Using VSEP Vibrating Membranes to Treat Offshore Produced Water

Overview

A unique membrane filtration system has been tested at several major onshore oil drilling sites to treat produced water, which is generated during the production of crude oil. The system is known as VSEP (Vibratory Shear Enhanced Process). The VSEP system has also been tested and installed for several refinery applications including Stripped Sour Water, Desalter Effluent, and End of Pipe Wastewater.

Just recently, test work was completed for an offshore oil platform in Northern Peru for treatment of produced water using VSEP. This Application Note summarizes the events and the results of two months of testing.

The VSEP system uses a polymeric membrane module with special construction for service with high solids loading and oil. The system is able to treat oil-bearing water and is able to recover greater than 90% of the oily wastewater as clean water for discharge or reuse. VSEP has very good overall usefulness. Membranes have the advantage of being simple efficient separating devices to hold back oil, grease, metals, TOC, and COD. Using Reverse Osmosis, VSEP is capable of producing much cleaner water for discharge overboard than conventional methods.

Membranes

Membrane separation technology has been around for many years. Initially, the use of membranes was isolated to a laboratory scale. However, improvements over the past twenty years have made it possible to use membranes on an industrial level. A membrane is simply a synthetic barrier, which prevents the transport of certain components based on various characteristics. Membranes are very diverse in their nature with the one unifying theme to separate. They can be manufactured to be electrically neutral, positive, negative or bipolar. There are four main categories of membrane filtration. These are determined by the Pore size or Molecular Weight cut off.

Filtration Type	Particle Size	Molecular Weight
Reverse Osmosis	≤ 0.001 µm	≤ 100 Dalton
Nanofiltration	0.001-0.01 µm	100 - 1000 Dalton
Ultrafiltration	0.01-0.1 µm	1000-500,000 Dalton
Microfiltration	≥ 0.1 µm	≥ 500,000 Dalton

Reverse Osmosis Membranes

These are the tightest membranes for separating materials. They are generally rated on the % of salts that they can remove from a feed stream. Usually, the rejection of NaCl will be greater than 95% in order to be classed as an RO membrane. An example of their use would be for filtering seawater in order to remove the salt. Reverse Osmosis membranes don't have structural pores. Filtration occurs as ionic species are able to diffuse their way through the membrane itself.

Nanofiltration Membranes

As the name suggests, these membranes are used to separate materials on the order of nanometers. These membranes are not usually rated based on their pore size because the pores are very small and difficult to measure accurately. Instead they are rated based on the approximate molecular weight of the components that they reject or the % of salts that they can remove from a stream. These membranes are used predominately for wastewater treatment but they are also used to concentrate material that has a wide range of particle sizes.

Ultrafiltration Membranes

Conventional Ultrafiltration membranes are composed of some type of polymer material with pores ranging from a little less than 0.01 µm to 0.1 µm. These membranes are used for many different separations including oily wastewater treatment, protein concentration, colloidal silica concentration and for the treatment of various industrial wastewaters.

What is Produced Water?

Oil drilling operations can create large quantities of contaminated water known as "Produced Water", or water that is produced from the well. Most underground oil reservoirs have a natural water layer called Formation Water, which lies underneath the hydrocarbons. As a well ages and oil becomes difficult to remove, water or steam is injected into the reservoirs to help force the oil to the surface. Both formation and injected water eventually make their way to the top and are produced at the well head along with the hydrocarbons. As the oil/water mixture is pumped out of the well, it is separated yielding the hydrocarbon product and the Produced Water. As the oil level drops in the reservoir, the amount of water injected increases to fill the void. In the United States, Produced Water coming from Oil wells is 8 times the volume of the oil produced.

Produced Water Regulation

International conventions have set provisional targets of 40 ppm for hydrocarbons in offshore operation discharge. This 40-ppm number is a target and is voluntary in some areas. In offshore environments, anything above 100ppm is considered an oil spill. At onshore installations, the oil companies have more space for large heavy equipment, and long process times to reduce the oil in water concentration to as low as 4 ppm. In US coastal waters, the EPA set limits in 1993 at 29ppm monthly average "oil and grease" content for produced water, with a daily maximum of 42ppm. Offshore, discharges of produced water that contain oil cannot be compared with large oil spills because the small amounts of oil are dispersed within the sea and do not form a surface slick. But, nearly all offshore installations usually have faint but visible streaks of sheen extending for hundreds of meters downwind of them, even when their water treatment plants are the best available. On calm water a visible sheen can form at 25ppm. Produced water volumes tend to increase dramatically as older oilfields pass their peak production

Onshore vs. Offshore Treatment

Offshore, there hasn't been time or space for the best treatment methods, whereas at onshore installations, oily water treatment can be intermittent allowing batch treatment and recirculation. Offshore water treatment must rely on equipment such as plate separators, gas flotation units, centrifuges, and hydrocyclones to get as much oil as possible out of the water. In offshore platforms, there is neither space nor time to allow treated water to lie for days in settlement ponds where oil can be skimmed off and purified using biological agents. Produced water discharged offshore may therefore be up to 10 times oilier than the discharges from onshore facilities. Some offshore facilities rely on floating water treatment by ships known as Storage and Offloading vessels (FSOs or FPSOs). The movement of the anchored ship in a swell can upset water treatment processes and lead to discharges above the allowable average levels. This problem is particularly acute when storms generate very large waves, which happen about 60 days a year in the North Sea.

Problems with Discharge

Produced water has elevated concentrations of heavy metals including barium, beryllium, cadmium, chromium, copper, iron, lead, and zinc. There are also small amounts of the natural radionucleides, radium226 and radium228. When diluted and mixed with seawater, treated produced water does not pose an environmental hazard. However, in shallow turbid waters near the shore or for onshore discharges to land based water bodies, elevated concentrations of hydrocarbons and metals in produced water can be toxic. As more information has become available on the possible long-term environmental effects of pouring large quantities of even mildly polluted water into the waterways every day; industry has continued the search for solutions. The oil industry was able to achieve an average for 1998 of 22ppm.

Test Project Information

During the months of October 2005 to November 2005, New Logic Research, (NLR), conducted pilot testing of its VSEP membrane filtration technology for the treatment of produced water in Northern Peru at an offshore oil-drilling rig. VSEP technology is a unique membrane system that uses vibration in order to limit the fouling/plugging of the membranes in use as the filtration media.

For this application, the client had recently expanded drilling and oil production at the site and this had created an urgent need for the treatment of produced water. The site included some existing wells and also some brand new wells brought online as part of exploration of a new leased area. While bringing these wells online, some were producing water and some were not. Without any method of treating the water, the wells producing water were shut in until a treatment system could be provided. It was also uncertain how long the producing wells would continue to only produce oil. It was only a matter of time until water was generated. As a stopgap measure, water generated was barged to shore and piped to an onshore wastewater treatment process. This process involved chemical treatment of the water and even with plenty of room and time, was having difficulty meeting the strict requirements for discharge

Treatment Objectives

The customer identified two primary quantitative objectives for this project. These two objectives were the reduction of Oil and Grease to discharge limits and also the reduction of Barium to discharge limits. Oil and Grease limits were reported to NLR as “below 30 ppm”. Barium limits were reported to NLR as “below 3 ppm”. Reaching these objectives was critical for the customer regardless of the variation in the feed quality to the VSEP system.

In addition to these quantitative objectives, the customer also communicated the desire to minimize the concentrate volume to a maximum degree. The economics of the project will depend heavily on the overall recovery of the filtration system. Due to the remote location (ocean platform) of the production facility, transportation of the final concentrate will be costly and must be minimized.

In addition footprint size is a prime concern. The VSEP system needed to demonstrate maximum throughput so that the amount of equipment could be minimized and the floor space required could be kept to a minimum. Weight and head height concerns also led to a desire for a small compact system with maximum efficiency.

Initial Feasibility Testing

In order to select the best membrane and to properly configure the test equipment for use offshore, a small sample of untreated produce water was shipped to NLR's testing lab in Emeryville, California. The sample contained 420 mg/L oil & grease and 20 mg/L Barium. The objective was to reduce these to <30 mg/L and <3 mg/L respectively.

A test procedure was developed based on information gathered from the customer and the stated objectives. 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. The variables were Membrane Type, Temperature, Pressure, Concentration Factor, and Rate of Fouling. In preparation for the Test, the sample material was pre-screened using a 100-mesh screen to remove large particles and then placed into a feed tank connected to the pilot scale VSEP system. Various membranes were installed and feed was introduced and pumped into the VSEP. Once settings were made on the VSEP, the Lab Technician recorded the data and measurements.

The following are the analytical results of testing:

Membrane	Barium	O&G
LFC-RO	0.077 mg/L	2.5 mg/L
ESPA-RO	0.064 mg/L	---
NTR-7450-NF	6.7 mg/L	---
NF-270	5.1 mg/L	42.7 mg/L
Final RO Permeate	0.98 mg/L	4.91 mg/L

Table 1: Initial Analytical Testing of Permeates

At this point, NLR focused on two of the membranes. The RO membrane, LFC, produced water quality that far exceeded the stated discharge limits. For that reason, it would be a great choice. However, its flow rate capacity was much lower than the NF membrane, NF-270. This membrane was almost able to meet the discharge requirements and had an excellent flow rate performance. Since one objective was to meet discharge requirements and one was to maximize throughput and minimize equipment size, the idea of using the NF membrane along with some other polishing step or pretreatment step was considered. This could result in a cheaper smaller solution than the straight VSEP RO concept.

Image 1: RO and NF Permeate Samples Collected

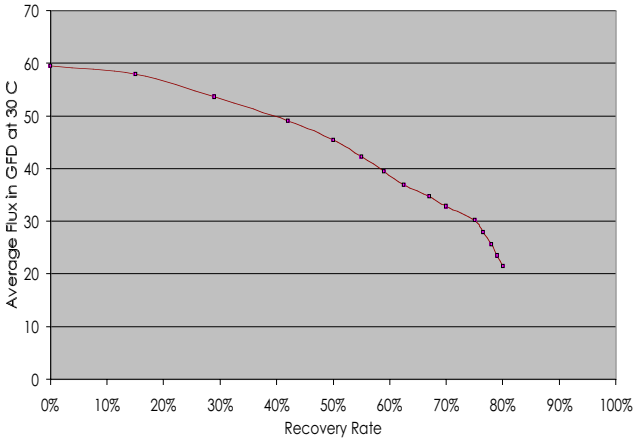
Equipment and Set-Up

NLR decided to try to test both options onsite and shipped a pilot VSEP membrane filtration unit and periphery equipment including a conventional spiral RO unit to be used for polishing of the NF if necessary. The VSEP was first tested using a Reverse Osmosis (RO) membrane in order to insure the achievement of the Oil & Grease and Barium discharge limits outlined in the study objectives. It was thought that the RO VSEP could produce permeate quality with extremely low levels of Barium and O&G and still be able to produce a high percentage of recovered permeate at a good throughput rate.

After demonstrating the RO performance, it was decided to also test Nanofiltration NF-270 membrane. This would theoretically produce better recovery and flux rates. The anticipation was that it might be possible for the NF VSEP to reach the discharge limits all by itself or possibly with some chemical pre-treatment. In the event that analytical results showed that the NF was unable to reach the discharge limits by itself or with aid of chemical pretreatment, it could easily be assumed that a 2nd stage of conventional RO membranes polishing the NF filtrate would certainly meet the discharge requirements.

RO VSEP Testing Results

Data was generated with a feed stream that had a starting TDS level of 6200 mg/L. A concentration study was completed to measure the permeate flow rate, (flux), at various concentration intervals. Under these conditions the VSEP RO system is able to achieve a recovery rate of 80% as permeate with an average flux of 21.5 GFD.



Graph 1: RO Flux vs Concentration Level

Use of the RO membrane in the VSEP system resulted in very good permeate quality. This was confirmed through laboratory analysis of permeate samples during testing. In all cases when using the RO membrane the discharge limits for O&G and Barium were met. Table 1 reports a typical sample collected on the RO VSEP system.

Sample	O&G	Barium
Feed	155 mg/L	4.439 mg/L
Permeate	2.5 mg/L	0.013 mg/L

Table 2: RO Analytical Results Onsite

NF VSEP Testing Results

The membrane chosen, NF-270, is a thin film composite membrane with a salt rejection rating of ~50%. When compared to RO membranes, this lower salt rejection rating of the NF membrane allows for higher permeate flux rates. This type of membrane is also able to reach higher recovery rates due to lower osmotic pressure constraints. The permeate quality won't be as good when compared to the RO membrane due to the lower salt rejection rating. The actual flux and recovery performance results of the NF membrane were as good if not better than expected.

Several scenarios were tested using the NF VSEP to verify optimum performance and the ability to meet the discharge requirements. The initial testing done on a small volume of sample indicated that the NF membrane would produce filtrate that is close to the discharge limits. Further testing was done here onsite to see whether in fact a single stage of NF VSEP could meet the discharge limits of 3.0 mg/L of Barium and 30.0 mg/L of O&G. The scenarios tested included the following:

- NF with no chemical addition or pre-treatment.
- NF with Iron based coagulant pretreatment
- NF with Aluminum based coagulant pretreatment

The following table shows the results of this testing:

Sample	O&G	Barium
Raw Feed	253 mg/L	4.91 mg/L
NF Permeate	29 mg/L	2.86 mg/L
Fe Treated Feed	253 mg/L	3.52 mg/L
NF Permeate	10 mg/L	1.71 mg/L
Al Treated Feed	165 mg/L	4.82 mg/L
NF Permeate	12 mg/L	0.23 mg/L

Table 3: NF Analytical Results Onsite

The following table shows throughput performance:

Sample	Flux	Recovery
Untreated Feed	48 gfd	95%
Fe Treated Feed	58 gfd	96%
Al Treated Feed	N/A	N/A

Table 4: NF Performance Results

At this point in the testing, NLR consulted with the client about the best method to use to decide how to complete testing. Unfortunately, analytical results were delayed and so this decision was made without the benefit of knowing exactly what the performance of the NF membrane was. The client did express some reservations about using chemicals offshore and even though NLR believed the analytical results would confirm good performance, the decision was made to go forward without any chemical pretreatment.

Testing Conclusions

Since the RO membrane performed well, but was limited to 80% recovery leaving 20% as reject that would need to be disposed of, it was decided to go further with the NF option which achieved > 95% recovery.

While the NF membrane was able to barely meet the discharge requirements, there was not enough room for safety in the numbers. Also, spikes in the feed would result in correspondingly higher spikes in the permeate. For this reason, NLR investigated the use of a primary VSEP NF system as a stage one. The design would also include a spiral RO module system that would polish the NF permeate as a stage two if and when needed.

Further testing was performed on the VSEP NF system and then filtrate was collected and sent for testing on the spiral RO system. This stage two system was able to operate at 89% recovery and achieved a flux rate of 15 gfd. The resulting combination of the VSEP NF followed by the spiral RO membrane would yield a cheaper smaller system than if VSEP RO were used as a single stage.

The RO system would only be used if needed and during times when it was not needed, the recovery of the VSEP system would produce >95% as filtrate leaving only 5% of the volume to dispose. At times when the 2nd stage RO spiral would be needed, it could either treat all the flow of the VSEP or a portion of the flow for blending. If it treated the entire flow, the overall recovery would be at worst 84.5%, which is better than the 80% that the VSEP RO would be capable of.

The ability of the VSEP NF followed by spiral RO if needed system to achieve very high recovery rates led to the conclusion that this configuration should be used.

Subsequent Conclusions

At the end of testing, NLR received the analytical results showing the performance of the coagulant treated feed. In the future, NLR believes that this option would be better than the two-stage membrane system. The capital and operating costs would be lower if a single stage of VSEP NF were used in conjunction with low dosing of coagulant prior to filtration. In addition, two new nanofiltration membrane have become available to NLR that are tighter than the NF-270 membrane that was tested. These membranes have been performing very well during other pilot trials and NLR now believes that either of these two membranes could produce adequate filtrate quality to meet the discharge requirements without the use of coagulant and still achieve very high recovery and flux. NLR is currently working with the same client to resume pilot testing using either or both of these new options.

The following table shows the final analytical results:

Analyte	Feed	NF270	Spiral RO
Aluminum	3.45	2.12	0.01
Arsenic	0.10	0.01	0.00
Barium	5.00	3.10	0.54
Boron	12.4	12.3	0.2
Calcium	400.0	100.0	17.5
Chloride	13,500	12,283	1,418
Iron	9.00	5.55	0.41
Magnesium	48.8	10.3	6.9
Potassium	30.0	29.9	3.6
Silica	240.0	123.2	0.8
Sodium	8,315	8,306	1,231
Sulfur	25.8	20.6	0.2
TDS	14,800	13,200	3,090
Alkalinity	200.0	54.5	18.5
Bicarbonate	293.0	62.9	22.0
Sulfate	20.0	1.5	0.0
TOC	261.0	104.4	19.0
Oil & Grease	220.0	26.0	0.4
Conductivity	29,600µS	26,300µS	920µS

In the end, both the RO VSEP and the NF VSEP/Spiral RO options provided excellent filtrate quality well below the discharge limits required. Due to the lower flux rate, the RO VSEP option would require more modules to handle 1200 bpd compared with one (1) module of NF VSEP. Even if one considers the additional Spiral RO system to polish the NF VSEP permeate, the capital and operating costs for the RO VSEP option would be higher than using the NF VSEP/Spiral RO option. With additional work, NLR believes that a single stage of VSEP NF can be used as a stand-alone system fully meeting the discharge requirements.

Successful pilot tests have been conducted at New Logic for many kinds of oily wastewater treatment. Depending on process temperatures, membrane selection and the requirement for solids concentration or BOD/COD removal for effluent streams, the permeate flux rate in the VSEP can range from 15 to over 150 gallons per day per square foot (GFD).

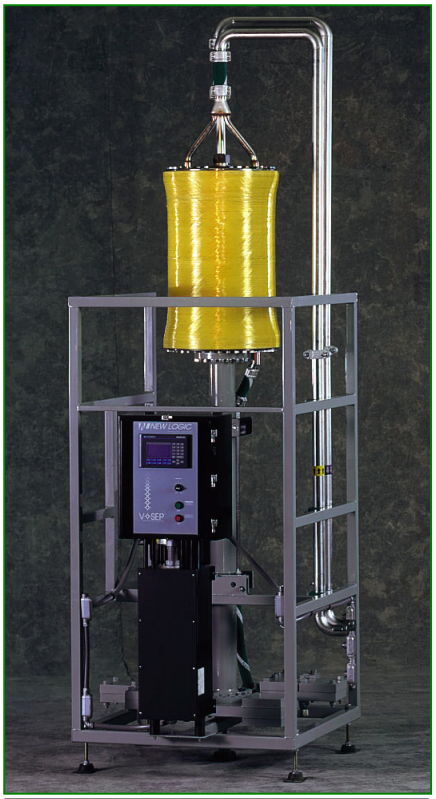
NEW LOGIC RESEARCH

APPLICATION NOTE

Summary

New Logic Research has supplied VSEP separation technology successfully into many industrial processes. Manufacturing plants' as well as the oil waste hauling industries' efforts to meet environmental regulations will be enhanced with the utilization of membrane filtration combined with "Vibratory Shear Enhanced Processing". The availability of new membrane materials and VSEP technology make it possible to treat the more difficult streams with very successful, economic results.

Contact a New Logic representative to develop an economic analysis and justification for the VSEP in your system. For additional information and potential application of this technology to your process, visit New Logic's Website @ http:/www.vsep.com or contact New Logic, 1295 Sixty Seventh Street, Emeryville, CA 94608, Phone: 510-655-7305, Fax: 510-655-7307, E-mail: info@vsep.com.



VSEP Module

About the Author:

Greg Johnson, a chemical engineer, is currently CEO of New Logic Research. New Logic Research manufactures unique membrane filtration systems for industrial and commercial customers. NLR distributes its products through direct sales and through a network of domestic and international distributors and agents.