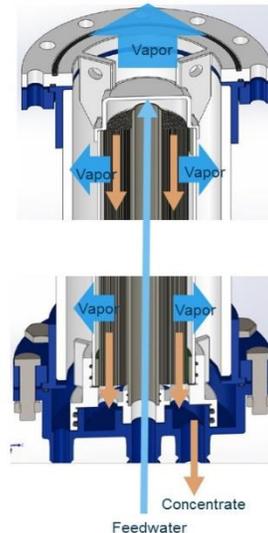


Pacific States Water, Inc.

Solution for the Treatment and Recovery of Oil & Gas Produced Water

The safe and sustainable treatment of its processed water remains a priority for the Oil & Gas industry. Increased reuse of this water will have significant environmental and economic benefits to the industry. Produced water constitutes one of the largest wastewater streams generated by the industry with a minimum of three barrels of produced wastewater generated for every barrel of oil. The total dissolved solids (TDS) in this wastewater stream can reach up to 200,000+ ppm or five times that of seawater. At these salinity levels, traditional desalination techniques are largely inadequate in recovering water to discharge and reuse standards. As such, oil companies have to pay as much as \$8 per barrel to dispose of this wastewater.

The “Vacuum Membrane Distillation” (VMD) technology solution provides for 90+% recovery of water at a purity level that allows for either discharge or reuse at a distinct competitive advantage over competing technologies. At a 90+% recovery rate, the disposal costs and environmental impact associated with this wastewater are significantly reduced.



VMD Module

The VMD technology uses low-temperature evaporation (65 degC) combined with a hydrophobic selective membrane to extract water from concentrated brine streams. It can produce distilled water quality from these streams at high recovery rate of 90+ % with low energy usage compared to alternative technologies such as thermal evaporators or crystallizers.

The VMD technology is able to achieve these results by extracting water from the feed stream which is transferred through the wall of the micro-porous hydrophobic membrane in vapor form under vacuum, leaving the salt behind. The pure water vapor (<20 TDS) is then condensed and collected in a finished product tank. The remaining salt in the feed stream is then saturated to a point of crystallization and is easily removed for disposal or sale. **The VMD is the only technology available in today’s market place that can deliver these results in a single step.**

The VMD technology has been successfully tested at both our lab and on a pilot scale across a wide range of O&G feedwaters (5-15% mixed salts, 0.5-1% solvents) with good results; 80-90+% water recovery, <20 TDS permeate quality and no deterioration in membrane performance.



O&G Samples pre-and post VMD Treatment

Trial	Feed	Permeate	Retentate	Water Recovered
Marcellus	Salt 2.4% Water 97.6%	Salt 10 ppm	Salt 38.4%	90%
Texas	Salt 8.1% Water 91.9%	Salt 23 ppm	Salt 52.0%	88%
Western Canada	Salt 13.8% Water 86.2%	Salt 7 ppm	Salt 60.0%	80%

O&G Water Test Results - 6-month pilot trial

As the next step in commercialization of the VMD technology, a 4 gpm demonstration unit will start in September 2017 in Edmonton, Alberta to treat O&G produced water from a variety of sources – Oil Sands, Frackwater, SAGD water. The unit will operate for a 6-8-month period to confirm the capabilities of the technology.



4 gpm Demonstration Unit

Our Team has conducted a series of lab and pilot scale trials to confirm the performance of VMD Membranes across a wide range of feedwaters. Below is a summary of various trial results.

1. Lab Trial Description and Results (Texas water):

Brine concentration trials were conducted on a 5-gal pre-treated Frack Water sample from Texas. The sample, containing dissolved salts at 140,000 ppm TDS was processed through the lab scale VMD membrane system. The final salt concentration achieved was 360,000 ppm. At this concentration, salt crystals formed and fell to the bottom of the feed tank (ref Figure 1 & 2 below). The permeate water recovered from the system contained a salt level of 9.8 ppm.

Figure 1: Picture of crystallized salt at the bottom of feed tank



Figure 2: Picture of crystallized salt at bottom of collection jar



Table 1: Water Recovery

Initial Feed Concentration	14%
Final Concentration	36%
Water Recovery	71%
Recovered Water Quality	9.8 ppm

2. Pilot Scale – Synthetic NaCl Trial

Brine concentration trials on feed containing synthetic NaCl salt were processed in the lab pilot scale (1 gpm feed). 63,000 ppm TDS brine water was processed through the membrane reaching a final concentration of 310,000 ppm. 86% of the water was recovered from the salt at a quality level of 10 TDS. The results are summarized below:

Table 3: Summary of NaCl Concentration Pilot Trial

Initial Feed Concentration	6.3% NaCl
Final Concentration	31% NaCl
Water Recovery	86%
Recovered Water Quality	10 ppm

3. Pilot Scale - “Alberta Frackwater”

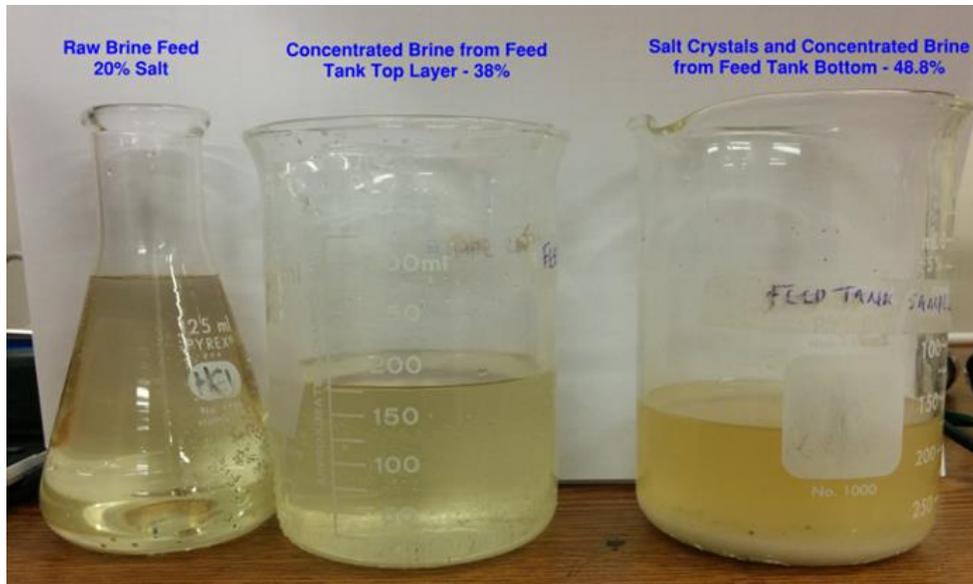
Produced water from a frack site in Western Canada was successfully processed in the lab pilot scale (1 gpm feed). Feed containing mixed salts with an initial concentration of 18 to 21% salt was concentrated to 40-52%. As this was above the saturation point of the salt, crystallization was observed in the conical bottom feed tank designed to collect the salt crystals. The permeate water quality achieved was 30 ppm TDS. A summary of results is shown in Table 3 below, and pictures of the crystallized salt in Figure 1 below:

Table 3: Summary of NaCl Concentration Pilot Trial

Batch #	Initial Feed Concentration	Final Salt Concentration	Water Recovery	Water Quality (ppm)
1	20.4 %	48.8 %	65%	30
2	18.7 %	40 %	60%	25
3	21 %	52.5 %	59%	35

Note – water recovery at 60-65% was only limited due to the size and configuration of the feed tank. With a redesigned tank, 85-90% recovery is easily attainable.

Figure 1 Produced water Brine Concentration and Salt Crystallization Results for Pilot Unit



4. Lab & Pilot Scale - Brine water sample containing Sodium Nitrate (NaNO_3)

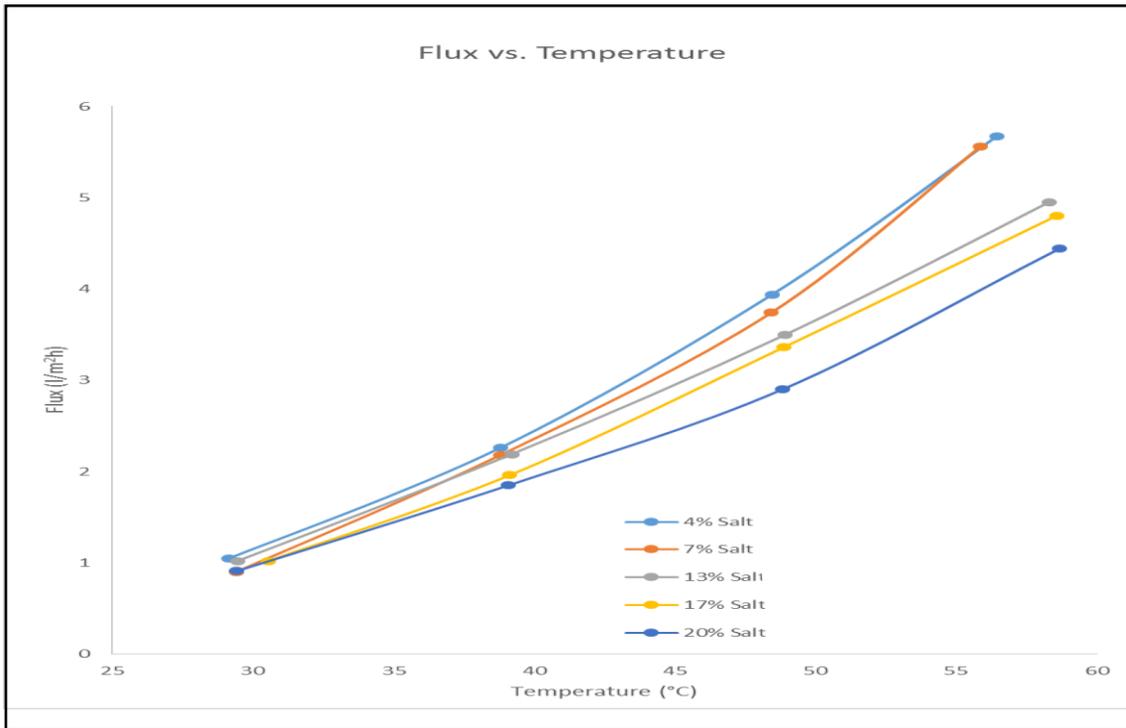
A client's brine water sample containing sodium nitrate was successfully concentrated at both the lab and with a pilot scale unit. Brine feed containing 4% Sodium Nitrate and 8% Alcohol was processed through the VMD membrane system. 91% of the water was recovered from this feed, resulting in a 32% salt concentration. The permeate water quality achieved was 34 ppm TDS. A summary of results is shown Table 4 below:

Table 4: Lab Results for NaNO_3 Concentration Trial

Initial Feed Concentration	4%
Final Salt Concentration	32%
Water Recovery	91%
Recovered Water Quality	34 ppm

In addition to concentrating the salt, an additional condensation process was used to separate the solvents from the water. At the first condensation step 75% of the alcohol was recovered and at the second condensation step 95+% was recovered.

5. VMD Flux vs Temperature vs Salt Concentration



6. 4 GPM Demonstration Unit Trials

In order to confirm the capabilities of the VMD technology over an extended period of time, a 4 gpm VMD demonstration unit has been installed at the InnoTech Alberta Research Center in Edmonton. This unit will be used to run a series of trials across a wide range of O&G feedwaters from Western Canada. The unit will be commissioned in September 2017 and run through March of 2018.



4 gpm VMD Demo Unit

VMD Demo Unit Specs

- 4 x 25 m2 hollowfiber membrane modules
- Mechanical vapour compression used to recover heat energy for re-use
- Removable fiber bundles
- Batch Process (1500 gal batches)
- 1-15% feed salt concentrations capable
- 90+% water removal at <20 TDS permeate
- Salt crystal formation and removal in the feed tank
- Pre-treatment includes DAF and UF systems (suspended solids, oil & grease removal)