SOLAR DESALINATION USING DEWVAPORATION^{TM}

Student: Prajwal Vikram
Advisor: Dr. Shuguang Deng
Department of Chemical Engineering
New Mexico State University
Las Cruces, New Mexico

INTRODUCTION

The main objectives of this project were to:

- Measure Dewvaporation performance when treating brackish groundwater
- Measure the equipment performance when treating concentrated brine
- Assess to what extent solar energy can be used to power the equipment
- Analyze costs associated with the process

The Dewvaporation technology uses the Dewvaporation towers to carry out water purification. These towers are fairly simple in construction, mainly using corrugated plastic. The process consists of two water streams. One of these is the process hot water loop and the other contains the water to be treated. Ideally the hot water loop can contain any type of water. The process water heating takes up the major energy requirement for the Dewvaporation process. This is where solar energy is deemed ideal to be used. A hot water heater may be used in combination with the solar panels for times when enough solar energy is lacking such as in the colder months. The two water streams are independent of each other.

This project was carried out at the New Mexico State University campus (NMSU) from summer of 2005 to September of 2006. The initial runs were carried out with NMSU geothermal well-water a TDS of 1700 ppm. Then high arsenic content water from Columbus, NM was used to test for arsenic removal. The water had between 0.028 and 0.053 ppm of arsenic. Later salt was added to the water to test for salt removal at higher TDS concentrations. Experimental runs were also conducted with a reverse-osmosis reject water sample from a pilot plant in El Paso, Texas. Finally the system was run on a continuous operation (24 hours per day and 7 days per week). The aim of the final test was to test for reliability and to obtain energy readings without start-up and shut-down effects.

Various tests were performed to estimate the overall performance and reliability of the Dewvaporation towers. Various parameters such as the air flow, temperatures and feed supply rate to the tower were modified, and distillate production and quality measured and monitored. Electric energy, solar energy and solar-electric hybrid modes were used to supply energy for the process heating.

The Dewvaporation technology performed very well with regard to producing good quality water. The Carbonate reduction was 100 %. Arsenic removal was between 95 % and 98 %. Uranium had removal efficiencies higher than 99 %. The dissolved solids were removed by more than 98.43 %. The TDS measurements carried out on-site with a hand held TDS meter regularly showed values less than 10 ppm. Over the course of the experiments, it was also established that higher operating temperatures yielded better results with regard to distillate production. It was also concluded that limiting the air flow proved to be detrimental to the operation. The energy requirements were best met by a solar-electric hybrid operation.

On the whole, the Dewvaporation units performed very satisfactorily. Some of the problems encountered were gradual degradation in performance. Also salt deposition was encountered. This was due to using fairly high TDS water at low feed rates.

Future experiments on Dewvaporation should be carried out at higher temperatures and greater air flow rates. Systems should be devised to monitor for salt deposition. Design modifications should allow for a back wash.

Variation of distillate production with feed rate

The variation of distillate production with feed rate was one of the most important experiments conducted. This was essential to optimize production and study recovery. Various feed rates were used and resulting distillate production noted. During the experiments rough set points were 800 ml/min, 1000 ml/min, 1200 ml/min and 1400 ml/min. Since the feed rates were set manually by timing the flow in a graduated cylinder, the set rates are not totally accurate. These flow rates were also standardized for other experiments, to help optimize production.

The chart in figure 1 shows the variation of distillate production with feed rate. It can be seen that there is no perfect correlation of the distillate production with the feed rate. Variation of the feed rates did not lead to a significant improvement in the distillate production. This could prove to be advantageous in that the process could be optimized for maximum recovery of distillate from a unit amount of feed.

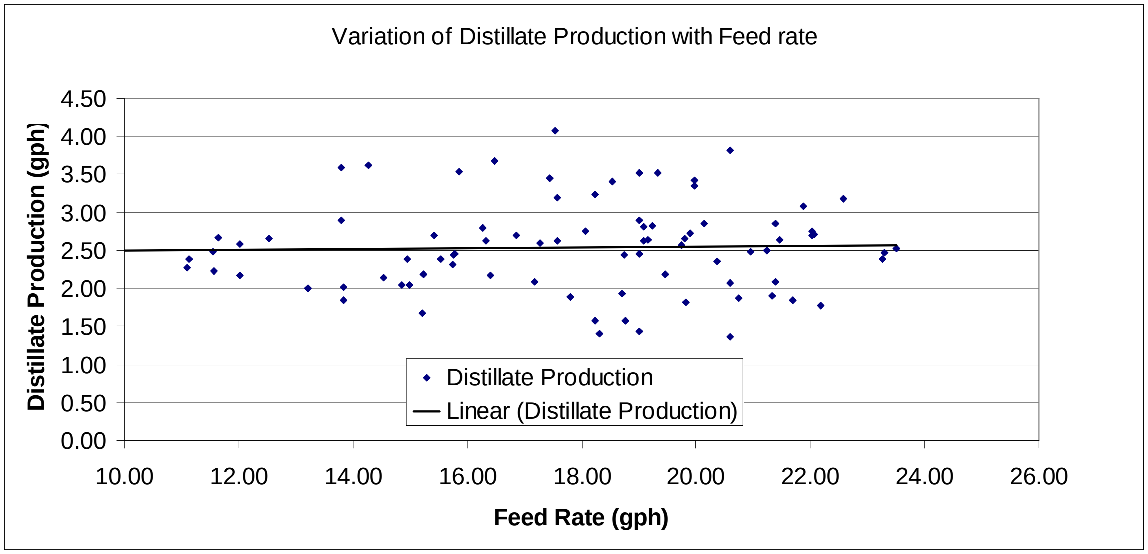

Figure 1: Variation of distillate production with feed rate

It was also observed that over the period of the experiments, the distillate production seemed to drop gradually. This may be attributed to degradation of tower performance. Various factors may have resulted in the degradation – wear in the sponges and the plastic or small leaks in the tower. These factors are discussed in detail in the following sections.

The data in tables 1 and 2 show the feed rate and corresponding distillate production. The plot in figure 1 is based on this data. The data shown takes into account various experiments, in that all the data do not have all the other parameters and variables in common. Though, all the data shown correspond to the process heating water temperature of 178 F. This generalization is justified because the process heating water temperature causes the greatest change in the distillate production rate. This is discussed in the section comparing distillate production at various process heating water temperatures. The other factors that do not adversely affect the distillate production are also discussed in the following sections.

Tables 1 and 2 each shows two sets of independent data. And as can be seen from both the chart and the tables, the distillate production only shows a weak correlation to the feed flow rate. A certain minimum feed flow rate is necessary to ensure proper wetting of the sponges and to avoid dry spots though. In earlier studies conducted this value was noted to be 4 times the surface area of the sponges.

Table 1: Two sets of data showing the feed flow rate and corresponding distillate production

Feed Flow Rate	Average Distillate Production		Feed Flow Rate	Average Distillate Production
Gallons/hr	***Gallons/hr***		***Gallons/hr***	***Gallons/hr***
19.97	3.35		14.27	3.62
19.02	1.44		21.87	3.08
19.02	2.89		22.03	2.70
18.23	1.58		22.59	3.18
20.61	1.36		18.31	1.41
19.02	3.52		21.24	2.50
18.23	3.23		19.02	2.45
16.48	3.67		20.37	2.36
19.34	3.52		22.03	2.76
20.61	3.82		21.40	2.85
13.79	3.59		15.53	2.38
17.58	3.20		15.22	1.68
15.85	3.53		21.40	2.08
19.97	3.42		20.61	2.07
18.54	3.41		11.57	2.23
17.44	3.45		18.70	1.93

Table 2: Two sets of data showing the feed flow rate and corresponding distillate production (continued)

Feed Flow Rate ***Gallons/hr***	Average Distillate Production ***Gallons/hr***		Feed Flow Rate ***Gallons/hr***	Average Distillate Production ***Gallons/hr***
22.19	1.78		14.94	2.38
17.28	2.60		12.03	2.58
11.65	2.67		7.06	2.59
16.28	2.79		19.83	1.82
23.27	2.38		12.54	2.65
17.58	2.62		15.75	2.31
15.42	2.70		19.74	2.57
14.99	2.05		23.30	2.47
20.75	1.87		19.23	2.82
21.33	1.90		15.77	2.44
19.08	2.81		19.47	2.19
13.79	2.90		14.53	2.15
16.86	2.70		15.24	2.18
21.46	2.64		14.86	2.05
22.08	2.71		11.13	2.39
19.89	2.73		17.54	2.04
19.16	2.64		17.18	2.09
18.75	2.44		21.70	1.85
23.51	2.53		11.10	2.27
18.07	2.76		11.54	2.48
20.15	2.85		16.40	2.17
19.81	2.65		13.21	2.00
19.08	2.63		12.02	2.17
20.96	2.48		17.81	1.89
16.33	2.63		13.83	2.01
15.78	2.46		18.76	1.58
			13.84	1.85

1.1.1 Distillate production at various top head temperatures

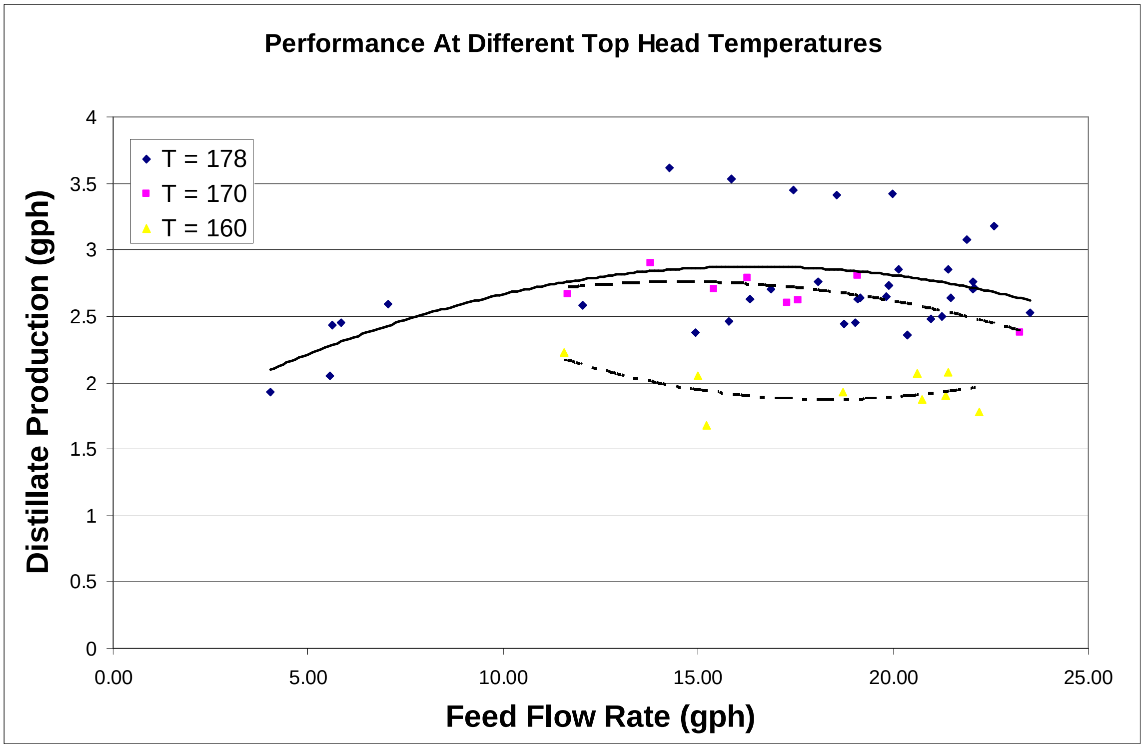

Figure 2: Performance at different top head temperatures

The chart in figure 2 shows the effect of top head temperature on distillate production. The maximum top head temperature was 178^o F. The distillate production was found to peak at this temperature. The other two operating temperatures were 160^o F and 170^o F. Higher temperatures were not tested due to equipment limitations. The maximum temperature achieved from the installed hot water heater was 178^o F. But after a certain temperature there might not have been any significant improvement in the distillate production. Also it can be seen that at 160 F the distillate production falls between 15 and 20 gph of feed flow. But this is not a conclusive result.

Table 3: Feed flow and distillate production at process water temperature of 178 F

Feed Flow (gph)	Distillate Production (gph)
15.85	3.53
19.97	3.42
18.54	3.41
17.44	3.45
14.27	3.62
21.87	3.08
22.03	2.7
22.59	3.18
21.24	2.5
19.02	2.45
20.37	2.36
22.03	2.76
21.40	2.85
16.86	2.7
21.46	2.64
22.08	2.71
19.89	2.73
19.16	2.64
18.75	2.44
23.51	2.53
18.07	2.76
20.15	2.85
19.81	2.65
19.08	2.63
20.96	2.48
16.33	2.63
15.78	2.46
14.94	2.38
12.03	2.58
7.06	2.59
5.85	2.45
5.63	2.43
4.03	1.93
5.56	2.05

Table 4: Feed flow and distillate production at process water temperature of 170 F & 160 F

Process Water Temperature (F)	Feed Flow (gph)	Distillate Production (gph)
170	17.28	2.6
	11.65	2.67
	16.28	2.79
	23.27	2.38
	17.58	2.62
	15.42	2.7
	19.08	2.81
	13.79	2.9
160	15.22	1.68
	21.40	2.08
	20.61	2.07
	11.57	2.23
	18.70	1.93
	22.19	1.78
	14.99	2.05
	20.75	1.87
	21.33	1.9

Tables 3 and 4 show the feed rated and distillate production for various process heating water temperatures. From the chart and the data it can be clearly seen that the production is better at higher temperatures.

Other limitations to operating at higher operating temperatures are the materials of construction of the tower. The sponges on the top head and the plastic would degrade rapidly if not, fail at very high temperatures.

1.1.2 **Comparison of distillate production with different feed types**

Various feed waters used were used during the course of the experiments –tap water, geothermal well water from the New Mexico State University campus, water from Columbus (NM), Reverse osmosis reject water from El Paso and tap water with added sodium chloride to boost the TDS.

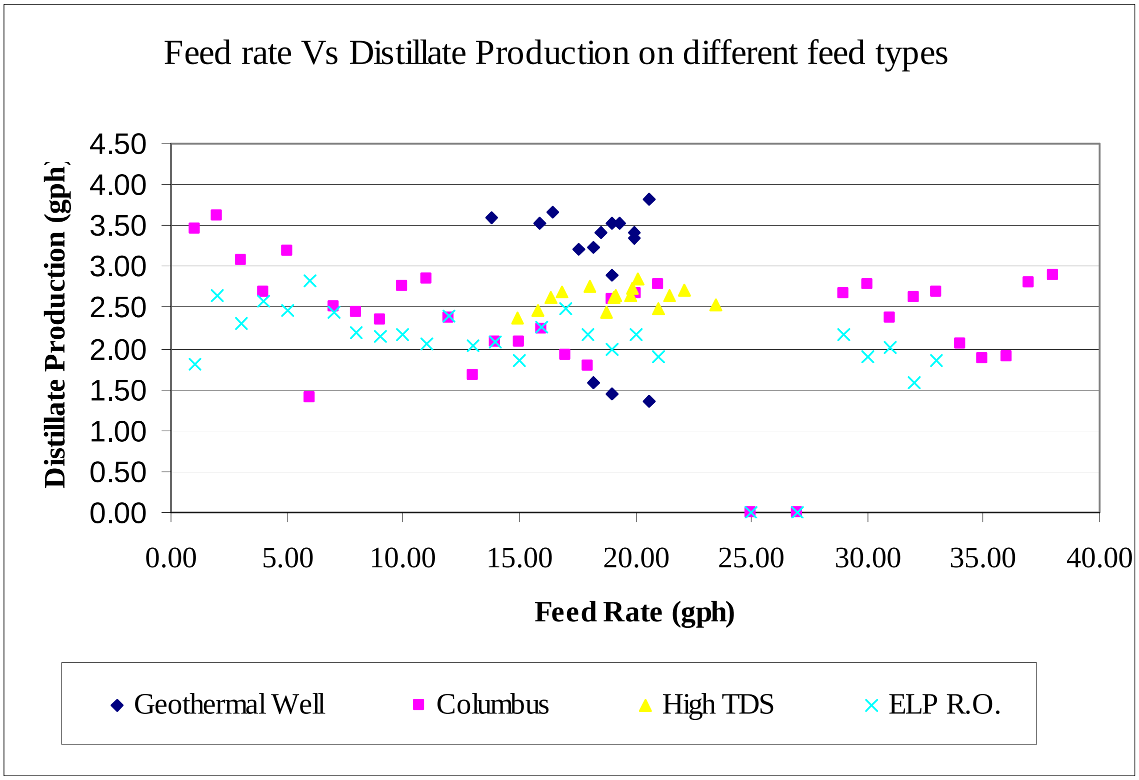

Figure 3: Comparison of distillate production with different feed types

Figure 3 shows the dependence of the distillate production rate depending on the type of feed. Based on theory, the results are not very surprising. From the design of the towers it can be expected that the type of feed water should not affect the performance of the towers. This is established by the chart shown in figure 3. It was already established that the feed rate correlates quite poorly to the distillate production. Hence another weak and fairly uniform correlation is observed in the chart.

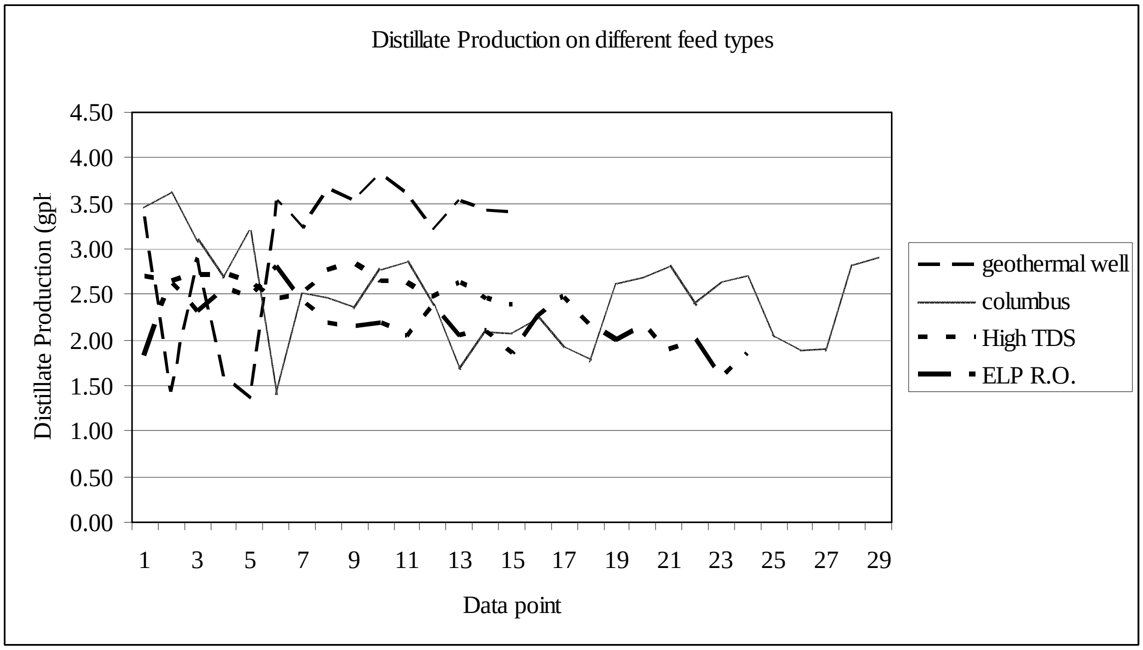

Figure 4: Distillate production on different feed waters without corresponding feed flow rates

Figure 4 is a plot of the distillate production rates on the different feed waters against a common axis.

The following tables show the distillate production for a specific feed rate and the type of feed water.

Table 5: Distillate production and feed flow for various feed types

	Feed Flow Rate	Average Distillate Production		Feed Flow Rate	Average Distillate Production		Feed Flow Rate	Average Distillate Production		Feed Flow Rate	Average Distillate Production
	Gallons/hr	***Gallons/hr***		***Gallons/hr***	***Gallons/hr***		***Gallons/hr***	***Gallons/hr***		***Gallons/hr***	***Gallons/hr***
Geothermal Wel	19.97	3.35	Columbus	17.44	3.45	High TDS	16.86	2.70	ELP R.O.	19.83	1.82
	19.02	1.44		14.27	3.62		21.46	2.64		12.54	2.65
	19.02	2.89		21.87	3.08		22.08	2.71		15.75	2.31
	18.23	1.58		22.03	2.7		19.89	2.73		19.74	2.57
	20.61	1.36		22.59	3.18		19.16	2.64		23.30	2.47
	19.02	3.52		18.31	1.41		18.75	2.44		19.23	2.82
	18.23	3.23		21.24	2.5		23.51	2.53		15.77	2.44
	16.48	3.67		19.02	2.45		18.07	2.76		19.47	2.19
	19.34	3.52		20.37	2.36		20.15	2.85		14.53	2.15
	20.61	3.82		22.03	2.76		19.81	2.65		15.24	2.18
	13.79	3.59		21.40	2.85		19.08	2.63		14.86	2.05
	17.58	3.20		15.53	2.38		20.96	2.48		11.13	2.39
	15.85	3.53		15.22	1.68		16.33	2.63		17.54	2.04
	19.97	3.42		21.40	2.08		15.78	2.46		17.18	2.09
	18.54	3.41		20.61	2.07		14.94	2.38		21.70	1.85
				11.57	2.23					11.10	2.27
				18.70	1.93					11.54	2.48
				22.19	1.78					16.40	2.17
				17.28	2.6					13.21	2.00
				11.65	2.67					12.02	2.17

Table 6: Distillate production and feed flow for various feed types (continued)

	Feed Flow Rate *Gallons/hr*	Average Distillate Production *Gallons/hr*		Feed Flow Rate *Gallons/hr*	Average Distillate Production *Gallons/hr*		Feed Flow Rate *Gallons/hr*	Average Distillate Production *Gallons/hr*		Feed Flow Rate *Gallons/hr*	Average Distillate Production *Gallons/hr*
Geothermal Well			Columbus	11.65	2.79	High TDS			ELP R.O.	17.81	1.89
				11.65	2.67					12.02	2.17
				16.28	2.79					17.81	1.89
				23.27	2.38					13.83	2.01
				17.58	2.62					18.76	1.58
				15.42	2.7					13.84	1.85
				14.99	2.05						
				20.75	1.87						
				21.33	1.9						
				19.08	2.81						
				13.79	2.9						

Comparison of distillate production with Electric Heater and Solar conditions

The Dewvaporation systems installed were to be tested for operability with solar conditions. The process heating water would be heated by virtue of solar energy in the installed solar panels. This test was important for the overall goal of the project i.e. use Dewvaporation in conjunction with solar energy.

By theory, the operation of the Dewvaporation system would not be affected by the mode of heating the process water. The differences expected, on using solar energy, were in attaining steady state. Also the system would be affected due to the irregularity of the solar power. These could be caused by a number of reasons such as clouds obstructing the sunlight or the position of the sun in the sky. Sudden loss of sunlight during operation would affect operating conditions and hence the distillate production. These factors were to be studied and understood. The solar and electric heating modes are shown and compared in the following charts.

The chart in figure 5 shows the distillate production on different heating sources. The distillate production rates for the different heating modes are plotted against a common x-axis. The y-axis represents the distillate production rates. Each line on the chart represents a separate heating mode. The lines stand for electric heater set at 178 F, electric heater set at 170 F, electric heater set at 160 F and solar heating. It can be seen that one data point on the solar line exceeds the production at 178 F. This point corresponds to a process heating water temperature of 184 F.

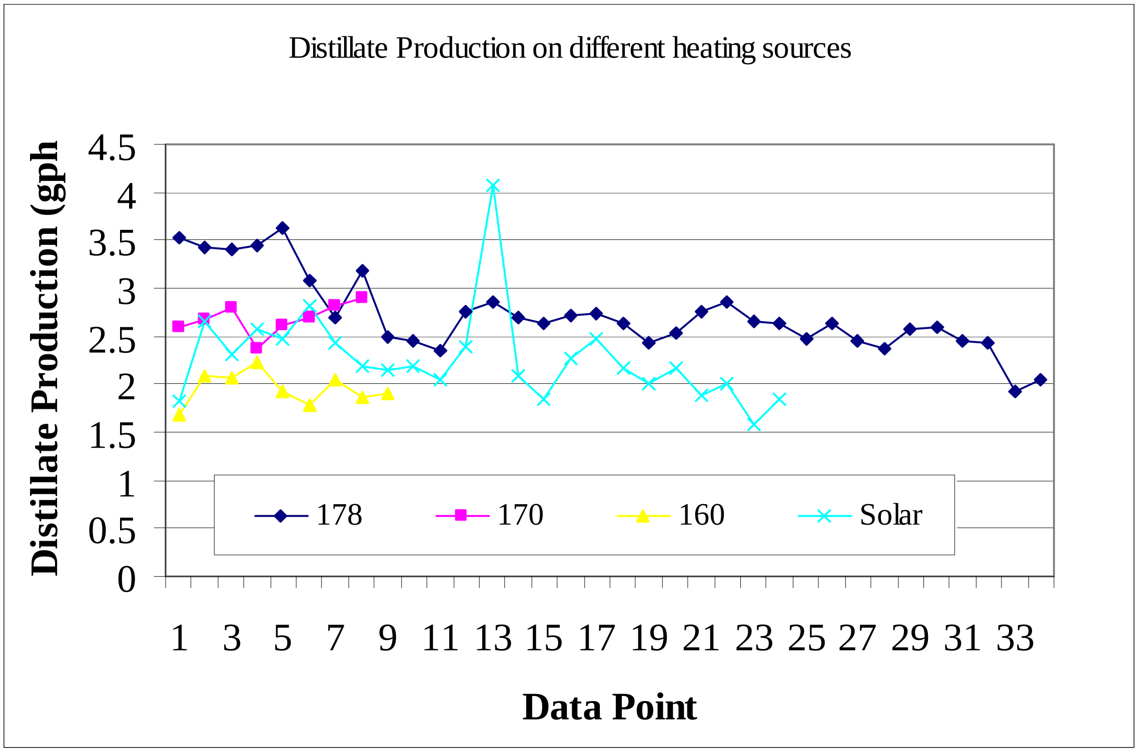

Figure 5: Distillate production on different sources of heat for the process water

The chart in figure 6 is a plot of distillate production against feed rate for electric heater set at 178 F and solar heating. Similarly figures 7 and 8 compare solar heating with electric heater set at 170 F and 160 F respectively. The motive of these charts is to show that solar heating compares with electric heating quite well. While process water heating on solar power may not give the highest production rates, the energy savings offer an attractive compensation.

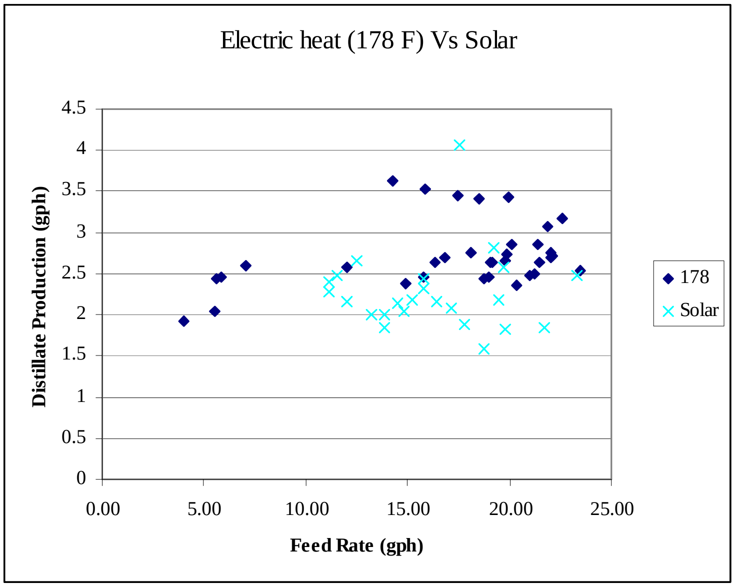

Figure 6: Comparison of process water heating with the electric heater to 178 F and solar heating by the panels

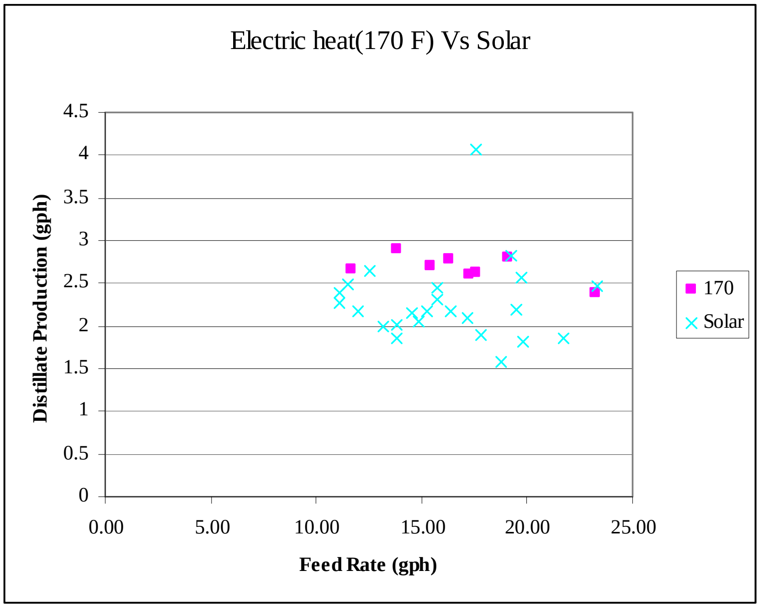

Figure 7: Comparison of process water heating with the electric heater to 170 F and solar heating by the panels

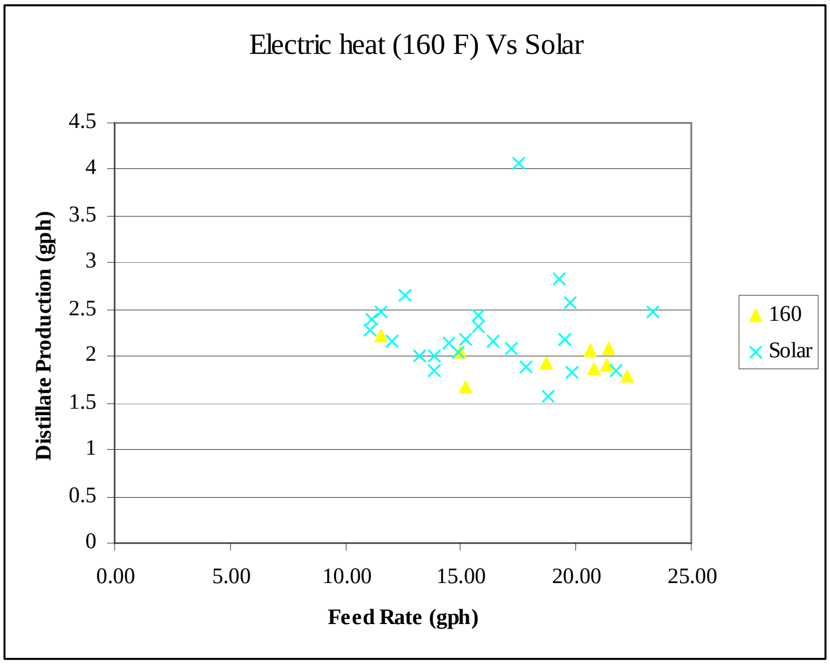

Figure 8: Comparison of process water heating with the electric heater to 160 F and solar heating by the panels

Table 7 shows the data considered for drawing the above charts. It represents the feed flow and corresponding distillate production for solar heating conditions. The charts shown above use the data from this table and tables 3 and 4.

Table 7: Distillate production on process heating with solar panels

Process Water Temperature (F)	Feed Flow (gph)	Distillate Production (gph)
Solar Heating	19.83	1.82
	12.54	2.65
	15.75	2.31
	19.74	2.57
	23.3	2.47
	19.23	2.82
	15.77	2.44
	19.47	2.19
	14.53	2.15
	15.24	2.18
	14.86	2.05
	11.13	2.39
	17.54	4.07
	17.18	2.09
	21.7	1.85
	11.1	2.27
	11.54	2.48
	16.4	2.17
	13.21	2.00
	12.02	2.17
	17.81	1.89
	13.83	2.01
	18.76	1.58
	13.84	1.85

Distillate Production at High TDS

The distillate production was measured by gradually increasing the dissolved salts content in the feed water. This was done by manually adding measured quantities of sodium chloride to the water. The system was run at each increment and distillate production and dissolved salt content in the distillate was checked.

This experiment was also to prove the ruggedness of the Dewvaporation system in handling water with high salt content. The chart in figure 9 shows the distillate production against the saturation of the feed water with sodium chloride. It is interesting to note that while the dissolved salt content in the feed water goes from 10 % to 50 %, the distillate production does not change appreciably. This could be attributed to the scale of the chart, but the actual values that can be found in the appendix and in the chart in figure 10, attest to this fact. Also it can be emphasized that 50 % saturation is a fairly tough water to treat and that Dewvaporation handled the water without stoppage.

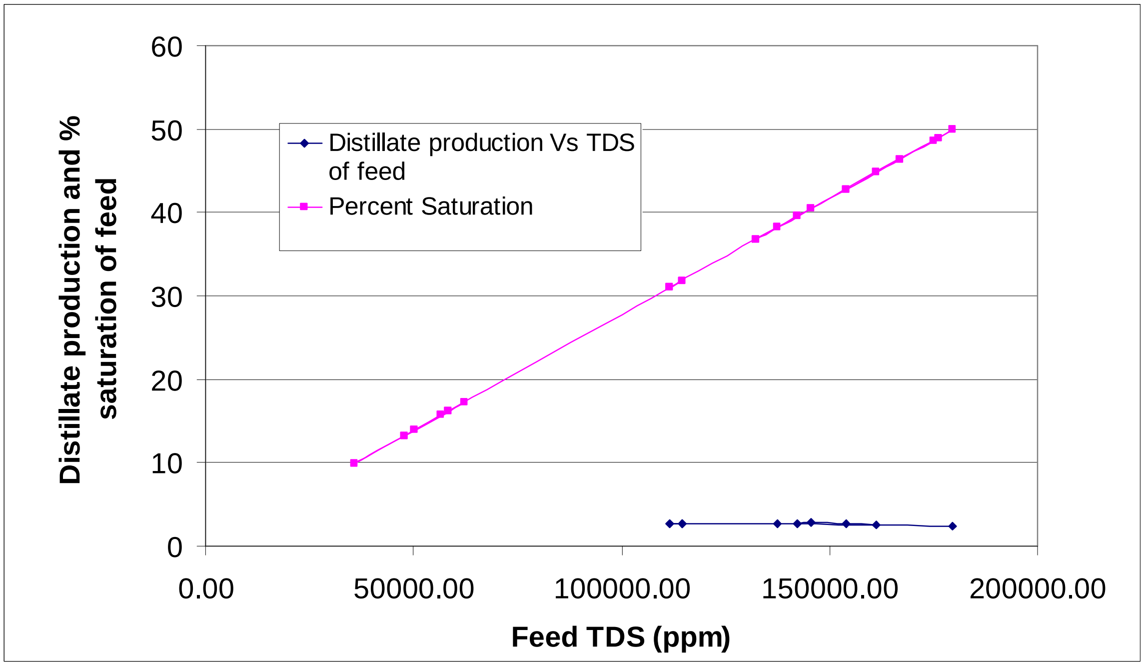

Figure 9: Distillate production at high TDS

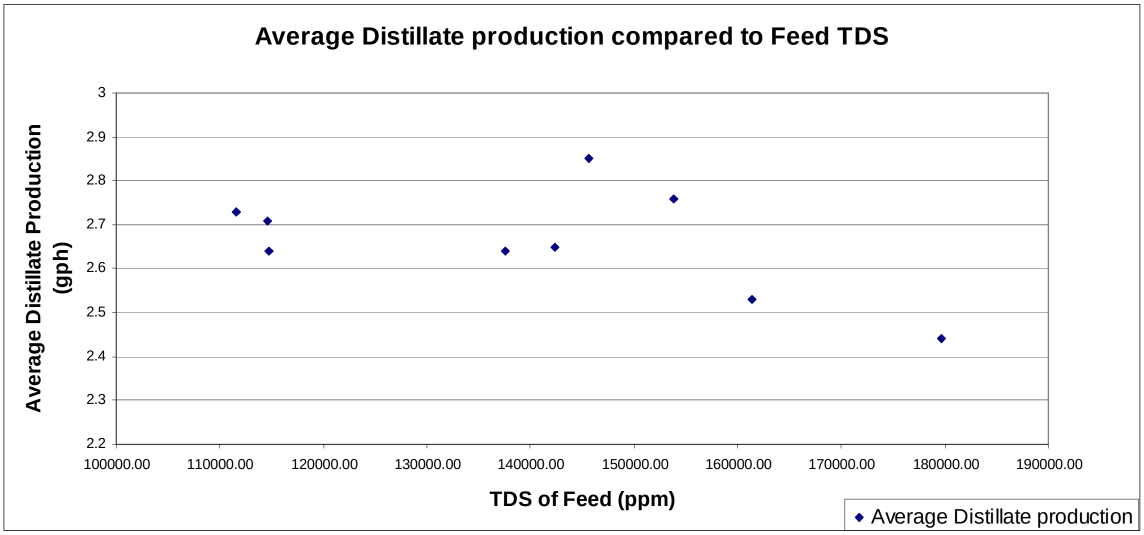

Figure 10: Variation of distillate production with feed TDS

The chart in figure 10 shows the distillate production for various concentrations of feed water. The initial concentration for the experiment was 500 ppm. The concentration was gradually increased to a final concentration of 1080000 ppm. The distillate production and distillate TDS data were collected for the different increments. As can be seen from the charts, even at concentrations as high as 145000 ppm, the distillate production does not change much. It is only after the concentration reaches a little more than 150000 ppm, that the distillate production shows a noticeable drop.

The photo in figure 11 shows the salt deposition on the inside of the Dewvaporation tower. This was a result of running the system on feed containing high amounts of dissolved solids.

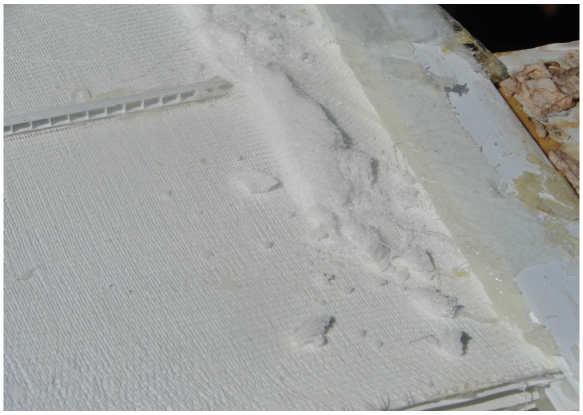

Figure 11: Salt Deposition

Comparison of distillate production with seasonal variations

The seasonal variations were found to affect the distillate production. The warmer summer months generally proved much better. The colder months saw a decline in the distillate production. This may be attributed to the temperature of the ambient air. Also, it would be difficult to draw any definitive conclusions as the experiments were started almost at the end of the summer of 2005 and carried on till September of 2006. But during the course of the experiments a variety of experiments were carried out and it was also found that the distillate production rates were dropping. During the summer of 2006, the distillate production seemed to improve since the colder months. But then again, the production rates did not go up to be as good as they were during the initial months of operation.

The chart in figure 12 shows the effect seasonal variations has on production costs. As can be expected, the costs are lower during the warmer summer months with good availability of solar energy.

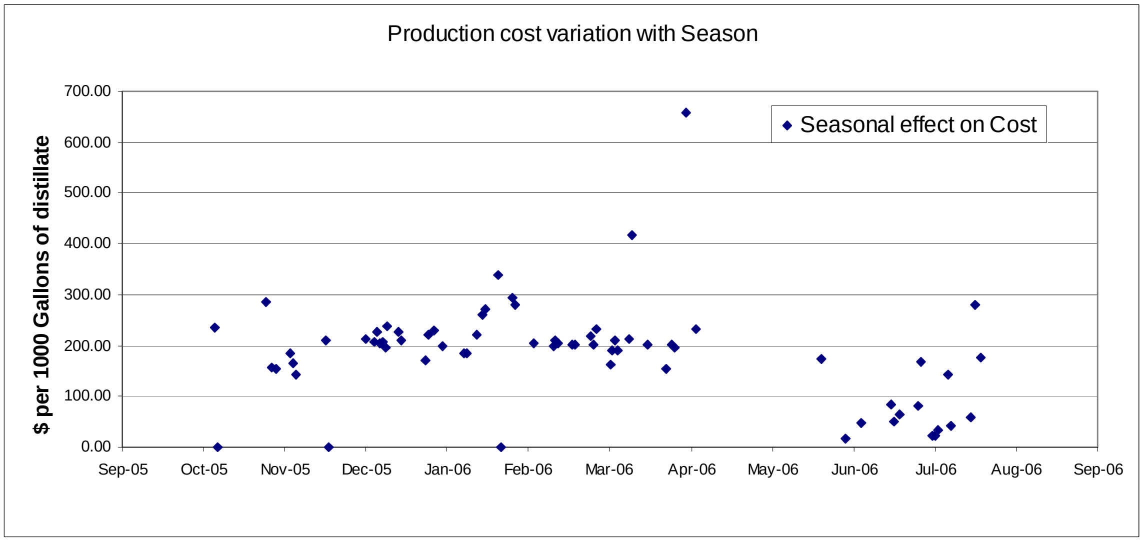

Figure 12: Seasonal effect on production cost

Water Recovery

Water Recovery may be described as the amount of distillate obtained from a unit amount of feed water. This is a very important aspect in any desalination process. The following charts show the recovery characteristics of the Dewvaporation towers. The recovery rates were calculated for the different experiments. The recovery rate is expressed in percentages.

The chart in figure 13 shows the recovery as percentage on the y-axis and timeline on the x-axis. The legend indicates the temperature of the process heating water. From the chart it is clear that the highest recovery is obtained at process heating water temperature of 178 F. This is also obvious as the highest distillate production rates are at process water temperature of 178 F. But it is interesting to note that the recovery, especially at 170 F, and at 160 F are comparable. This is a key to optimization of energy usage.

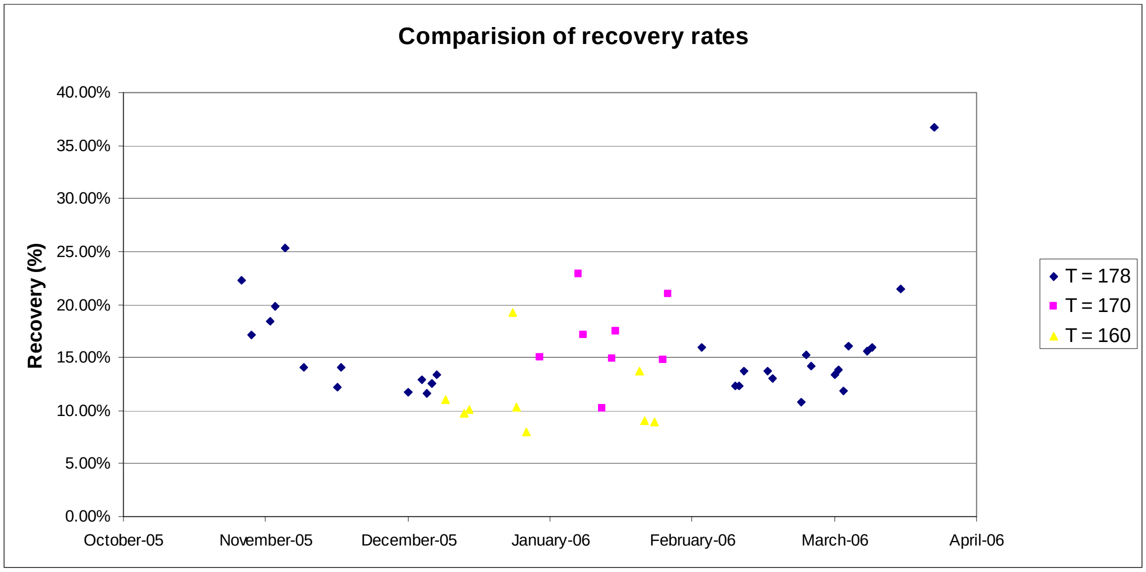

Figure 13: Recovery rates at different process heating water temperatures

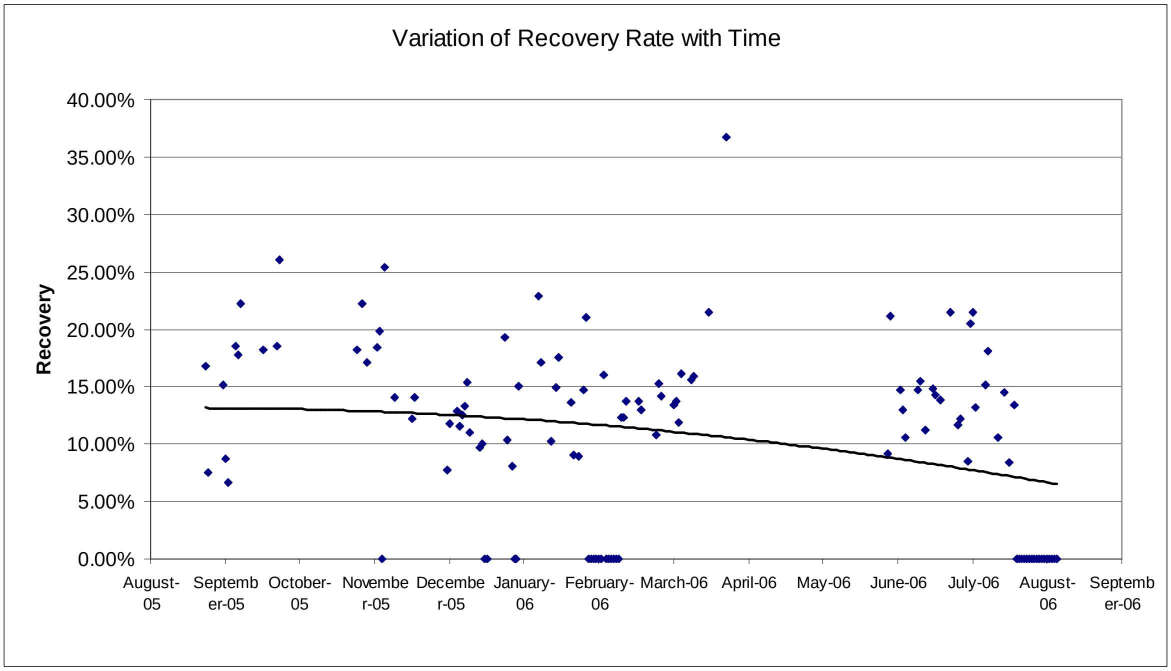

Figure 14: Recovery rates over time

The chart in figure 14 shows the recovery percentages over time. It may be noted that there is a gradual drop in the recovery. The drop is a little sharper towards the end. This may be attributed to degradation of the tower and overall drop in performance. Also it should be noted that the sharper drop can be attributed to solar experiments with a lower process water temperature and slightly lower distillation rates.

Table 8: Average water recovery at different process water heating conditions

Heating type	Average Water Recovery (%)
Electric Heater; 178 F	18.86
Electric Heater; 170 F	16.69
Electric Heater; 160 F	11.11
Solar	14.73

The data in table 8 shows the average recovery values for process water temperatures of 178, 170 and 160 F. It also shows the average recovery for solar heating. It can be seen that process water at 178 F yields the highest recovery of 18.86 %. Also of interest is the fact that solar heating yields a 14.73 % recovery.

Mass Balances

The mass balances were worked out to estimate the recovery of distillate from the feed and also to establish that the process heating water did not constitute any part of the distillate. Flow rates of the feed, brine and distillate were taken. The amount of water being lost from the process heating water loop was measured as well.

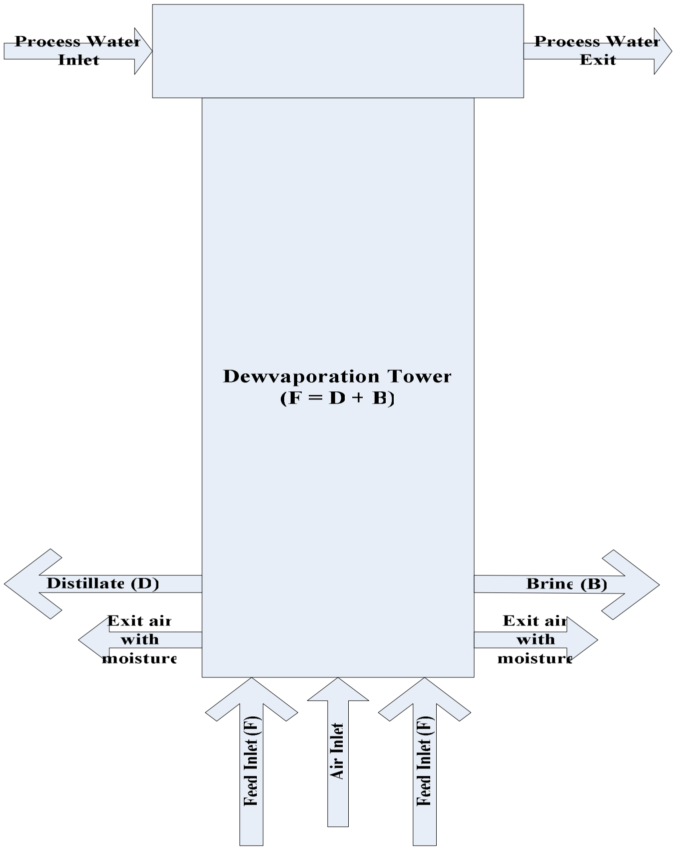

Figure 15: Schematic of water and air flows in Dewvaporation

The schematic shows all the major mass flows into and out of the dewvaporation system. The brine and distillate are obtained from the feed. And since the system is operated on a recirculation mode, ideally the exit streams should equal the amount of feed.

The following calculation shows the amount of moisture lost in the exit air. This is crucial to prove that the distillate does not constitute any water from the process heating loop. A steady loss of water was noted in the process heating loop. The following calculation confirms that the loss of water from the process heating loop is actually lost in the exit air. The amount of water lost from the process water loop matches the number calculated theoretically as the amount of moisture in the exit air, for all three process water temperatures.

Assumptions and simplifications:
Gravity of water = 1 gm/cc
Exit air is completely saturated

<u>Water in Exit Air at 160 F</u>
Temperature of exit air @ 160^{o} F = 30.7^{o} C
Corresponding Saturated Vapor Density = 31.69 gm/m3 = 31.69 x 10e-3 (L H20/m air)
= 8.3 x 10e-3 gall H2O/m3 air
Air flow in tower = 108 cfm = 3.024 m3/min

Therefore, water in exit air = 8.3 x 10e-3 x 3.024 = 0.025 gall/min = **1.5 gph**

Water in Exit Air at 170 F

Temperature of exit air @ 170^{o} F = 41.7^{o} C

Corresponding Saturated Vapor Density = 55.38 gm/m3 = 14.63 x 10e-3 gall H2O/m3 air

Water in exit air = 14.63 x 10e-3 x 3.024 = 0.0442 gall/min = **2.65 gph**

Water in Exit Air at 178 F

Temperature of exit air @ 178^{o} F = 42.5^{o} C

Corresponding Saturated Vapor Density = 57.52 gm/m3 = 15.19 x 10e-3 gall H2O/m3 air

Water in exit air = 15.19 x 10e-3 x 3.024 = 0.0459 gall/min = **2.75 gph**

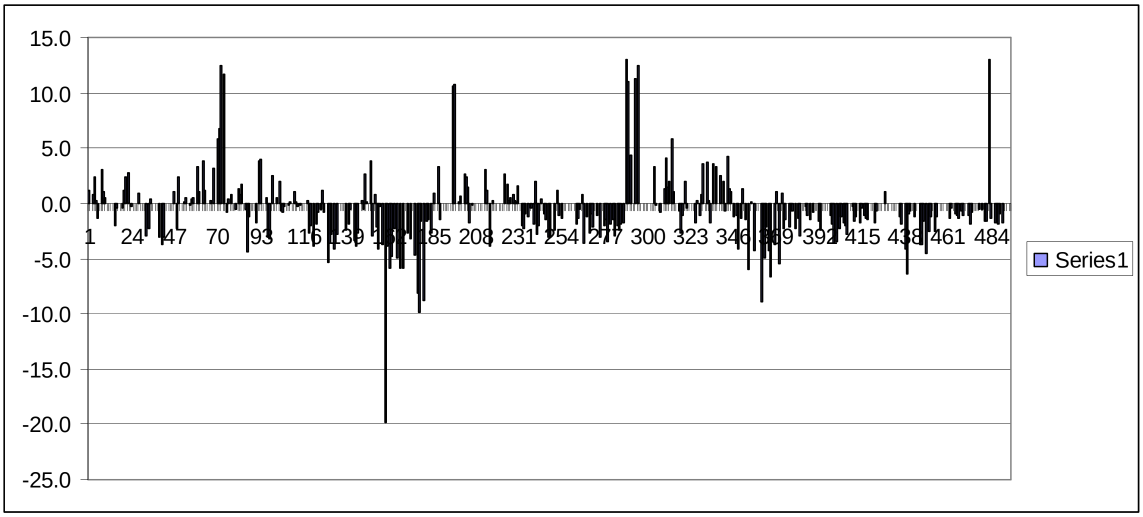

Figure 16: Water Difference between inlet and exit streams

The chart in figure 16 shows the disturbance in mass balance. The mass imbalance or the deviation from zero required for a perfect mass balance is shown. It should be noted that the flows used to compute the mass balances were measured manually by timing the flow in a graduated cup. This makes room for unavoidable error.

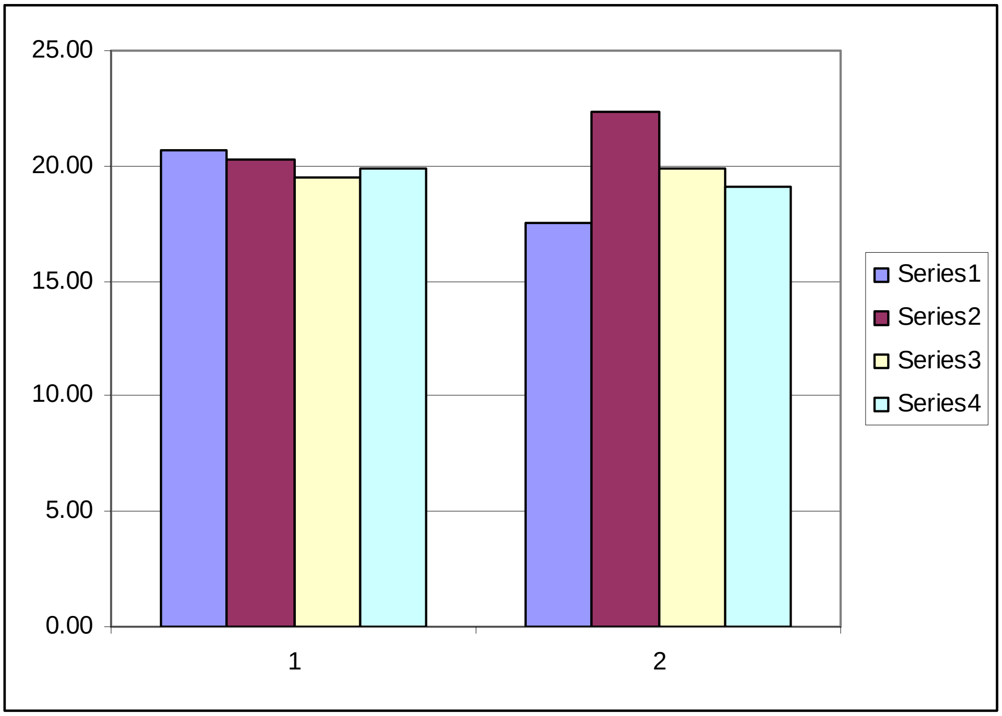

Figure 17: Bar Chart comparing the total water inlet and outlet

The bar chart shows the total inlet water and outlet water for 5 sets of readings. The chart aims to show that the difference is negligible and could be easily caused by an error in measurement.

Energy Consumption

The aim of doing the energy consumption calculations is to see and compare the energy differences for solar-electric hybrid and electric only operations.

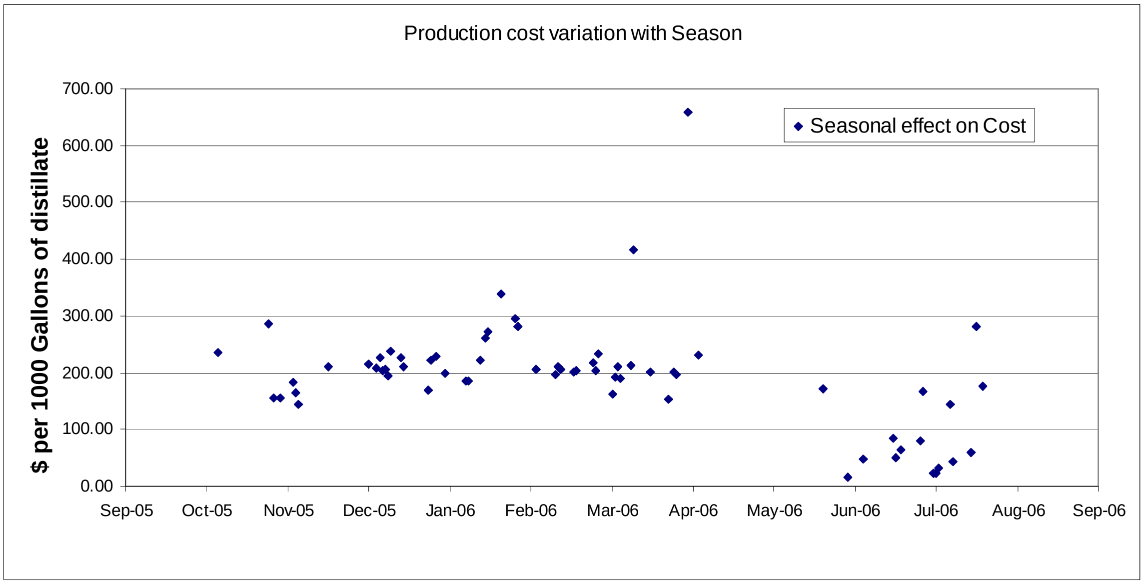

Figure 18: Production cost dependency on season of the year

The chart in figure 18 shows how the cost for producing 1000 gallons of water by Dewvaporation varies with the season. It can be seen that the production cost is lower in the summer months due to the usage of solar energy. The cluster of data points from the months of June 2006 to August 2006 represents solar operation.

The chart in figure 19 is a comparison of energy consumption on electricity only and solar-electric hybrid. It can be clearly seen how much less energy is expended in making distillate during the solar-electric hybrid operation.

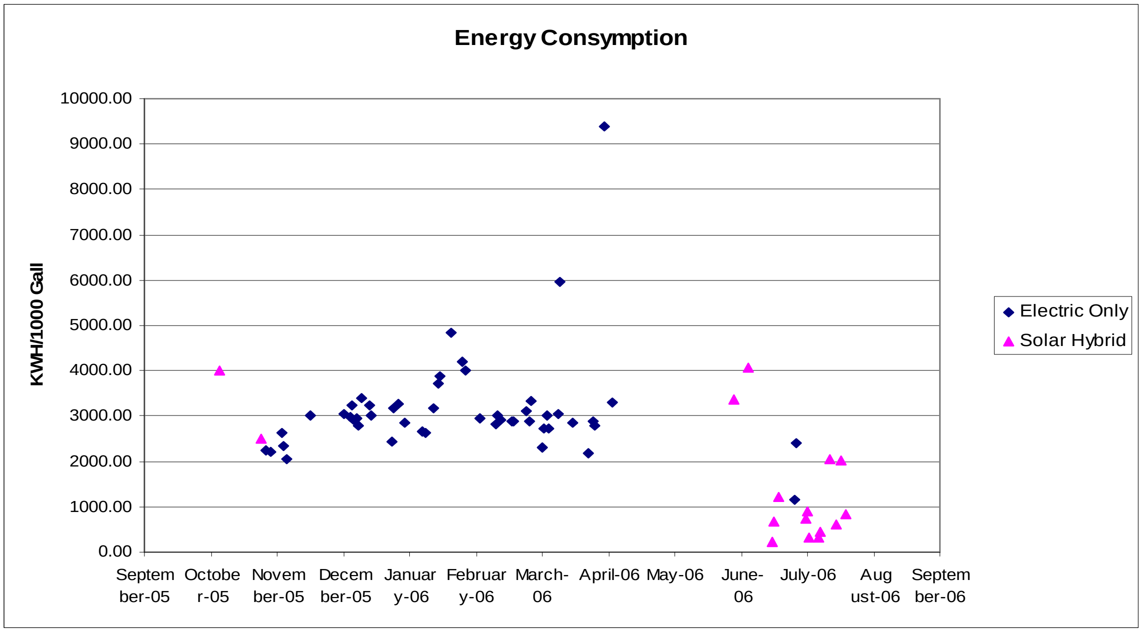

Figure 19: Energy consumption on electric heater and solar-electric hybrid operations

Figure 20 shows a plot of energy consumed compared to the distillate production and figure 21 shows energy consumption as a function of recovery. While the chart in figure 20 is not wholly conclusive, the chart in figure 21 clearly shows that higher recoveries may be possible even at lower energy consumption. This is a vital conclusion for the operability and feasibility of Dewvaporation technology. This points to the fact that optimization for maximum recovery and minimum energy expenditure can be carried out.

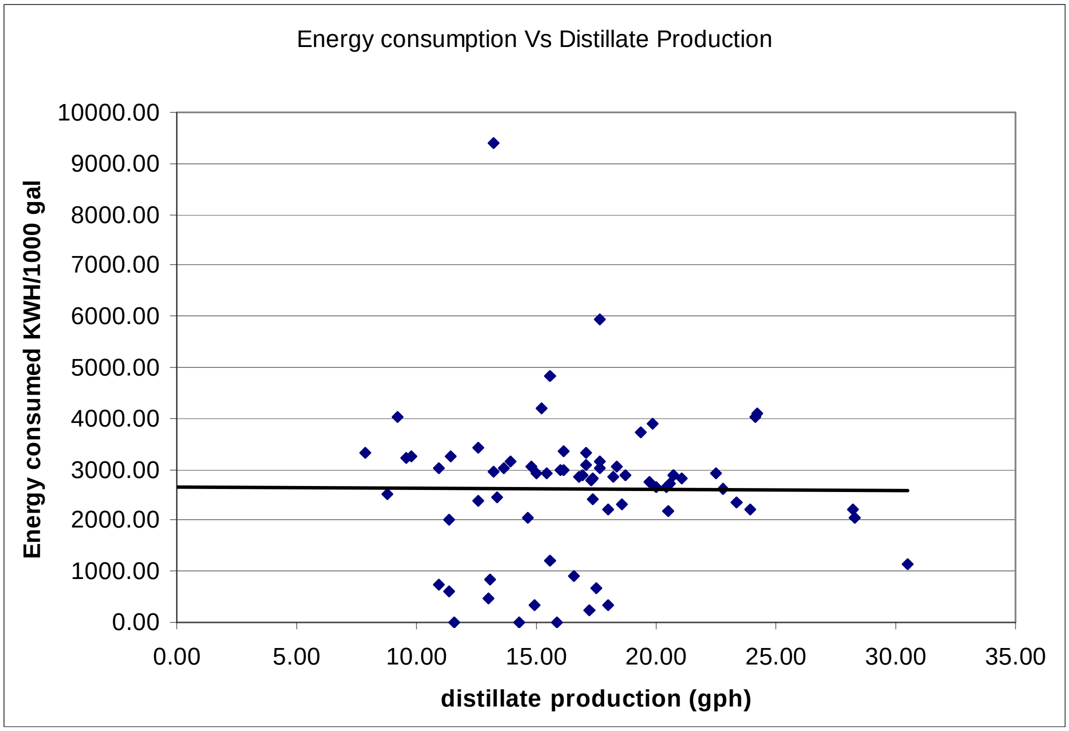

Figure 20: Energy consumption Vs Distillate production

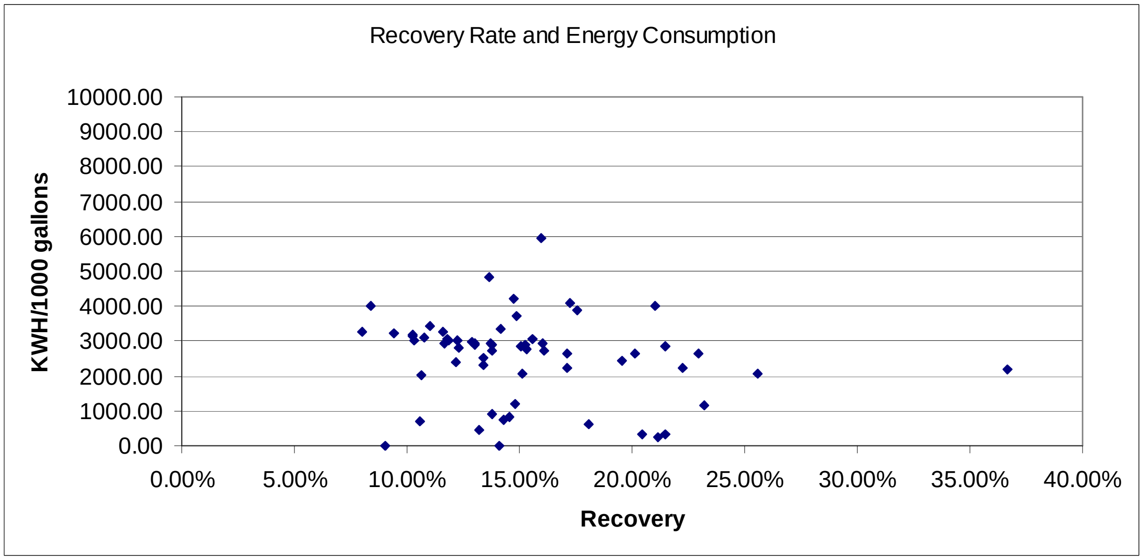

Figure 21: Energy consumption plotted as a function of recovery

Further it can be seen from figure 19 that the energy consumption for solar-electric hybrid operation is in the range of 0 to 4000 KWH/1000 gallons, with most values lying below 2000 KWH/1000 gallons. Comparatively for the electric-only operation, the energy consumption exceeds 4000 KWH/1000 gallons.

The energy consumption for the solar only operation would be zero as the power consumption of the pumps and the blowers is not considered in this calculation.

The data in tables 9 and 10 show the energy consumption data and consequent values of cost of production for 1000 gallons.

Table 9: Energy consumption data

Date	Operation	Duration (hours)	Energy Consumed (KWH)	Distillate produced (gallons)	$/1000 gallons
19-Oct-05	Hybrid	6.50	54	16.12	234.49
7-Nov-05	Hybrid	8.00	99	24.24	285.89
9-Nov-05	Electric Only	8.00	63	28.24	156.16
11-Nov-05	Electric Only	7.00	53	23.94	154.97
16-Nov-05	Electric Only	6.50	60	22.82	184.09
18-Nov-05	Electric Only	7.75	58	28.29	143.53
29-Nov-05	Electric Only	5.92	48	15.98	210.21
14-Dec-05	Electric Only	7.33	56	18.33	213.92
17-Dec-05	Electric Only	6.58	48	16.12	208.42
18-Dec-05	Electric Only	4.83	37	11.40	227.22
19-Dec-05	Electric Only	6.00	45	15.42	204.28
20-Dec-05	Electric Only	4.75	39	13.21	206.74
21-Dec-05	Electric Only	7.25	48	17.26	194.73
22-Dec-05	Electric Only	7.50	43	12.60	238.89
5-Jan-06	Electric Only	7.67	42	17.33	169.61
6-Jan-06	Electric Only	7.25	44	13.92	221.26
8-Jan-06	Electric Only	5.50	32	9.79	228.80
11-Jan-06	Electric Only	7.00	52	18.20	200.00
19-Jan-06	Electric Only	7.50	53	20.03	185.27
20-Jan-06	Electric Only	7.33	54	20.45	184.83
24-Jan-06	Electric Only	7.42	56	17.66	221.98
26-Jan-06	Electric Only	7.42	72	19.37	260.25
27-Jan-06	Electric Only	7.33	77	19.86	271.34
1-Feb-06	Electric Only	7.58	75	15.54	337.86
6-Feb-06	Electric Only	5.42	64	15.23	294.15
7-Feb-06	Electric Only	8.33	97	24.16	281.08
14-Feb-06	Electric Only	8.33	66	22.49	205.42
21-Feb-06	Electric Only	6.58	49	17.37	197.45
22-Feb-06	Electric Only	6.50	53	17.62	210.62
23-Feb-06	Electric Only	5.50	44	15.02	205.13
28-Feb-06	Electric Only	7.08	54	18.69	202.23
1-Mar-06	Electric Only	8.50	60	20.74	202.51
7-Mar-06	Electric Only	6.75	53	17.08	217.24

Table 10: Energy consumption data (continued)

Date	Operation	Duration (hours)	Energy Consumed (KWH)	Distillate produced (gallons)	$/1000 gallons
8-Mar-06	Electric Only	7.50	60	20.70	202.90
9-Mar-06	Electric Only	6.00	57	17.10	233.33
14-Mar-06	Electric Only	7.00	43	18.55	162.26
15-Mar-06	Electric Only	7.50	54	19.73	191.63
16-Mar-06	Electric Only	5.50	41	13.64	210.41
17-Mar-06	Electric Only	7.83	56	20.59	190.36
21-Mar-06	Electric Only	6.00	45	14.76	213.41
22-Mar-06	Electric Only	7.42	105	17.66	416.20
28-Mar-06	Electric Only	6.50	48	16.77	200.36
4-Apr-06	Electric Only	7.92	45	20.51	153.56
6-Apr-06	Electric Only	6.92	49	16.95	202.31
7-Apr-06	Electric Only	8.66	59	21.04	196.26
11-Apr-06	Electric Only	6.83	124	13.18	658.48
9-Jun-06	Hybrid	6.50	4	17.23	16.26
15-Jun-06	Hybrid	7.08	12	17.49	48.03
26-Jun-06	Hybrid	7.25	19	15.59	85.32
27-Jun-06	Hybrid	5.00	8	10.90	51.38
29-Jun-06	Hybrid	8.08	15	16.56	63.39
6-Jul-06	Electric Only	7.50	35	30.53	80.26
7-Jul-06	Electric Only	6.00	30	12.54	167.46
11-Jul-06	Hybrid	6.58	5	14.94	23.43
12-Jul-06	Hybrid	7.25	6	17.98	23.36
13-Jul-06	Hybrid	6.00	6	13.02	32.26
17-Jul-06	Hybrid	7.33	30	14.66	143.25
18-Jul-06	Hybrid	5.25	7	11.39	43.01
25-Jul-06	Hybrid	6.50	11	13.07	58.94
27-Jul-06	Hybrid	5.83	37	9.21	281.17
29-Jul-06	Hybrid	4.75	22	8.79	175.25

Comparison of Dewvaporation Towers

The effect of time and the resulting wear and tear on the operation of the towers was desired to be studied. To do this, two towers were compared. One is relatively new and the other is older by 6 months. The resulting comparison is shown in the following chart. All the process variables such as temperature of process heating water, amount of inlet air, temperature of ambient air and feed flow rates were relatively constant for both the towers. The older tower already in operation is referred to as tower 1 while the other newer tower is denoted tower 2.

Table 11: Distillate production data from the two towers

Date	Average Distillate Production	
	Tower 1	Tower 2
26-Jan-06	2.62	2.53
27-Jan-06	2.71	3.07
1-Feb-06	2.05	2.49
2-Feb-06	1.87	2.3
4-Feb-06	1.9	2.48
6-Feb-06	2.81	3.78
7-Feb-06	2.9	3.63

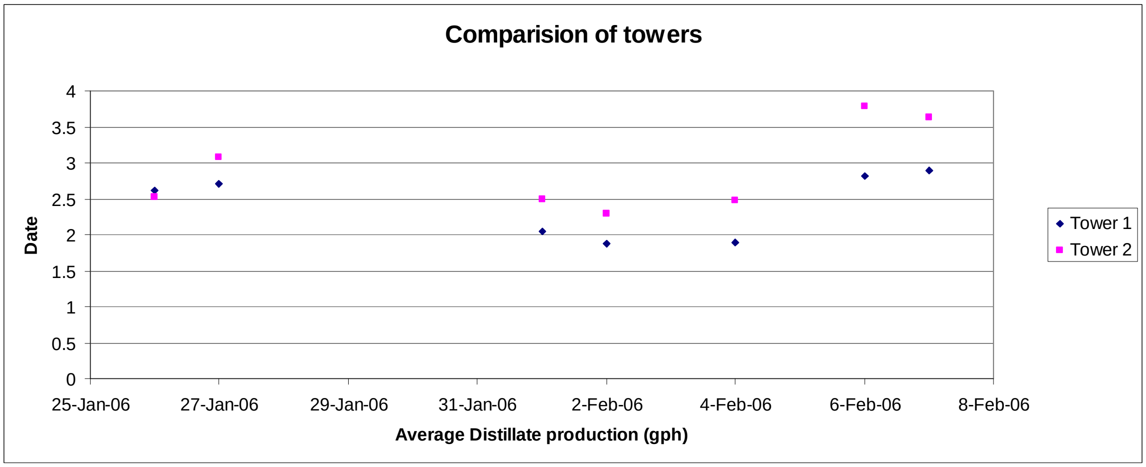

Figure 22: Tower Comparison

It can be seen from the chart in figure 22 that the newer tower, labeled tower 2, consistently performed better than the older tower. This hints the possibility of possible wear and tear. On the other hand, some leaks were noticed on the newer tower. There is a possibility of the process heating water or the feed water making it to the distillate stream. The distillate TDS of the newer tower was higher than that of the older tower. But as seen from the previous section, the tower did begin to show some signs of degradation. So it can be concluded that over a period of time there is drop in tower performance. But the drop is not severe enough to stop or adversely affect production.

Figure 23: Top view showing the sponges at the base

Probable, reason for decline of tower performance is the degradation of the sponges that are vital to the operation of the Dewvaporation system.

Analytical Data

Different analytical tests were carried out by the SWAT lab. The feed waters were initially subjected to a comprehensive baseline analysis to spot the different contaminants. Later certain key parameters were identified and were tested for. These parameters differed for differed experiments and were based on the focus of the experiment. For instance, arsenic removal was of primary importance while using water from Columbus as feed.

The average reductions as deducted from the results from the swat lab are shown in table 14. It can be seen that, Dewvaporation performs extraordinarily well. The carbonate removal is 100 %. Also removal of most other parameters is in excess of 99 %. The Dissolved solids removal, which is a prime parameter, is more than 99.43 %.

From the analytical results, the arsenic removal is computed to be in the range of 95 % to 98 %. Also, uranium removal was greater than 99 %. The data for the analytical test results from the lab is shown in the appendix. The removal efficiencies for each sample are calculated. The data presented in table 12 is an average.

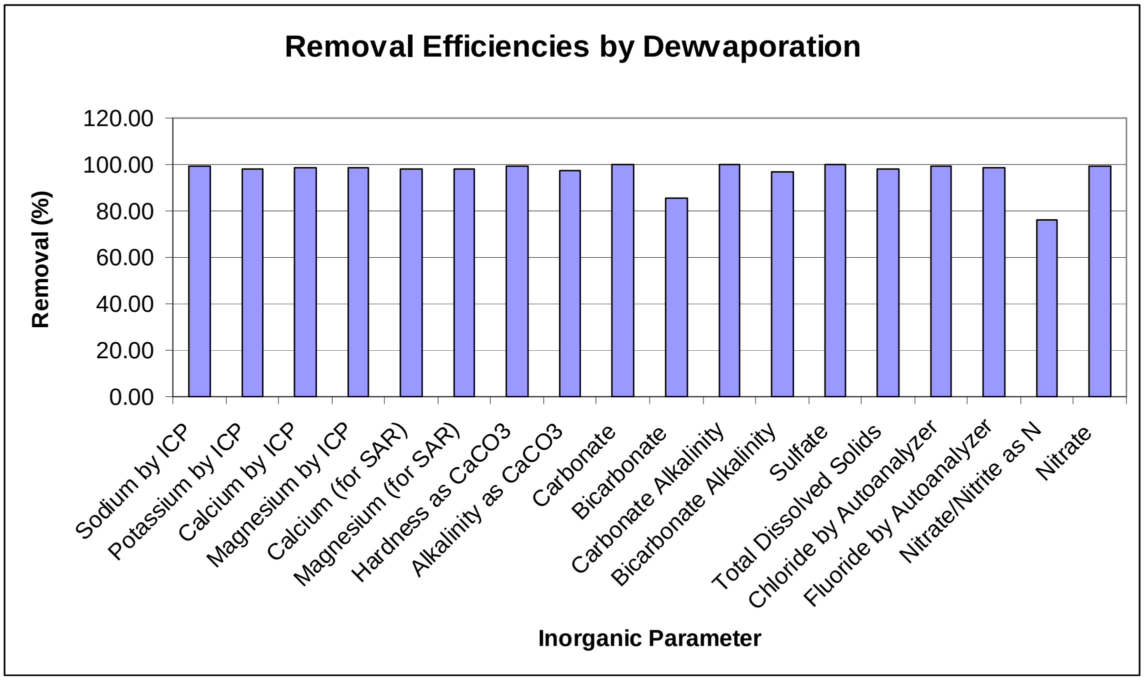

Figure 24: Dewvaporation removal efficiencies for common inorganic parameters

Table 12: Average Reductions of inorganic parameters by Dewvaporation

Parameter		Removal Efficiency
Sodium by ICP	>	99.49
Potassium by ICP	>	98.40
Calcium by ICP	>	99.01
Magnesium by ICP	>	98.89
Calcium (for SAR)	>	98.25
Magnesium (for SAR)	>	97.85
Hardness as CaCO3	>	99.45
Alkalinity as CaCO3	>	97.53
Carbonate		100.00
Bicarbonate	>	85.80
Carbonate Alkalinity		100.00
Bicarbonate Alkalinity	>	97.06
Sulfate	>	99.70
Total Dissolved Solids	>	98.43
Chloride by Autoanalyzer	>	99.41
Fluoride by Autoanalyzer	>	98.66
Nitrate/Nitrite as N	>	76.20
Nitrate	>	99.33

Continuous Operation Data

The data represented in table 13, shows the energy consumption figures on continuous operation for all three process water temperatures. The purpose of running the system on continuous mode was not only to test for performance reliability but also to note energy consumption without start-up and shut-down detriments.

Table 13: Energy consumption figures on continuous operation

Top Head Temperature (F)	Date	Time	Energy Meter Reading	Difference	KWH/hr
178	10-Sep-06	17:00	5328		
	11-Sep-06	12:00	5455		
	11-Sep-06	16:15	5482		
	11-Sep-06	17:10	5488	160	6.67
	12-Sep-06	10:00	5599		
	12-Sep-06	17:00	5642	154	6.42
160	12-Sep-06	17:30	5645		
	13-Sep-06	13:45	5729		
	13-Sep-06	15:10	5735	90	4.19
	18-Sep-06	19:00	5960		
	19-Sep-06	11:40	6062		
	19-Sep-06	19:00	6098	138	5.75
	20-Sep-06	15:00	6193		
170	16-Sep-06	19:00	5735		
	17-Sep-06	19:00	5848	113	4.71
	18-Sep-06	19:00	5960	112	4.67

CONCLUSIONS

Dewvaporation technology was thoroughly tested over a span of more than 12 months at the New Mexico State University. A number of experiments were conducted during this time to characterize and study the process. A number of conclusive decisions can be drawn from these experiments. While to comment on some aspects of the performance and economy of usage, some more tests would have to be carried out.

One of the things that can be emphasized about the technology is that it delivers good quality product water that can meet drinking water standards. The method of storage and usage will have to be improved upon though.

As already discussed, the removal efficiencies of common inorganic parameters is in excess of 99 %. It should be note that carbonate reduction is 100 %. These values are shown in table 14. One of the primary parameters monitored i.e. the total dissolved solids has a removal efficiency greater than 98.43 %. It can be concluded that removal of dissolved species is greater than 99 %, irrespective of the charge on the species. Arsenic removal is in the range of 95 to 98 %, which is very good. This was demonstrated by using water from Columbus (NM). The arsenic in the feed water was removed to levels that were not detected by the analytical instruments. Also Uranium removal is greater than 99 %.

It can also be concluded that the type of feed water does not really affect the Dewvaporation system. Different feed waters were used and the corresponding performance discussed in the previous sections. The Dewvaporation system was also able to handle really high TDS water. The system was able to satisfactorily handle water up to 108000 ppm. But running the system at on feed with high total dissolved salts has its disadvantages. The production rates began to fall and deposition was observed on the plastic layers in the tower.

Also, it was observed that increasing the temperature of the process water improved the distillate production rates. The maximum temperature of operation was 178 F. It is unclear how higher temperatures would affect the overall performance of the system.

One of the final experiments was to use the reject from a reverse osmosis plant as the feed water. The towers handled the reject and concentrated it. It proved to be an ideal treatment method to be coupled with reverse osmosis to enhance the overall efficiency of both processes.

From the exit air moisture calculations, it can also be seen that no part of the distillate volume is contributed by the water in the process loop. The water lost from process loop exits the system in the air. Condenser units to recover this moisture will improve the overall efficiency of the process.

From the studies on recovery, it is clear that Dewvaporation could be driven towards higher recovery. The feed rate would have to be optimized taking into consideration, the number of Dewvaporation units available, the space available and required distillate production. The key to remember here is that the feed rate cannot be too low.

Also from the solar testing, it can be seen that the process is fairly sensitive to changes in operating conditions. So a hybrid system for heating the process water may be most attractive. It can be seen from the energy consumption studies that the energy requirements for a hybrid system are way lesser than when compared to running the system on electricity alone.

Although, the Dewvaporation technology proved to be a great new method for brackish water treatment, some observation were made during the course of the testing period which need attention in future prototypes. There was a noticeable wear over the period of the experiments. This could be due to a variety of reasons. Though on inspection of the inside of the tower, one obvious reason was that the cheesecloth on the plastic layers had degraded. Also the sponges in the top head could be degraded though no obvious wear was found.

Dewvaporation is a novel technology that can prove to be a great method for treatment of brackish water by using renewable sources of energy. There is more research and development to be done though. Currently it would be a great technology to couple with Reverse Osmosis or even other desalination technologies such as distillation or ultrafiltration.

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