RESEARCH STUDY RESULTS FOR VIBRATORY MEMBRANE FILTRATION AS AN EFFECTIVE ALTERNATIVE FOR PHOSPHOGYPSUM EFFLUENT TREATMENT

RESEARCH STUDY
for FIPR's Reclamation and Environmental Research Program

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INTRODUCTION

New Logic has developed a proprietary reverse osmosis membrane system that is unique. Since the creation of this new vibratory membrane filtration system, many new applications for membrane filtration have been found. Previously, many applications would not be possible with conventional membrane systems or would be fraught with problems. Since the advance of the Vibratory Shear Enhanced Process known as VSEP®, new opportunities for membrane filtration have come about. Some that can now employ effective membrane filtration include mineral processing, polymer diafiltration, carbon black concentration, pulp and paper wastewater, acid mine drainage, groundwater leachate remediation, latex concentration, filtration of raw hog manure, and many more. VSEP has opened doors to many industries and allowed for an advanced and effective technology that can provide treatment where no practical or easy solution was available.

Initial studies have been completed focusing on VSEP filtration of Phosphogypsum Process Water. These results have shown great promise for the potential that exists. Phosphogypsum process water spills and remediation have long been a problem for the Phosphate industry and for the surrounding local communities and state governments. The recent bankruptcy and closure of a major facility in Florida has demonstrated the need for planning and preventative action plans for dealing with this toxic wastewater.

Due to slight radioactivity, alternate uses of Phosphogypsum process water has not yet been approved. Only recently has investigation begun on possible treatment methods to treat this water. Currently the only stopgap methods that are available are emergency releases of slightly treated waters to the environment. This kind of action plan is not sustainable, and long-term solutions must be found that can deal with treatment of pond process water. Current methods being tested including a conventional spiral RO membrane filtration system and advanced chemical treatment methods have only had limited success.

The purpose of this research study is to test and validate the VSEP technology as a suitable solution for Phosphogypsum effluent.

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STATEMENT OF SOURCE AND MAGNITUDE OF THE PROBLEM

Background Information

The wet process manufacture of phosphoric acid as practiced requires a large volume of process water. This water is used for many of the operations during the manufacture of Phosphoric Acid from Phosphate Ore. The water is stored in vary large ponds known as phosphogypsum stacks. These ponds can be used as storage areas and also as a heat transfer mechanism for cooling. In Florida the average yearly rainfall and the evaporation rate are approximately equal. Careful water balance management must be used to operate the system at par or with a negative water balance. However, during rainy periods it may become necessary to treat the surplus water and release it to the surface waters in order to avoid an uncontrolled discharge of the untreated process water when rainfall exceeds evaporation.

Before it can be discharged, the water in these ponds must be treated. The volume of water that needs treatment is in the billions of gallons. A typical Gypsum Stack can cover an area of 600 acres. The cooling pond water also has a very low pH and contains a mixture of regulated inorganic chemicals that cannot be discharged without treatment. In addition, trace levels of Radium and other radioactive nuclei mean alternative uses other than disposal are not practical and have not been approved by the EPA. Studies have been conducted to investigate use of Phosphogypsum for roadbeds, concrete additives, soil amendments, and many other possible value added solutions. Due the radioactivity of the slurry, such use has not yet been accomplished.

Piney Point's Closure

One such closed plant, located at Piney Point is currently being treated. Due to heavy rains and limited capacity, the pond has been in danger of overflowing since the plant closing. The Florida DEP has implemented several emergency orders for dealing with the problem. Actions taken have included installation of a reverse osmosis filtration system to dewater the pond for discharge, emergency lime treated discharges to surface waters, and most recently a plan for ocean discharge in the Gulf of Mexico of untreated process water.

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AVAILABLE TREATMENT METHOD OPTIONS

Existing Treatment Method

Even after installation of an RO filtration system designed to handle 500,000 gallons per day, extreme measures are needed to prevent an environmental catastrophe. Due to very high levels of dissolved solids, treatment methods are difficult and virtually limited to reverse osmosis membrane filtration techniques. Use of conventional spiral wound membrane systems for this application are effective at producing clean water, but are difficult to operate and complicated in their design due to fouling and scaling problems. Extensive pre-treatment is required to limit fouling and scaling. Conventional spiral membranes are only able to concentrate waters up to the solubility limits of various scaling ions and this will determine the % recovery that is possible of clean water. In cases with high TDS, this recovery can be very low, even as low as 40% of the incoming feed water.

Emergency Discharge Methods

Present treatment practice is to lime to a pH of approximately 4.5, remove the solids formed, lime the water to a pH of approximately 11, remove the solids formed, air strip the water to remove ammonia, and add acid to reduce the pH to approximately 6.5. While the treated water still has dissolved solids and conductivity above discharge standards, it can still be discharged to the surface waters under an emergency permit from the Florida Department of Environmental Protection. This is not a final solution and only used when necessary to prevent a much more catastrophic discharge.

Hauling the Water to Other Locations

In the case of Piney Point, Manatee County is reportedly trucking about 100,000 gallons per day to its wastewater treatment plant where it is treated and then sold as reclaimed water for use on farms and lawns. The water has been double-limed and aerated, a process which removes all the phosphorus, most of the nitrogen and normalizes acidity levels. Manatee County commissioners have asked U.S. Rep. Dan Miller to help get federal funding for a $50 million pipeline to connect Piney Point with FP&L's Parish power plant for storage that may eventually tie into the county's agricultural water reuse system. Cargill and CF Industries, which operate Phosphate processing plants in Plant City and Riverview, also are expected to take some of the water from Piney Point. Negotiations are still underway, but plans call for about 73 million gallons to be trucked to nearby plants.

Ocean Dumping

In extreme cases, the risk of an accidental spill at a facility may require emergency methods such as Ocean dumping. This would be the case where no pond level reductions have been made and an approaching hurricane season can pose a threat of overflow or dam bursting. The Piney Point site borders U.S. highway 41, a designated major hurricane evacuation route. In the case of Piney Point, after a thorough review of the permit application and an exhaustive review of possible alternatives, the EPA began the international consultation process. A permit to allow the DEP to transport and disperse treated process wastewater and treated contaminated rainfall-runoff from the former Piney Point Phosphates facility to the waters of the Gulf of Mexico in areas free of critical marine habitat has been issued.

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Vibratory Membrane Filtration (VSEP)

New Logic Research has developed a vibratory membrane technology for effective filtration of high TDS applications that does not suffer from colloidal fouling and is resistant to mineral scaling. New Logic is a privately held corporation located in Emeryville, CA approximately 10 miles from San Francisco. New Logic markets, engineers, and manufactures a membrane dewatering and filtration systems used for chemical processing, wastewater streams, pulp & paper processing, mining operations, and drinking water applications. Dr. Brad Culkin invented the Vibratory Shear Enhanced Process (VSEP) technology in 1985. Dr. Culkin holds a Ph. D. in Chemical Engineering and was formerly a senior scientist with Dorr-Oliver Corporation. VSEP was originally developed as an economic system that would efficiently separate plasma from whole blood.

VSEP's unique separation technology is based upon an oscillating movement of the membrane surface with respect to the liquid to be filtered. The result is that blinding of the membrane surface due to the build up of solids is eliminated and free access to the membrane pores is provided to the liquid fraction to be filtered. The shear created from the lateral displacement caused suspended solids and colloidal materials to be repelled and held in suspension above the membrane surface. This combined with laminar flow of the fluid across the membrane surface keeps the filtered liquid homogeneous and allows very high levels of recovery of filtrate from the feed material.

The focus of this research proposal is to investigate the comparative results when using vibratory shear enhanced filtration of the Phosphate pond water. It is believed that a more efficient and easier to use system would result. In addition, higher recovery of clean water as a percentage of the raw water and lower operating costs would result. These advantages have been demonstrated many times in the past with full-scale industrial installations that have been completed for other similar applications. In addition some initial trial testing of cooling pond water has shown that these same benefits would apply to Phosphogypsum process water.

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SPECIFIC RESEARCH PROJECT GOALS

It is expected that vibratory shear enhanced RO membrane filtration can achieve higher recoveries than conventional membrane filtration and also not be subjected to the fouling and scaling problems typical with spiral membranes. It is also expected that operating costs for VSEP filtration would be lower than any other option including spiral membranes or chemical precipitation.

Initial studies were conducted using pilot equipment that would simulate a full-scale installation sized for throughput of 1000 gpm or 1,440,000 gpd. Qualitative and quantitative data was collected during pilot trails that would allow the following specific measurements of success to be calculated:

- Membrane Life and Resiliency
- Membrane Throughput Rates
- Power Consumption
- Permeate Quality

Initial lab studies have shown that VSEP can produce water at an effective rate that would comply with the special Florida DEP requirements

Table 1. Florida DEP Permeate Specifications for Surface Water Discharge

Section 1	Constituent or Property	Requirement
	pH	6.5 - 8.5
	Fluoride	< 5 mg/L as ion
	Total Ammonia	< 1 mg/L
	Total Nitrogen	< 2 mg/L
	Total Phosphorous	< 0.5 mg/L
	Total Dissolved Solids (TDS)	< 50 mg/L

Table 2. Water Quality Standards for Drinking Water and Surface Waters

Contaminant		40 CFR 141	Class I	Class II	Class III	Class IV
Antimony	Sb	0.006	14.0	4300	4300	none
Arsenic	As	0.070	none	36	none	none
Beryllium	Be	0.004	0.0077	0.13	0.13	100
Chromium	Cr	0.100	11.0	50.0	11.0	11.0
Copper	Cu	1.300	3.7	3.7	3.7	500
Cyanide	Cn	0.200	5.2	1.0	5.2	5.0
Dissolved Solids	TDS	50.0	500	none	none	none
Fluoride	F	4.000	1.5	1.5	5.0	10.0
Selenium	Se	0.050	5.0	71.0	5.0	none
Thallium	Tl	0.002	1.7	6.3	6.3	none
Conductivity	µS	-	1275	1275	1274	1275

1] All units are mg/L and are maximum values except for Conductivity which is given in microseimens (µS)

Legend:
40 CFR 141 - National Primary Drinking Water Standards
Class I - Standards for Potable Surface Water Supplies
Class II - Standards for Surface Water for Propagation of Shellfish
Class III - Recreation Areas and Healthy Fish and Wildlife Populations
Class IV - Agricultural Water Supplies (Irrigation Water)

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IMPACT IF SPECIFIC OBJECTIVES ARE MET

New Options for Water Balance Control

Very few operating Phosphate plants are self-contained with no importation of water or discharges of waste (Zero Discharge). VSEP would offer plants the ability to have clean economical water on demand that can be taken from the Phosphogypsum stack. This would provide great flexibility in managing water balances. This water source could be turned on or off as needed. Currently, managing water balance is a delicate and complicated operation. A nice benefit would be that the water source would be coming from a potential wastewater that is a liability.

Solution for Plant Closures

Even if the VSEP system wasn't installed until after closure, it could be used as a solution for closure of Phosphogypsum Stacks. Reverse Osmosis has already been identified as a suitable treatment method. The only remaining problem is efficiency and throughput. The vibratory nature of VSEP filtration would provide a more stable and reliable treatment system with lower operating costs for remediation of closed facilities. In cases where plant closure is planned, a treatment system can be designed and constructed as part of the closure plan. VSEP would also provide a solution in the closure plan that would be politically favorable and may help to facilitate a speedy approval of the plan. In advance of actual closing or plans submitted for approval. VSEP could be used to volume reduce the pond water to shorten the time for eventual plant closure and remediation.

Emergency Remediation

Current methods for discharge in emergency situations, such as heavy rainfall or uncontrolled positive water balance, include lime treating and pH adjusting prior to surface water discharge. There have been many spills and emergency discharges over the years that could have been avoided if a dewatering technology existed for level control in the pond. VSEP systems can be installed when heavy hurricane seasons are expected or when pond levels are predicted to rise to unsafe levels. This would represent a very effective failsafe mechanism for pond water management.

Phosphorous Recovery

Because of high recoveries possible with VSEP, the reject from filtration will be very high in phosphorous concentration. These levels may warrant product recovery and may help improve mining yield. The use of VSEP would make P2O5 recovery feasible and would allow for additional study on treatment methods for product recovery from the wastewater.

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METHODOLIGY FOR TESTING

Brief Membrane Introduction:

Shear Enhanced Filtration is a technique for the separation of suspended or dissolved materials according to molecular weight and size. Application of pressure causes the membrane to act like a sieve. The action of vibration prevents premature fouling of the membrane. Particles smaller than the pore size pass through the membrane as permeate and particles larger than the pore size are rejected as concentrate. The use of membranes is growing and studies are being conducted around the world at Universities, Fortune 500 Company Research Labs, and Government Facilities.

There are four main categories of membrane filtration. These are determined by the pore size

Table 3. Categories of Membrane Filtration

Filtration Type	Particle Size Cut Off	Molecular Weight Cut Off
Reverse Osmosis	≤ 0.001 µm	≤ 100 Daltons
Nanofiltration	0.001 - 0.01 µm	100 - 1000 Daltons
Ultrafiltration	0.01 - 0.1 µm	1000 - 500,000 Daltons
Microfiltration	≥ 0.1 µm	$\geq 500{,}000$ Daltons

Membranes are rated for suitability as an application filter based on the following criteria:

Pore size	Hydrophilicity
Chlorine Resistance	Salt Rejection Rate as a % of total NaCl
Chemical Resistance	Temperature & Pressure Tolerances
pH range Tolerance	Permeability vs pressure (Energy Saving Features)
Cleanability	Stability of the pore structure
Fouling Resistance	Consistency and Quality of the membrane

Membrane Technologies

VSEP has employed the most effective technique for membrane separation. For many years membrane companies have relied on the “crossflow” of the fluid and the resulting dynamics to enhance performance and to keep layers of foulants and cakes from blinding off the membrane surface. This technique has limited success; however, there are many drawbacks. This type of system is still prone to fouling. Because of the needed crossflow, the % recovery of permeate vs. concentrate is very low.

New Logic utilizes vibratory shear induced by cyclical torsional rotation. The surface of the membrane is moving inversely at a rate of 55 hertz. This action greatly reduced fouling and eliminates the formation of blinding cakes on the membrane surface. Because of this, VSEP is capable of single pass concentration and efficient operation. Other companies have tried to simulate this technique by spinning the membrane or by using giant wiper blades at the membrane surface to create these shear waves. Neither of these technologies can duplicate the effective shear created by VSEP. Also, the power consumption for these methods is huge in relation to the power consumed by the harmonic resonant frequency of VSEP

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Pilot Testing Strategy

Stage One testing is used to quickly process dozens of test samples in order to determine which membranes are possible candidates for further consideration. The smallest VSEP pilot machine, the Series L, is used for this step. The main objectives are:

- Confirm the permeate quality needed and adequate separation criteria is met
- Record representative flow rates on various membranes
- Determine optimum membrane for further work
- Batch concentrate to determine the concentration factor which can be achieved
- Verify that the membrane can be cleaned and does not foul adversely

Equipment Used for Testing

The smallest VSEP unit offered by New Logic is the "Series L" laboratory unit. The primary use of this unit is to provide initial test work in order to determine project feasibility. The system contains 0.4785 ft2 (0.0465 m2) of membrane area. The unit can process approximately 2 to 4 gallons per hour (8-16 liters per hour) for most microfiltration and ultrafiltration processes. For nanofiltration and reverse osmosis applications, the L unit can process approximately 0.5 to 3 gallons per hour (roughly 2.4 to 12 liters per hour). These ranges, of course, will vary depending upon feed material, pressure, temperature, membrane material, and other process parameters. The overall dimensions of the VSEP unit are 30” x 30” x 84”. (76 cm x 76 cm x 213 cm). The unit is mounted on wheels for facilitated mobility. There is one inlet to the VSEP system from the pump, and two outlets; an outlet for concentrated material, and one for permeate.

The Series L system is ideal for testing many different membranes on the same feed material. The membrane used in the VSEP systems is modified from stock supplied by outside vendors. It is configured as a disc, similar to those used in the industrial units. However, there is a single sheet of membrane in the laboratory system. The Series L VSEP consists of the following: a large seismic mass, a torsion bar, inlet and outlet piping, a 2 hp motor, bearing assembly, and pressure shells that house the membrane.

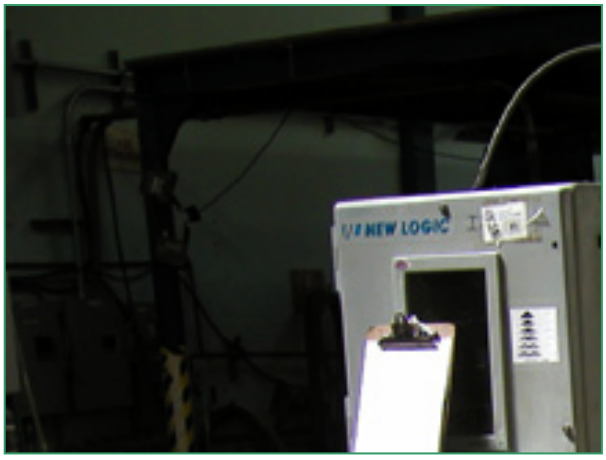

Image #1 VSEP Series L Pilot Test Set up

Special modifications in materials and construction can be made to the Series L to accommodate testing of certain chemical components. The Series L can also be manufactured with explosion-proof specifications. In addition to the VSEP Series L Machine, the process includes a 2 hp “Hydra-Cell” progressive cavity pump capable of 3 GPM at 1200 psi as well as a Polypropylene Tank for storage of the feed material. Many materials of construction are available and can be interchanged depending on the situation.

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Test Protocol

A test procedure was developed based on information gathered. The test work was set up so that performance can be measured against each of the process objectives shown above. The process of filtration is dynamic and involves many variables. This test was conducted by isolating as many of these variables as possible to determine the optimum in each case.

STEP 1 MEMBRANE SELECTION.

This step is used to evaluate a variety of membranes on the sample material to determine the best membrane in terms of flux and/or permeate quality. The performance is measured in what we refer to as re-circulation mode. This simply means we are not concentrating the material but returning the separated streams back to the feed tank and only measuring the relative performance of each membrane under the same conditions. This step is used to determine the optimum membrane

STEP 2 PRESSURE STUDY.

This step is used to determine the optimum pressure of the chosen membrane on your particular feed material. The permeate rate is measured as incremental increases in pressure are made to the system. It is possible to reach a point where increased pressure does not yield significant increase in permeate flow rate. This test will determine if this is the case and at what pressure this begins to occur.

STEP 3 SHORT LINE-OUT STUDY.

This step is used to measure the flux versus time to determine if the permeate rate is stable over a period of a few hours. This information can also be used to determine the cleaning frequency if one is necessary.

STEP 4 CONCENTRATION STUDY.

This part of the test is designed to measure flux vs. concentration or recovery. The test is completed in batch mode, as the membrane area is only 0.5 square feet. The permeate is continually removed from the system while the concentrated material is returned to the feed tank. This data is used to determine the average flux over the concentration/recovery range that in turn allows for preliminary system sizing.

STEP 5 CLEANING STUDY.

This part of the test is used to develop a preliminary cleaning routine if one is necessary. Various cleaners will be tested and the performance of each will be measured. In this way, the optimum cleaning procedure can be developed.

These steps were repeated for each stage of filtration testing

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PRELIMINARY TESTING INFORMATION

Application Information

Application:	Dewatering of Cooling Pond Water
Raw Feed Ph:	3.0
Total % Solids:	0.94%
Process Temperature:	10ºC to 30ºC (25ºC Temperature Correction Base)

Representative Cooling Pond water was sent to New Logic for testing. This water came in 55-gallon drums from the Piney Point site.

Test Conditions

Test Temperature:	15º-35ºC (Material was not intentionally heated)
Ph Level:	Initially 3.0
Sample Size:	55 Gallons
Pilot Unit:	Series L VSEP Machine
Membrane Area:	0.5 SF
Feed Solids:	~0.94%

The relative performance of several membranes was tested. The feed tank was prepared with the sample feed material and the system was configured in "Re-circulation Mode". Several membranes were installed and a short "Line-Out Study" for relative comparison. The membranes are compared based on flux & permeate quality.

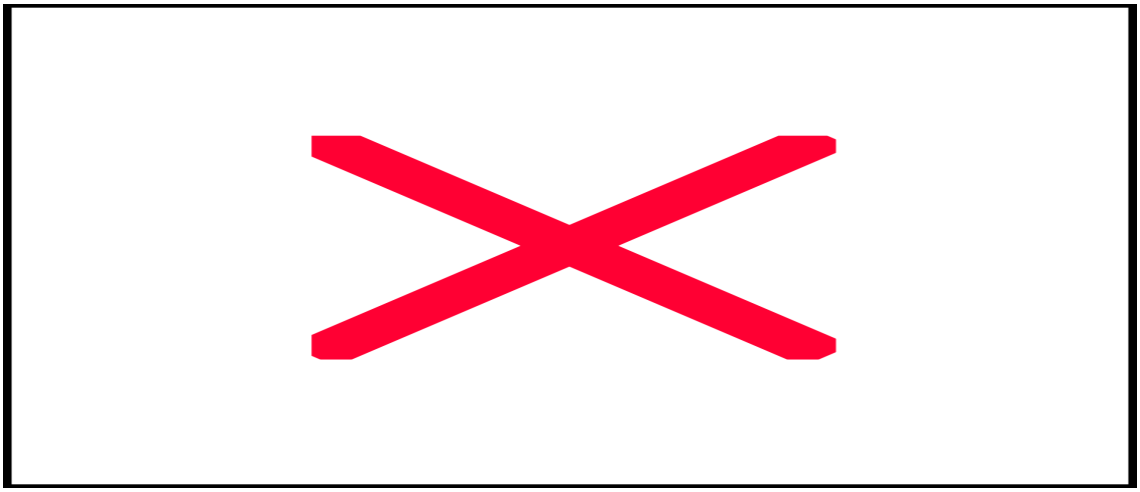

Image #2 Pilot Test Set up in Recirculation Mode

The study involves straight multiple stage reverse osmosis filtration of the untreated pond water. Prior to discharge, the water would need to be pH adjusted to 6.0 and this was not tested. Further study would be required on the best way to pH adjust and at what sequence this is done. pH adjusting prior to reverse osmosis filtration would improve the results shown here.

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TEST RESULTS

Stage One Membrane Selection

Table 4. Membranes Chosen for Study

Based on the Test Objectives, the following membranes were chosen for study:

Membrane	Type	Size Rating	Max Temp	Water Flux	Composition
X-20	RO	99% NaCl rej	60ºC	14 gfd	Polyamide
ESPA	RO	99% NaCl rej	60ºC	13 gfd	Composite Polyamide
LFC 1	RO	99.5% NaCl rej	60ºC	9 gfd	Thin Film Composite

- Average Batch Cell Test Results in GFD on new membrane @ 60 psi & 20ºC

Each membrane was run for several hours and data was collected during this time to measure performance. Flow rates, pressure, temperature and vibration amplitude are all recorded. The following table shows the relative performance of each membrane:

Table 5. Relative Membrane Performance

Membrane	Initial Flow*	Ending Flow*	Pressure	% Solids	pH	Conductivity
X-20	121 ml	78 ml	400 psi	0.22%	3.10	243 µS
ESPA	132 ml	90 ml	400 psi	0.00%	3.02	238 µS
LFC 1	92 ml	85 ml	400 psi	0.16 %	3.02	256 µS
			Feed was:	0.94 %	3.23	8,880 µS

- Flow rates are in ml/min and are temperature corrected to 25ºC

Samples of each RO membranes were collected and analyzed. Flow rates are recorded all during the line out study. The beginning and ending rates are shown above. For the purpose of comparison, 400 psig was used as the driving pressure. The % solids number shown above is a total solids number and was derived by using a left on drying technique. Grab samples of each permeate were collected for analysis.

ESPA membrane was chosen for further study. It provided the best permeate quality both in terms of conductivity and of % solids as measured by evaporation. It also produced the highest flow rate at the end of the line out period.

RO membrane study results are shown in the attached Graph#1: Stage One Membrane Comparison

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Stage One Pressure Selection

The Optimum Pressure was determined by measuring the flux at various pressures. The Optimum Pressure for RO of this application was determined to be 700 psi.

The results of this study are shown in the attached Graph #2: Pressure Study

Stage One Concentration Study

For this study a larger filter pack was installed. The test unit was converted to "P mode" using a membrane filter pack containing 16.8 SF of membrane. The system was started up first in "Recirculation Mode" and also set to the Optimum Pressure. The system was run for a few hours to verify that the flux is stable and the system has reached equilibrium. Then an actuated valve is used to throttle the concentrate outlet flow to control the % recovery of filtrate through the system. The permeate flow rate was measured at timed intervals to determine flow rate produced by the system at various levels of concentration. The average flux rate can be calculated from these numbers and is used to size the full-scale equipment.

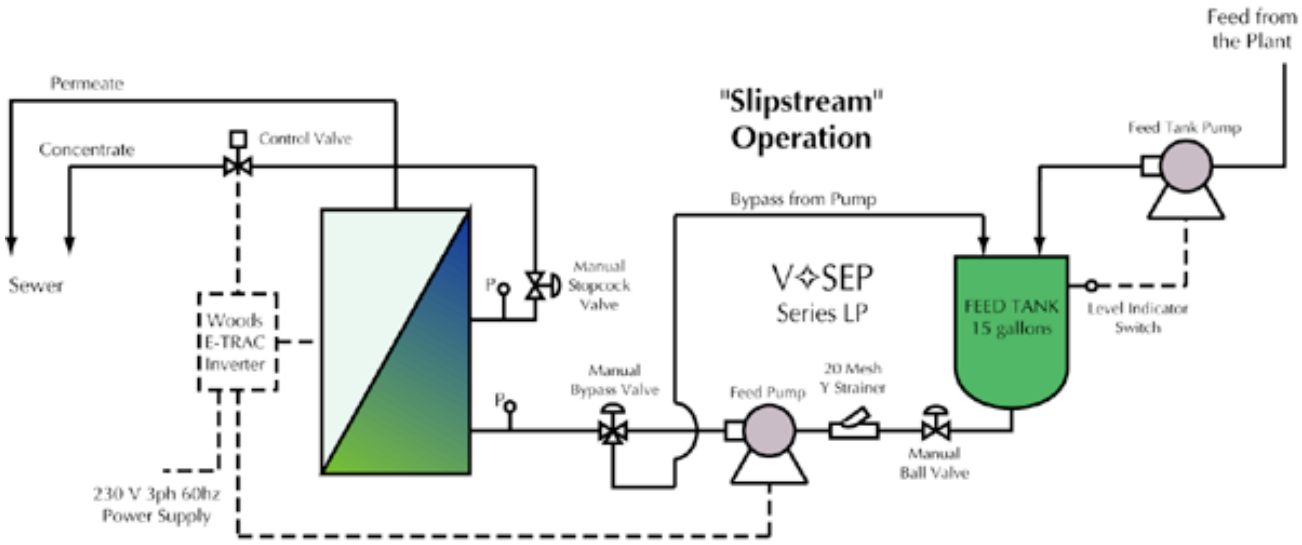

Image #3 Pilot Test Set up in Slipstream Mode

Four studies were done at various recovery or concentration levels. Each of these was done at 700 psi. The following Table shows the performance of each concentration study:

Table 6. Flow Rate vs. % Recovery of Filtrate

% Recovery	Initial Flow Rate	Flow Rate @ 2 Hours	Flow Rate After 1 Day
65%	50 gfd	39 gfd	23 gfd
70%	46 gfd	33 gfd	10 gfd
80%	38 gfd	30 gfd	7 gfd
85%	29 gfd	8 gfd	3 gfd

* Flow Rates are ml/min corrected to 25ºC @700 psi

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The results of the concentration study are shown in Graph #5: Flux vs. Time @ various recoveries Since multiple stages of filtration are to be used 65% recovery was determined to be the optimum for the first stage of filtration. The following Table shows the performance of the "Stage One RO Concentration Study":

Table 7. Stage One Membrane Performance @ Optimum % Recovery

Ave Flux	Initial Flux*	Ending Flux*	Initial Solids	Ending Solids	% Recovery
30.2 gfd	50 gfd	23 gfd	0.94%	2.68%	65%

* Flow Rates are ml/min corrected to 25ºC @700 psi

The results of the RO Stage One study are shown in the Graph #6: Flux vs. Time @ Optimum

During the concentration study, suspended solids were actually created as dissolved solids at saturation precipitated out of solution once their solubility limit was surpassed. This event would cause great problems for conventional membrane systems, but, with vibratory filtration, the precipitated solids are held in suspension away from the membrane and washed away.

Image #4 Stage One Samples

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Feed, Permeate, and Concentrate Samples from Stage One Testing

Grab samples were collected as shown on the previous page. These samples were sent out for analysis. The following table shows the results of one stage of filtration. The complete results plus estimates for all metals and other contaminants are shown in the appendix later in this report.

Table 8. Stage One Analytical Results (abbreviated)

Stage One Results		Limits	Initial Raw Feed	Estimated RO Permeate	Estimated Reject
		ppm (mg/l)	ppm (mg/l)	ppm (mg/l)	ppm (mg/l)
pH		6.5	3.0	3.0	
Fluoride	F	5.0	66.0	37.0	130.00
Ammonia	NH4	1.0	370.0	30.0	820.00
Total Nitrogen	TN	2.0	450.0	16.0	1100.00
Phosphorous	P	0.5	1,030.0	13.0	2918.71
Total Dissolved Solids	TDS	50.0	8,260.0	120.0	14900.00

From these results, you can see that one stage of filtration made significant reductions in all of the target components, but did not produce filtrate clean enough for discharge. Additional filtration was done and is shown later in this report.

Stage One Cleaning Study

The system was flushed with warm water, running the permeate & concentrate to the drain for 10 minutes. A water permeate flow measurement, (Fouled Flow), was taken. The cleaning tank was prepared with NLR 404 Acidic cleaning solution using 45ºC water and pH adjusted to 2.5 using some HCl. The system was started & the first 15% of cleaner diverted to the drain. After 30 minutes of cleaning, the system was flushed and the first post-cleaning water flux,(Cleaning Flow)was taken.

The second cleaner, NLR 505, is prepared in the cleaning tank with 45ºC water and is pH adjusted to 11.5 using some NaOH. The system is run for 60 minutes in recirculation mode after diverting the first 15% of cleaning solution to the drain. After this, the system is flushed once again with warm water and the 2nd Cleaning Flow is recorded.

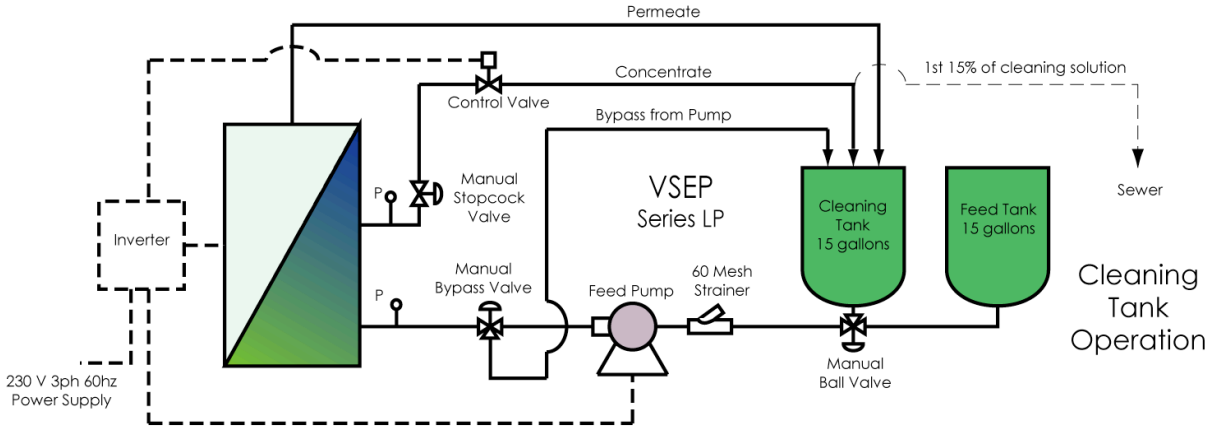

Image #5 Pilot Set up in Cleaning Mode

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Cleaning Results:

The Following Table Shows the Results of Cleaning:

Table 9. Stage One Cleaning Results

Membrane	Cleaning Step	Cleaner Temp	pH	Flow Rate	% of New Flow
ESPA	New Membrane	-	-	24 ml	100%
	Warm Water Flush	40ºC	-	8 ml	33%
	After NLR 404	45ºC	2.5	16 ml	63%
	After NLR 505	45ºC	11.5	22 ml	92%

* Flow rates are on water and are temperature corrected to 25ºC and are given in terms of ml/min

Based on these results, it can be said that warm water flushing and NLR 404 and 505 cleaners are effective at cleaning the membrane and recovering flux rates. Warm water use is critical to the success of the cleaning.

Stage Two Concentration Study

65% recovery of permeate was determined to be ideal for Stage One. The idea is to set up a flow scenario that would yield high flow rates and make a good first cut at the separation. Then the reject from the first stage would be further concentrated in a much smaller "Concentrator Stage" This stage is referred to as Stage Two in this report.

The following Table shows the performance of the “Stage Two RO Concentration Study”:

Table 10. Stage Two Concentration Study

Ave Flux	Initial Flux*	Ending Flux*	Initial Solids	Ending Solids	% Recovery
7.9 gfd	26.8 gfd	2.4 gfd	2.28%	9.25%	75%

* Flow Rates are ml/min corrected to 25ºC @700 psi

The results of the RO Stage Two study are shown in the Graph #7: Stage Two Flux vs. Recovery

Table 11. Stage Two Analytical Results (abbreviated)

Stage Two Results			Initial	Estimated	Estimated
		Limits	Raw Feed	RO Permeate	Reject
		ppm (mg/l)	ppm (mg/l)	ppm (mg/l)	ppm (mg/l)
Fluoride	F	5.0	130.00	48.0	390.00
Ammonia	NH4	1.0	820.00	46.0	2,500.00
Total Nitrogen	TN	2.0	1,100.00	48.0	4,300.00
Phosphorous	P	0.5	2,918.71	20.7	11,777.35
Total Dissolved Solids	TDS	50.0	14,900.00	420.0	61,200.00

The complete results plus estimates for all metals and other contaminants are shown in the appendix later in this report.

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Stage Three Concentration Study

The filtrate from Stage One is still high is dissolved solids, some of them near their solubility limit. For that reason it was decided that a second stage of filtration would be required, and that the membrane system that should be used would be the vibratory VSEP RO system. The permeate from stage one was collected and used for the polishing step here called Stage Three.

The following Table shows the performance of the "Stage Three RO Concentration Study":

Table 12. Stage Three Concentration Study

Ave Flux	Initial Flux*	Ending Flux*	Initial Solids	Ending Solids	% Recovery
50.9 gfd	70.0 gfd	45.7 gfd	0.02%	0.15%	95%

* Flow Rates are ml/min corrected to 25ºC @550 psi

The results of the RO Stage Two study are shown in the Graph #8: Stage Three Flux vs. Recovery

Table 13. Stage Three Analytical Results (abbreviated)

Stage Three Results			Initial	Estimated	Estimated
		Limits	Raw Feed	RO Permeate	Reject
		ppm (mg/l)	ppm (mg/l)	ppm (mg/l)	ppm (mg/l)
Fluoride	F	5.0	37.0	23.0	92.00
Ammonia	NH4	1.0	30.0	1.4	93.00
Total Nitrogen	TN	2.0	16.0	2.0	110.00
Phosphorous	P	0.5	13.0	0.4	253.33
Total Dissolved Solids	TDS	50.0	120.0	40	1340.00

After two passes through an RO membrane, the water is pretty clean but is still not quite good enough. At this point, Total Nitrogen and Ammonia are right at the limit. Fluoride is the remaining stubborn element that is over limit. For this reason, a third pass through RO was done using conventional spiral wound membrane modules. This is called Stage Four in this report and the results are shown below. The complete results plus estimates for all metals and other contaminants are shown in the appendix later in this report.

Stage Four Concentration Study

Table 14. Stage Four Analytical Results (abbreviated)

Stage Four Results			Initial	Estimated	Estimated
		Limits	Raw Feed	RO Permeate	Reject
		ppm (mg/l)	ppm (mg/l)	ppm (mg/l)	ppm (mg/l)
Fluoride	F	5.0	23.0	4.6	372.6
Ammonia	NH4	1.0	1.4	0.1	26.8
Total Nitrogen	TN	2.0	2.0	0.3	35.3
Phosphorous	P	0.5	0.4	0.00	6.8
Total Dissolved Solids	TDS	50.0	40.0	13.3	546.7

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SUMMARY OF RESULTS

Summary by Stage

The Laboratory Testing of the Pond Water sample was successfully completed and the feasibility of the project was verified. The ending results of testing and optimum process variables include:

Stage One - First Pass of RO Filtration

Most Suitable Membrane:	ESPA
Cleaning Solution/s:	Warm water flush, NLR 404, NLR 505
Optimum Pressure:	700 psi
Design Basis Temperature:	25ºC
Optimum % Recovery:	65%
Actual Average Flux*:	30.24 GFD

Stage Two - Concentrating the Reject from Stage One

Most Suitable Membrane:	ESPA
Cleaning Solution/s:	Warm water flush, NLR 404, NLR 505
Optimum Pressure:	700 psi
Design Basis Temperature:	25ºC
Optimum % Recovery:	75%
Actual Average Flux*:	11.3 GFD

Stage Three - Polishing the Filtrate from Stage One

Most Suitable Membrane:	ESPA
Cleaning Solution/s:	Warm water flush, NLR 404, NLR 505
Optimum Pressure:	550 psi
Design Basis Temperature:	25ºC
Optimum % Recovery:	95%
Actual Average Flux*:	50.85 GFD

Stage Four - Spiral Polishing the Filtrate from Stage Three

Most Suitable Membrane:	ESPA
Cleaning Solution/s:	Warm water flush, NLR 404, NLR 505
Optimum Pressure:	300 psi
Design Basis Temperature:	25ºC
Optimum % Recovery:	85%

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Process Flow Scheme

Based on the results of testing, the following flow scheme was developed:

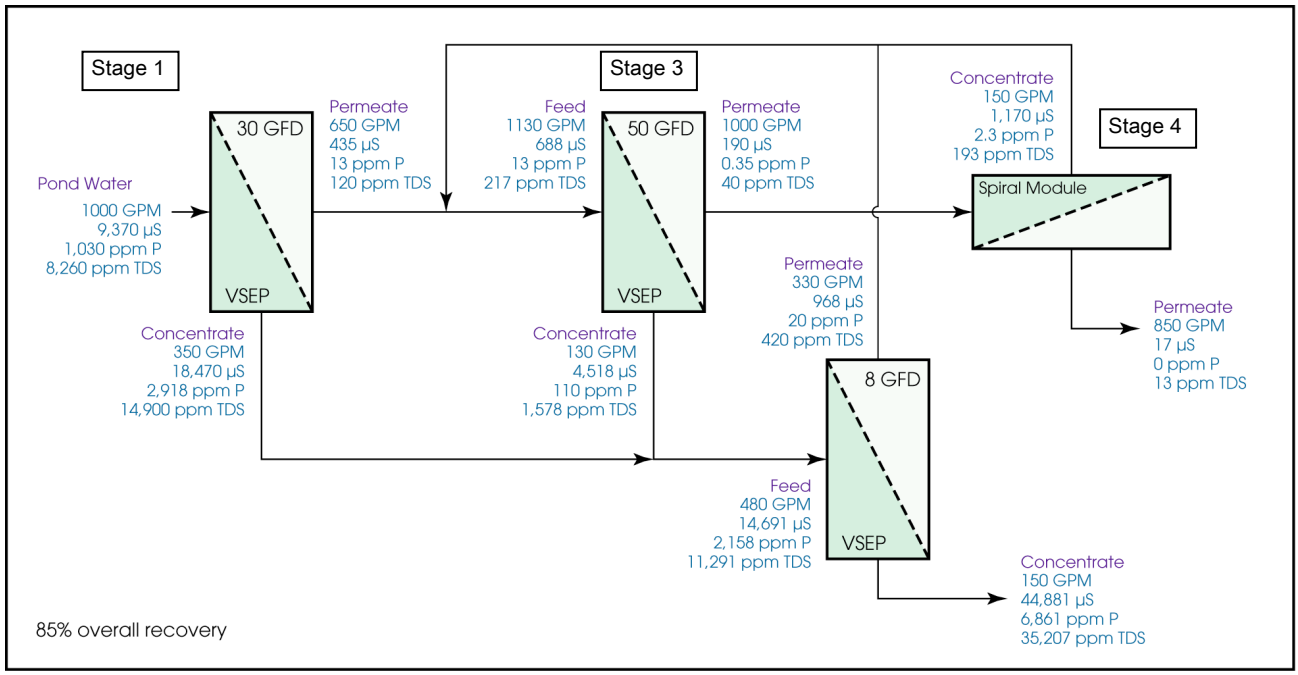

Image #6 Pond Water Block Flow Diagram

The main objective is to make very clean water for discharge and at the same time, try to minimize the reject volume left over. It was determined that three passes through Reverse Osmosis would be required to meet the strict discharge requirements for Fluoride, Ammonia, and Total Nitrogen. Then with each stage of filtration optimized and balanced, the remaining reject streams should be further concentrated as much as possible.

In the case shown above, the reject from the spiral unit can be sent back to the inlet to the second pass step. The reject from the first two RO passes are collected and sent to a smaller concentrator stage of filtration also using Reverse Osmosis

Stage 2

The end result is that the overall recovery can be as high as 85% of the initial volume.

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Final Analytical Results

After three stages of filtration, the final water quality is below the discharge limits for surface water discharge in Florida. The Table below shows the beginning and ending numbers as they relate to the discharge limits.

Detailed analytical results are shown later in the appendix for each stage of filtration.

Table 15. Analytical Result Summary

Typical VSEP Results:	Untreated	RO Filtrate	Discharge Limits
Fluoride, Fl	66 mg/L	4 mg/L	5 mg/L
Ammonia, NH4	370 mg/L	0.1 mg/L	1 mg/L
Total Nitorgen, TN	450 mg/L	0.3 mg/L	2 mg/L
Phosphorous, P	1,030 mg/L	ND	0.5 mg/L
Total Dissolved Solids, TDS	8,260 mg/L	13 mg/L	40 mg/L
Conductivity, µS	9,370 µS	17 µS	1275 µS
Aluminum, Al	220 mg/L	0.002 mg/L	0.2 mg/L
Magnesium, (Mg)	223 mg/L	0.03 mg/L	200 mg/L
Potassium, K	210 mg/L	1.7 mg/L	10 mg/L

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Calculating Membrane Area Needed

In order to determine what size or how many VSEP Series i Filter Packs are needed for a project, calculations are made from the pilot data shown above. The number used as a basis is the Actual Average Flux at the desired % recovery. With this number, you can ascertain the amount of membrane area that will be necessary to process a desired flow rate. The calculations are as follows:

Stage One Given:

Process Flow Rate:	1000 gpm
Actual Average Flux:	30.24 gfd
% Recovery Filtrate:	65%

Gallons per day = (1000 gal/min)*(1440 min/day) = 1,440,000 gpd

Membrane needed = (1,440,000 gpd x 65%)÷(30.24 gfd)÷(22/24 hour/day) = 33,644 Sq. Ft.

Stage Two Given:

Process Flow Rate:	480 gpm (350 gpm from Stage One, 130 gpm from Stage Three)
Actual Average Flux:	11.3 gfd
% Recovery Filtrate:	75%

Gallons per day = (480 gal/min)*(1440 min/day) = 691,200 gpd

Membrane needed = (691,200 gpd x 75%)÷(11.3 gfd)÷(22/24 hour/day) = 49,865 Sq. Ft.

Stage Three Given:

Process Flow Rate:	1130 gpm (650 gpm stage 1, 330 gpm stage 2, 150 gpm stage 4)
Actual Average Flux:	50.85 gfd
% Recovery Filtrate:	95%

Gallons per day = (1130 gal/min)*(1440 min/day) = 1,627,200 gpd

Membrane needed = (1,627,200 gpd x 95%)÷(50.85 gfd)÷(22/24 hour/day) = 33,043 Sq. Ft.

Stage Four Given:

Process Flow Rate:	1000 gpm
Actual Average Flux:	10 gfd (estimated)
% Recovery Filtrate:	85%

Gallons per day = (1000 gal/min)*(1440 min/day) = 1,440,000 gpd

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Membrane needed = (1,440,000 gpd x 85%)÷(10 gfd)÷(22/24 hour/day) = 133,043 Sq. Ft.

Conclusion

The main driving force for expansion of the use of membranes has been tighter and tighter controls on product quality and discharge limits. Membranes are precise and accurate tools that will yield a predictable result. Membranes are made according to specification and can be constructed using various polymers and be made with specific pore size ratings or rejection characteristics. Once made and put online, the permeate quality from operation is consistent and constant. The selectivity of membranes is not dependent on the dosing of chemicals, the expertise of the operator, or any other mitigating factor. Use of membranes can greatly reduce the impact of varying process conditions when it comes to the end result of the separation.

In addition, the selectivity is extremely fine. Membranes can be sized to selectively reject one dissolve solid while allowing another to pass. This ability to selectively isolate particulates is extremely useful and not accomplished with greater efficiency by any other technology. The selectivity also allows for plenty of safety factor in design when it comes to meeting environmental discharge regulations. New Logic has over 200 types of membranes available and can select the most appropriate membrane for any particular application.

Operating a chemical plant in today's world is no easy task. Plant managers need to deal with everything from processing bottlenecks, automation glitches, safety concerns, public opinion, and environmental regulations. Most chemical production plants are massive operations with thousands of employees and contract workers. The job of any good manager is to make sure the system runs smoothly and risk of process upset is minimized.

New regulations have arrived and even more are approaching when it comes to discharge of waste product from manufacturing. The Clean Water Act and pending Arsenic Regulations are just two examples. In addition water is becoming a more valuable resource due to strained infrastructure for water delivery. In order to deal with new regulations, many facilities are attempting to go Zero Discharge. This can be the best of both worlds, when water is reused in the process and hazardous materials are recovered for proper disposal or reuse in the operations. Very often valuable product is part of the discharge and this can be recovered and added to the bottom line.

Membrane filtration offers the ultimate is wastewater treatment and the results often exceed even the most stringent regulations. Membrane separation is precise and predictable. With VSEP, no chemical addition is required and consistent results can be attained. The first choice is to re-use the water in the manufacturing process and to reduce demand on local water delivery systems.

The results of this study show that Vibratory Membrane filtration can be used effectively to produce clean water for discharge. This option represents a very attractive alternative both in terms of environmental impact and cost.

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Glossary:

Average Flux: The time weighted average flux measured over a particular concentration range

Batch Concentration: The machine configuration where a fixed amount of feed slurry is progressively concentrated by removal of permeate from the system. The concentrate from the system is returned to the feed tank.

Concentrate: The part of the fluid solution, which does not permeate through the membrane

Concentration Factor: The ratio of feed flow rate to the concentrate flow rate

Feed: Also called feed slurry. It is the raw solution, which is offered for filtration. It typically has suspended solids, bacteria, or molecules, which are to be segregated from a clear filtrate, and reduced in size making a concentrate solution of feed slurry.

Filter Pack: The filtering module, which contains the membrane, layers and is housed by a fiberglass enclosure

Fouling: The accumulation of materials on the membrane surface or structure, which results in a decrease in flux

Flux: Not the same as flow rate. Flux is a measurement of the volume of fluid, which passes through he membrane during a certain time interval for a set area of membrane, ie GFD, LMH

Instantaneous Flux: Flux measured at a given moment in time

L Mode: The configuration where a single piece of membrane is used and supported by clamshells on a Series L or LP Machine. This also means that the Feed slurry enters the filter pack from below and the permeate exits from the top

Line Out Study: The procedure of measuring the membrane flux over time in order to determine eventual stability

Microfiltration: Filtration of particles suspended in solution, which are ≥ 0.1 µm or 500,000 daltons in size or weight.

Micron: A unit of measurement. 1 Micron is equal to one-millionth of a meter (10^{-6}). 1 Micron also equals 12,000 mesh or .0000394". The limit of human visibility is 40 Microns.

Molecular Weight: The number that expresses the average mass of the molecules of a compound to the mass of an atom of Carbon 12 at a value of exactly 12

Nanofiltration: Filtration of particles suspended in solution which are ≥ 0.01 µm or 1000 daltons in size or weight.

Optimum Pressure: The value of maximum pressure at which above that pressure is detrimental to performance

P Mode: The configuration where 19 layers of membrane are used as a filter pack on a Series LP Machine. This also means that the Feed slurry enters the filter pack from the top and the permeate also exits from the top. The actuated valve is typically used in "P Mode".

Percent Recovery: The ratio of permeate flow rate to the feed flow rate

Permeate: Also called filtrate. It is the part of the solution, which is able to or allowed to filter through the membrane. The particle size of solids still suspended is determined by the pore size of the discriminating membrane.

Retentate: The part of the solution, which is rejected by the membrane pores, also known as concentrate

Reverse Osmosis: Filtration of particles suspended in solution, which are ≥ 0.001 µm or 100 daltons in size or weight.

Ultrafiltration: Filtration of particles suspended in solution which are 0.01 to 0.1 µm or 1000 to 500,000 daltons in size or weight.

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BIBLIOGRAPHY

The following Publications or Articles were used for preparation of this study:

Metcalf & Eddy , 1991, Wastewater Engineering 3rd Edition, Boston: McGraw-Hill, 1334 p.

American Society of Civil Engineers, 1997, Water Treatment Plant Design 3rd Edition, New York: McGraw-Hill, 806 p.

Florida Institute of Phosphate Research, Guidelines for the Preparation of Applied Research Proposals, http://www.fipr.state.fl.us/applygr.htm

Florida Institute of Phosphate Research, December 2000, Style Manual

United States Environmental Protection Agency (EPA), 2003, 40 CFR 141 & 143, National Primary Drinking Water Standards, 5 p.

United States Environmental Protection Agency (EPA), 2003, 40 CFR 141 & 143, National Secondary Drinking Water Standards, 5 p.

United States Environmental Protection Agency (EPA), September 2000, Publication # EPA 832-F-00-018, Wastewater Technology Fact Sheet - Chemical Precipitation, Office of Water, Washington DC

State of Florida, Department of Environmental Protection (DEP), Chapter 62-673 Phosphogypsum Management

State of Florida, Department of Environmental Protection (DEP), Chapter 62-302-530 Criteria for Surface Water Quality Classifications

State of Florida, Department of Environmental Protection (DEP), Chapter 62-302 Surface Water Quality Standards

State of Florida, Department of Environmental Protection (DEP), Case No. 02-1054, Emergency Authorization to the Receiver Allowing for the Discharge of Treated Process Wastewater from the Piney Point, Inc. Process Water System

United States Environmental Protection Agency (EPA), April 2003, Fact Sheet: Piney Point. EPA Process of Issuing an Emergency Permit for Ocean Disposal of Treated Wastewater in the Gulf of Mexico from the Piney Point Phosphate Facility in Manatee County Florida.

United States Environmental Protection Agency (EPA), June 2003, Federal Register/Vol 67, no. 106 Proposed Rules 40 CFR 141

United States Environmental Protection Agency (EPA), December 1995, Mineral Processing Facilities Placing Mixtures of Exempt and Non-Exempt Wastes in On-site Waste Management Units, Office of Solid Waste, Washington DC

United States Environmental Protection Agency (EPA), April 1998, Identification and Description of Mineral Processing Sectors and Waste Streams, p. 281-303, Office of Solid Waste, Washington DC

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Chemical Processing Magazine, March 2003, Industrial Strength Membrane Filtration - VSEP® Vibrating Membrane System Proves Membranes Aren't Just for Water Anymore

Filtration Separation Magazine, Jan/Feb 2003, Vibratory Shear Guards Against Mineral Scale Membrane Fouling

Technical Articles:

Kinetics of Mineral Scale Membrane Fouling - A Comparison of Conventional Crossflow Membranes and VSEP, a Vibratory Membrane System, Nov 2002

Various Technical Articles Posted at: http://www.vsep.com/downloads

- Membrane Filtration of Waste Oil - An Economical and Environmentally Sound Solution,
- Case Study - Membrane Filtration of Hog Manure
- Technical Summary - Membrane Filtration of Phosphoric Fertilizers
- Case Study - Membrane Filtration of Colloidal Silica, 2001
- Case Study - Membrane Filtration of Acid Mine Drainage
- Using VSEP for Polymer Diafiltration and Desalting
- VSEP Filtration of Desalter Effluent
- Membrane Filtration of Metal Plating Wastewater
- VSEP Filtration for Glycol Recovery
- Membrane Filtration and Precious Metals Recovery
- Using VSEP to Treat Produced Water
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Publications:

Chemical Engineering Progress, January 1998, Solve Membrane Filtration Problems with High-Shear Filtration

Technical Articles:

Various Technical Articles Posted at: http://www.vsep.com/downloads

- Membrane Filtration of Landfill Leachate
- Using VSEP for Filtration of Oily Wastewater from a Waste Hauler
- Concentrating Carbon Black using Membrane Filtration
- An Examination of the use of VSEP Nanofiltration Technology to Replace Cold, Warm, and Hot Lime Softening

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