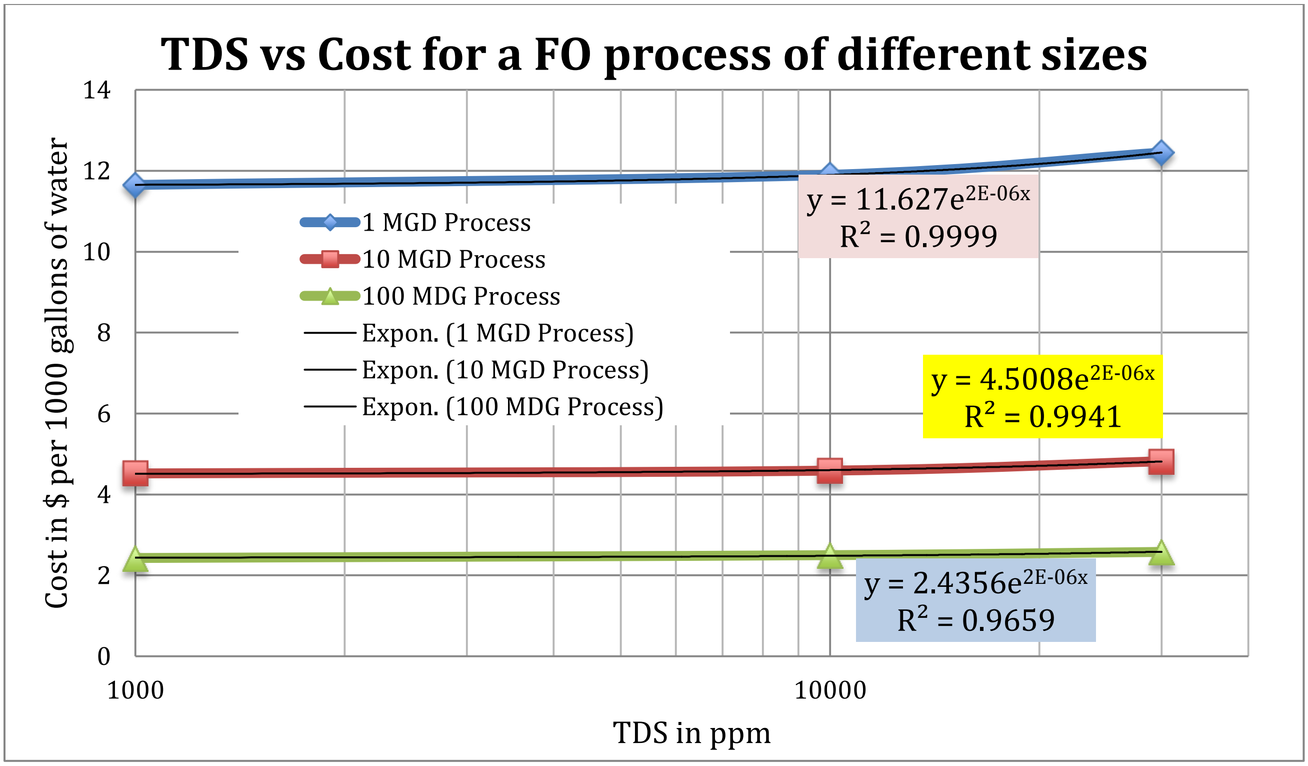


Figure 31: Cost versus TDS for FO process

Preliminary economic analysis demonstrated that a well-designed FO process will outperform an RO process for feed solution having a dissolved contaminant concentration more than around 10,000 ppm. Most produced water generated in SENM has TDS higher than 10,000 ppm, so it is logical to use FO to desalinate this water. Since the issues associated with concentration polarization have only recently been solved by our mechanically enhanced membrane module, the level of system maturity is not at the same level as that for RO.

5.2 Renewable Energy

Renewable energy development is one of the thrust areas of research in the world today because of the rising demand and price for crude oil. Also, the environmental impact of burning fossil fuel and its finite nature are additional reasons for renewed interest towards their discovery and exploitation. As a result, renewable energy sources were investigated for use with the NMT FO process as a possible way to reduce operating costs.

In New Mexico 6% of its electricity is generated from renewable sources, (New Mexico Public Regulation Commission [NMPRC]), with wind being credited for generating approximately 400 Megawatts of power. In order to economically generate electricity from these sources, the proposed site for the pilot scale study must meet some basic criteria. Wind speed is the main factor for the generation of wind energy. For solar energy, the critical factor is the number of hours of sunshine per day. There are additional criteria that must be taken into consideration while selecting the site. Potential environmental impacts associated with renewable energy generation have to be critically evaluated.

5.2.1 Wind Energy

In order to treat produced water from the oil wells, renewable energy sources can be used to yield cost effective solutions. Lea County receives abundant sunshine throughout the year. The city of Jal, in Lea County, experiences an average of 320 sunshine days per year and an annual precipitation of 13.8 inches. The average yearly wind speed for Lea County from 2003 to 2008 is summarized in Table 9. These data were obtained from weather station Hatch 2002, located at **Elevation:** 1241 m, **Latitude:** 32° 41' 38.04" N, **Longitude:** 107° 11' 45.96" W in Hobbs, Lea County and operated by New Mexico State University. In order to fund any wind project, financial institutions require a minimum of 1 year of on-site wind data using industry-accepted equipment.

The speed of the wind is the most important factor that influences the potential of wind energy as given by equation 8. It should be noted that the total power in the wind may not be extracted entirely due to different losses.

$$P = 0.5\,\rho\,A\,V^3 \text{ (Watts)} \qquad \text{Equation 8}$$

Where,

P = power in the wind
ρ = density of the air in Kg/m^3
A = area in m^2
V = wind velocity in m/s

Table 14. Average yearly wind speed for Lea County

YEAR	Mean wind speed (MPH)	Mean humidity (%)
2003	11.756	45.363
2004	9.823	53.893
2005	9.871	50.667
2006	10.34	45.918
2007	10.228	46.492
2008	10.841	46.566

Source: NMSU Weather Station in Hobbs, NM

To generate energy from a wind turbine economically, wind has to have a certain minimum velocity. According to Robert Putnam in the *New Mexico Wind Development Handbook,* the wind speed of more than 7 m/s can generate wind power economically. Table 15 displays the categories of wind and the speed associated with each category. Class 4 and higher is ideal for wind power generation. Class 3 can be used if the tower is around 60-70 m high. However, the density of the air decreases with increase in elevation, so consideration must be made when designing very tall wind turbine towers.

Currently, there are five wind farms in the State of New Mexico and another one is under construction, generating a potential 400 Megawatt of power. These wind farms are all located in the eastern side of the state. Figure 32 shows a map of the average wind speed of New Mexico. New Mexico ranks within the top 10 states in wind power generation potential and ranks 2nd in solar energy generation potential (NMPRC).

There is little adverse impact a wind farm can have depending on its location and the type of materials used to construct the turbines.

Table 15: Wind power classes

Wind Power Class	30 m		50m	
	Wind Power Density (W/m^2)	Wind Speed m/s (mph)	Wind Power Density (W/m^2)	Wind Speed m/s (mph)
1	≤160	≤5.1 (11.4)	≤200	≤5.6 (12.5)
2	≤240	≤5.9 (13.2)	≤300	≤6.4 (14.3)
3	≤320	≤6.5 (14.6)	≤400	≤7.0 (15.7)
4	≤400	≤7.0 (15.7)	≤500	≤7.5 (16.8)
5	≤480	≤7.4 (16.6)	≤600	≤8.0 (17.9)
6	≤640	≤8.2 (18.3)	≤800	≤8.8 (19.7)
7	≤1600	≤11.0 (24.7)	≤2000	≤11.9 (26.6)

Some of the negative impacts of a wind farm are noise, electromagnetic interference, and visual impact, possibly including ‘flicker’ cause by the reflection of sunlight on the rotating blades. The noise produced by a wind turbine can sometimes interfere with nearby habitat.

The noise generated from a wind farm falls in two categories; noise caused by the electrical equipment, such the gear box and generator – classified as mechanical noise and those cause by the interaction of the turbine blades and the wind – referred to as aerodynamic noise. Another negative impact of wind turbine is electromagnetic interference. This can occur when a turbine is placed between a radio, television, or microwave transmitter and receiver. The turbine can reflect some of the electromagnetic radiation in ways that the reflected waves interfere with original signal. The extent of the distortion depends on the surface shape of the tower and the material used in manufacturing the blades. Some turbines use laminated timber blades, which have the potential to absorb rather than reflect electromagnet radiation. If the turbines are made of metal blades or glass-reinforced plastic, then they may cause electromagnetic interference if located next to transmitting towers.

Lea County is the oil and gas capital in New Mexico, so it is reasonable to carry out an investigation to determine the location of communication towers and zoning regulations in order to prevent any negative impact a wind farm may pose on the inhabitants in this area.

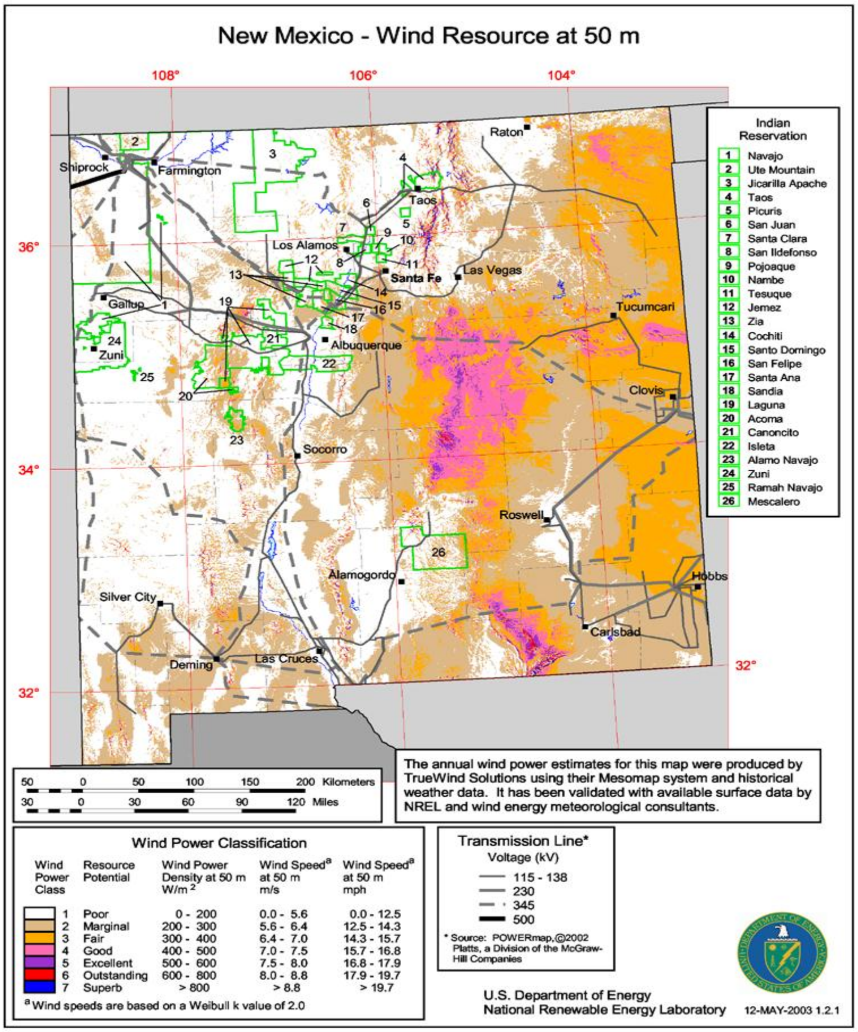


Figure 32: Wind speed map of New Mexico (US DOE)

5.2.2 Solar Power

As far as renewable energy is concerned, solar power is one of the most popular resources available for extracting electrical energy from the environment. New Mexico is one of the prime areas in the United States to use solar panels, and Lea County is no exception. Solar panels consist of a number of photovoltaic cells that are connected as a group to gather, convert, and distribute electrical power. These photovoltaic (PV) cells are made from semiconductors, which convert sunlight into potential electrical energy. When installing solar panels, there are a number of key factors to be considered:

- Angle of tilt;
- Orientation;
- Average annual solar radiation;
- Weather; and
- Type of photovoltaic cell.

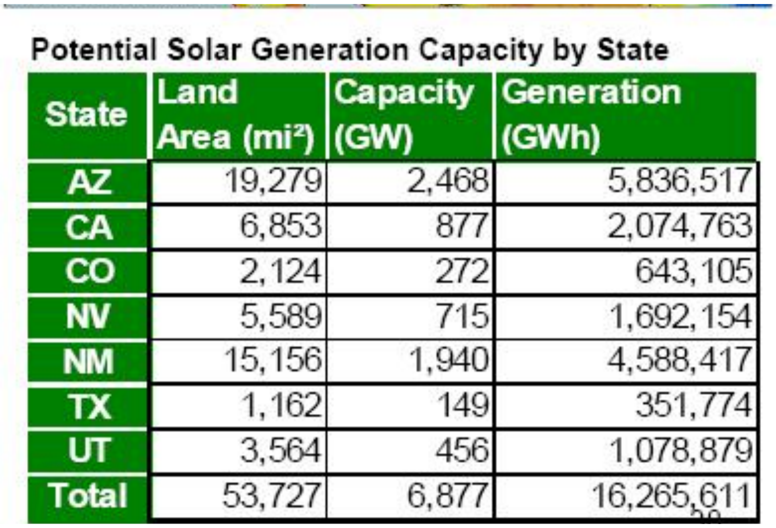
Angle of tilt refers to the angle of the installed solar panel in relation to the horizontal plane. This angle is important because it will allow the cells to receive the maximum amount of photons each solar day. This angle will vary according to the latitudes and elevations of a place.

Orientation is the compass direction that the solar panel is angled toward, such as North, East, South, West, or any in-between direction. The default direction is usually set at 180 degrees (south). For Lea County, the orientation of the panels can be set to the standard default.

Solar radiation is the type of energy received on the earth's surface directly from the sun. Due to the shape of the earth and its atmosphere, this energy is not constant in either quantity or quality. The farther away from the equator, the lesser is the average radiation. Lea County will receive, on the average, 6 to 6.5 kWh/m^2/a day of solar radiation, which is close to some of the highest recorded levels in the country. Figure 33 gives the map of solar power generation capacity of the Southwest US.

In many ways, weather is one of the largest deciding factors on the ultimate value and quantity of solar radiation that will reach the surface of the planet. The less congested the local air, sky, and atmosphere are, the more solar radiation a solar panel will receive. The more radiation a panel receives, the more energy it generates, therefore, making the process of energy generation more cost effective. The greater area of Hobbs enjoys, on average, 340 days of sunshine a year.

The type of photovoltaic cells used and the scale of the project, will greatly affect the estimated voltage output. There are many different kinds of photovoltaic cells and each has its own set of efficiency factors. With the best available technology, thin film panels are best. The best kind of photovoltaic is a concentrating PV. This particular type of solar gathering technology is at the head of the pack with an average efficiency rating of 33% (DOE Solar Energy Program Overview). The scale of the project is directly proportional to the surface area needed of the photovoltaic cells. The more the area of the photovoltaic cells, the higher is the generation potential.



Potential Solar Generation Capacity by State

State	Land Area (mi²)	Capacity (GW)	Generation (GWh)
AZ	19,279	2,468	5,836,517
CA	6,853	877	2,074,763
CO	2,124	272	643,105
NV	5,589	715	1,692,154
NM	15,156	1,940	4,588,417
TX	1,162	149	351,774
UT	3,564	456	1,078,879
Total	53,727	6,877	16,265,611

Direct-Normal Solar Resource for the Southwest U.S.

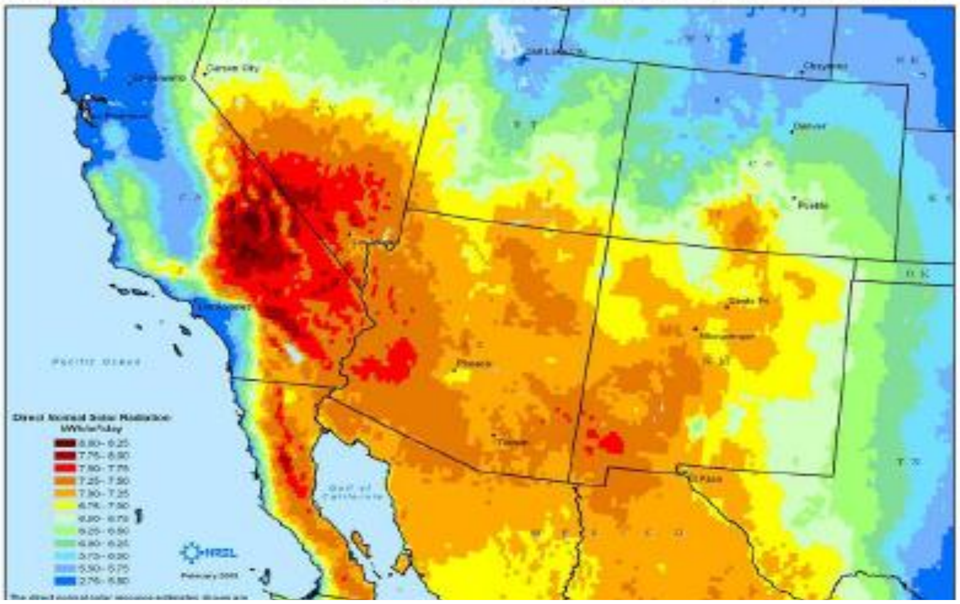


Figure 33: Map of solar power generation capacity of southwest US.

5.2.3 A Hybrid System

The more cost effective renewable energy system for Lea County would be based on a hybrid system consisting of energy generation through solar and wind. Connection to the power grid would be necessary as a backup when no renewable energy could be generated due to weather conditions. If these criteria can be met, its sustainability can be ascertained. Thus the system will take maximum advantage of existing renewable energy sources at the site. Research is ongoing to achieve this goal.

The investigation will require several steps:

1. Determine and characterize the power load by physical composition and time dynamics;
2. Identify and characterize potential power generation components;
3. Study the complexities of integrating these subsystems and their interactions from a power budget and power quality perspective both in steady and transient states; and
4. Evaluate the results by the criteria of economics, technical complexity, portability, and feasibility.

The first stage involves introductory work to gather data on the load components and learning how and when they will operate in an effort to fully characterize the power load and how it will change over time. This information will provide a theoretical description of the power needs at the site. This stage will likely involve some evaluation and decisions about whether to attempt an AC or DC system. The main electrical components will include approximately five water pumps in the 1 to 1.3 horsepower range; heating and cooling elements for the water in various stages of treatment; instrumentation and control equipment, and environmental heating, cooling, and lighting. Estimated maximum static power load is approximately ten kilowatts.

The second stage will be to identify and characterize renewable energy generation options. These options will likely include photovoltaic solar cells and/or wind generators as power sources (in addition to passive solar heating elements). Consideration of cost, physical installation, environmental conditions at the treatment sites, and availability of components will play into the selection. At a later stage of the greater project, an intelligent system will be developed to control the hardware for maximum economy and power efficiency, so the proposed research stage will aim to utilize components compatible with this requirement. Evaluation of meteorological data will contribute to the power generation expectations.

Stage three will require modeling and simulation to determine how the desired components will perform and interact with each other. Ascertaining a power factor of the load and generators will determine if reactive power compensation will be needed and, if so, what type and what size. Transient analysis of load and generator dynamics will determine the need for power buffering devices such as batteries and motor starting capacitors. Other considerations will include evaluating the need for rectifiers, inverters, associated monitoring and control systems, and other components. The combined picture provided by these evaluations will help determine how much power will be needed from the grid, and whether net metering of power back to the grid is a possibility.

The fourth and final stage of this investigation will be to consider the big picture perspective of the first three steps and make feasibility conclusions based on the results. This portion will also involve consideration and optimization of economics, an overall green factor, technical complexity and portability of the resulting system. Hopefully this information will result in a proposed component list that would contribute to the integrated system design as a future project.

5.3 Energy Calculation

In order to supply the desalination pilot plant with the needed 5,000 kWh/day, it is first necessary to determine what renewable energy source should be used. The amount of power needed is far too large to entertain the idea of small-scale wind power. The installation and tower cost would make this option far too costly. Large wind power would still be a viable option. A Vestas or Gamesa 0.85 MW turbine would provide all of the power needed as well as a surplus to be sold during extraordinarily windy times. The large height of this structure would allow for more consistent power production than smaller turbines. One of these turbines would cost approximately $1,100,000. This number is the installed cost of the turbine and has not been adjusted for state and federal renewable energy credits.

Another option for powering this unit is photovoltaic (PV) modules. Using Unirac solar racking, an adequate power system could be constructed using high efficiency panels. Cost estimation was based on a similar installation and adjusted for solar insolence levels and array size. This would give our system a cost of $1,123,200 before incentives.

One solar option that has been rapidly emerging is Stirling engine technology. This system uses heat generated by a large solar concentrator to power an engine and generator. These dishes are manufactured by Stirling Engine Systems and are capable of producing the needed power using only 16 units at 25kW each. Costs for this option have yet to be determined, but the company claims that the energy is competitive with the California market price referent (MPR).

The size of the system does not lend itself to using a mixed solar and wind system and forces a choice between the two. Wind power offers a consistent solution with the ability to generate excess power for sale. The PV solution offers the proper amount of power with a very large footprint. By using Stirling dishes, the proper amount of power could be produced without a large footprint or structure.

In order to accurately determine the energy potential of a location, data from the site must be compared with performance data from specific product specifications. Due to the large number of data points, a computer algorithm is necessary to perform the calculations. Four separate renewable energy sources were considered for a potential power supply. These were fuel cells, wind turbines, photovoltaic (PV) modules, and solar thermal heating systems.

5.4 Weather Station

Empirical data from the site is necessary before any type of analysis can be completed. This is been collected by a wireless transmitting weather station placed just west of Jal, NM. Prior to being installed in Jal, the weather station was on the top of Workman Center on New Mexico Tech Campus to verify functionality. This station takes readings of temperature, pressure, wind speed, relative humidity, solar radiance, and rainfall. These sensors are self-calibrated and work in conjunction with the HOBO U30 data logger, which logs and transmits data. This raw data is then transmitted via cellular communications towers to an online server where it is stored and readily accessed by the user. The HOBO U30 data logger outputs to a text file that can readily be read. In addition to this convenience, the Hobo link internet server is set up to display the data in graphical form.

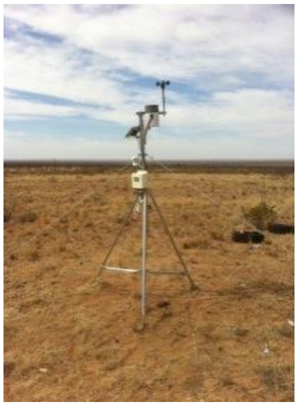


Figure 34 – Weather Station Installed in Jal, NM

5.4.1 Wind Energy

In the analysis of potential wind energy, four wind turbines were selected, two small scale and two large-scale turbines. These turbines were the Gamesa G58, Vestas V52, Proven WT2500, and Whisper 500 turbines. The basic code structure for finding real power output is the same for all turbines. This code uses temperature, pressure, and relative humidity data to compute the air density. This input can make a very large difference in the final power output of the turbine as the air density determines how much energy is in the air.

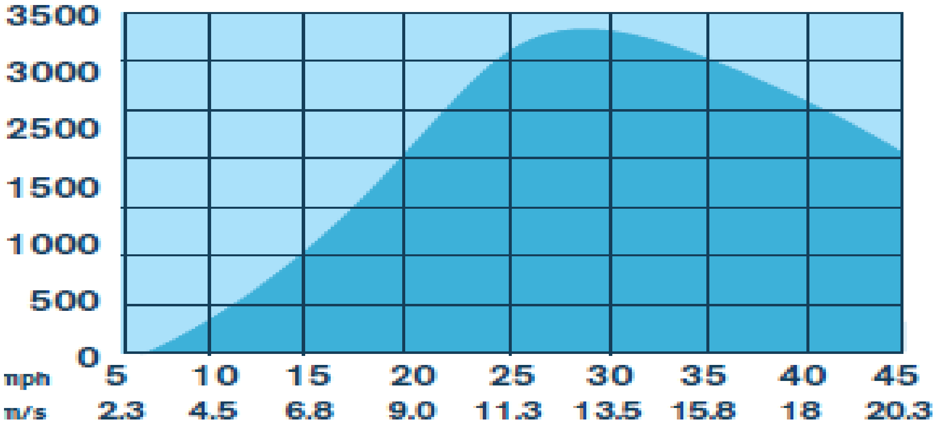


Figure 35 - Whisper 500 power curve (Courtesy of windenergy.com)

Power curves were obtained from wind turbine manufacturers. These curves were used to create piecewise energy production equations for the large-scale wind turbines, as the error is inherently lower in these applications. For the smaller turbines, the curve was loaded into the program in the form of an array of data points. The wind speed values from the weather station were plugged into the output equations for large turbines and were linearly interpolated between data points for the smaller ones. This calculation gives the average power output for the logging interval of that data point. These values can be summed to give a total power output over the given time in kWh and kW.

5.4.2 Photovoltaic Energy

The PV module analysis was performed on two widely produced high capacity modules. These were the Evergreen Solar ES-E 220W and the Canadian Solar SP 220W. Unlike wind turbines whose output varies greatly on both design and wind speed, PV modules have a maximum output that degrades linearly based upon solar radiation levels as well as temperature. This information makes the energy output approximation much more accurate. These panels produce their rated output at a solar radiation level of 1000 W/m^2 at 25 degrees C. This means that output decreases linearly if either the solar radiation levels are below the rated value or the temperature increases beyond 25 degrees C. As with the wind turbine analysis, each data point is compared with this power output scheme then summed to give an overall average power output.

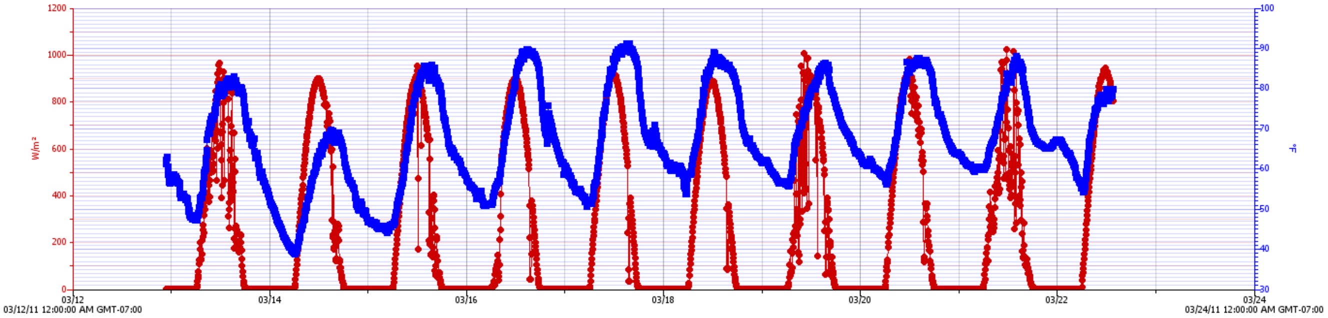


Figure 36 – Solar radiation (red) and temperature (blue) vs. time

5.4.3 Solar Thermal Heating Systems

Due to the fact that a sizable portion of electricity produced will be used for heating water, it is more effective to heat the water directly using solar collectors. These collectors are rated very differently than most renewable energy sources. Using the Solar Rating and Certification Corporation's (SRCC) performance data categories, solar thermal collector output can be normalized and effectively compared to each other as well as other energy sources. The code does this by first determining the two categories that a data point falls between, then linearly interpolating between these categories to give an accurate value for power output. By adding the values for all data points, the power output can be found in kWh for sunny (blue line); partly cloudy (redline); and cloudy (yellow line).

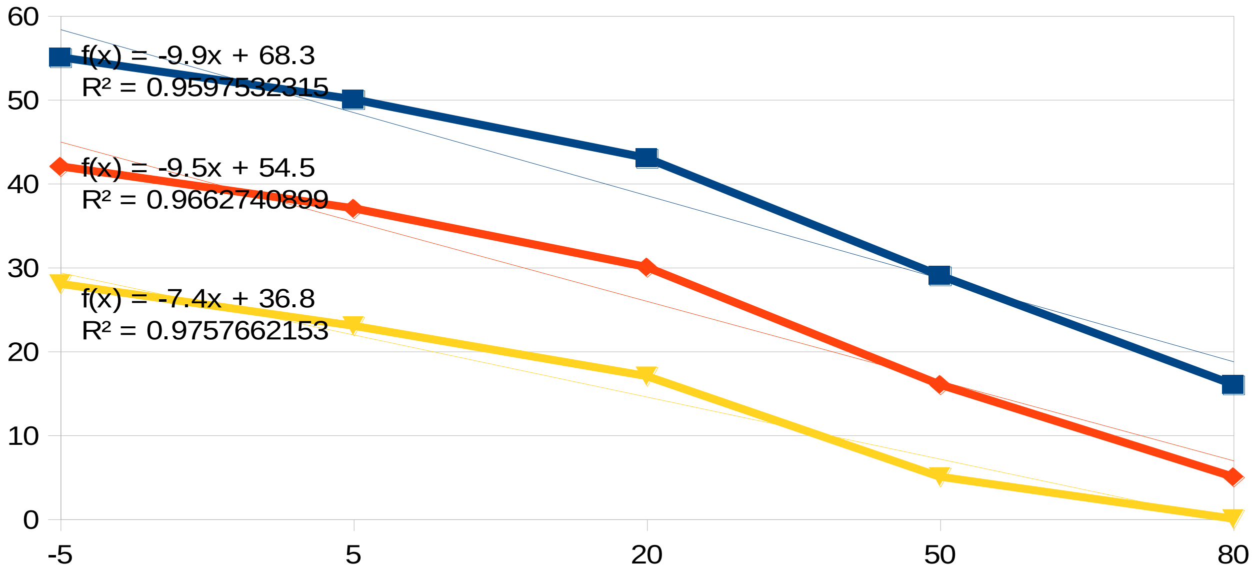


Figure 37 – Gobi 410 Performance at three radiation conditions (sunny, partly cloudy, cloudy)

5.5 Product Selection

In order to determine the products that would best fit the needs of the consumer, part of the code will match consumption inputs to product outputs. These inputs are power needed for the application, amount of that power used for water heating, acceptable error, and percentage of the output desired from wind and solar sources. Using this, the program decides the best way to meet your energy needs by using the highest capacity units possible in order to reduce installation costs. The program outputs the number and type of units necessary to provide power within the given parameters.

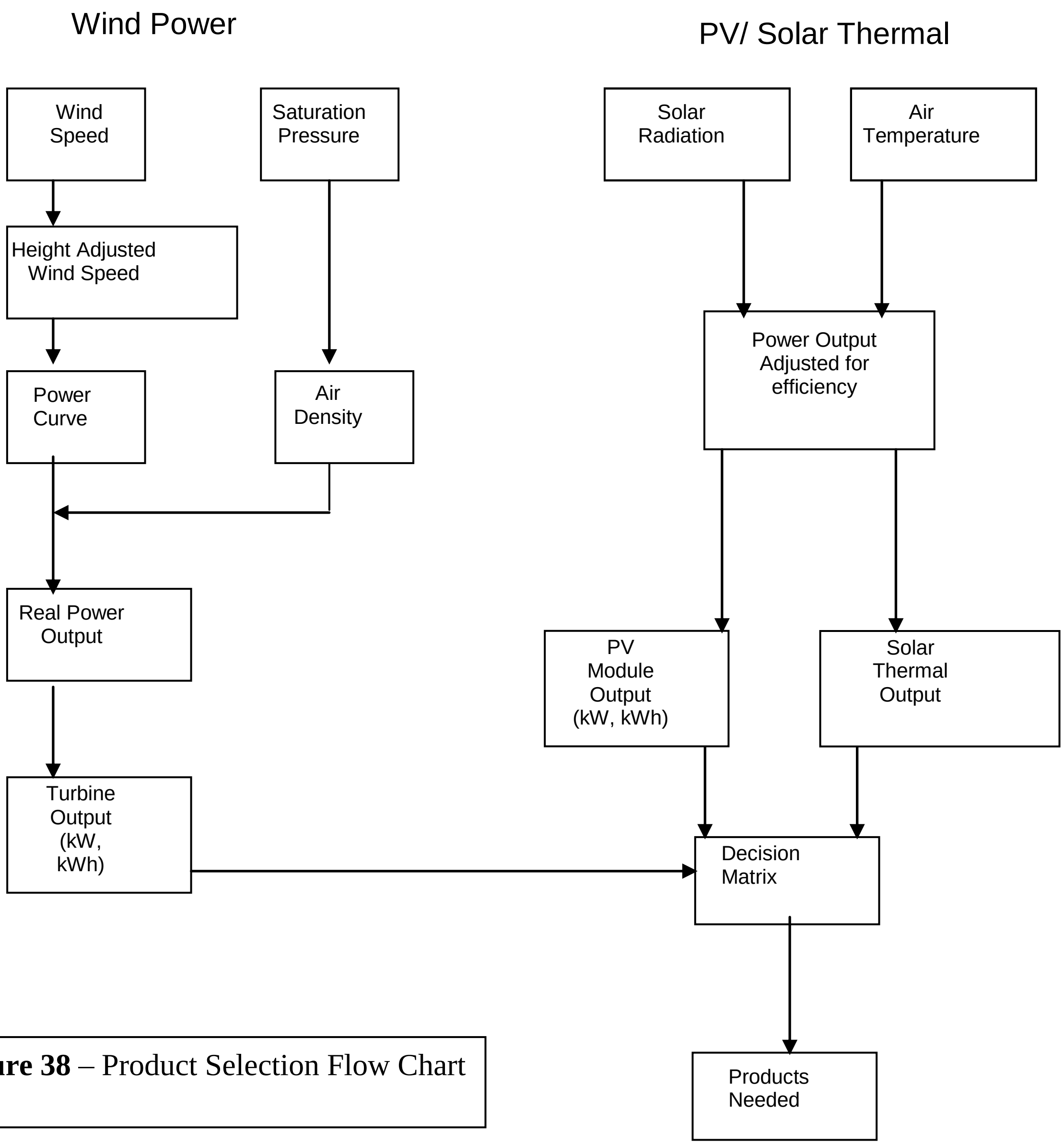


Figure 38 – Product Selection Flow Chart

5.6 Alternative energy sources as a source of electricity for the NMT FO system

NMT has focused effort on evaluating the potential for solar and wind as alternative energy sources to provide the necessary energy for the FO process. In this section the focus will be on a different energy source, fuel cells. The question is whether or not fuel cells can be used as a source of electricity for the NMT FO system, and if so, what are the costs? A fuel cell is essentially a battery that converts chemical energy to electrical energy. An oxidation reaction at the cathode releases electrons that flow through a circuit to the anode where a reduction reaction takes place. A membrane allows the transport of hydrogen ions to balance the reaction. A diagram is shown below.

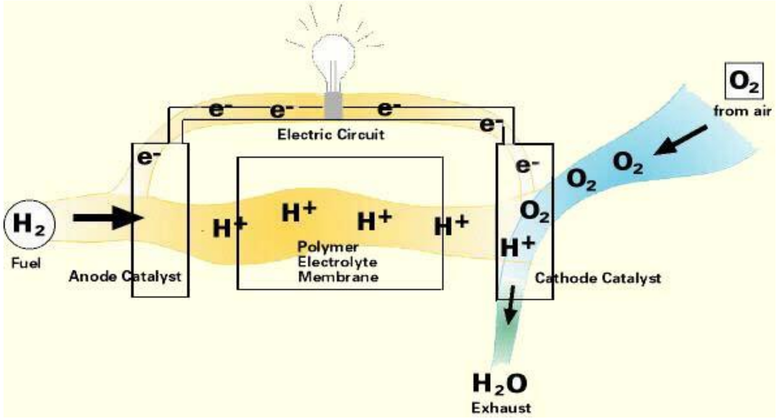


Figure 39 Hydrogen fuel cell process [www.fuelcells.org]

The complete balanced chemical equations for a hydrogen fuel cell are given by

Oxidation: $2\,H_2 \;\rightarrow\; 4\,H^+ + 4\,e^-$

Reduction: $O_2 + 4\,e^- \;\rightarrow\; 2\,H_2 0$

Cell Reaction: $2H_2 + O_2 \;\rightarrow\; 2\,H_2 0$

We can estimate the amount of electrical energy that is available from the Gibbs free energy, ΔG.

$$-\omega_{elect} = -\Delta G = -\Delta H + T\Delta S$$

Where ΔH is the electrochemical heat of reaction and TΔS is the amount of energy not available due to entropy. For this reaction with a ΔG of 237kJ/mol the useable energy is 1.23V.

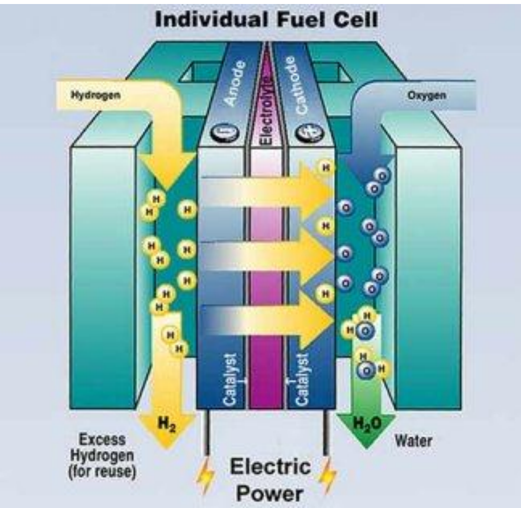


Figure 40: Fuel cell battery [www.scienceforkids.org]

There is ongoing research into making fuel cells more efficient and less costly, and recently they have been available commercially, although at the present time government subsidies are required to make them affordable for general commercial applications. Bloom Energy makes a commercial unit that is slightly different in that it uses natural gas (methane) as the fuel [No endorsement of Bloom Energy should be implied and none was intended. Bloom Energy was chosen solely as an example of a fuel cell system that is available.] Bloom has installed many units at such places as eBay, Google, and Wal-Mart. The Bloom ES-5000 100kW commercial units are shown below.

Figure 41: Bloom units installed in operation [www.bloomenergy.com]

The important question is whether or not fuel cells are viable as a source of electricity for the NMT FO system. Bloom Energy does not specifically say what the cost of an ES-5000 unit is but rather says that they will work with potential customers to get government subsidies. The subsidized cost is on the order of \$700-800k per unit. The ES-5000 can produce a constant supply of 100kW over a 24 hour period, or a daily output of 2,400kW-hr. Right now the NMT FO system requires 32kW-hr to process 1000 GPD or a daily need of 32kW-hr. In this case, to get to 1MGD the 32kW-hr becomes 32,000kW-hr and (32,000/2,400 = 13.3), 14 of the Bloom units would be required. This is a significant capital cost at a per-unit cost of \$700k (or \$9.8M for 14). When amortized over 10 years, this amounts to a \$1M annual cost for the energy generating hardware. This does not include the cost of fuel to operate, which in this case is natural gas.

We know that the oil drillers produce natural gas in addition to the oil and produced water. Presently they sell this natural gas back to the utility companies at about \$4.40/1000cu-ft.

$$\frac{\frac{\$4.40}{1000\,cu-ft}}{\frac{930\,BTU}{cu-ft}} \cdot \frac{1BTU}{2.93\,x\,10^{-4}kW-hr} = \frac{\$0.016}{kW-hr}$$

This is significantly less than the cost to buy electricity, which runs for industrial needs in New Mexico between \$0.07-0.09/kW-hr. So a potential solution would be for the oil drillers, who would be paying to have the produced water removed, pay some of this cost.

With a daily need of 32,000 kW-hr or annual need of 365 x 32,000kW-hr = 11,680,000kW-hr, a reduction of the electrical costs of 1 - 0.02/0.07 = 0.714 (71%) would save about $584,000 annually. This is significant but not sufficient to overcome the amortized hardware costs of $1M. Other savings need to be found.

5.7 Energy Recommendation

The most important thing that can be done is to find ways to reduce the overall energy requirement. With that goal in mind, we need to compare and contrast the various alternative energy sources e.g., wind, solar, fuel cells, etc. in order to make a more fair assessment of the choices.

5.8 Commercialization Efforts

As indicated, the complete produced water cleanup process requires both a pretreatment process to remove organic material and suspended solids followed by a FO step that essentially removes all dissolved contaminants. In our initial tests, the pretreatment process included a basic flocculation step. While this was successful in removing most organics (oil and grease and BETX) it remains to be seen how robust and cost effective this simple flocculation process will be for 24/7 operations over a wide range of contaminants. For this reason alternate sources of pretreatment were sought. During our search, a process was identified that we feel has significant promise. This patented process utilizes ethylene acrylic acid (EAA) [US Patent 7,750,066] and is being considered as an alternative to the Aquastream/CTI pretreatment process in an effort to further improve the end-to-end NMT process and to make it more cost effective. A process utilizing this patented process has been proposed by ERIN Consulting, which is based in Saskatchewan, Canada and owns the patent rights. This process is described below.

The key to this patent is the use of Ethylene Acrylic Acid (EAA) as a micro-encapsulating flocculating dispersion. Utilizing EAA has many advantages over the conventional flocculation process like the one used by Aquastream/CTI. EAA has a very large overall surface area, which allows it to remove many times its weight in contaminants. In addition since it has both polar and nonpolar molecular sites, it is able to floc a wide variety of contaminates which is extremely useful when cleaning produced water. Another advantage is the ability to tailor the flocculation process allowing the floc'd contaminates to either precipitate out or rise to the surface through the adjustment of the EAA polymer size. The EAA floc is generated by the polymerization of ethylene gas with acrylic acid both of which can be obtained commercially. Adjustment of the EAA polymer size can be made during the production process by varying the ethylene/acrylic acid ratio and reaction time.

It is anticipated that this EAA flocculation pretreatment will be more cost effective and result in lower overall produced water cleanup costs. Overall packaging requirements which will vary depending on the water flow rate through the cleaning system are presently being looked at. A pilot system is being considered that will handle up to 100,000 gallons per day of produced water.

5.8.1 Micro-encapsulating Flocculating Dispersion Short Description [provided by Erin Consulting]

The ERIN Consulting Ltd. Micro-encapsulating Flocculating Dispersion (MFD) technology involves the use of a proprietary polymer to encapsulate and isolate oil and iron sulphide from produced water. The polymer/water dispersion and an activator are mixed into the produced water stream followed by a conditioner. All three reagents are added in low ppm amounts. The result of the reagent additions is the formation of a flocculant layer that contains the oil and any iron sulphide contaminants present in the water. Depending on the density of the oil, the resulting flocculant can be made to either float or sink. For lighter oils, the flocculant will float and can be removed with a skimmer. If the oil is heavy, then the flocculant will sink and can be removed with an in line cyclone separator. A flow diagram for a typical MFD oilfield setup is shown below.

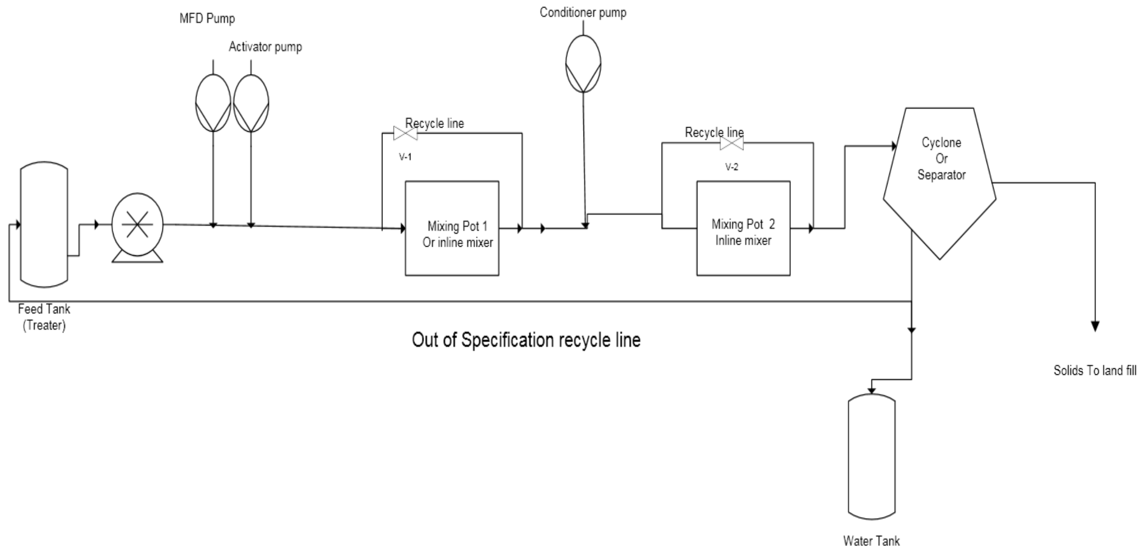


Figure 42: Typical MFD flow diagram for a produced water application [ERIN Consulting, 2011]

The following pictures show field test results for a produced water sample before and after the MFD treatment.

Figure 43: Produced water samples before and after MFD treatment [ERIN Consulting, 2011]

The original sample was high in both oil and iron sulphide. The treated water is clear with a floating flocculant layer containing both of these contaminants. The field testing showed that MFD treatment can reduce oil levels in produced water exiting a treater from over 800 ppm to less than 10 ppm without filtration. Filtration drops the oil levels below 5 ppm. Table 1 shows the results of MFD treatment on three successive samples of produced water.

Table 16: MFD treatment results for three separate samples of produced water.

Sample Location	Oil in Water (ppm)		
	Pre-MFD	Post-MFD	Post MFD and Filtration
Treater Water Dump S1	840	8.5	3.3
Treater Water Dump S2	603	5.1	2.4
Treater Water Dump S3	842	4.8	2.5

5.8.2 Market Potential

Potash mining requires a significant amount of water during the ore extraction process. A typical potash mining process can use 2,400 gallons/min (3.4 million gallons/day) [“Potash, Soda Ash, and Borates” Energy and Environmental Profile of the U.S. Mining Industry, ITP Mining]. There has been consideration within the community on using RO to clean brine water to meet this need therefore FO should also be considered due to the potential to lower energy costs.

In order for the NMT FO process to fill this need, the engineering issues associated with the scaling to the necessary volumes that are required to economically supply water to the potash industry need to be considered. While nothing in the NMT design appears to limit scaling, it remains to be demonstrated and for this reason it is recommended that the engineering work go forward.

To meet the water requirements of the potash mining industry, the chloride and potassium concentrations are important to consider.

For organics, further testing should be conducted to 1) better predict potential fouling on the FO membranes and 2) ensure minimal organic contamination. Intrepid Potash also requested very low organic content in any supply water although they could not give a target ppm level. Cardinal Laboratories chose tests for the heavy organics (Oil & Grease) and the light volatiles (BETX). It might be valuable for a test for total organic carbon (TOC) using SM-5310-B or similar test.

5.9 Conclusions & Recommendations

The NMT FO process has been designed and tested as a fielded demonstration unit and tests indicate that there is nothing inherent in design that precludes scaling to a larger device. The unit processed about 2 gallons per hour or 48 gallons per day. To meet the demands of the potash industry, this would require a scaling of the present system by about 167,000 times to reach 8 MGD. Several things can be done to make this goal more achievable:

1. Scale to a larger membrane area. A factor of 100-1,000 is conceivable.
2. Increase the number of fielded units by 10-100 which is also possible.

Taking the most optimistic of these values, a 100,000 (1,000 x 100) improvement (implying that 48 x 100,000 = 4.8 MGD) is possible. Therefore, an 8 MGD is not unrealistic for a scaled NMT system. However, engineering issues still need to be identified and addressed.

The pretreatment process provided by Aquastream/CTI did show very good results based on the chemical tests conducted by Cardinal Laboratory. What still needs to be examined is how to integrate this system into the NMT FO system. Also it is not clear that the Aquastream/CTI process is the best overall process. That was the reason for opening discussions with ERIN Consulting on using their patented process, which has the potential to be useful over a wider range of contaminants.

Since the goal for the cleaned up produced water is to supplement water use in the potash mining operations, the removal of all TDS may not be necessary. Based on discussions with the potash mining people (Intrepid Potash), it was concluded that the cleaned up produced water requirements were as follows:

- Chloride content – < 1.5 % (0.015 or 15,000 ppm)
- Hardness – < 800 ppm
- Oil – none
- Organics – none or minimal so that it may not cause foaming problem in the potash process

The chloride and hardness levels should be the goals for the NMT FO cleaned up produced water if the potash industry is the end user. For oil it seems that it should be possible to reach the above levels. The rationale for this is the following: Oil that needs to be removed refers primarily to oil and grease and Aquastream/CTI did a pretty good job at this. Volatiles might also be present that could be removed via packed aeration methods with activated carbon if necessary. The foaming issue should not be a problem after the Aquastream/CTI process. Foaming is usually a problem with the higher concentrations of the heavier organic carbon constituents and is found quite often with the gas floatation methods of removing oil and grease.

Lastly, engineering issues associated with scaling both the Aquastream/CTI process and the NMT FO process need to be explored. Scaling the FO system to larger volumes will likely lead to an increased energy requirement and an alternative energy system will likely be necessary to cut energy costs.

In conclusion, due to the importance of finding additional water sources for an ever-expanding population in the US southwest, it appears that a commercial system can be built to clean produced water and offset industrial water use. This might take a concerted effort from both the private industry to finance and build the system and state and local governments to provide the political will to change present attitudes on water use.

6.0 References

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[9] Mallevialle, J. (1996) " Water treatment Membrane Process" McGraw-Hill.

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We are also grateful to Controlled Recoveries, Inc. for providing us with the water samples from their disposal ponds near Hobbs. We are grateful to Hydration Technologies, Inc. for providing us with the CTA membranes.

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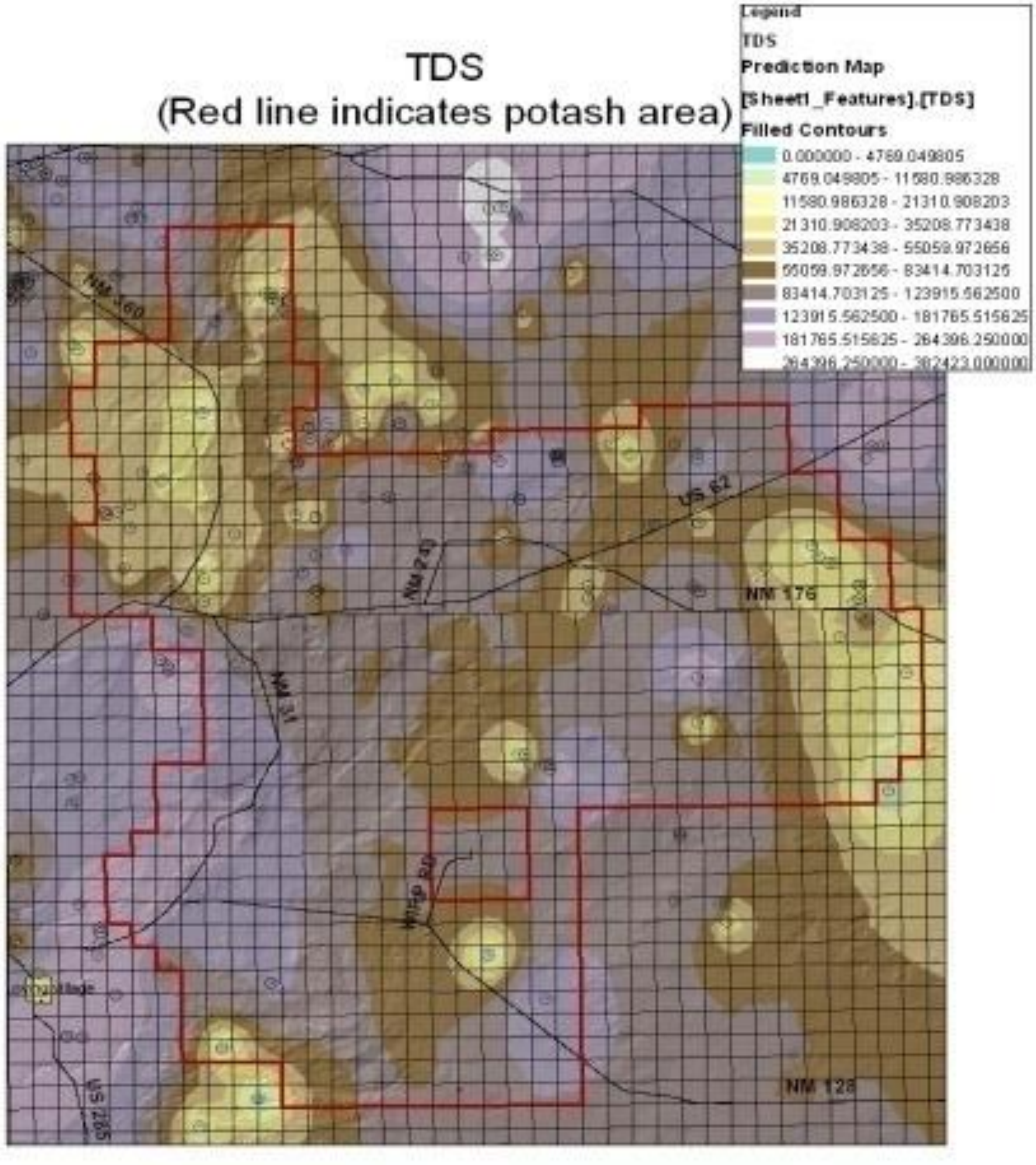
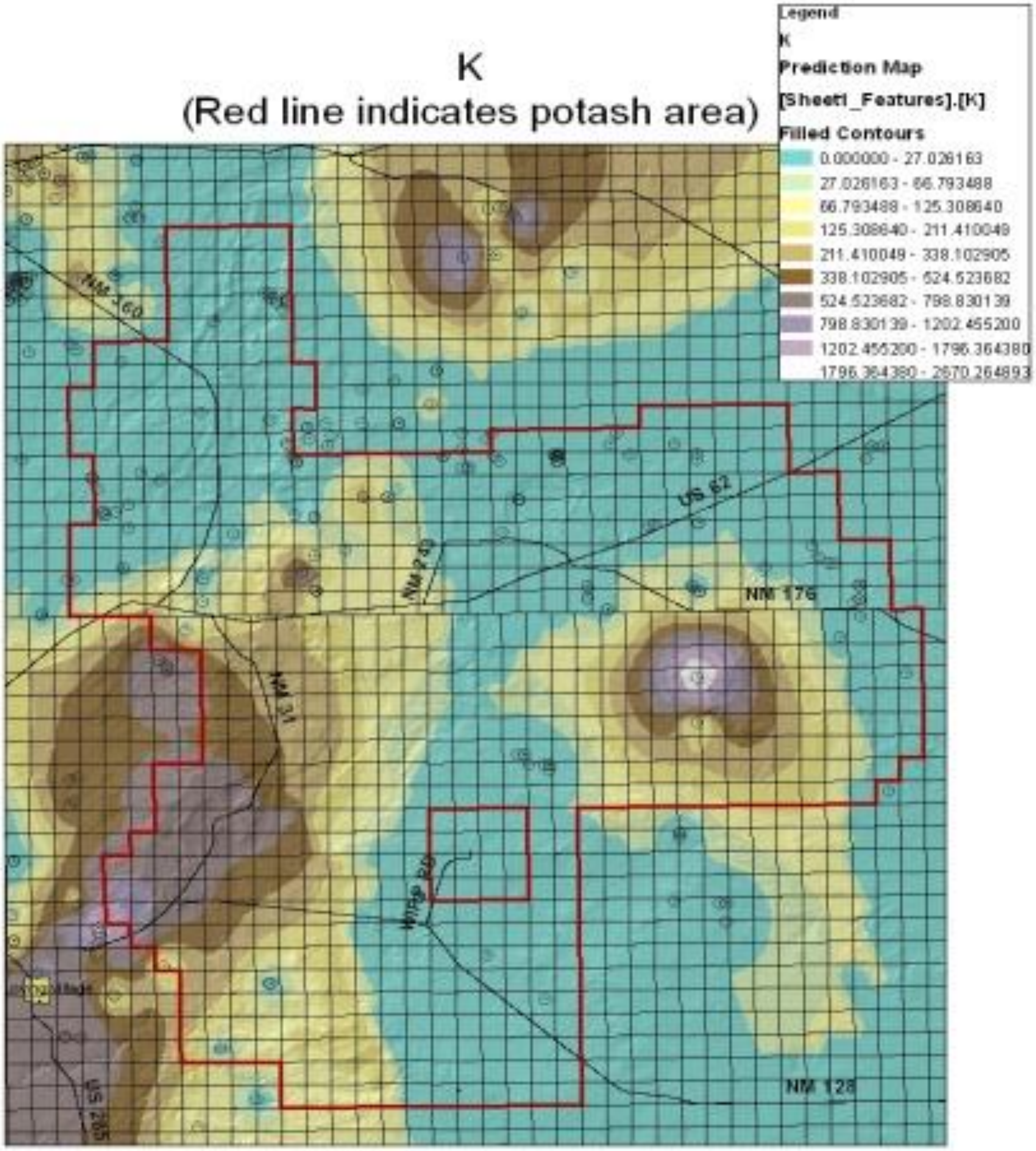
Appendix A: The Arc-Info plots of the Concentration of Various Elements



K
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66.793488 - 125.308640
125.308640 - 211.410049
211.410049 - 338.102905
338.102905 - 524.523682
524.523682 - 798.830139
798.830139 - 1202.455200
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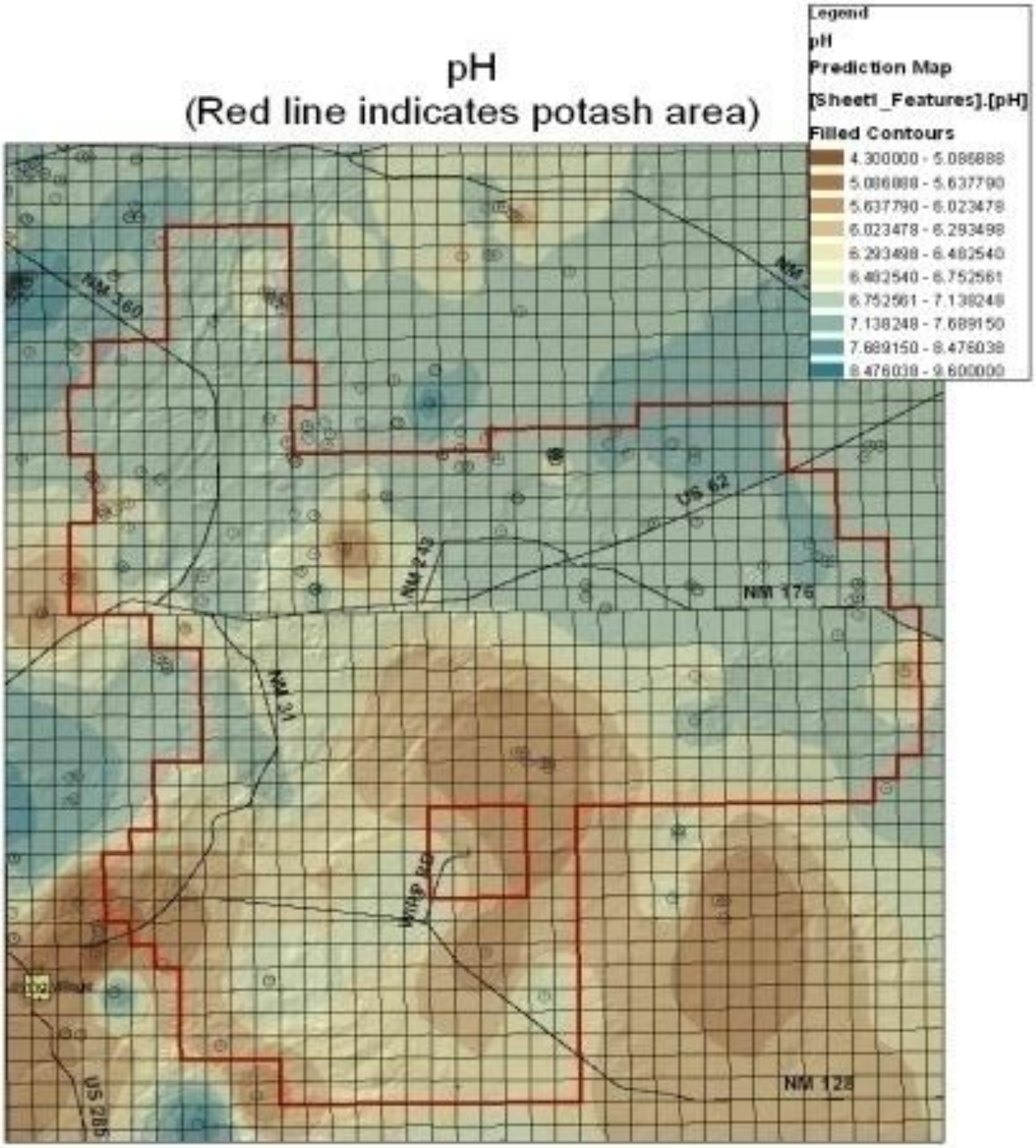
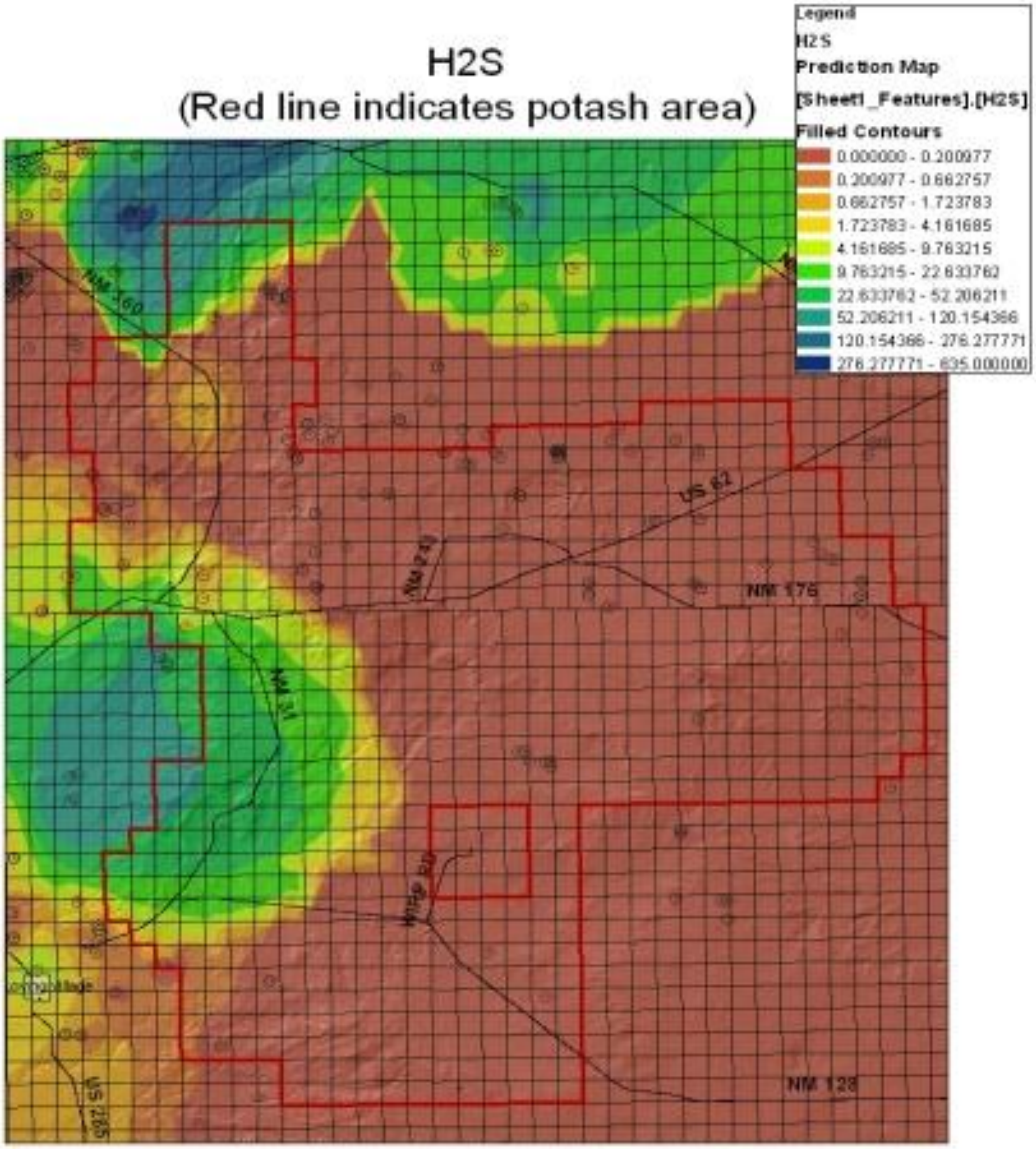
NM 31
WIPP Rd
NM 128
US 285



pH
(Red line indicates potash area)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9.763215 - 22.633762
22.633762 - 52.206211
52.206211 - 120.154366
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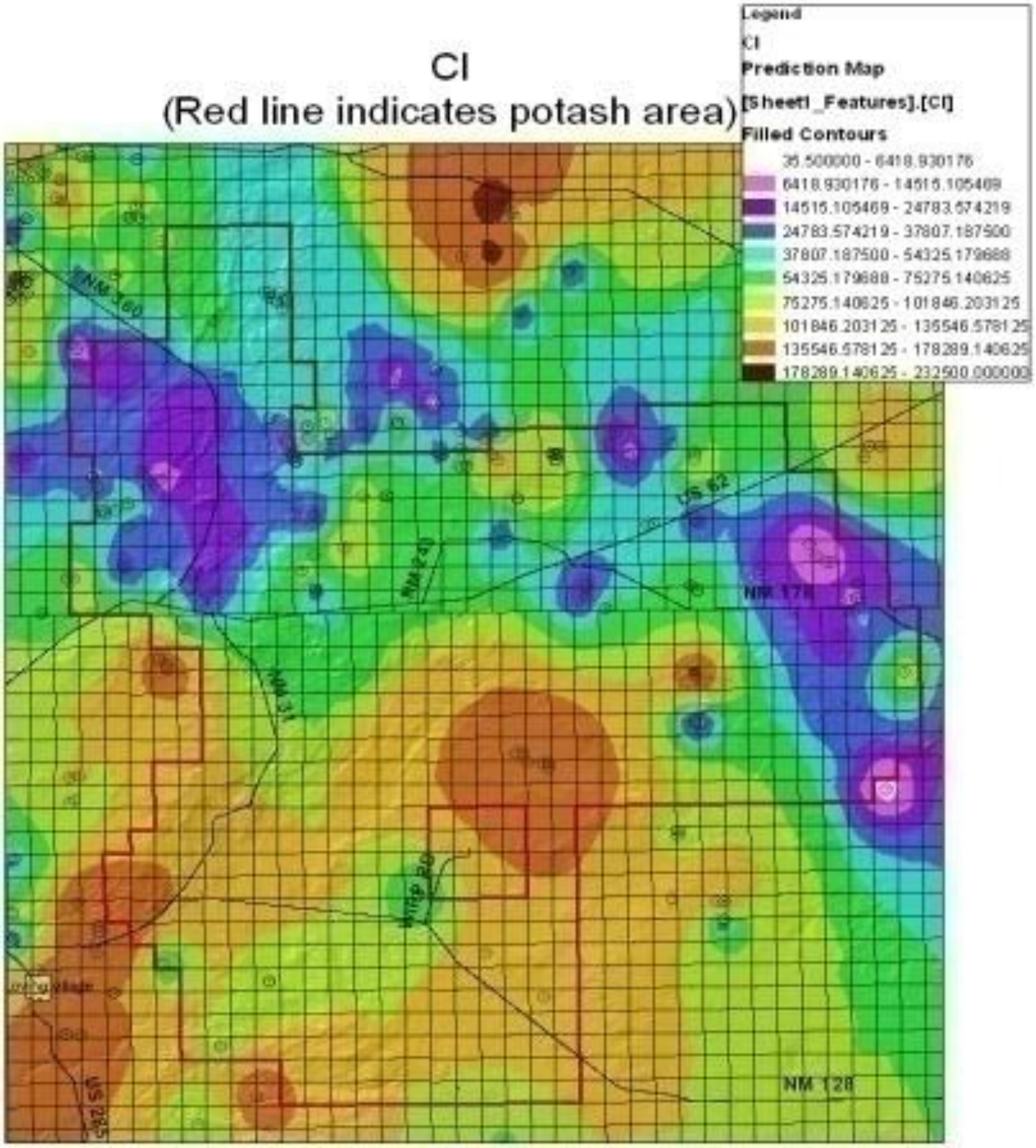
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54325.179688 - 75275.140625
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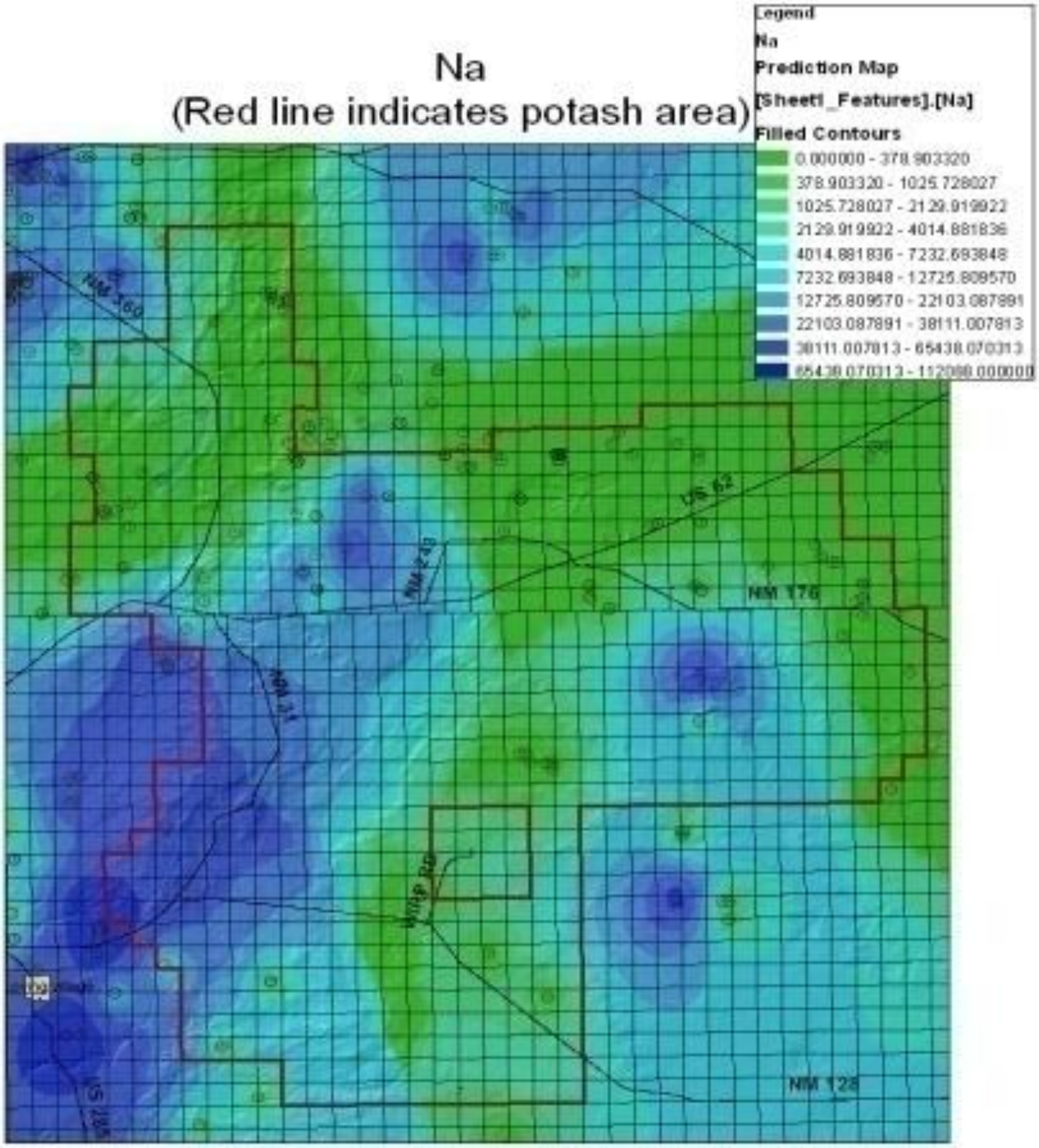
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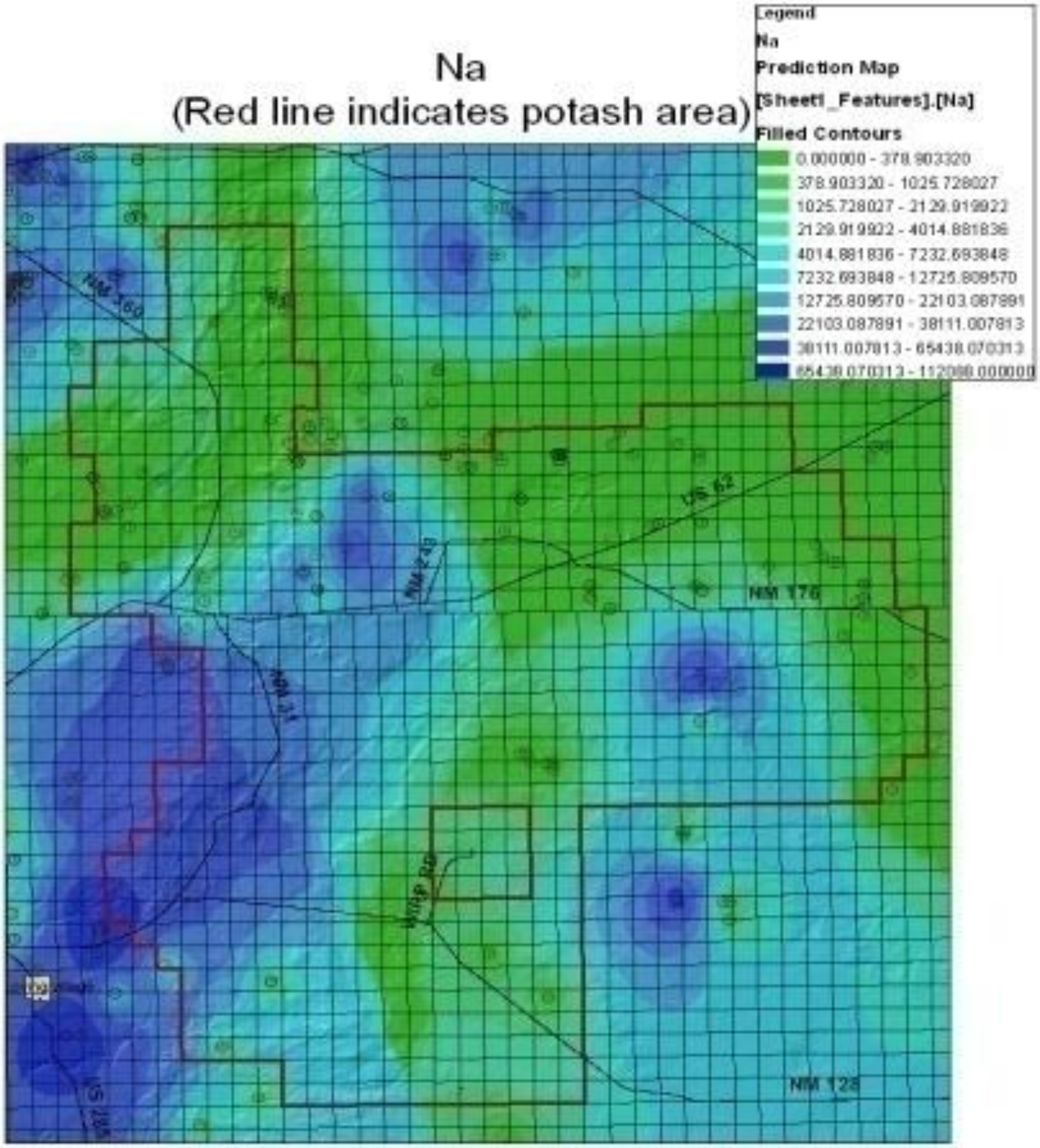
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Legend
Na
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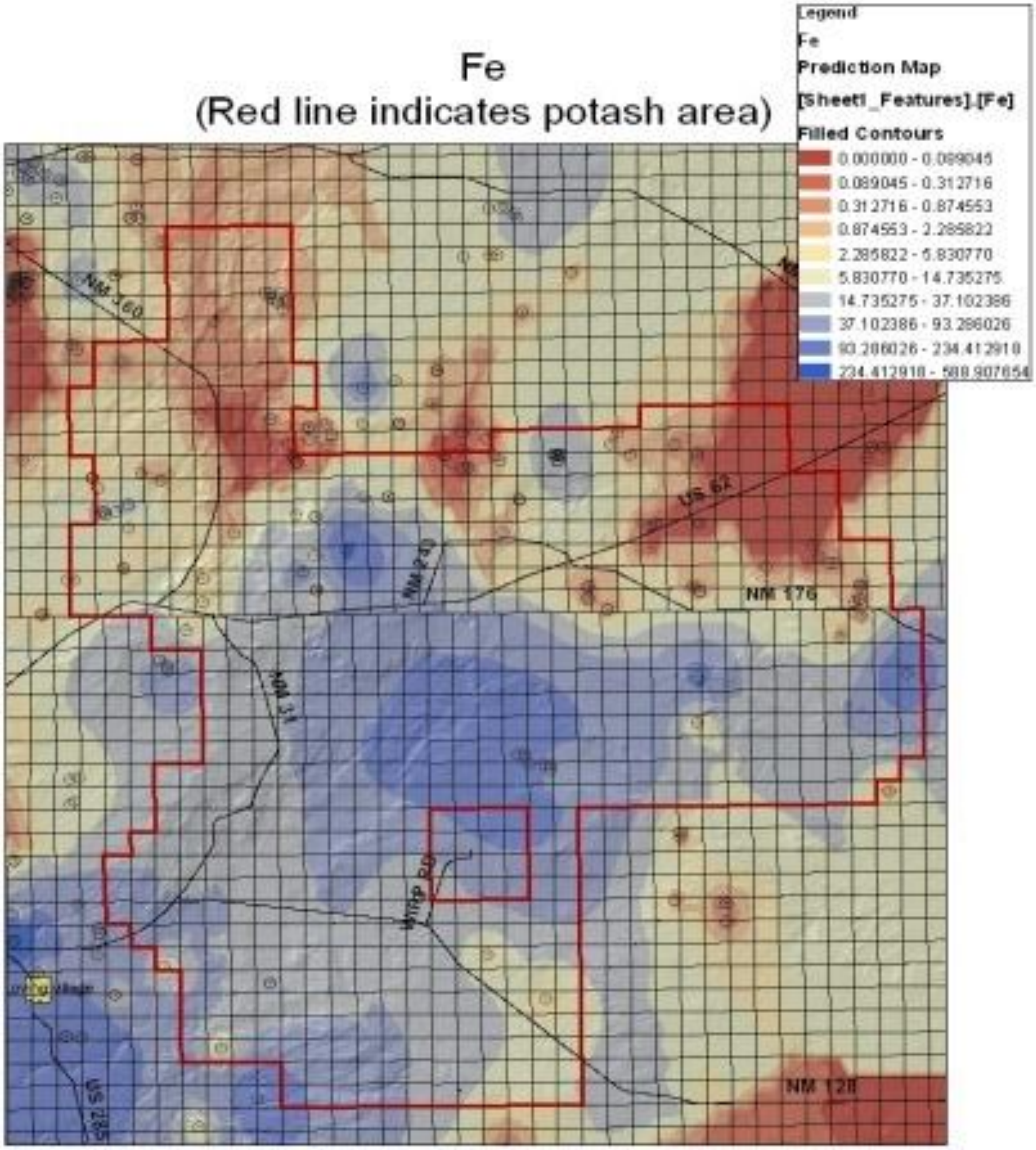

Fe
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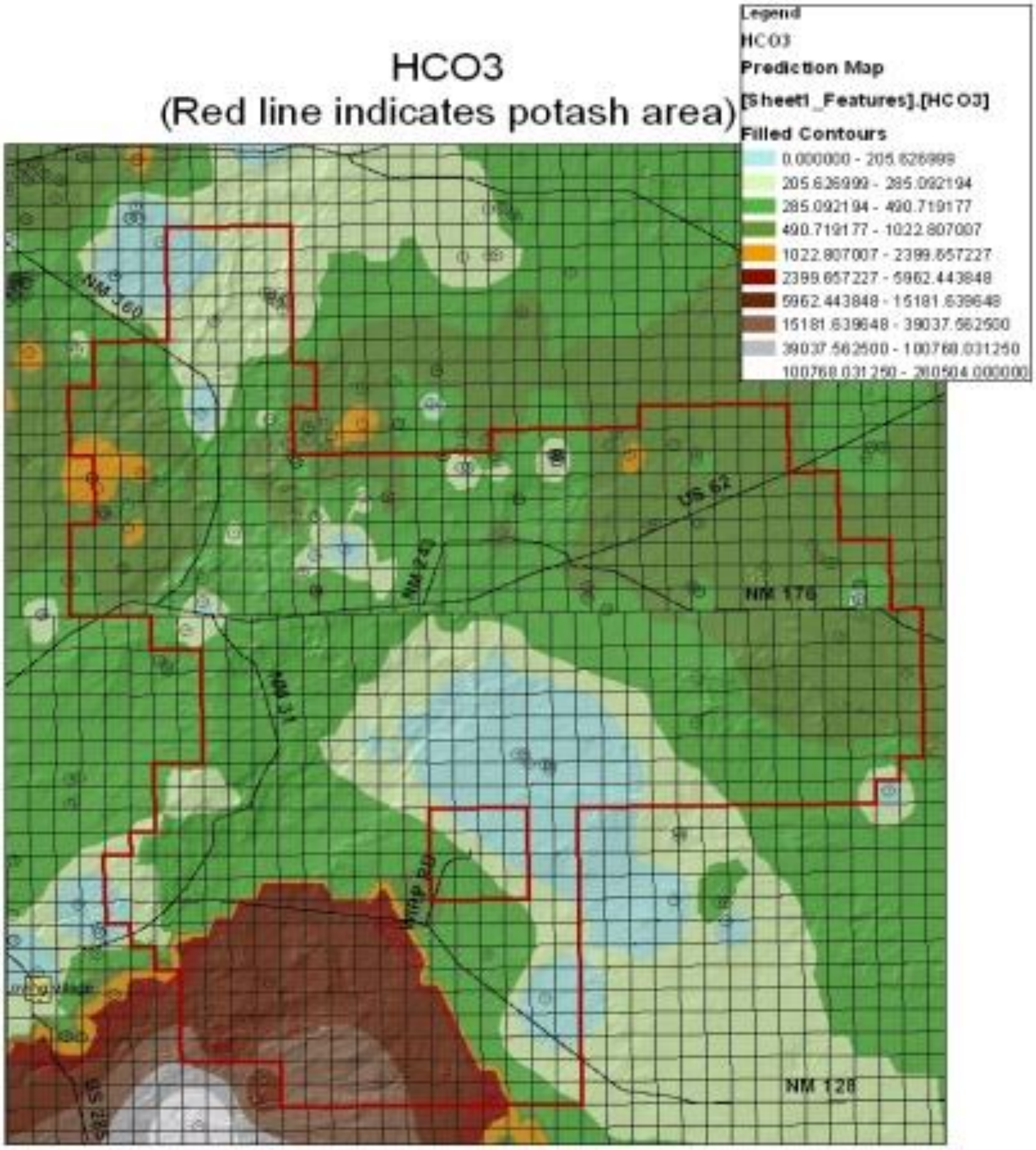
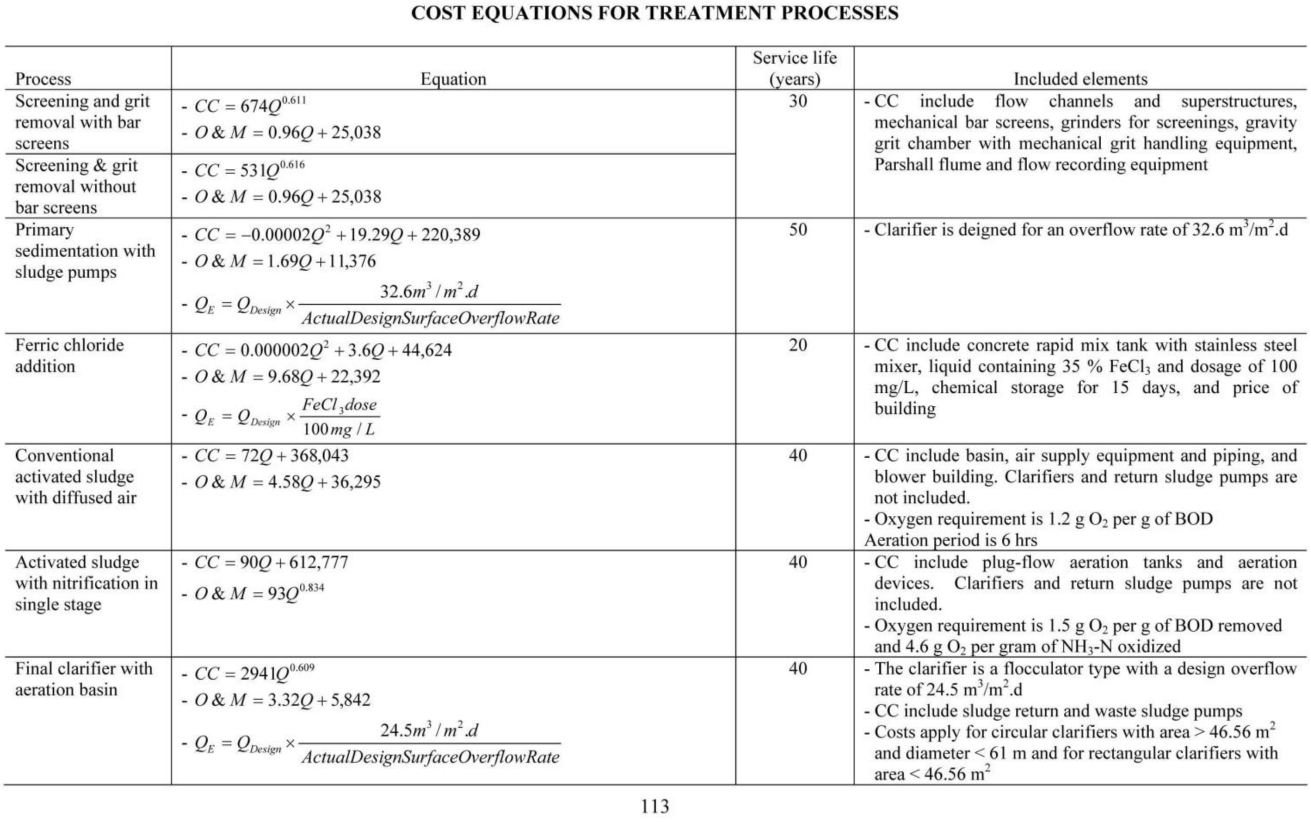


HCO3
(Red line indicates potash area)

Appendix B. Economic Formulation

The following charts a synopsis of work of Qasim, *Wastewater Treatment Plants* and USEPA, *Detailed Costing Document* and taken from a UN report, *Economic aqnd Social Commission For Western Asia, Waste-Water Treatment Technologies: A General Review* E/ESCWA/SDPD/2003/6, 11 September 2003. This table is useful for comparing various pretreatment methodologies.

These equations are very useful in identifying the costs associated with various processes. They include both the cost of the process itself and all its associated costs.



COST EQUATIONS FOR TREATMENT PROCESSES

Process	Equation	Service life (years)	Included elements
Screening and grit removal with bar screens	- $CC = 674Q^{0.611}$ - $O\&M = 0.96Q + 25{,}038$	30	- CC include flow channels and superstructures, mechanical bar screens, grinders for screenings, gravity grit chamber with mechanical grit handling equipment, Parshall flume and flow recording equipment
Screening & grit removal without bar screens	- $CC = 531Q^{0.616}$ - $O\&M = 0.96Q + 25{,}038$		
Primary sedimentation with sludge pumps	- $CC = -0.00002Q^2 + 19.29Q + 220{,}389$ - $O\&M = 1.69Q + 11{,}376$ - $Q_E = Q_{Design} \times \frac{32.6m^3/m^2.d}{ActualDesignSurfaceOverflowRate}$	50	- Clarifier is deigned for an overflow rate of 32.6 m^3/m^2.d
Ferric chloride addition	- $CC = 0.000002Q^2 + 3.6Q + 44{,}624$ - $O\&M = 9.68Q + 22{,}392$ - $Q_E = Q_{Design} \times \frac{FeCl_3 dose}{100mg/L}$	20	- CC include concrete rapid mix tank with stainless steel mixer, liquid containing 35 % $FeCl_3$ and dosage of 100 mg/L, chemical storage for 15 days, and price of building
Conventional activated sludge with diffused air	- $CC = 72Q + 368{,}043$ - $O\&M = 4.58Q + 36{,}295$	40	- CC include basin, air supply equipment and piping, and blower building. Clarifiers and return sludge pumps are not included. - Oxygen requirement is 1.2 g O_2 per g of BOD Aeration period is 6 hrs
Activated sludge with nitrification in single stage	- $CC = 90Q + 612{,}777$ - $O\&M = 93Q^{0.834}$	40	- CC include plug-flow aeration tanks and aeration devices. Clarifiers and return sludge pumps are not included. - Oxygen requirement is 1.5 g O_2 per g of BOD removed and 4.6 g O_2 per gram of NH_3-N oxidized
Final clarifier with aeration basin	- $CC = 2941Q^{0.609}$ - $O\&M = 3.32Q + 5{,}842$ - $Q_E = Q_{Design} \times \frac{24.5m^3/m^2.d}{ActualDesignSurfaceOverflowRate}$	40	- The clarifier is a flocculator type with a design overflow rate of 24.5 m^3/m^2.d - CC include sludge return and waste sludge pumps - Costs apply for circular clarifiers with area > 46.56 m^2 and diameter < 61 m and for rectangular clarifiers with area < 46.56 m^2

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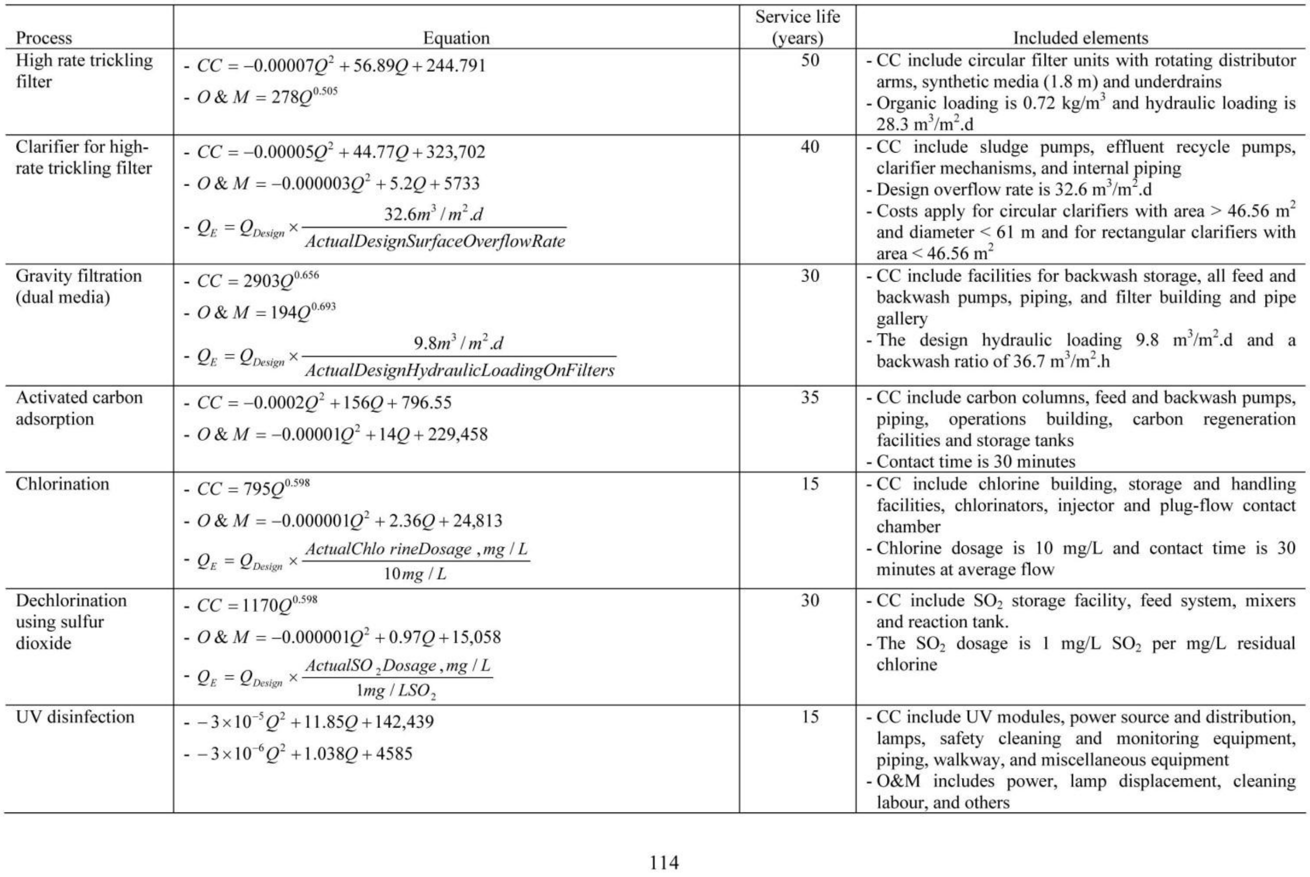
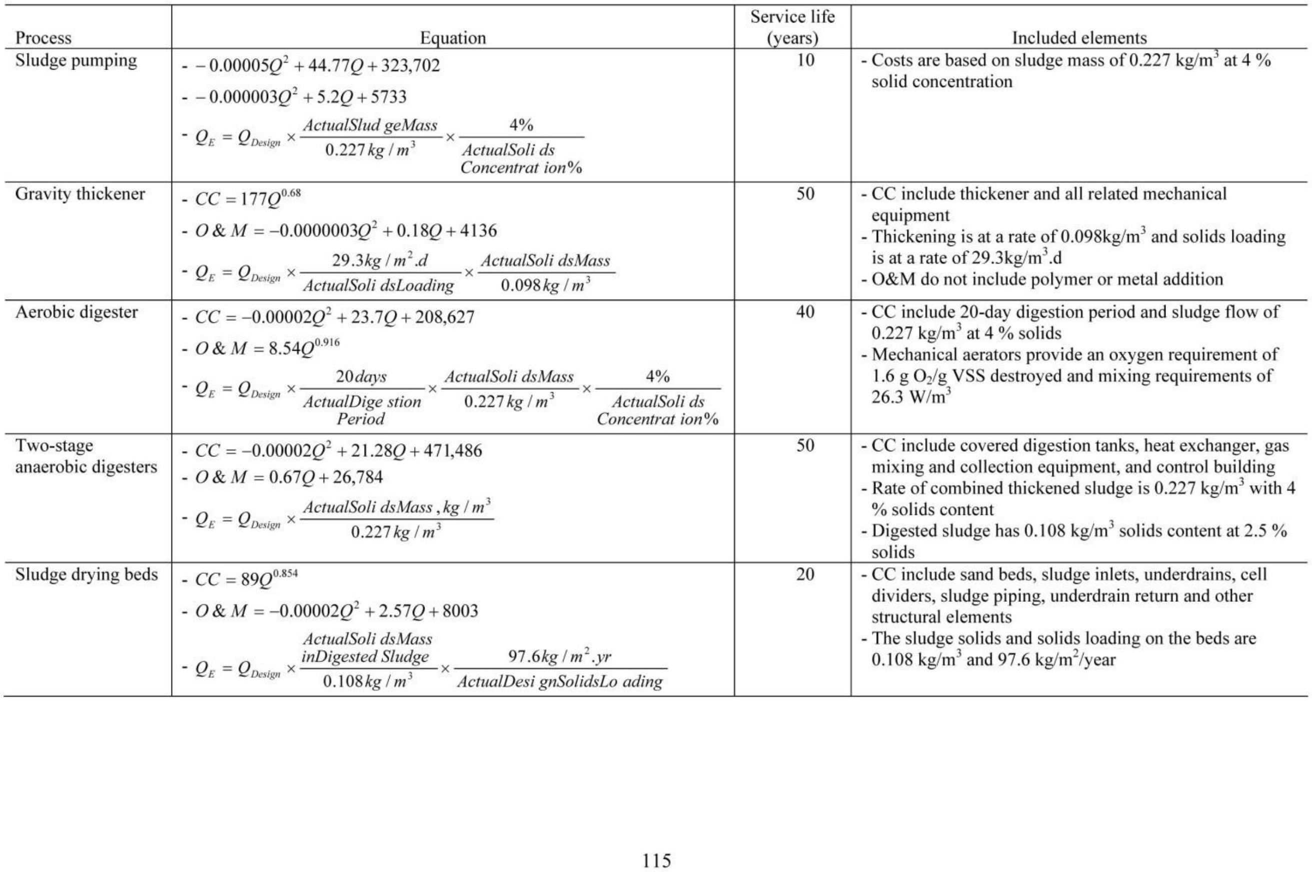


Process	Equation	Service life (years)	Included elements
High rate trickling filter	- $CC = -0.00007Q^2 + 56.89Q + 244.791$ - $O\,\&\,M = 278Q^{0.505}$	50	- CC include circular filter units with rotating distributor arms, synthetic media (1.8 m) and underdrains - Organic loading is 0.72 kg/m^3 and hydraulic loading is 28.3 m^3/m^2.d
Clarifier for high-rate trickling filter	- $CC = -0.00005Q^2 + 44.77Q + 323{,}702$ - $O\,\&\,M = -0.000003Q^2 + 5.2Q + 5733$ - $Q_E = Q_{Design} \times \frac{32.6m^3/m^2.d}{ActualDesignSurfaceOverflowRate}$	40	- CC include sludge pumps, effluent recycle pumps, clarifier mechanisms, and internal piping - Design overflow rate is 32.6 m^3/m^2.d - Costs apply for circular clarifiers with area > 46.56 m^2 and diameter < 61 m and for rectangular clarifiers with area < 46.56 m^2
Gravity filtration (dual media)	- $CC = 2903Q^{0.656}$ - $O\,\&\,M = 194Q^{0.693}$ - $Q_E = Q_{Design} \times \frac{9.8m^3/m^2.d}{ActualDesignHydraulicLoadingOnFilters}$	30	- CC include facilities for backwash storage, all feed and backwash pumps, piping, and filter building and pipe gallery - The design hydraulic loading 9.8 m^3/m^2.d and a backwash ratio of 36.7 m^3/m^2.h
Activated carbon adsorption	- $CC = -0.0002Q^2 + 156Q + 796.55$ - $O\,\&\,M = -0.00001Q^2 + 14Q + 229{,}458$	35	- CC include carbon columns, feed and backwash pumps, piping, operations building, carbon regeneration facilities and storage tanks - Contact time is 30 minutes
Chlorination	- $CC = 795Q^{0.598}$ - $O\,\&\,M = -0.000001Q^2 + 2.36Q + 24{,}813$ - $Q_E = Q_{Design} \times \frac{ActualChlo\ rineDosage\ ,mg/L}{10mg/L}$	15	- CC include chlorine building, storage and handling facilities, chlorinators, injector and plug-flow contact chamber - Chlorine dosage is 10 mg/L and contact time is 30 minutes at average flow
Dechlorination using sulfur dioxide	- $CC = 1170Q^{0.598}$ - $O\,\&\,M = -0.000001Q^2 + 0.97Q + 15{,}058$ - $Q_E = Q_{Design} \times \frac{ActualSO_2Dosage\ ,mg/L}{1mg/LSO_2}$	30	- CC include SO$_2$ storage facility, feed system, mixers and reaction tank. - The SO$_2$ dosage is 1 mg/L SO$_2$ per mg/L residual chlorine
UV disinfection	- $-3\times10^{-5}Q^2 + 11.85Q + 142{,}439$ - $-3\times10^{-6}Q^2 + 1.038Q + 4585$	15	- CC include UV modules, power source and distribution, lamps, safety cleaning and monitoring equipment, piping, walkway, and miscellaneous equipment - O&M includes power, lamp displacement, cleaning labour, and others



Process	Equation	Service life (years)	Included elements
Sludge pumping	- $-0.00005Q^2+44.77Q+323{,}702$ - $-0.000003Q^2+5.2Q+5733$ - $Q_E=Q_{Design}\times\frac{ActualSlud\ geMass}{0.227\,kg/m^3}\times\frac{4\%}{ActualSoli\ ds\ Concentrat\ ion\%}$	10	- Costs are based on sludge mass of 0.227 kg/m^3 at 4 % solid concentration
Gravity thickener	- $CC=177Q^{0.68}$ - $O\&M=-0.0000003Q^2+0.18Q+4136$ - $Q_E=Q_{Design}\times\frac{29.3kg/m^2.d}{ActualSoli\ dsLoading}\times\frac{ActualSoli\ dsMass}{0.098\,kg/m^3}$	50	- CC include thickener and all related mechanical equipment - Thickening is at a rate of 0.098kg/m^3 and solids loading is at a rate of 29.3kg/m^3.d - O&M do not include polymer or metal addition
Aerobic digester	- $CC=-0.00002Q^2+23.7Q+208{,}627$ - $O\&M=8.54Q^{0.916}$ - $Q_E=Q_{Design}\times\frac{20\,days}{ActualDige\ stion\ Period}\times\frac{ActualSoli\ dsMass}{0.227\,kg/m^3}\times\frac{4\%}{ActualSoli\ ds\ Concentrat\ ion\%}$	40	- CC include 20-day digestion period and sludge flow of 0.227 kg/m^3 at 4 % solids - Mechanical aerators provide an oxygen requirement of 1.6 g O_2/g VSS destroyed and mixing requirements of 26.3 W/m^3
Two-stage anaerobic digesters	- $CC=-0.00002Q^2+21.28Q+471{,}486$ - $O\&M=0.67Q+26{,}784$ - $Q_E=Q_{Design}\times\frac{ActualSoli\ dsMass\,,kg/m^3}{0.227\,kg/m^3}$	50	- CC include covered digestion tanks, heat exchanger, gas mixing and collection equipment, and control building - Rate of combined thickened sludge is 0.227 kg/m^3 with 4 % solids content - Digested sludge has 0.108 kg/m^3 solids content at 2.5 % solids
Sludge drying beds	- $CC=89Q^{0.854}$ - $O\&M=-0.00002Q^2+2.57Q+8003$ - $Q_E=Q_{Design}\times\frac{ActualSoli\ dsMass\ inDigested\ Sludge}{0.108\,kg/m^3}\times\frac{97.6kg/m^2.yr}{ActualDesi\ gnSolidsLo\ ading}$	20	- CC include sand beds, sludge inlets, underdrains, cell dividers, sludge piping, underdrain return and other structural elements - The sludge solids and solids loading on the beds are 0.108 kg/m^3 and 97.6 kg/m^2/year

Process	Equation	Service life (years)	Included elements
Filter press or belt filter	- $CC = 10{,}255Q^{0.481}$ - $O\,\&\,M = 3165Q^{0.348}$ - $Q_E = Q_{Design} \times \frac{ActualSolidsMassInDigestedSludge}{0.108kg/m^3}$	15	- CC include filtration and conveyor equipment, chemical feed and storage facilities, conditioning and sludge storage tanks, and building. - Digested primary and secondary sludge is 0.108 kg/m^3 at 2.5 % solids - Conditioning chemicals dosage is 4.2 g/m^3 $FeCl_3$ or 10.8 g/m^3 CaO
Landfilling	- $-0.00005Q^2 + 2.33Q + 87{,}2571$ - $-0.000001Q^2 + 1.11Q + 25{,}026$ - $Q_E = Q_{Design} \times \frac{\begin{array}{c}ActualSoli\ dsMass\\ inDewatere\ dSludge\end{array}}{0.108\,kg/m^3} \times \frac{20\%}{\begin{array}{c}ActualSoli\ ds\\ Concentrat\ ion\%\end{array}} \times \frac{\begin{array}{c}QuantityOf\ Sludge\\ Landfilled\end{array}}{\begin{array}{c}TotalQuant\ ityOf\\ Sludge\ \mathrm{Pr}\ oduced\end{array}}$	20	- CC include site preparation, front-end loaders, monitoring wells, fencing, leachate collection, and treatment - O&M include labour costs and fuel for equipment operation - Digested solids quantity is 0.108 kg/m^3
Biosolids utilization	- $-0.00005Q^2 + 2.047Q + 76{,}790$ - $-0.000001Q^2 + 0.978Q + 22{,}031$ - $Q_E = Q_{Design} \times \frac{\begin{array}{c}ActualSoli\ dsMass\\ inDewatere\ dSludge\end{array}}{0.108\,kg/m^3} \times \frac{20\%}{\begin{array}{c}ActualSoli\ ds\\ Concentrat\ ion\%\end{array}} \times \frac{\begin{array}{c}QuantityOf\ Sludge\\ UtilizedAs\ Biosolids\end{array}}{\begin{array}{c}TotalQuant\ ityOf\\ Sludge\ \mathrm{Pr}\ oduced\end{array}}$	20	- CC include transportation vehicles and application vehicles, sludge loading and unloading apparatus, concrete pad and storage facility - O&M include oil, gas, preventive maintenance, labour and material - No land costs are incurred
Miscellaneous structures	- $CC = 1438Q^{0.567}$ - $O\,\&\,M = -0.000003Q^2 + 1.97Q + 57{,}349$	50	- CC include administrative offices, laboratories, machine shops, and garage facilities - O&M include utilities and normal upkeep
Support personnel	- $O\,\&\,M = 8.31Q^{0.717}$	-	Includes manpower for supervision and administration, clerical work, laboratory work, & administrative costs

Source: Qasim, *Wastewater Treatment Plants* and USEPA, *Detailed Costing Document.*

CC = capital costs, USD.

O&M = annual operation and maintenance costs.

Q = Q_{Design}= average design flow through the facility.

Q_E = Adjusted flow rate.

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Appendix C: Review of US Patent 7,750,066B2

This patent centers on the use of aqueous polymer dispersions (APD) capable of undergoing phase inversion for the production phase-inverted polymer compositions as a method for cleaning contaminants like oil and metals from water. These generated phase-inverted polymer compositions are comprised of the water dispersed polymer (the APD) and one or more contaminants. The “phase-inversion” process thus serves as a way to remove oil and metals from contaminated water.

The key aspect of this patent and what makes it different from standard flocculation methods is that the phase invertible APD is substantially water insoluble in the aqueous carrier (the medium in which the contaminant resides). This is in contrast to the homogeneous nature of conventional aqueous flocculating polymers where the polymer is essentially soluble in the aqueous carrier (aqueous polymer solutions (APS). In addition the claimed method allows for reuse of the APD through regeneration methods, something the author claims is not possible with standard APS.

APD’s exist in solution as finely divided dispersed particles containing hundreds or thousands of polymer chains forming a particulate structure. They are unique in that they do not exhibit high bulk viscosity typical of conventional APS of similar concentrations. It is claimed in the patent that APDs containing 20-60 weight percent can be readily prepared.

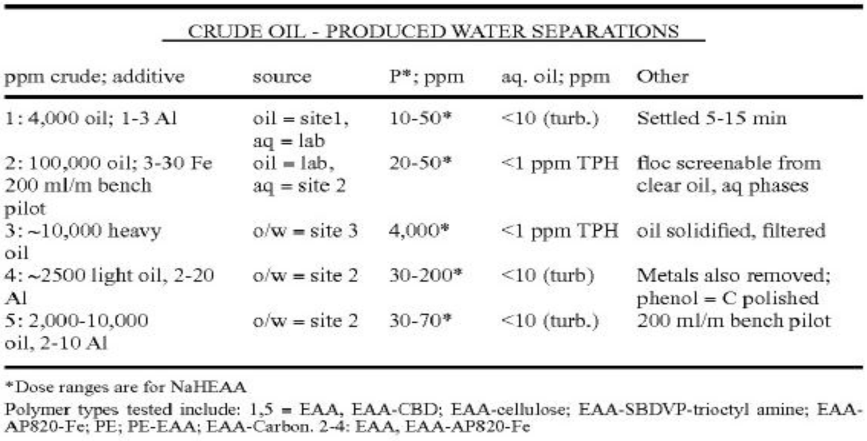
The structure and physical properties of these APD are going to be highly dependent on many factors (e.g., pH, temperature, particle size, zeta potential, concentration of contaminants, mixing, etc.) and this is noted in the patent. What is not stated is that the overall effectiveness may be dependent on controlling these factors, which may be difficult. The patent claims that the structure and physical properties are features of the method in that controlling these properties allows the user to vary properties of the APD. Controlling these factors in practice will be difficult because, as the dispersed polymer and the contaminant interact and the contaminant is removed from the aqueous layer, the factors listed above can and probably do change somewhat leading to a variation of the properties of the aqueous layer. Whether or not this has an overall effect of the APD ability to remove contaminants from the aqueous layer remains to be tested.

In this patent one example that was tested was the removal of heavy oil as might be typical of that found in produced water. For this test, a mixture of ethylene acrylic acid (EAA) and calcium (most likely in the form of calcium carbonate) in an acidic environment was added to the contaminated water sample. Below is the prescription that was given in the patent identified as example 1a.

1a: Oil solidification via in-situ acid-induced EAA phase inversion. 2.3g of emulsified [waste-crude-kerosene (1-1-1)] in 450 ml of water + 20 ppm Ca, 2.3 g dispersed EAA) 20% acrylic acid, ~6000 MW), HCl to pH<4, >5 min stir @RT, coarse cellulose filter=clarified water plus oil-polymer solid.

This percentage (20%) of EAA appears to be a very large. Will this 1) be expensive to use and 2) how will this affect separation?

The following table presents the results of example 1a listed above.



CRUDE OIL - PRODUCED WATER SEPARATIONS

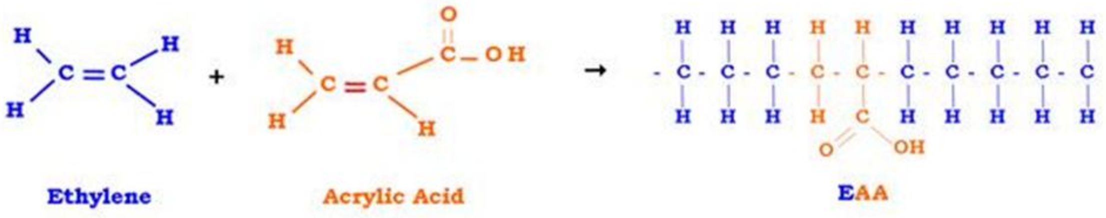
ppm crude; additive	source	P*; ppm	aq. oil; ppm	Other
1: 4,000 oil; 1-3 Al	oil = site1, aq = lab	10-50*	<10 (turb.)	Settled 5-15 min
2: 100,000 oil; 3-30 Fe 200 ml/m bench pilot	oil = lab, aq = site 2	20-50*	<1 ppm TPH	floc screenable from clear oil, aq phases
3: ~10,000 heavy oil	o/w = site 3	4,000*	<1 ppm TPH	oil solidified, filtered
4: ~2500 light oil, 2-20 Al	o/w = site 2	30-200*	<10 (turb)	Metals also removed; phenol = C polished
5: 2,000-10,000 oil, 2-10 Al	o/w = site 2	30-70*	<10 (turb.)	200 ml/m bench pilot

*Dose ranges are for NaHEAA

Polymer types tested include: 1,5 = EAA, EAA-CBD; EAA-cellulose; EAA-SBDVP-trioctyl amine; EAA-AP820-Fe; PE; PE-EAA; EAA-Carbon. 2-4: EAA, EAA-AP820-Fe

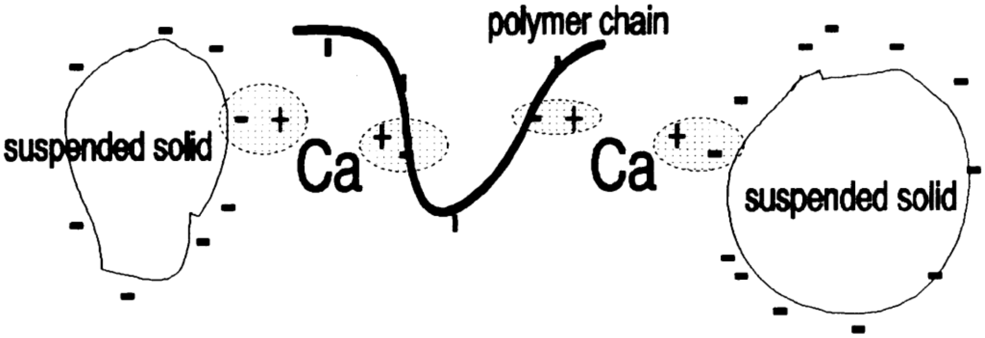
These results appear to be very impressive for heavier oil, i.e. crude. What is not presented is what the results showed for dissolved organics. Was a test performed on the volatile organics like BETX? Also, what is the source of the turbidity in the ‘cleaned’ water?

Ethylene acrylic acid is formed though the following reaction. The ratio of the two allows some variation in the overall physical properties. More of the ethylene components will lead to longer hydrocarbon chains, which represent the nonpolar portion and are responsible for the water insolubility properties. Increasing the Acrylic acid inserts more carboxylic groups into the hydrocarbon chain thus giving it more polar sites increasing its solubility in water but providing more sites to attach polar contaminants. This is shown below (figure taken from Michelman web site ad for EAA).



ETHYLENE ACRYLIC ACID (EAA) [MICHELMAN]

The EAA molecule can then further polymerize into very large structures which are very stable. These long chain polymers have both polar and nonpolar aspects which make it very good at attaching to both polar and nonpolar contaminants. EAA is just one of many organic polymers of this type. Others include poly ethylene-imine, poly vinyl alcohol and poly acrylamide to name just a few. One potential mechanism for use as a flocculant to remove organic contaminants from contaminant water is through a bridging mechanism. This ‘bridge’ can form through an interaction like that shown below in which the positive charge on the calcium ions forms polar interaction with the negative charge on the carboxylic group (Poirier, 2001). In the example below the suspended solid can be taken as suspended oil or grease.



FLOCCULATION PROCESS SHOWING HOW LARGE POLYMER CHAINS WITH BOTH POSITIVE AND NEGATIVE SITES CAN BE EFFECTIVE IN REMOVING A WIDE CLASS OF CONTAMINANTS

The ability of the APD or any flocculating agent that will be used to remove contaminants form waste water to attach to negative charges is important since while suspended contaminant particles could be either positive or negative, those typically found in waste water are negative (Armenante, 1997).

The patent is very thorough and lists many different APD prescriptions for various contaminants and sources of contaminated water. It would also be of interest to find out how Aquastream/CTI’s methods followed one or more of the prescriptions listed in the patent. On the specifics of the EAA flocculating process and its ability to remove contaminants from contaminated water, the arguments appear to be sound and more work would have to be done with the specific examples to find any valid arguments.

Appendix D

INDUSTRIAL/ENERGY TRAINING PROGRAM FOR TECHNICIANS

(Produced Water Technicians)

To train workers on installing, operating and maintaining the new systems once they are developed.

4 COURSES: (<u>THESE MUST BE TAKEN IN THE FOLLOWING ORDER</u>)

<u>Course 1) ELECTRICAL</u>

1. INDUSTRIAL ELECTRICAL 4.3
    a. **Electrical Fundamentals** – Analyze the basic physics laws and terminology that govern the operation of electrical systems
    b. **Circuit Fundamentals** – Recognize the different sections of a circuit, its components and functions, as well as the laws governing voltage and current
    c. **Circuit Analysis** – Examine the impact of circuit components on electrical systems and the techniques used to analyze the effects of components connected in various configurations
    d. **Basic Magnetism** – Explore the different kinds of magnets and how magnetic fields interact with each other
    e. **Circuit Components** – Understand the many components of electrical circuits, their flow, and how they convert electrical energy into other forms of energy
    f. **Electrical Testers** – Gauge the effects of technology on electrical testing and how technology has improved our ability to measure and work with electronics and electricity. Explore safety guidelines when using testers
2. ELECTRICAL THEORY 4.2
    a. **Fundamentals** – Build a solid base for the course by reviewing the fundamentals of electricity: The atom, units and symbols, charge, voltage, current, electrical laws, and electrical energy
    b. **Basic Physics** – Learn the terminology, principles, and laws that explain how electricity reacts in electrical circuits.
    c. **Circuit Fundamentals** – Recognize the different sections of a circuit, its components and function, and the laws governing voltage and current through a circuit
    d. **Circuit Analysis** – Examine the impact of circuit components on electrical systems, and the techniques used to analyze the effects of components connected in various configurations
    e. **Basic Magnetism** – Learn about the different kinds of magnets, how magnetic fields interact with each other, and how the properties of magnet materials affect magnetic fields
    f. **Magnetic Circuits** – Discover the forces created by magnetic fields, the flow of magnetic flux through a magnetic circuit, and more about electrical laws
    g. **Single-Phase AC Circuits** – Gain an understanding of the alternating current parameters and constants required to understand AC machines and equipment used in the power industry

    h. **Magnetic Induction** – Explore magnetic induction and the many applications in which it is used, as well as some principles applied when repairing equipment with magnetic circuits
    i. **Poly-phase AC Circuits** – Learn the tools used to analyze poly-phase systems, and examine several types of three-phase connections commonly used in industry
3. MOBILE ELECTRICAL 4.2
    a. **Electrical Fundamentals** – Examine how the components and operation of an electrical system are governed by basic physics laws and understand the related terminology
    b. **Circuit Fundamentals** – Recognize the different sections of a circuit, its components and functions, as well as the laws governing voltage and current through a circuit
    c. **Circuit Analysis** – Understand the impact of circuit components on electrical systems and the techniques used to analyze the effects of components connected in various configurations
    d. **Basic Magnetism** – Learn about the different kinds of magnets, how magnetic fields interact with each other, and how the properties of magnetic materials affect magnetic fields
    e. **Circuit Components** – Understand the many basic electrical components and what they can do in a circuit, their flow, and how other components convert electrical energy into other forms of energy
    f. **Electrical Testers** – Gauge the effects of technology on electrical testing and how technology has improved our ability to measure and work with electronics and electricity. Explore safety guidelines when using testers
    g. **Charging and Starting Systems** – Understand how lead-acid batteries operate and how the charging and starting systems work in almost all combustion engine vehicles
4. AC/DC MOTORS AND DRIVES 4.3
    a. **System Components** – Study the basic terminology and principles involved with motors and drives to develop a foundation for the other principles presented in this course
    b. **AC/DC Motors** – Understand the torque-related principles of AC motors and the magnetism-related principles of DC motors and how the laws of magnetism, speed, horsepower, and torque produce power
    c. **Selecting a Replacement Motor** – Interpret a motor’s nameplate and understand the nameplate data so you can find a replacement motor or an acceptable substitute
    d. **Line Protection and Filtering** – Examine the reasons behind understanding fuses and filtering devices:
        i. Protect personnel from electrical dangers
        ii. Operate an electrical code compliant system
        iii. Extend the life of equipment through proper fusing and filtering
    e. **Electrostatic Concepts** – Avoid electrostatic discharges by understanding what causes them and what components are affected by them
    f. **AC/DC Drives Hardware** – Consider the differences between AC and DC drives, and learn more about the functions, components, and firmware of AC drives
    g. **AC and DC Braking** – top a motor using three different methods, learn the advantages and disadvantages of each, and explore the two main electrical braking methods and how they relate to AC or DC drives

   - h. **Testing the System** – Study the five different electrical measuring tools that can be used to help diagnose problems in AC/DC drives
   - i. **Checking the System** – Master the pre-power and power-on checks that will locate bad alignment and bad wiring in a drive
   - j. **Using the HIM with the Drive** – Monitor the parameters of a drive that will help you program, maintain, and troubleshoot an AC/DC drive using a Human Interface Module, commonly call the H-I-M or HIM
   - k. **Selecting a Drive** – Analyze the applications of variable speed and motion control, matching the proper drive with the proper application
5. PLC FUNDAMENTALS 4.2
   - a. **What is a PLC**—Learn what PLCs are, what they can do, and how they differ from other computers
   - b. **PLC Hardware**—Study about the two main types—fixed and modular PLC Numbering Systems—Discover the math functions related to PLCs
   - c. **How a PLC is Structured**—See the different sections of PLC systems and learn how they store data, memory processes and data operations
   - d. **How to Program a PLC**—Master the language of PLCs using graphical images and learn how to upload to and download from a PLC
   - e. **Devices Connected to a PLC**—Learn how to properly connect your controller to

<u>Course 2) FLUID POWER</u>

1. INDUSTRIAL HYDRAULICS 4.3
   - a. **Industrial Hydraulics Physics** – Build a foundation for the course by reviewing the basic physics principles that govern fluid power: horsepower, torque, heat, flow, and pressure
   - b. **Pumps** – Observe various types of hydraulic pumps in 3D, and learn more about gear, vane and piston pumps, their differences and similarities, their fluid displacement capabilities and their proper application
   - c. **Actuators** – Learn how hydraulic actuators convert hydraulic horsepower back into mechanical horsepower
   - d. **Pressure Control** – Understand the basics behind force manipulation using control valves, the two basic designs, and their operating principles
   - e. **Directional Control** – Discover how directional control valves determine hydraulic system design and see how these valves operate; start, stop, and change the direction of fluid flow
   - f. **Flow Control Valves** – Learn about the various types of flow control valves as well as their applications and locations in hydraulic systems
   - g. **Modular Control Valves** – Analyze modular valves, how they enhance system design, and troubleshooting
   - h. **Fluid Conditioning** – Maintain proper operation of your hydraulic systems by knowing fluid temperature implications as well as the location and importance of filters in keeping hydraulic fluids clean
   - i. **Check Valves** – Understand the function of different valves and where they are used
   - j. **Accessory Components** – Learn about the components and use of accumulators, pressure switches, gauges, flow meters, and manifolds

   k. **Fluid Conductors** – Study the benefits of conductors, including hydraulic hoses, steel tubing, and steel pipes, and how they carry fluid to the various components in the hydraulic circuit
   l. **Understanding Schematics** – identify the basic symbols of a hydraulic schematic and learn to read the layout of systems on paper or computer
   m. **Basic System Design** – Observe the components, pictures, and labeling of hydraulic power units and multi-valve, 4-station valve stack

2. INDUSTRIAL PNEUMATICS 4.3
   a. **Basic Physics** – Build your foundation for the course by understanding the basic physics principles that govern pneumatics—energy, work, power, horsepower, heat, torque, flow, and pressure—as well as laws such as Boyle's and Charles' Gas Laws
   b. **Compressors** – Learn the terminology associated with compressors, see how compressors operate, and become familiar with the components that ensure safe and efficient operation of systems
   c. **Air Dryers** – Discover the various ways air is dried to help preserve the metal parts exposed to air pressure
   d. **Air Preparation** – Understand the steps of final preparation associated with filtering, regulating, and lubricating air before use in hydraulic systems, and when these techniques are necessary
   e. **Air Distribution** – Study the various points of air consumption, the pipe networks and how distribution is used to eliminate many potential problems
   f. **Directional Control Valves** – See the designs, operation techniques, port layouts, positions, and pressure configurations that help make pneumatic systems operate
   g. **Actuators** – Learn the interface components that convert pneumatic energy into mechanical energy and the motions used by actuators in pneumatic systems
   h. **Miscellaneous Valves** – Examine how various valves operation and learn their application within pneumatic systems—check, shuttle, pulse, quick exhaust, to name a few
   i. **Accessories** – Get an overview of several accessory components used in pneumatic circuits—pressure gauges, flow meters, mufflers, air nozzles, and more
   j. **Airline Conductors** – Learn the types of airline conductors and how they are best used to carry air to all the various components in the pneumatic circuit
   k. **Vacuum** – See demonstrations on how vacuum is created to help your system work
   l. **Understanding Schematics** – Identify the different basic symbols of a pneumatic schematic and learn to read the layout of a Industrial Pneumatic system on paper or computer

3. MOBILE HYDRAULICS 4.2
   a. **Fluid Power Physics** – Build a foundation for the course through reviewing the basic physics principles that govern fluid power: Horsepower, Torque, Heat, Flow, Pressure Drop, Velocity, and Viscosity
   b. **Pumps**– Observe various types of hydraulic pumps in 3D, and learn more about gear, vane, and piston pumps, their differences and

similarities, their fluid displacement capabilities, and their proper applications

c. **Actuators** – Learn how hydraulic actuators convert hydraulic horsepower back into mechanical horsepower and other valuable information about how actuators work inside your hydraulic system
d. **Hydrostatic Transmissions** – Understand the difference between an open and closed circuit, the purpose of the components used in these circuits, and the basis of operation of basic hydrostatic circuits
e. **Pressure Control** – Understand the basics behind force manipulation using control valves, the two basic designs, and their operating principles
f. **Directional Control Valves** – Discover how directional control valves determine hydraulic system design and the importance of their play in these systems, and see how these valves operate; start, stop, and change the direction of fluid flow
g. **Flow Control Valves** – Experience an overview of flow control valves, the types, and their applications and locations in hydraulic systems
h. **Modular Control Valves** Analyze modular valves, how they enhance system design, and troubleshooting
i. **Fluid Conditioning** – Maintain proper operation of your hydraulic systems by knowing the temperature implications and the filters, their locations, and their importance in keeping hydraulic fluids clean
j. **Check Valves** – Understand the function of different valves and the strategy of where they are used in the system
k. **Accessory Components** – Learn about accumulators, pressure switches, gauges, flow meters, and manifolds, and how these components are used in your mobile hydraulic systems
l. **Fluid Conductors** – Examine the benefits of conductors, including hydraulic hoses, steel tubing, and steel pipes, and how they carry fluid to all the various components in hydraulic circuits
m. **Understanding Schematics** – Identify the basic symbols of a hydraulic schematic and learn to read the layout of systems on paper or computer

Course 3) MANUFACTURING

1. INDUSTRIAL SAFETY 4.3
    a. **Introduction to Safety** – Begin this course with an overview of effective Safety and Health programs and an understanding of their importance to both employers and employees. Discover methods for implementing safety programs in the industrial workplace.
    b. **Walking and Working Surfaces** – Identify common hazards that may increase the probability of workplace accidents. Study proper “housekeeping”, and the correct use of ladders and stairways. Identify when to use covers and guardrails and the steps that can be taken to minimize slipping, tripping, and falling in the workplace.
    c. **Prevention and Protection Plans** – Study the importance of an effective emergency management plan in reducing workplace injuries and deaths. Learn that an effective safety plan includes proper and clearly marked exits, functioning and regularly maintained fire-fighting equipment, and employee training programs.

    d. **Personal Protective Equipment** – Describe a variety of personal protective equipment. Understand the purpose of each and its role in maintaining a safe working environment.
    e. **Electrical Safety** – Review basic electrical terminology. Study the hazards of working with electricity and the steps for ensuring safety. Identify the preventive measures that can protect you from injury or death.
    f. **Machine Guarding** – Explore the potential dangers of industrial machinery. Study the procedures required for creating a safe, hazard-free workplace.
    g. **Chemical Safet**y – Learn about industrial chemicals and the impact they can have on health and safety. Discover methods for protecting yourself when handling these chemicals.
    h. **Powered Industrial Trucks** – Learn the potential hazards involved and how to prevent them.
    i. **Industrial Hygiene** – Study air quality, biological hazards, radiation, lasers, and occupational illness.
    j. **Ergonomics** – Learn how to perform your job comfortably with a minimum of physical and mental stress.

2. MSSC: HIGH PERFORMANCE MANUFACTURING TECHNICIAN TEST PREP

Course 4) MECHANICAL

1. INDUSTRIAL MECHANICAL 4.3
    a. **Basic Physics** – Build a solid foundation for the course by understanding the physics principles that govern mechanical power transmissions: energy, torque, horsepower, current, voltage, and more. Examine the laws that form the concepts behind these physical properties
    b. **Linear Actuators** – Understand how linear actuators convert rotational motion into linear motion and the operations that surround this conversion
    c. **Clutches** – Explore different types of clutches, including various components, differences and similarities, capabilities, and proper application within mechanical power transmission systems
    d. **Brakes** – Analyze the four types of brakes, their differences and similarities, their capabilities, and their proper application within mechanical power transmission systems
    e. **Clutch/Brake Combinations** – Based on your understanding of clutches and brakes, this module presents additional information about the different types of clutch/brake combinations
    f. **Bearings** – Understand the purpose and terminology of bearings and where they are used within mechanical power transmissions
    g. **Gears** – Examine the different kinds of gears, how they operate, and where they are best used to transmit power
    h. **Drives** – Observe the different types of belt and chain drives, how they are designed, and their basic theory of operation
    i. **Couplings** – Explore the correct usage and applications of couplings, and the different types, functions, and features of these critical components of mechanical power transmissions

A CERTIFICATE WILL BE GIVEN FOR EACH MODULE PASSED:

- INDUSTRIAL/ENERGY TECHNICIAN IN ELECTRICAL
- INDUSTRIAL/ENERGY IN FLUID POWER
- INDUSTRIAL/ENERGY TECHNICIAN IN MANUFACTURING
- INDUSTRIAL/ENERGY TECHNICIAN IN MECHANICAL
- ALSO THE MSSC: HIGH PERFORMANCE MANUFACTURING TECHNICIAN WILL PREPARE THE STUDENT FOR THE NATIONAL TEST

Office of Fossil Energy

National Energy Technology Laboratory

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880

13131 Dairy Ashford, Suite 225
Sugarland, TX 77478

1450 Queen Avenue SW
Albany, OR 97321-2198

2175 University Ave. South
Suite 201
Fairbanks, AK 99709

Visit the NETL website at:
www.netl.doe.gov

Customer Service:
1-800-553-7681

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UNITED STATES OF AMERICA