"Treatment of Flowback – Marcellus Shale" - Mark Galimberti - VSep – New Logic Research

1.0 Background Information

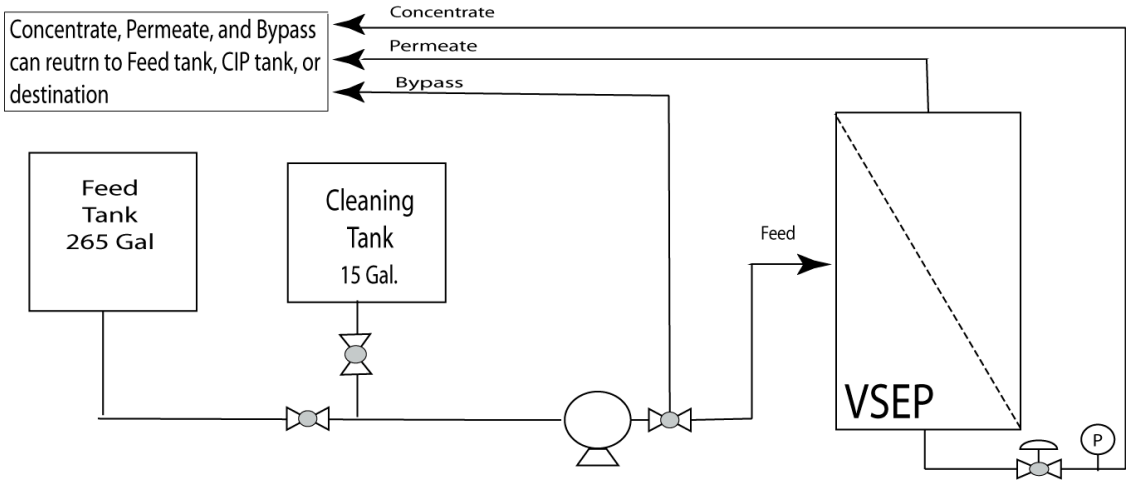
Customers have had samples of flow-back water resulting from hydro-fracturing of gas wells drilled in the Marcellus Shale in Pennsylvania. They would like to treat the wastewater to a quality suitable for reuse in the fracturing of the next well. This re-use water will likely be diluted with fresh water. The water is currently being hauled off site.

New Logic has conducted many P-Mode VSEP test (pilot mode) to demonstrate the separation ability of VSEP. VSEP is a unique membrane filtration technology that uses vibration to minimize fouling of the filtration media.

2.0 Study Objectives

The primary objective of the testing was for the VSEP to produce permeate that could be reused as frac water. Maximizing the recovery rate was also an important objective during this test. Maximizing the overall recovery will reduce the volume of waste being hauled and thus reduce operation costs. There is a natural variation in this type of feed material, and the feed conductivity will increase over time. The VSEP needs to produce consistent results despite this variation in feed.

3.0 Equipment and Set-Up



NLR provided a VSEP membrane filtration unit and periphery equipment. The figure above illustrates the basic set up for a VSEP Series LP. The VSEP pilot unit was tested in P-mode which has 16.7 square feet of membrane area. The P-unit was installed with a nanofiltration (NF) membrane called NF-270. This membrane was chosen based on previous in house lab testing.

The standard system was run in batch mode in which the feed tank is filled with a limited volume of feed material and the concentrate line is returned to the feed tank. The permeate is allowed to leave the system thus concentrating the feed tank. Batch mode was chosen as the mode of operation for pilot testing in order to handle the high TDS of feed and maintain economical flow rates. The VSEP set up is shown in Figure 1.

Figure 1: Examples of VSEP Set up

4.0 Results

As part of pilot testing, various operating variables were optimized for the best performance and economic balance. The operating pressure was optimized by collecting permeate flux readings at various pressures. The relationship between pressure and flux was found to be linear. There was no increased rate of fouling or flow threshold at higher operating pressures up to 500psi. The operating pressure chosen was 480psi. The results are shown in Figure 2.

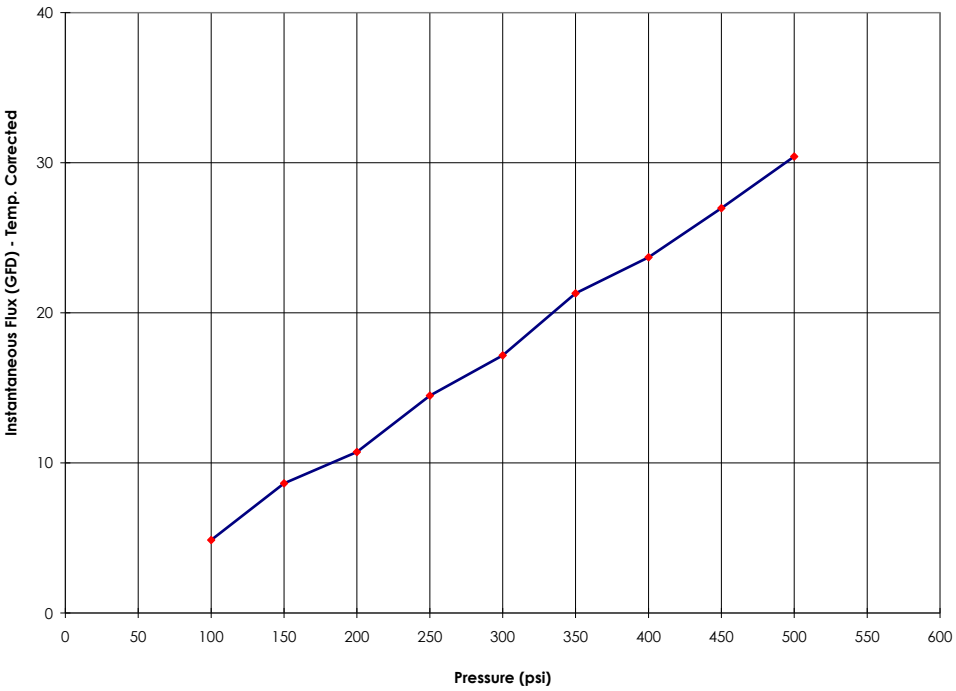


Figure 2: Pressure Study

One case showed a total of 8 batch runs of varying feed quality. The first batch was a single pass through the membrane with no concentration and will not be included in the calculations. The end point of each batch was determined by a low permeate flux rate or a low feed level (not enough feed to pump through the

system). A chemical pre-treatment of Ferric Chloride and Soda Ash was tested but was not successful in reaching higher recovery or flux rates and actually performed worse than raw feed. The results of the instantaneous flux rates for the batch concentrations are shown in Figure 3 and Tables 1, 2, and 3.

The average performance of the system: 17.2 GFD and 92% recovery at 20°C and 480psi. The average flux is based on the six batches on raw feed and these values will be used for system sizing calculations. The average flux was calculated by fitting an exponential trend line to the average flux rates for each batch. The equation used for calculating the average flux based on percent recovery is: Ave Flux = $31.465e^{-0.6574*\%Rec}$. The average recovery is based on the arithmetic mean of the six batches. These values will be used for system sizing calculations. The results can be seen in Figure 4 and 5.

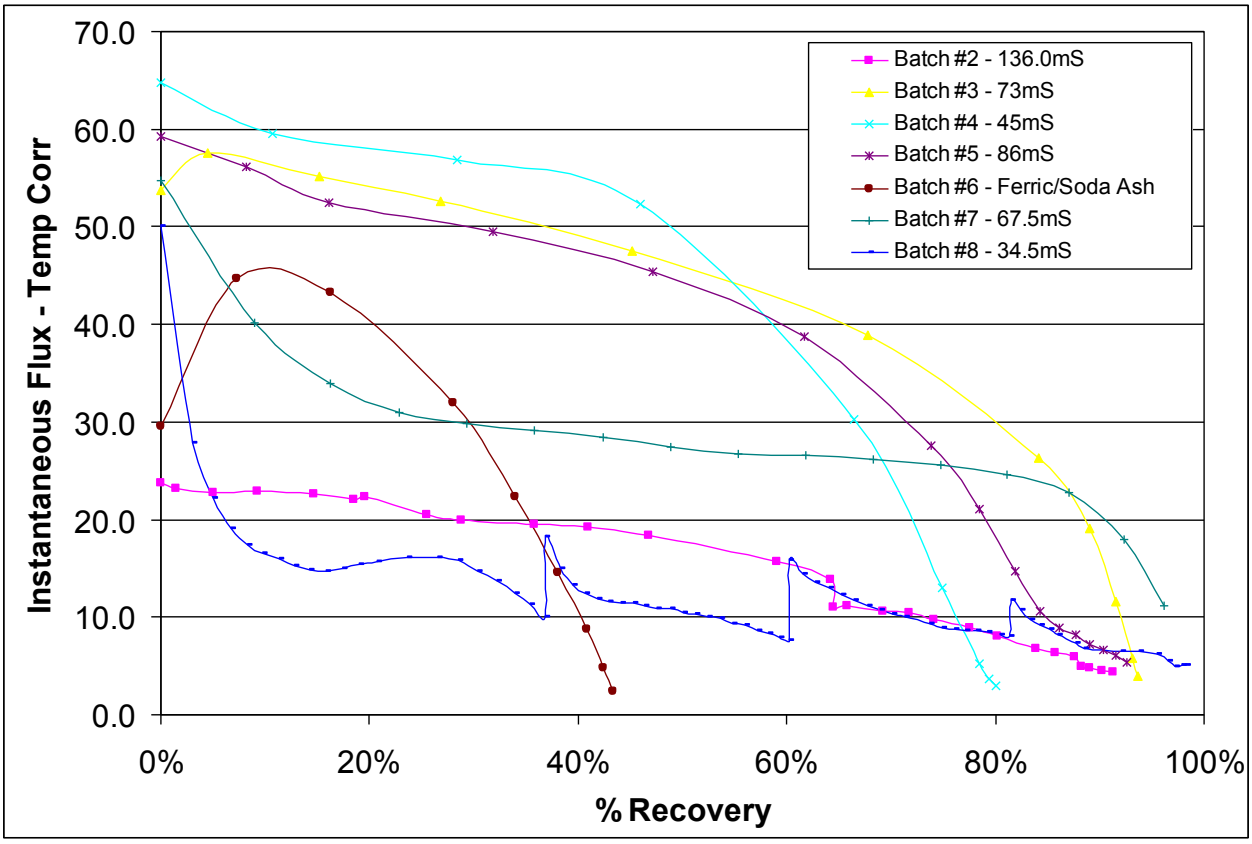


Figure 3: Batch Concentration

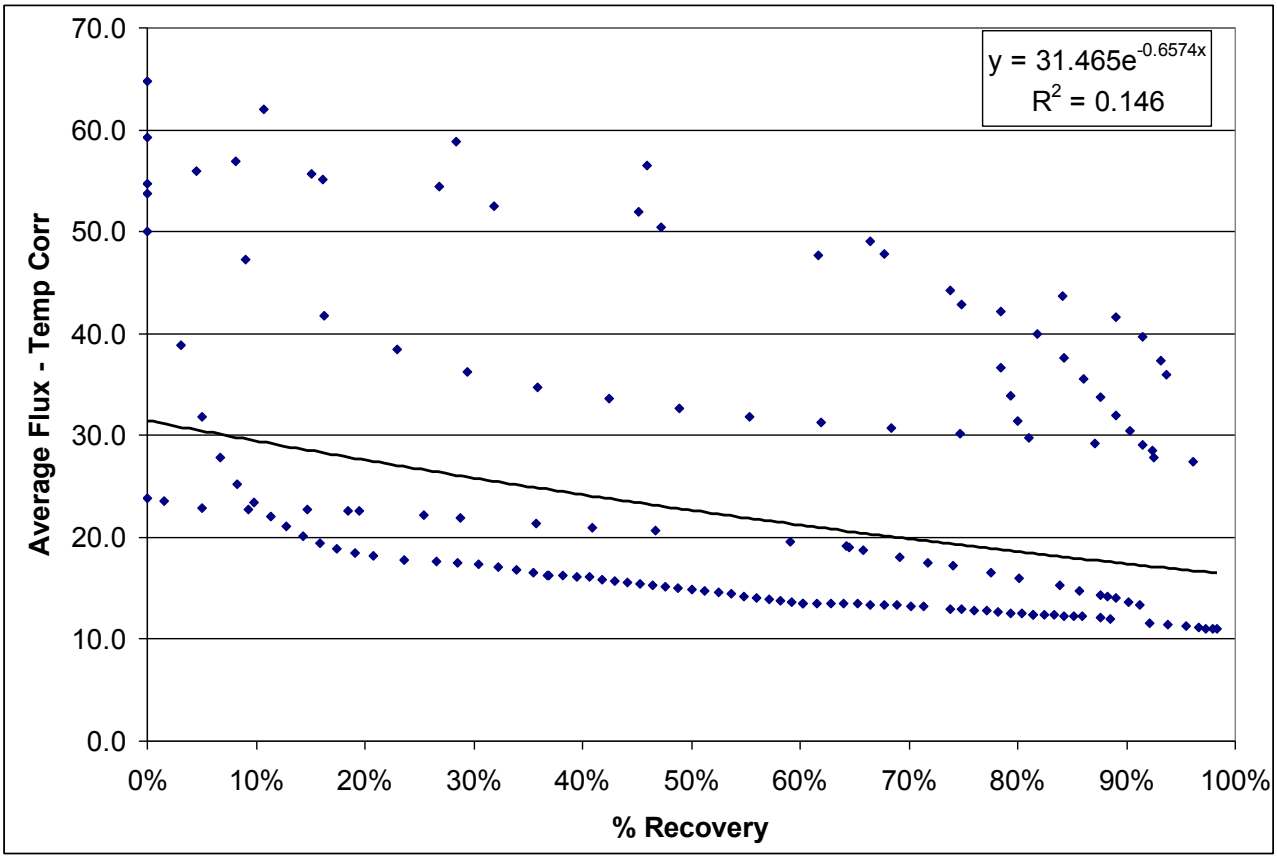


Figure 4: Average Flux

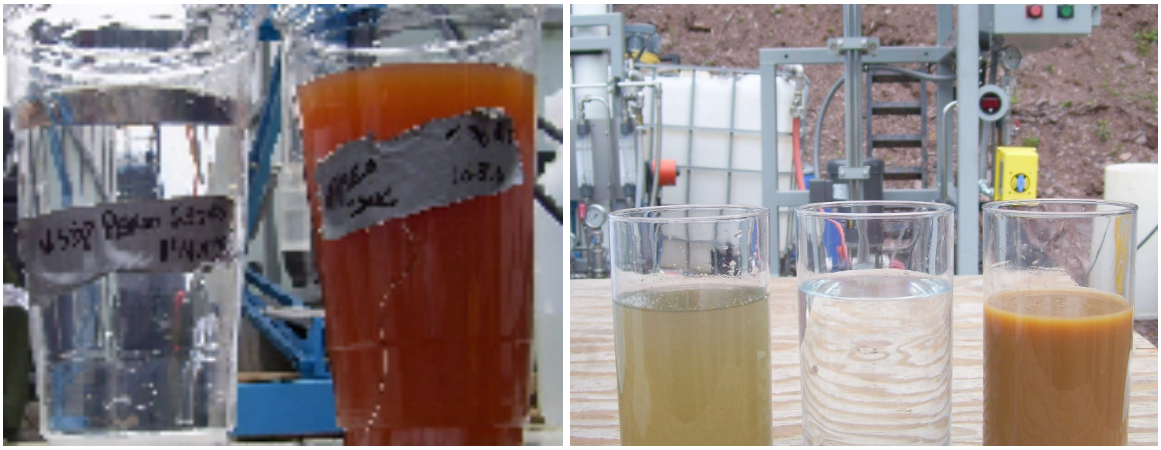


Figure 5: VSEP Permeate and Concentrate

Table 1: Quantitative Results

Batch	Pressure	Average Flux	%Recovery
2	480psi	13.3 GFD	91%
3	480psi	35.9 GFD	94%
4	480psi	31.4 GFD	80%
5	480psi	27.8 GFD	93%
6	480psi	22.7 GFD	43%
7	480psi	27.5 GFD	96%
8	480psi	11.0 GFD	98%

*All Flux values are corrected to 20°C

Table 2: Analytical Results

Batch	Sample	pH	Conductivity
2	Feed	6.26	136.0 mS
	Permeate	6.99	129.0 mS
	Concentrate	5.63	173.2 mS
3	Feed	6.27	72.7 mS
	Permeate	6.36	67.3 mS
	Concentrate	6.56	134.3 mS
4	Feed	6.39	44.7 mS
	Permeate	6.38	43.9 mS
	Concentrate	6.75	69.0 mS
5	Feed	6.34	86.4 mS
	Permeate	6.25	72.7 mS
	Concentrate	6.62	136.4 mS
6	Feed	8.52	87.0 mS
	Permeate	7.31	71.6 mS
	Concentrate	7.04	98.1 mS
7	Feed	6.94	65.7 mS
	Permeate	7.18	63.8 mS
	Concentrate	7.02	123.2 mS
8	Feed	6.64	34.5 mS
	Permeate	7.74	31.0 mS
	Concentrate	7.17	71.2 mS

Table 3: Analytical Results – Batch #8 at 98% Recovery

Parameter	Permeate	Concentrate
Conductivity	29.44 mS	36.5 mS
Alkalinity	130 mg/L	225 mg/L
TDS	17,806 mg/L	21,286 mg/L
pH	7.35	7.53
Chloride	17,800 mg/L	14,800 mg/L
Barium	194 mg/L	352 mg/L
Calcium	424 mg/L	716 mg/L
Magnesium	32.0 mg/L	70.8 mg/L
Strontium	137 mg/L	215 mg/L

5.0 Cleaning

Chemical cleaning of the membrane is used to restore the flux rate. While VSEP can prevent colloidal fouling of the membrane and can reduce the polarization of rejected materials at the membrane surface, like other membranes, it cannot avoid chemical bonding type fouling that will occur. For this reason, chemical cleaners are used to solubilize the foulants and restore the membrane. During chemical cleaning, cleaners are re-circulated through the membrane system and then flushed out. Multiple cleaning cycles are used.

The cleaning procedure used was a two-part process. The steps in sequence were: NLR 404 acid cleaning followed by NLR 505 caustic cleaning. The procedure was based on previous experience with similar applications. The cleaners were used in a 3% by volume solution. After each batch run, a cleaning was completed and the starting flux on feed was recovered each time. When a new membrane is exposed to feed material, the membrane will take time to be conditioned. Once the membrane is conditioned, a new base line can be used for measuring a successful cleaning. The effectiveness of the cleanings can be seen in Figure 6 and the new base line can be seen around 120 GFD. Cleaning frequency is estimated after each batch with NLR 404 and 505. Hot water will need to be available for fully effective cleaning.

NLR 404 is an acidic liquid cleaner designed to provide superior and rapid mineral scale cleaning of wide range of RO, NF and UF membranes. It removes metallic salts such as iron, aluminum, barium and strontium sulfate, calcium sulfate, calcium carbonate, as well as dyes and polymers.

NLR 505 is a caustic liquid membrane cleaner designed to provide superior and rapid soil removal properties. It contains a combination of ingredients, which provide cleaning actions that include lifting, dispersing, emulsifying, sequestering, dissolving and suspending. It removes biological and organic materials, silt, particulates, colloids, silica and emulsified oil from a wide range of RO, NF, UF and MF membranes.

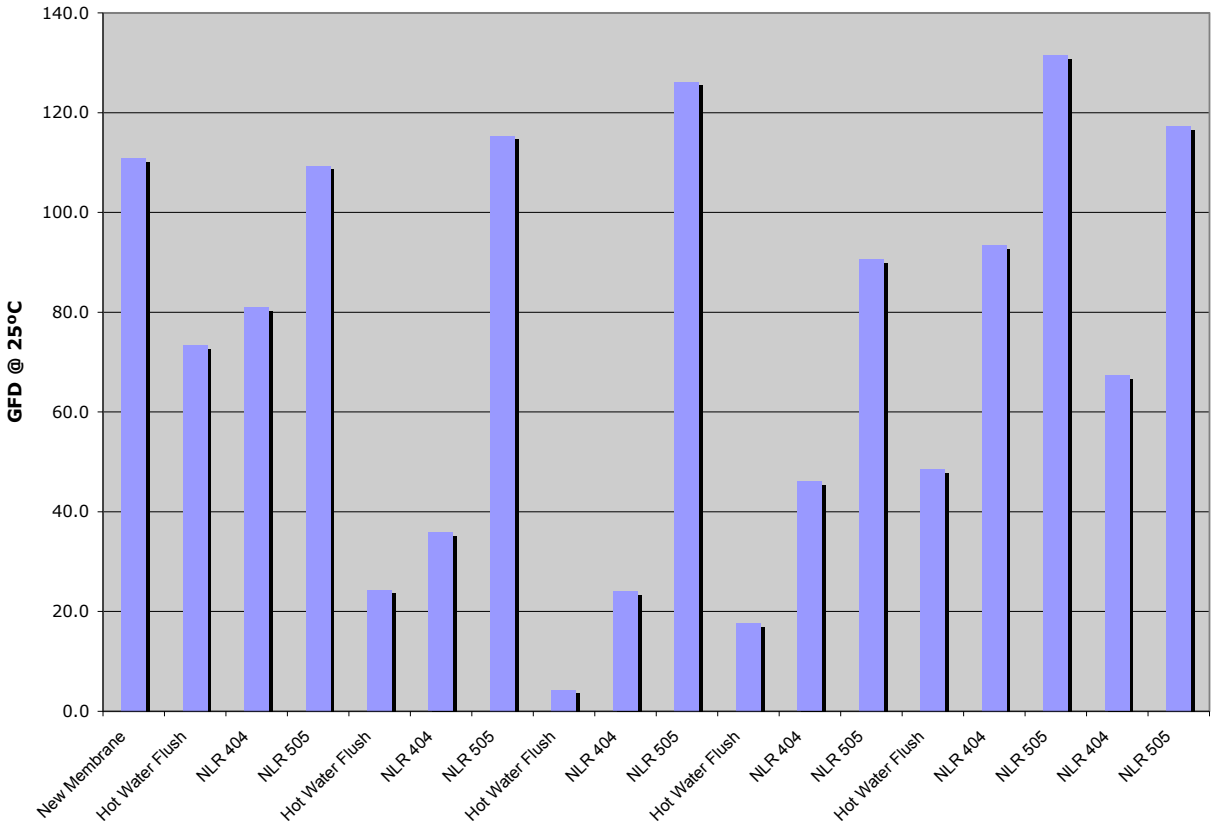


Figure 6: Cleaning Data

6.0 Summary

Based on the objectives and results presented in this report it can be said that we were successful in demonstrating the ability of VSEP to treat Frac-flow back water. The following is a list of process recommendations/results:

Test Results:

Membrane:	NF-270
Mode of Operation:	Batch Mode
Average Flux Rate:	17.2 GFD
Percent Recovery:	92%
Pressure:	480psi
Temperature:	20ºC
Cleaner Needed:	NLR 404/505
Cleaning Frequency:	Every week, Hot water flush every day

System Sizing Estimates For a process of 28 GPM:

EXAMPLE CALCULATION (92% recovery, 20°C):

28 gal of feed*1440 minutes/day*92% recovery rate = 37,094 gallons of permeate generated per day

37,094 gallons of permeate per day / 17.2 GFD * 24/22 hours (2 hours for cleaning) = 2,353 sf

2,353 * 1.3 (30% over design) = 3,058 sf needed.

Module size = 3,058/1500sf = 2.03, therefore, 2 units needed at 20° C and 92% recovery.

NF-270	92% Recovery
Membrane SF	3,058 SF
VSEP Modules	2 - 84” 1500 SF units

7.0 System Design Requirements

Stage Type:	2 - 84" 1500 VSEP	**Elastomers:**	EPDM
Mode of Operation:	Batch	**Drain Cloth:**	Polyester
Membrane Type:	NF-270	**Resin:**	Epoxy
Operating Temperature:	20° C	**End Plates:**	Polypropylene
Design Pressure:	480psi (600max)	**Membrane Trays:**	304
Feed Flow Rate:	28 GPM	**Operation:**	Automated
Recovery Rate:	92%	**Pre-treatment:**	None
Design Flux Rate:	17.2 GFD AVE		
Max Flux After Clean:	140 GFD @ 200psi	**Cleaning Chemicals:**	NLR 404/505
Feed Pump Max Flow:	70 GPM @ 480psi	**Cleaning Frequency:**	After every week

Permeate Destination:	Reuse as Frac water
Concentrate Destination:	Hauled for disposal

Some Photos of VSEP units used in Flowback Mobile Treatment in Pennsylvania:

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