SUSTAINABLE FRACTURING: REDUCING FRESH WATER DEMAND AND DISPOSAL VOLUMES

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ABSTRACT

Multiple-stage hydraulic fracturing has dramatically increased hydrocarbon production in the United States. Large fresh water requirements, coupled with recent concerns over water sustainability, have increased the importance of oilfield water management.

FIML Natural Resources, LLC was using fresh water for hydraulic fracturing, and then hauling the waste water to a disposal site. To reduce fresh water consumption and the cost for disposal, a pilot study was performed to assess reuse of all their fracturing flowback fluid, produced water, and drilling waste water. Instead of extensive multistep water treatment to bring the water to a near-fresh state, Baker Hughes took a holistic approach, resulting in a single-step mobile treatment system to remove critical contaminants and sufficiently clean the water to design a fracturing fluid.

This paper will discuss the optimized recycling and reuse operation, fracturing fluid development from recycled water, the field application and a cost savings comparison.

INTRODUCTION

Every step in oil and gas operations—whether its completion, production, stimulation or work over—requires water. In the United States, 18 billion bbl of produced water, 149 million bbl of drilling waste and 21 million bbl of associated waste generated through E&P operations are disposed of or managed at the well site (Puder, 2007).

Hydraulic fracturing used for stimulating unconventional plays has grown from single to multistage operations, often requiring in excess of 100,000 bbl of fresh water per job. This tremendous demand for fresh water is expected to significantly influence its supply and availability for future operations. Also, when using such large volumes, the cost of sourcing fresh water for hydraulic fracturing and other E&P operations becomes substantial.

Produced water treatment and disposal have gained importance due to increasing volumes, stringent discharge standards, and the more attractive option of reducing capital and operating costs (Evans & Robinson, 1999; Khatib and Verbeek, 2002). Typical costs associated with disposal range from $0.30 to $10.00/bbl for injection or cavern disposal, and $15 to $22/bbl for solidification and burial in a landfill (Puder, 2007). Offshore produced water treatment and disposal costs were reported to be over US $400 million per annum (Khatib and Verbeek, 2002).

The potential savings by reducing or recycling these waste waters can be significant. Recycling could reduce or eliminate the cost of disposal. At the same time it would reduce the cost of sourcing fresh water for E&P operations.

Literature has documented the use of recycling or treating waste waters from E&P operations. Though many studies focus on using the treated water for slickwater fracturing (Rimassa and Howard, 2009; Blauch *et al*., 2009; Horn, 2009) not much can be found on using the treated water for a conventional borate-crosslinked fracturing fluid.

TECHNOLOGY

Multiple technologies have been discussed to treat waste water in O&G operations, including chemical, mechanical, electrical, or a combination of these methodologies (Platt *et al*., 2011 ; Hum *et al*., 2005; Lee and Frankiewicz, 2005; Horn, 2009). Oilfield water treatment has its own challenges. The treatment methodology selected must be economically viable to treat the volumes of waste generated. Next, it should be technically capable of removing the components that can negatively impact a fracturing fluid formulation. It should also be flexible enough to treat waste water of inconsistent quality.

One technology that fits most of these criteria, electrocoagulation (EC), was used to treat the waste water of an operator in West Texas. In the EC process, the coagulant is generated in situ through electrolytic oxidation of a proper anodic material.

Water contaminants are ionic species like heavy metals and colloids (organic and inorganic) held in solution by electrical charges. EC removes the contaminants from the waste water by allowing the reaction with an ion having opposite charge and or with floc of metallic hydroxide generated within the effluent. These reactants neutralize the electrostatic charges on suspended solids, oil droplets, colloids, etc., which facilitates agglomeration or coagulation, resulting in their separation from the aqueous phase.

Advantages of EC

- Reduce suspended solids, colloids, and emulsions without the use of chemicals

- Simplicity and flexibility in equipment and operation

- Lower sludge volume as compared to any other processes; any sludge produced settles easily and can be dewatered

- Better separation efficiency due to the applied electric field, which sets the charged particles in faster motion for better coagulation

One of the major disadvantages of the conventional EC process is formation of an impermeable oxide and scale layer on the electrodes. The patent pending technology described herein uses a sacrificial anode that is inexpensive and non-scaling. This eliminates the need for chemical cleaning and grinding, and removes the risk of chemical exposure. Reduction in nonproductive time (NPT) and longer life are additional benefits. Secondly, this proprietary sacrificial anode allows for higher current densities without concern for scaling, which can result in the production of higher concentration of oxidants.

The paper discusses the use of a single step mobile EC treatment to eliminate critical components from the waste water which can then be used as a borate cross-linked fracturing fluid. This water treatment technology was applied for FIML in the Permian Basin. In this region, the relationship between the high level of activity and the high volume of water required for fracture treatments makes water availability a significant issue.

FLUID DEVELOPMENT

FIML was interested in developing a fracturing fluid compatible with various sources of produced, flow-back, reserve pit and fresh water. As discussed earlier, although these waters create minimal compatibility problems in slickwater, they pose many challenges for developing a stable crosslinked fluid.

Test Conditions

The test criteria required a formation bottomhole temperature of 160°F, and pump times of approximately one hour. Composite brine was created by commingling produced, flow-back, reserve pit and fresh water in the lab. This mixture was then treated through the EC technology as discussed previously. A representative analysis of the composite brine before and after the treatment is presented in Table 1.

To test compatibility, additives and processes used in formulating conventional crosslinked systems were used.
Fluid viscosity measurements were performed using FANN 50 C viscometers configured with R1B5 rotor-bob. The rheological performance of the fluid for the two polymer loadings, based on 100 sec^{-1} apparent viscosities, are as depicted in Figure 1. The fluid was initially sheared at 100 sec^{-1} for 0.1 minutes, followed by a shear rate sweep of 100, 80, 60, and 40 sec^{-1} to calculate the power law indices, n’ and K’. The fluid was sheared at 100 sec^{-1} between shear rate sweeps, and the shear rate sweep was repeated every 15 minutes for the two-hour test.

Rheology measurements at 160ºF indicate that the fluid is thermally stable and has proper viscosity for proppant suspension and placement as required for the pump time. After it was determined that 100% of the treated water could be used to mix a viable fracturing fluid, the decision was made to do a pilot operation using a 50/50 blend of EC-treated waste water and fresh water. This was done so that the fluid pumping company and FIML could gain more experience and confidence in the functionality of the fluid. A representative post-job water analysis of the 50/50 blend is presented in Table 3. The fluid was tested under the criteria stated in the Test Conditions section. The viscosity measurements are given in Figure 2. Even though this is fundamentally a borate-crosslinked system, it had to be perfected and tailored for use with treated, high chloride, oil-laden waste water. Modified fluid design helped in the development of a gelled fluid that kept a high enough viscosity (16 cp) throughout the duration of each stage and a crosslinked fluid stable enough to carry sand at its maximum concentration (4 ppg).

HYDRAULIC FRACTURING

The first treated water hydraulic fracture treatment performed in the Wolfberry play took place in Reagan County. The treatment consisted of nine stages, fracture treated with a 25-pptg borate-crosslinked system carrying a total of 550,000 lb of 20/40 white sand and 420,000 lb of 16/30 brown sand. The maximum sand concentration was 3 to 4 ppg. Pump rates ranged from a minimum of 40 bpm to a maximum 65 bpm, depending on the rock characteristics. Treating pressures throughout the nine stages remained within the range of typical fracture stimulation with fresh water as the base of the fracture fluid system. Table 5 illustrates average surface treating pressures throughout the nine stages of the fracture stimulation.

Figure 3 shows a comparison between five conventional fracture stimulations with fresh water as the baseline of the fracture fluid system and the first treated water hydraulic fracture done in the Wolfberry play. No significant change in surface treating pressure was observed. No changes were made to the pump schedule or desired pump rates for this operation as compared to earlier conventional fresh water hydraulic fracturing jobs in comparable wells. Pump rates of 40 to 65 bpm on the treated water fracture stimulation were achieved similar to the fresh water fracture stimulations done previously. Stage sizes, perforation schemes, sand concentration, and proppants remained the same—the only variable was that the base fluid for the fracture fluid system was a mixture of treated and fresh water. It can be safely concluded that a successful fracture treatment was accomplished using the treated water system.

ECONOMICS

A model was developed to compare the scenarios with and without treatment as it related to water management for hydraulic fracturing. To show the environmental impacts of the treatment onsite, a comparison of the trucking is presented in Figure 4. For disposing 25,000 bbl of waste, the number of trucks required was calculated to be around 192. Applying EC technology reduced the waste generated to about 2% by volume. To dispose the waste generated through EC treatment required only about four trucks, a 98% reduction in the number of trucks required for disposal. Apart from the economic impact, this means less wear and tear of the roads, and a lower carbon footprint.

The economic impact of the treatment takes into account the costs associated with sourcing fresh water, the cost of transporting waste water for disposal, the cost of renting frac tanks for storage and the cost of technology for treating the water. Savings increase with increasing the volume of water treated for hydraulic fracturing. The current study is based on treating 25,000 bbl. As presented in Figure 5, with EC treatment, it is projected that a saving of approximately 20% was achieved when treating water as opposed to disposal.

CONCLUSION

- Single-step mobile EC treatment was effective in eliminating critical components from the waste water
- The treated water was used to custom-design a borate-crosslinked fracturing fluid
- Successful hydraulic fracturing was conducted to stimulate nine zones
- Significant environmental and economic benefits were achieved with the implementation of EC technology

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Table 1
Water Analysis Pre and Post Treatment

Ionic Species	Pre treatment	Post treatment
Cations	**MIXED WATER**	**MIXED WATER**
Calcium (Ca)	**1490**	**1,290**
Barium (Ba)	**24.6**	**12**
Magnesium (Mg)	**277**	**247**
Iron (Fe)	**60.4**	**ND**
Potassium (K)	**229**	**176**
Sodium (Na)	**34,200**	**29,950**
Boron (B)	**30.5**	**28**
Copper (Cu)	**0.01**	**ND**
Manganese (Mn)	**1.9**	**2**
Molybdenum (Mo)	**0**	**ND**
Phosphorus (P)	**1.62**	**ND**
Silica (Si)	**10.7**	**4**
Strontium (Sr)	**488**	**402**
Zinc (Zn)	**0.14**	**ND**
Aluminum (Al)	**0.01**	**ND**
Anions	**Concentration, mg/L**	**Concentration, mg/L**
Chloride	**59,200**	**48,500**
Sulfate	**213**	**43**
Carbonate	**NA**	**NA**
Bicarbonate	**529**	**395**
pH	**6.74**	**6.31**
Specific Gravity	**1.065**	**1.06**
Total Dissolved Solids	**96,757**	**80,108**
Total Hardness as $CaCO_3$	**5,437**	**4,238**

Table 2
Viscosity Measurements of 20 and 25pptg Guar Fluids

20 pptg Guar Borate System						
Time (min)	Temperature (°F)	n'	K'	Viscosity @ 40 sec^{-1} (cP)	Viscosity @ 100 sec^{-1}(cP)	Viscosity @ 170 sec^{-1}(cP)
2.1	98	0.8128	0.02247	539	454	411
17.1	153	0.4994	0.05877	444	281	215
32.1	160	0.5039	0.0555	426	271	208
47.1	162	0.5745	0.03513	350	237	189
62.1	162	0.6199	0.02304	271	192	157
77.1	162	0.6928	0.01447	223	168	143
92.1	161	0.6096	0.01641	186	130	106
107.1	162	0.6269	0.0124	150	107	87
122.1	162	0.6731	0.00832	119	88	74

25 pptg Guar Borate System						
Time (min)	Temperature (°F)	n'	K'	Viscosity @ 40 sec^{-1} (cP)	Viscosity @ 100 sec^{-1}(cP)	Viscosity @ 170 sec^{-1}(cP)
2.1	96	0.9362	0.02614	989	933	902
17.1	155	0.4899	0.07426	542	339	259
32.1	160	0.4812	0.07237	511	318	241
47.1	162	0.4963	0.06874	513	324	248
62.1	161	0.6436	0.02628	338	244	202
77.1	161	0.5133	0.03715	295	189	146
92.1	162	0.6792	0.01817	266	199	167
107.1	161	0.7309	0.00928	165	129	112
122.1	161	0.7244	0.01008	175	136	117

Table 3
Water Analysis - Post Treatment for a 50/50 blend of Waste and Fresh Water

Ionic Species	Post treatment
Cations	**MIXED WATER**
Calcium (Ca)	**734**
Barium (Ba)	**ND**
Magnesium (Mg)	**370**
Iron (Fe)	**2.65**
Potassium (K)	**ND**
Sodium (Na)	**16,660**
Boron (B)	**ND**
Copper (Cu)	**ND**
Manganese (Mn)	**ND**
Molybdenum (Mo)	**ND**
Phosphorus (P)	**ND**
Silica (Si)	**ND**
Strontium (Sr)	**ND**
Zinc (Zn)	**ND**
Aluminum (Al)	**ND**
Anions	**Concentration, mg/L**
Chloride	**27,200**
Sulfate	**813**
Carbonate	**NA**
Bicarbonate	**453**
pH	**6.4**
Specific Gravity	**1.0275**
Total Dissolved Solids	**46,234**
Total Hardness as $CaCO_3$	**3,363**

Table 4
Viscosity Measurements of 25pptg Guar Fluids with 50/50 Treated Water and Fresh Water

25 pptg Guar Borate System (50/50 Dilution)						
Time (min)	Temperature (°F)	n'	K'	Viscosity @ 40 sec^{-1} (cP)	Viscosity @ 100 sec^{-1}(cP)	Viscosity @ 170sec^{-1}(cP)
0	75	1.1047	0.0077	545	600	634
15	156	0.471	0.1077	732	451	340
30	159	0.4518	0.0958	607	367	274
45	159	0.5314	0.0673	572	372	290
60	159	0.5654	0.0574	553	371	295
75	159	0.477	0.0869	604	374	283

25 pptg Guar Borate System (Retest)						
Time (min)	Temperature (°F)	n'	K'	Viscosity @ 40 sec^{-1} (cP)	Viscosity @ 100 sec^{-1}(cP)	Viscosity @ 170sec^{-1}(cP)
0	75	1.211	0.0088	918	1114	1245
15	156	0.4719	0.1029	702	432	327
30	159	0.3904	0.1127	569	325	235
45	159	0.5675	0.0532	516	347	276
60	159	0.5234	0.0631	521	336	261
75	159	0.4143	0.0980	540	316	231
90	159	0.5359	0.0570	492	321	251

Table 5
Average Surface Treating Pressure throughout the Fracture Stimulation

Zone	Average STP (psi)
Canyon	4878
Lower Wolfcamp	4204
Middle Wolfcamp	5886
Upper Wolfcamp	5205
Upper Wolfcamp	4548
Dean	3288
Lower Spraberry	2316
Middle Spraberry	2072
Upper Spraberry	1406

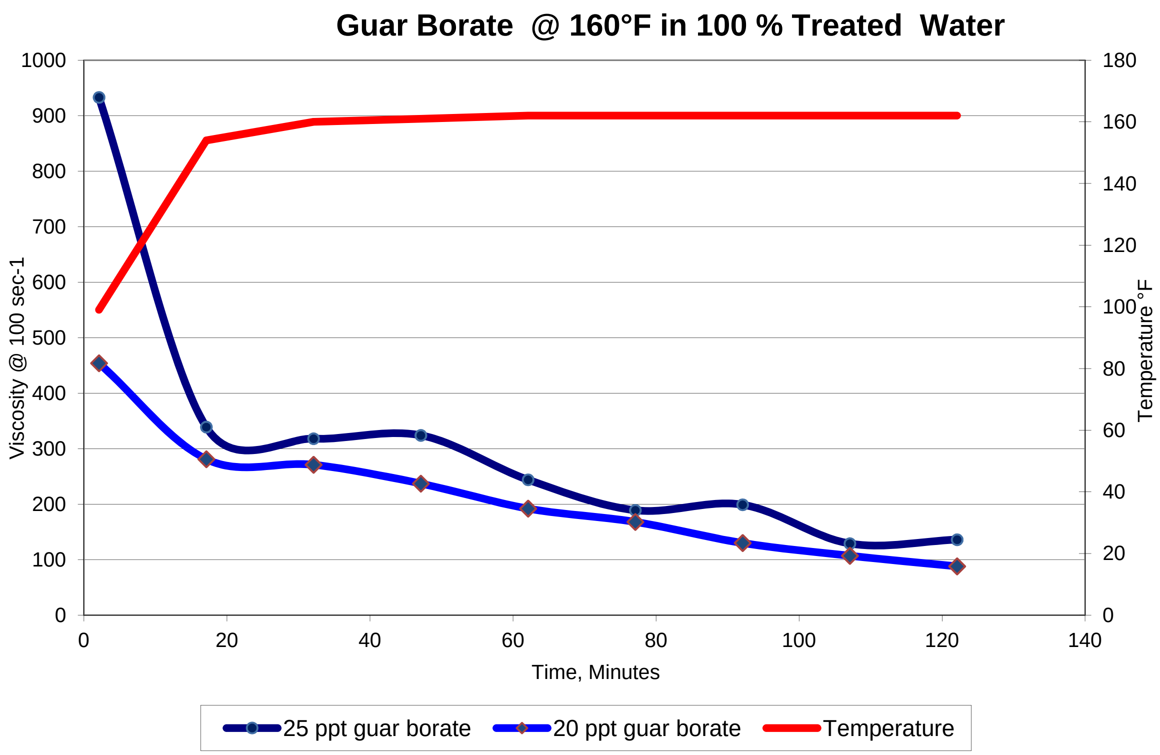

Figure 1 - Viscosity of Guar Borate Fluids with 100% Treated Water

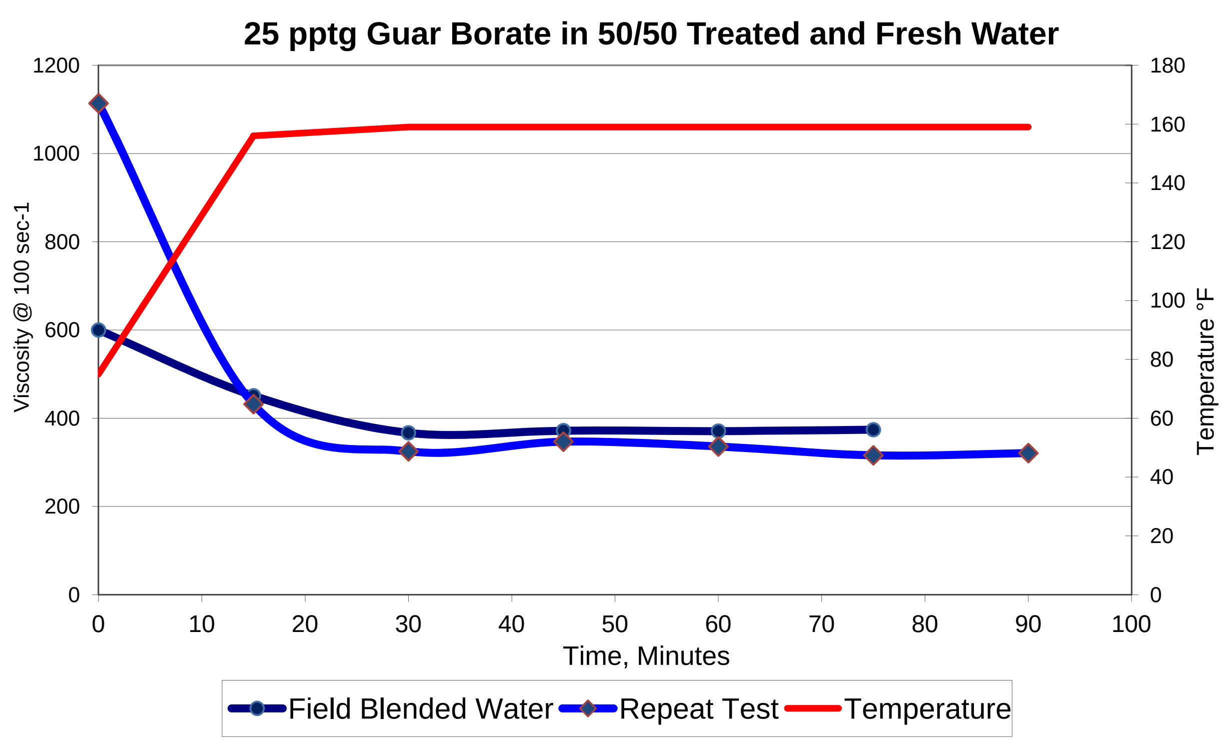

Figure 2 - Viscosities of 25pptg Guar Borate Fluids with 50/50 Treated and Fresh Water

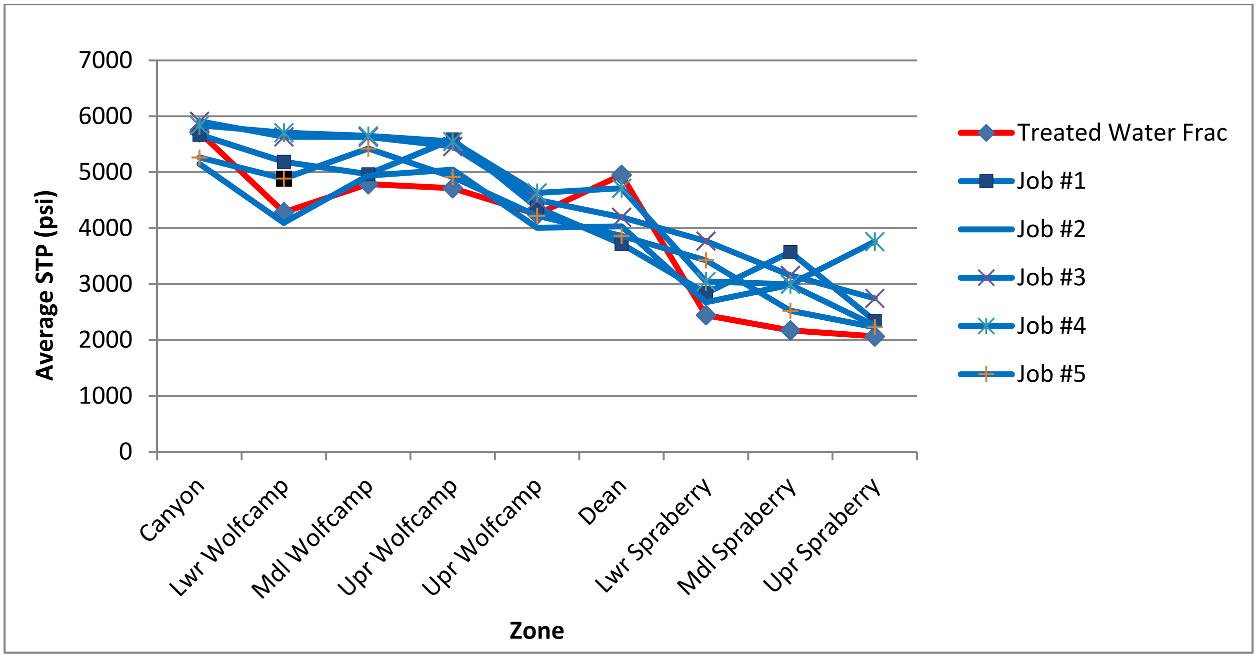

Figure 3 – Comparison Chart Showing Conventional Fracture Stimulations and the Treated Water Stimulation

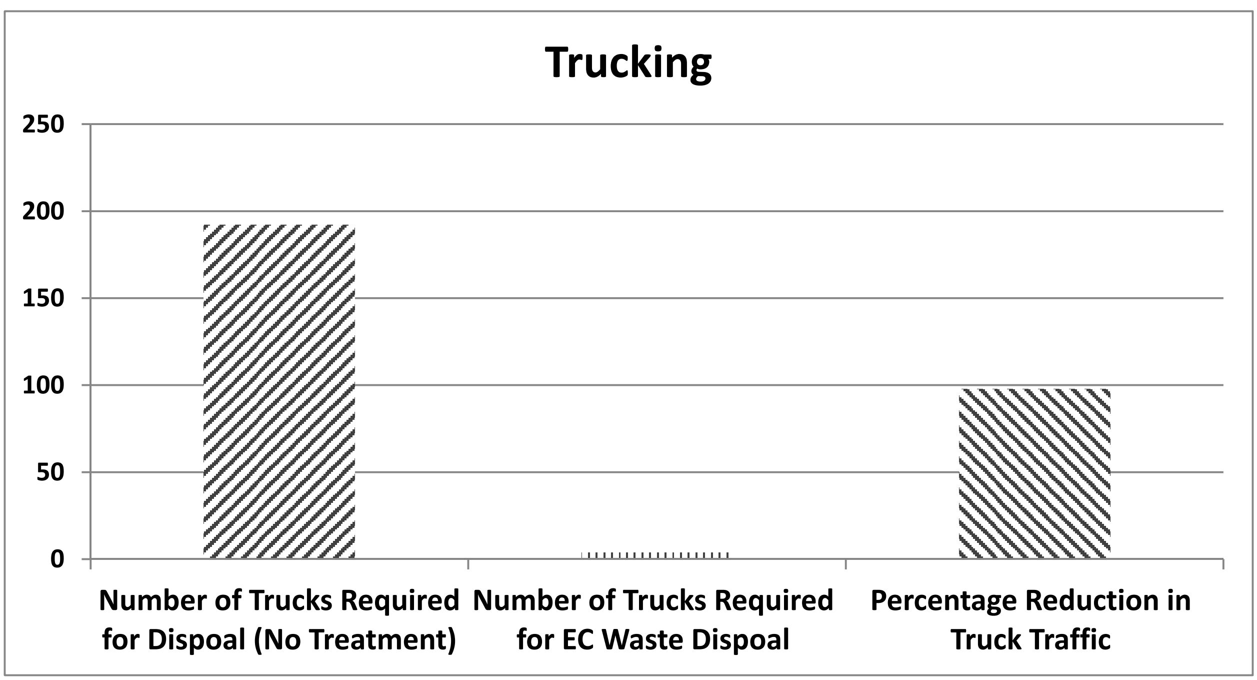

Figure 4 – Comparison Chart Showing Reduction in Truck Traffic with EC Treatment

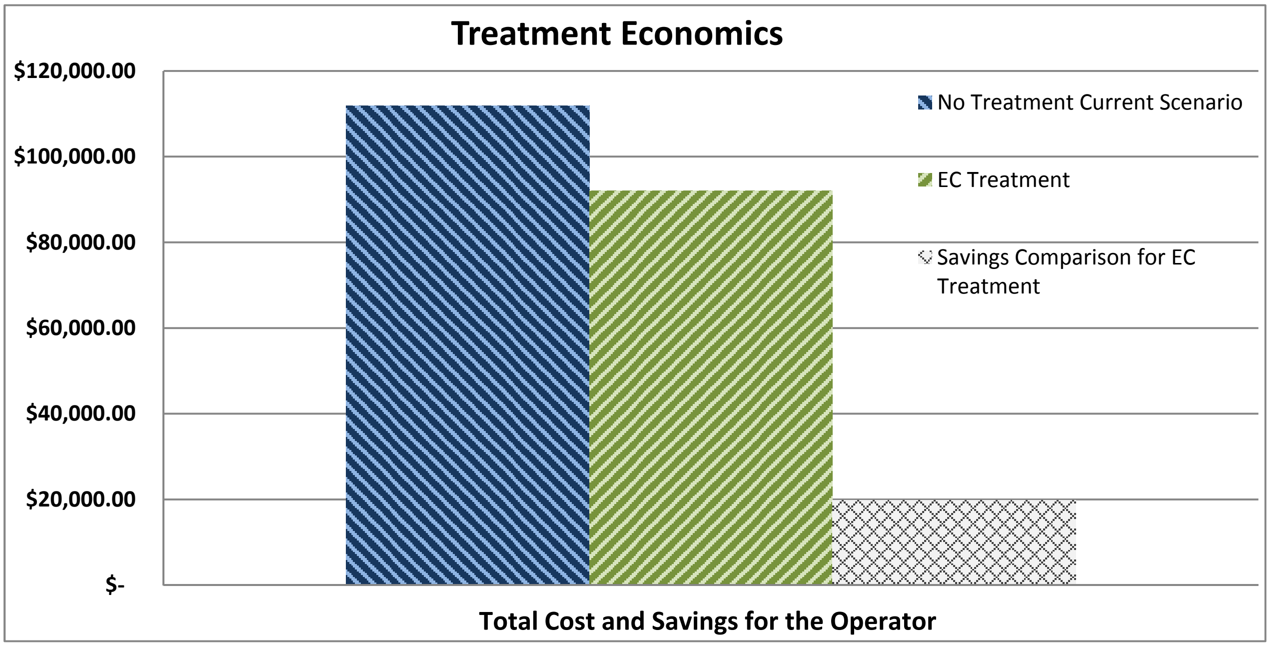

Figure 5 – Cost and Savings Comparison for EC Treatment