Nanofiltration Study

The nanofiltration (NF) study was essentially completed in January 2016. Removal of Ca and Mg was evaluated utilizing a bench-scale NF system in the configuration shown in Figure 1. Simulated brines are added to the reservoir. The brines are then processed through the NF until approximately 70% of the feed was recovered as permeate. The reject from the NF is recycled back to the feed.

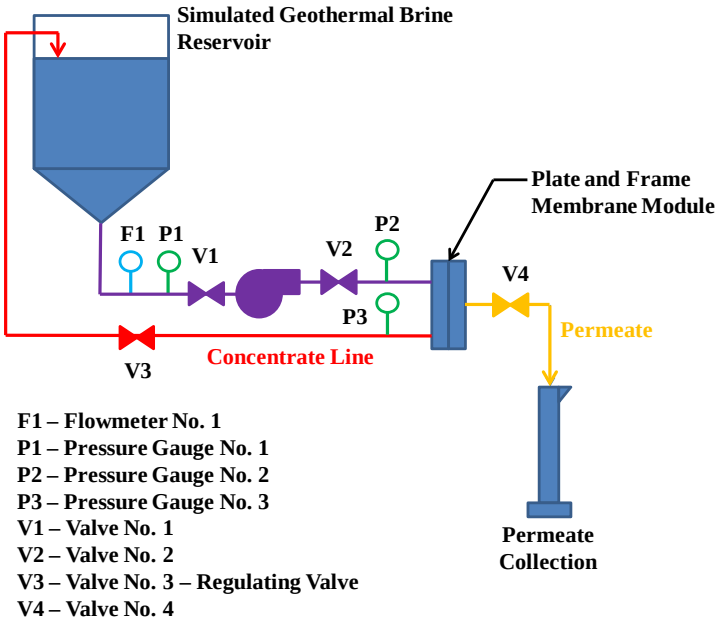

Figure 1. Experimental membrane configurations for batch evaluation.

Three samples are analyzed for each NF evaluation. The first sample is the feed simulated brine (before the experiment). The final permeate is analyzed following the end of the experiment. The concentrate, which is the brine remaining in the feed tank following processing to approximately 70% recovery, is also analyzed. The feed, permeate, and concentrate are analyzed utilizing inductively coupled plasma – mass spectrometry (ICP-MS) to determine Ca, Mg, Na, and Si concentrations. Some samples were also analyzed for Cl, SO_4, and Li utilizing ion chromatography (IC).

Three NF membranes were evaluated as shown in Table 1. The table also shows the specifications for the membranes. The molecular weight cut-offs (MWCO) for the membrane varies from 100 to 500 Daltons.

Table 1. Nanofiltration membranes utilized in experiments.

No.	Manufacturer	Type	Polymer	MWCO (Daltons)	$MgSO_4$ Rejection (%)
1	TriSep	TS80	Polyamide	~100 - 200	>99%
2	Snyder	NFX	Polyamide-TFC	~150-300	99
3	Snyder	NFW	Polyamide-TFC	~300-500	97

Table 2 shows the composition of the simulated brines utilized as feed for the project. The brines utilized included a low strength (LS) brine, high strength (HS) brine, and HS brine with additional Si added. The pH of this HS brine was adjusted to a pH of 5.0 specifically for these samples. In addition, a separate brine was utilized for the TriSep membrane which was very similar to the HS brine in Table 2 except that the Ca, Mg, Na, and Si concentrations were 398, 60, 3,378, and 1 mg/L, respectively. The Cl and SO_4 in the brine utilized for the TriSep membrane would be similar to those of the HS brine.

Table 2. Brine composition of feed simulated brine for experiment.

Component	Low Strength Brine (mg/L)	High Strength Brine (mg/L)	High Strength Brine with Si (mg/L)
Ca	21	418	456
Cl	1,796	7,026	14,220
Li	1	20	21
Mg	13	60	226
Na	885	3,666	7,050
Si	2	0	12
SO_4	62	375	405

Figures 2 through 8 show the results from the NF study. The results shown in Figures 2 and 3 show that only the TriSep membrane was able to achieve the project goal of 85%

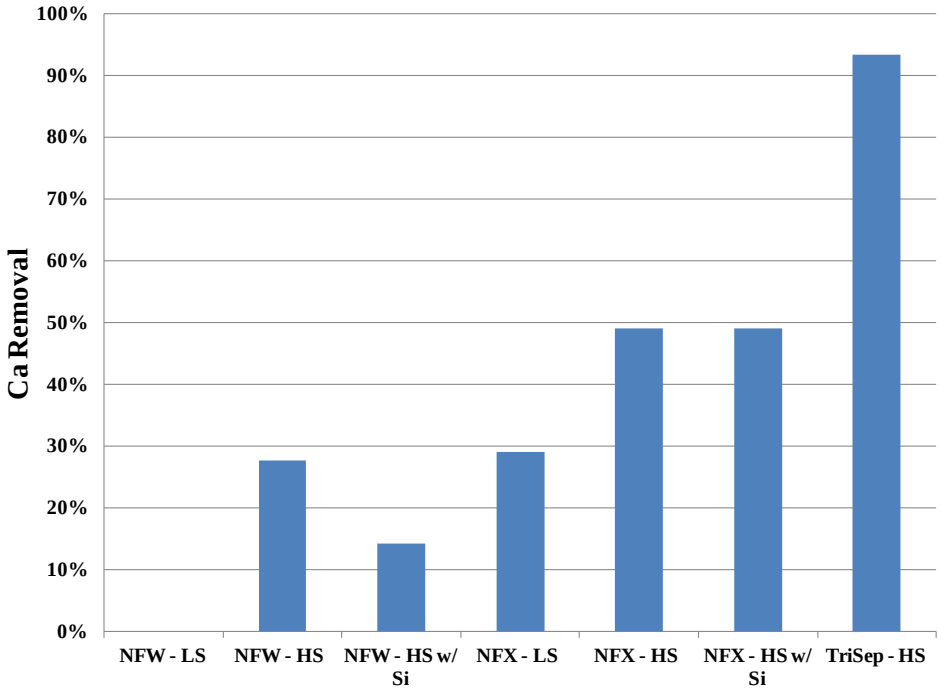

Figure 2. Ca removal for NF experiments.

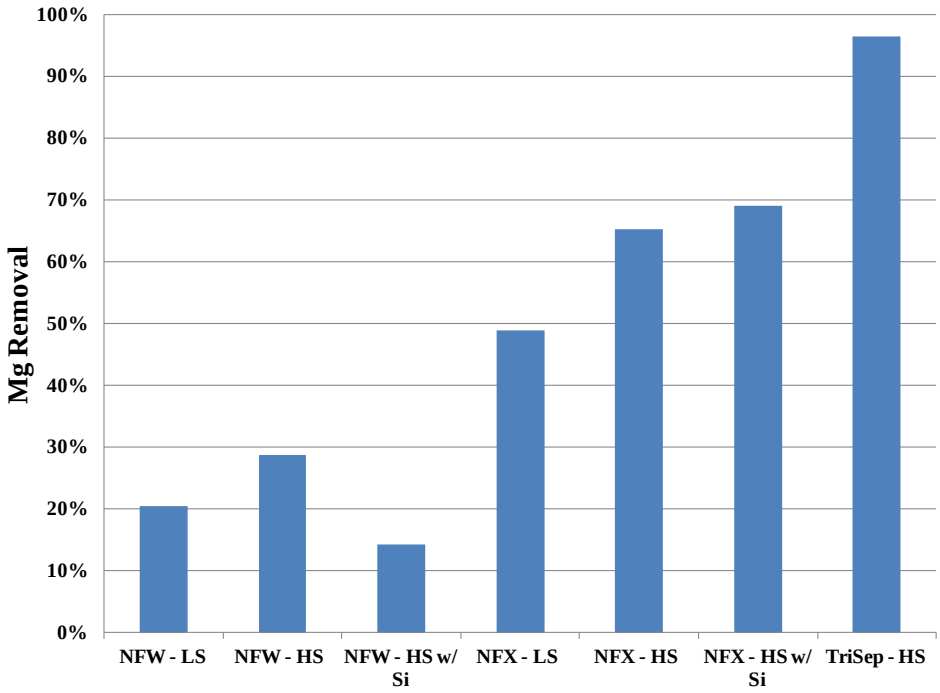

Figure 3. Mg removal for NF experiments.

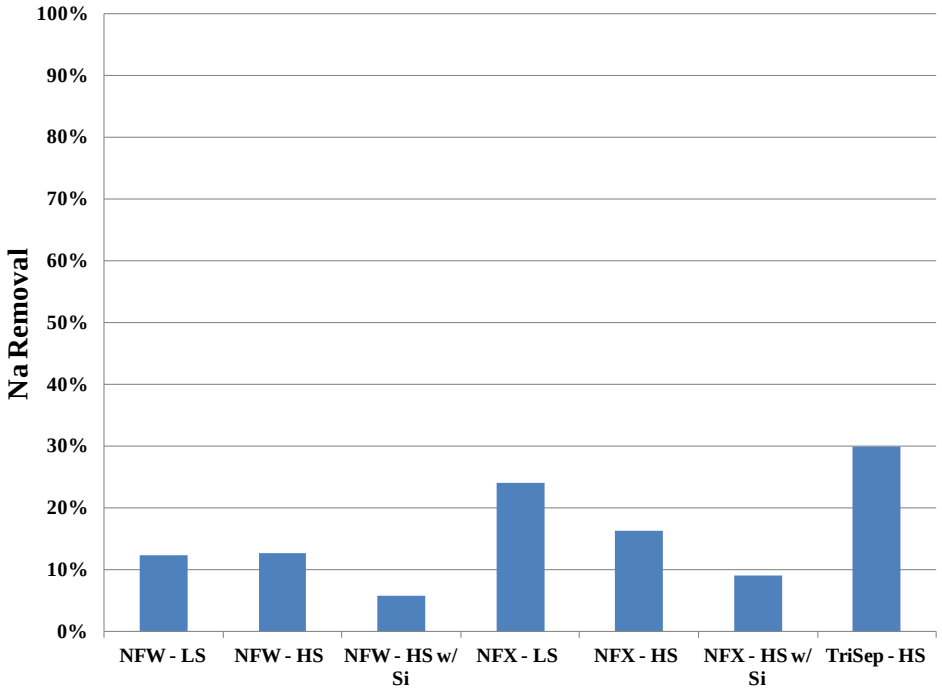

Figure 4. Na removal for NF experiments.

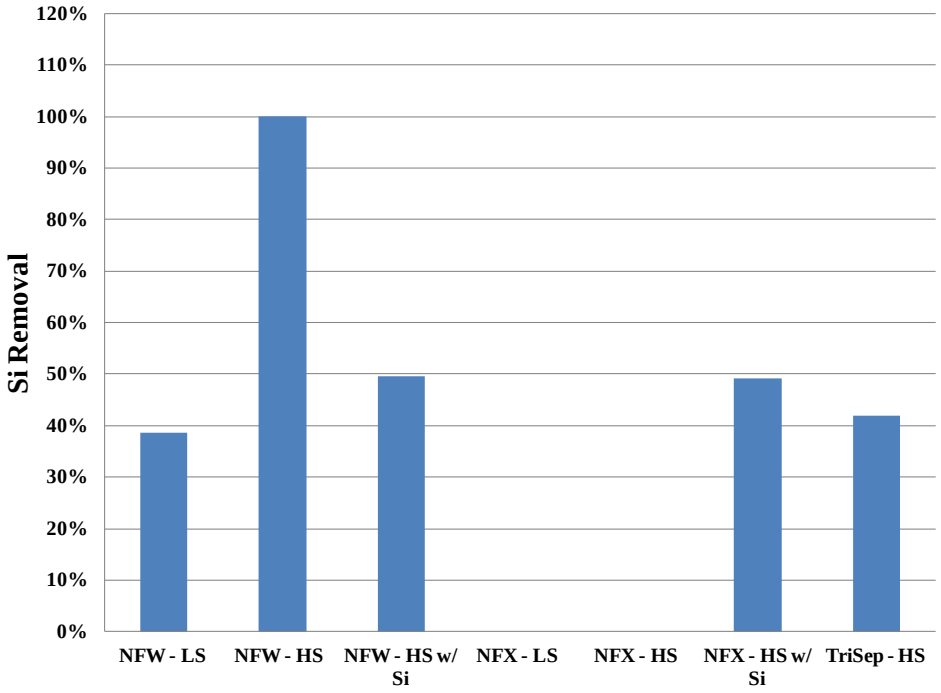

Figure 5. Si removal for NF experiments.

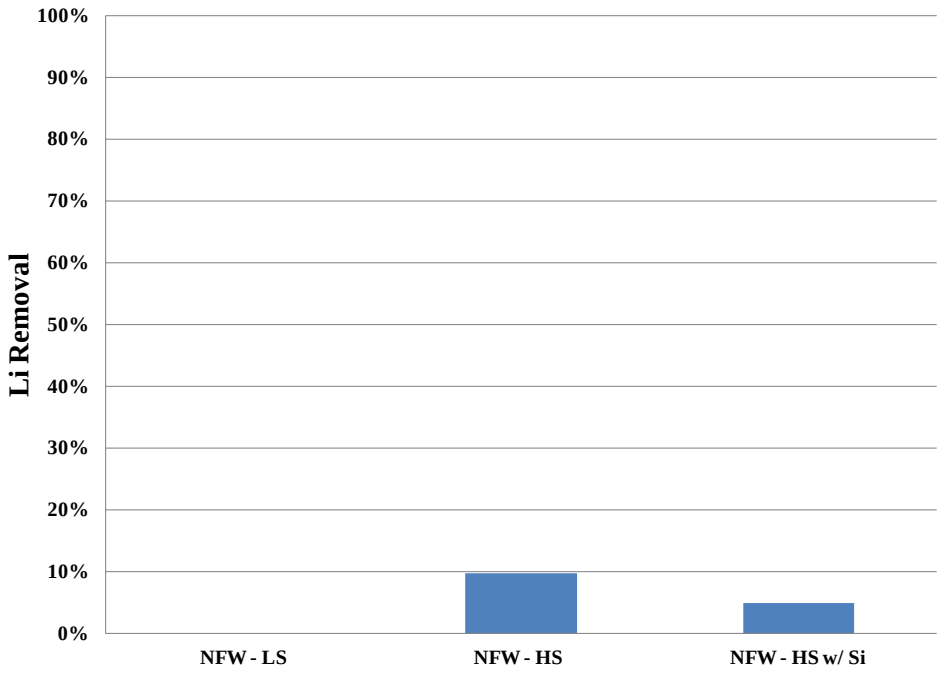

Figure 6. Li removal for NF experiments.

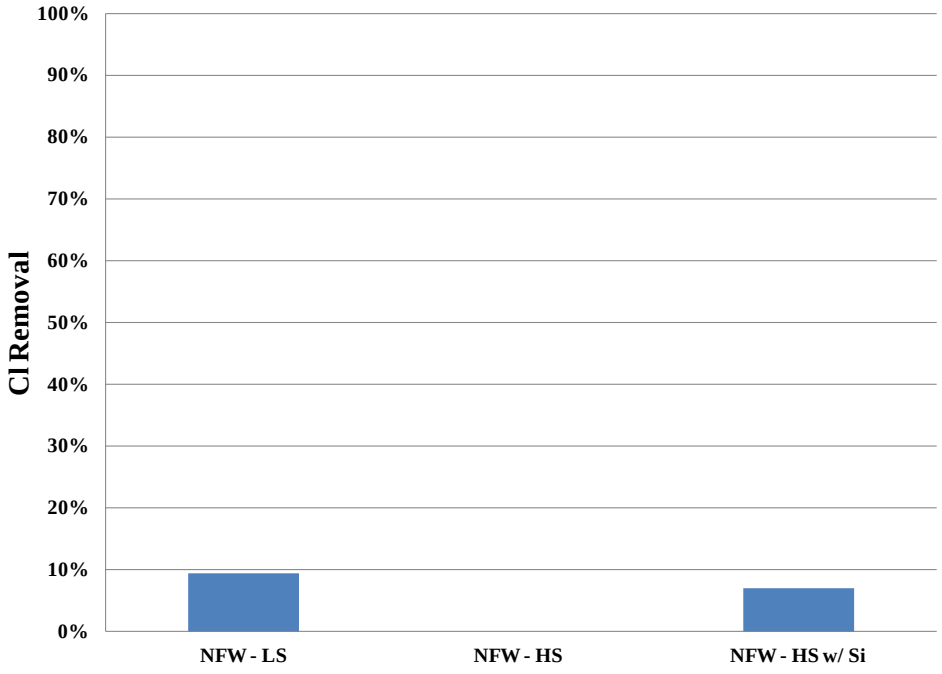

Figure 7. Cl removal for NF experiments.

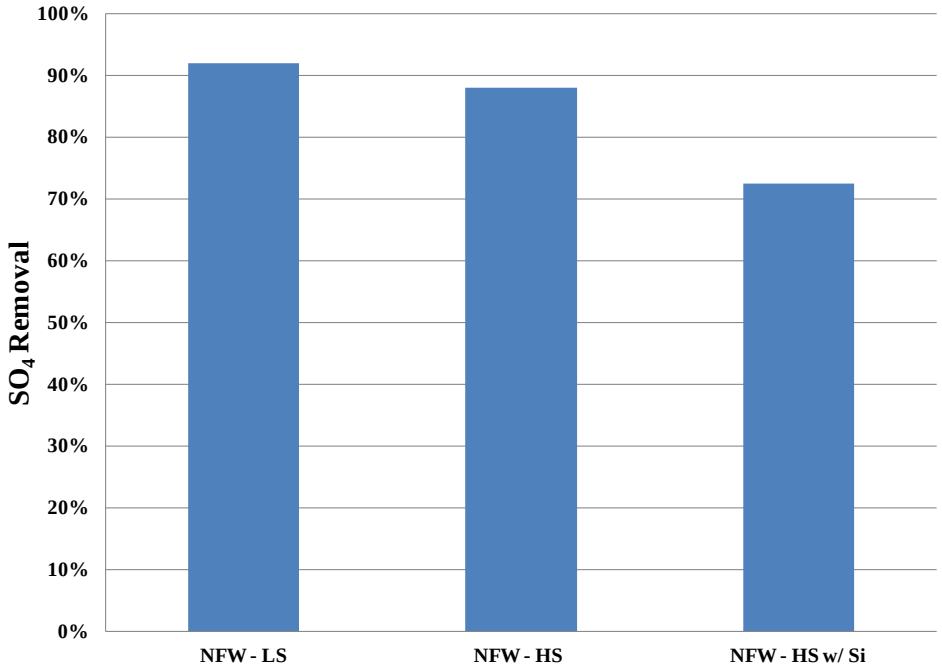

Figure 8. SO_4 removal for NF experiments.

Ca and Mg removal. Apparently the lower MWCO (~100 – 200 Daltons) of the TriSep membrane is required to meet the objectives of the technology.

Figure 4 shows that not much Na was removed by any of the NF membranes as expected for the monovalent Na. Figure 5 shows that almost 50% of the Si was removed in the brine that contained almost 12 mg/L Si. This level of Si removal is significant. These results indicate that utilization of a NF process to remove Si instead of Si precipitation process may be feasible. These results will be explored in the next quarter.

Figure 6 shows that very little of the monovalent Li was removed by NFW membrane as expected. Figure 7 shows that little monovalent Cl was removed by the NFW membrane. A large portion of the multi-valent SO_4 was removed by the NFW membrane.