SOLAR POWERED ELECTROKINETIC SOIL DESALINATION OF BRINE RELEASES

Oil and Gas Research Program

North Dakota

Industrial Commission

Application

Project Title: SOLAR POWERED ELECTROKINETIC SOIL DESALINIZATION

Applicant: Terran Corporation/Oasis Petroleum

Principal Investigator: Christopher Athmer

Date of Application: 10/27/17

Amount of Request: $149,960

Total Amount of Proposed Project: $346,120

Duration of Project: 2-3 Years

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ABSTRACT

Objective: The objective of this project is to demonstrate the viability and cost effectiveness of using direct current (DC) power to reduce the sodium and chloride mass contamination in soil and groundwater from brine releases. Typical releases may be from leaking pipelines or storage pit. A secondary objective is to integrate an electrokinetic (EK) remediation system with solar power. Since the EK process relies on DC power to induce migration of chloride and sodium ions (as well as other soluble ions) to emplaced electrode wells, solar panel arrays that generally provide 24-48 volts, could prove to be the ideal power source at remote sites, or eventually any site. This project will include the design, installation and operation of solar powered electrokinetic soil desalinization system along with soil monitoring and reports showing the efficacy of the process and comparison to previous traditional remediation efforts.

Expected Results: Based on laboratory experiments and computer modeling scenarios, we expect to remove up to 70 to 80% of the chloride and sodium mass from the soil in the contaminant source zone. The solar power costs should compare favorably with traditional line power and rectifier costs. This demonstration should prove the technology is viable for treating remote sites effectively and economically**.**

Duration: The project is expected to operate over 3 summer seasons. The system will be idled and secured during the winter season since the fluid handling systems will be difficult to manage during the cold periods. This schedule coincides with the maximum solar incidence cycle.

Total Project Cost: The estimated cost for this pilot demonstration is $346,120. We are proposing to cost share on a 57% basis.

Participants: Terran Corporation of Beavercreek, OH, Oasis Petroleum of Williston, ND, and local subcontractors American Engineering and Testing and Stealth Energy Group.

PROJECT DESCRIPTION

Objectives: Soil near the Schmitz pad site near Williston, North Dakota became contaminated due to a leaky flange in a brine pipeline. Oasis Petroleum and Terran Corporation found the site to be suitable for the electrokinetic soil desalinization (EKSD) process to extract the salt contamination from the soil using a proprietary extraction system based on electromigration techniques.

The EKSD process is an effective and economical alternative to conventional excavation or pump and treat. The goal is to remove as much chloride and sodium mass as practical. This project will demonstrate the ability to operate the system using solar power at remote sites where line power is not available and generators are not economically viable.

Methodology:

Salt in water (groundwater or soil pore water) dissociates as chloride and sodium ions. These ions can be directed to polar electrodes placed in the contaminated soil and removed. When placing anodes and cathodes in the soil, sodium migrates toward the cathodes while chloride migrates toward the anodes. This process is called electromigration. There is also a process called electroosmosis that also occurs. Electroosmosis is a phenomena that causes the bulk pore water to move toward the cathode, but at a slower rate than electromigration. Therefore, sodium ions move with electromigration + electroosmosis while chloride moves with electromigration but against electroosmosis flow and is therefore slower and less efficient. Laboratory experiments show nearly complete removal of free sodium and 70-80% removal of chloride are attainable. The remaining chloride tends to build up in the immediate vicinity of the anode. Running power to the system as pulse reverse, or pulse rest, can increase the chloride removals by 5-10% but will require longer operation period. Tests are on-going with the aim at reducing the residual chloride accumulating near the anode. If it is imperative to remove the residual chloride near the anode, the anodes can be over-drilled at demobilization.

There is also basic electrochemistry of water and other ions taking place around the electrodes. Some water will be dissociated into oxygen gas and H^+ at the anode and H_2 gas and OH^- at the cathode. Gas formation rate is low and not enough to cause an explosive condition. Based on the H^+ formed at the anode, an acid front is created. Likewise, a base front is created at the cathode due to the OH^- formation. These two fronts ultimately meet and cancel each other as H_2O is reformed. At the end of the operational period, the polarity is reversed for a short period to reduce the acid and base regions of the electrodes.

Other mobile ions will be mobilized to their respective electrodes. Many of the cations (naturally occurring calcium, magnesium, etc.) will precipitate prior to reaching the cathode due to pH changes at the cathode (pH~10). Most soluble anions (naturally occurring sulfate, nitrate, etc.) will be removed at the cathode. However, the amounts of chloride and sodium ions are orders of magnitude higher in the brine spill area.

Approximately 200 bore-hole based electrodes will be emplaced in the contaminated area that will be connected to a direct current (DC) power supply. The chloride in solution will migrate to the anodes where it is removed while the sodium ions will migrate to the cathode where they are removed. The extraction effluents will be collected in a brine frac tank for disposal. All siphon tubing, pumps, and pump tubing are made from materials that best suited for the chloride or sodium rich fluids.

The electrodes are installed much like monitoring wells. Typically, 1-inch PVC well screen and riser is used. The screen and riser is spiral wrapped with a dimensionally stable anode (DSA) mixed-metal oxide coated wire. The borehole annulus is backfilled with electrically conductive backfill material common to cathodic protection devices. The DSA wires are then connected to common buss bars which are in turn connected to a large DC power supply.

The power supply will be an array of solar panels capable of producing 50 KW of electricity. The power will be delivered directly to the soil with no battery storage. In laboratory studies, we have found that pulsing the power with periods of rest, or even reversal, can help the overall removal of chloride from soil. Given that, running the system during the day for 14-16 hours followed by a night-time resting

should work well, other than lengthening the overall operational period. This technique has not been attempted on a field scale installation. We realize some adjustments may need to be made at this site to accommodate the power output of the solar array. However, there is line power available if needed to augment the system or speed up the remediation for any reason. According to the operation plan, the system will not be operated during the winter months. It is estimated the process will take 18 months and will be operated in warmer months only over the course of 3 summers.

Anticipated Results: Based on laboratory studies, removal of chloride typically reaches 70% and free sodium removal reaches 95+%. The chloride removal can reach 80% or more if reverse-pulse (periods of DC forward followed by shorter periods of DC reverse, or even off). For even higher chloride removals, the anodes can be overdrilled at the conclusion of operations since the remaining chloride generally exists next to the anode.

Facilities:

The proposed demonstration will be operated to remediate a reach of Timber Creek near the Schmitz 44-30H well pad. The project site is located approximately 14 miles southeast of Williston off of County Road 29 where a produced water release occurred in February 2017. The released brine water originated on the pad. It then flowed down gradient from the pad southward toward Timber Creek, impacting soil, surface water and groundwater. The constructed depth of the remediation will extend up to 15 feet deep while the areal extent will cover about 4000 square feet.

Resources:

The resources required to install and operate the electrokinetic system are minimal. The electrodes are installed using direct-push technology with no waste soils to manage. The disposal of the removed brine components is accomplished using collection totes that are pumped to trucks and delivered to deep well injection points. Electricity will be provided using solar panels, significantly reducing the carbon footprint.

Techniques to Be Used, Their Availability and Capability:

The installation and operation will be similar to the Oasis Petroleum's Connie EK site but will benefit from some lessons learned. Since there is a slight hydraulic gradient present at the Schmitz site, the electrodes will be arranged to take advantage of the hydraulic flow. Alternating rows of electrodes (anodes, cathodes) will be arranged perpendicular to the flow in order to help steer the contaminants to the electrode collection wells. The electrode wells are installed using conventional direct-push technology. Photovoltaic panels will be used for the DC electrical component. A 50 KW grid will be installed at the well pad site.

Environmental and Economic Impacts while Project is Underway:

Anticipated environmental impacts will be positive. The remediation of brine impacted soils and groundwater will effectively reduce the potential for groundwater contamination. The brine components chloride and sodium will be extracted, contained and transported to a licensed disposal well.

If this demonstration is successful, this technology can be used as an alternative to excavation and soil replacement significantly reducing disruption of the surface soils and biota. Also, the solar component makes the system attractive at remote locations with no available line power.

Ultimate Technological and Economic Impacts:

There are thousands of brine release site in the Bakken area. Many of the sites can be addressed with this technology without the need for non-native soil replacements or electrical grid power. This technology, when fully developed, will be most beneficial in environmentally sensitive areas.

Why the Project is Needed:

Currently available treatments for produced water releases are disruptive, costly and sometimes not effective. This process should prove to be economically attractive as an alternative to excavation, backfilling or pump and treat methodologies.

STANDARDS OF SUCCESS

The purpose of this project is to further develop an alternative method of treating brine contaminated soils and groundwater, especially in remote or sensitive areas. The electrokinetic soil desalinization process is a mass removal based system that extracts chloride and sodium, along with other minor ionic species, from the soil pores and groundwater. To be successful, the system must remove a majority of the chloride and sodium in order to protect underlying or nearby aquifer systems. Initial target removal is 70% of the chloride and 90% of the free sodium. Current laboratory studies are underway to investigate operating conditions that will improve the mass removals. There are indications that temporary voltage reversal or rest states (voltage turned off) may help the overall removal. However, this could slow down the process, lengthening the remediation time.

To measure the effectiveness, soil samples will be collected before, during and after treatment. A statistically based sampling protocol will be developed following existing regulatory criteria. Costs will also be tracked to determine the economic advantages of using this system. We expect to find ways to reduce the costs in the future through field innovations, which are common to most field pilot installations. Reduction in cost during the installation and/or operations will be realized as the more conservative estimates are refined, better methods are developed, or more appropriate equipment is utilized.

If successful, the modified EK desalinization process will be fully commercialized and presented to the industry as an alternative to current technologies. This in turn, should help the oil and gas industry to address more of the thousands of brine release sites across the state. There will also be a positive impact on the reputation of the oil and gas industry if more brine release sites are being addressed, especially with a "greener" solar powered process.

BACKGROUND/QUALIFICIATIONS

Oasis Petroleum Environmental Department in Williston manages oil and brine releases for the corporation. Under the direction of Dustin Andersen, they have already spent a great deal of effort at the Schmitz site. The release was addressed promptly by excavation and pumping. The remaining contamination was quickly assessed and a conventional groundwater recovery system was put in place. The recovery system is working to contain the release but will need to be operated for many years due to residual soil and groundwater contamination. American Engineering and Testing and Stealth Energy Group have provided valuable assistance at the Schmitz site excavation, containment, and assessment efforts to date and will continue providing support for this proposed project. Much of the assessment information will be used to design the EKSD system.

Terran is the leader in large scale electrokinetic process installations. The principle investigator, Chris Athmer (Professional Engineer), has been involved in developing electrokinetic processes for environmental remediation since 1994. As part of the first Research Technology Development Forum (RTDF) under the USEPA Technology Innovation Office (TIO), Chris worked on the Lasagna™ process and its successful full scale implementation at the Paducah Gaseous Diffusion Plant. Since then he has worked on the development of other electrokinetic soil and groundwater remediation processes. The EKSD process is the latest effort. Chris has managed the development from laboratory to pilot demonstration. The results of these efforts have been patented and presented in several published peer reviewed articles listed below. Currently, Terran is working with a local solar power engineer to design and test an effective system to provide the needed power.

Terran and Oasis are using EKSD presently at the Connie site where a brine pipeline release near the well pad caused contamination in a small slough. The EKSD system at Connie consists of 93 well-based electrodes (24 cathodes, 69 anodes) installed in a hexagonal pattern. The system has been installed and operated seasonally for 2 years. Results of year 1 yielded a greater than 40% chloride removal that closely matched the modeling. Year 2 results are pending. A few operational issues during year 2

occurred due to the winter freeze and electrode design. The issues will be addressed at the next installation. American Engineering and Testing has provided valuable assistance in installing and operating the EKSD at Connie.

Patent:

Electrokinetic Desalinization System and Method - 9,545,651

Published papers on the project subject:

Athmer, Christopher J., *"Use of Large-Scale Electrokinetic and ZVI Treatment for Chlorinated Solvent Remediation at an Active Industrial Facility"*, Remediation, Vol. 24, No. 4, Wiley Periodicals, 2014, pp. 41.

Athmer, C.J. and R.J. Wilkens, *"Desalinization of Field Soil Using Radial Electromigration and Electroosmosis"*, Journal of Hazardous, Toxic, and Radioactive Waste, Vol. 18, No. 1, 2014, pp. 83.

Athmer, C.J., Ruef, C.J., Jones, T.J. and R.J. Wilkens, *"Desalinization of Kaolin Soil Using Radial Electromigration and Electroosmosis"*, Journal of Hazardous, Toxic, and Radioactive Waste, Vol. 17, No. 1, 2013, pp. 16.

Athmer, C.J., *Chapter 27: Cost Estimates for Electrokinetic Remediation*, "Electrochemical Remediation Technologies for Polluted Soils, Sediments and Groundwater", Edited by Reddy and Cameselle, John Wiley & Sons, 2009, pp 583-587.

Athmer, C.J. an d S.V. Ho, *Chapter 30: Cost Field Studies: Organic-Contaminated Soil Remediation with Lasagna Technology*, "Electrochemical Remediation Technologies for Polluted Soils, Sediments and Groundwater", Edited by Reddy and Cameselle, John Wiley & Sons, 2009, pp 625-646.

"In-situ Remediation of TCE in Clayey Soils Using Lasagna™", 2003 in Calabrese, E.J., P.T. Kostecki and J. Draagun. *Contaminated Soils* Vol. 8 Chapter 16, Amherst Scientific Publishing

Ho, Sa V, Athmer, C.J et al. "*The Lasagna^{TM} Technology for In Situ Soil Remediation. 1. Small Field Test*", Environmental Science and Technology, Vol. 33, No. 7, 1999, pp. 1086.

Ho, Sa V, Athmer, C.J et al. *"The Lasagna^{TM} Technology for In Situ Soil Remediation. 2. Large Field Test*", Environmental Science and Technology, Vol. 33, No. 7, 1999, pp. 1092.

Ho, Sa V, Athmer, C.J. et al. *"The Lasagna^{TM} Process technology for in-situ bioremediation of low permeability soils*", Bioremediation Technologies, Vol. III, Technomic Publishing, Lancaster, PA, 1998, pp. 393.

Ho, Sa V, Athmer, C.J. et al. *"Scale-up aspects of the Lasagna^{TM} process for in situ soil decontamination*", Journal of Hazardous Materials, #55, 1997, pp. 39.

Ho, Sa V, Athmer, C.J et al. *"Integrated In-Situ Soil Remediation technology – The Lasagna^{TM} Process*", Environmental Science and Technology, Vol. 29, No. 10, 1995, pp. 2528.

MANAGEMENT

This demonstration will be managed jointly by Terran Corporation of Beavercreek, OH and Oasis Petroleum of Williston, ND. Terran will manage the technical aspects of the design, installation and operation as well as the data management. Oasis will provide the local field support, oversee local contractors, manage any waste, and maintain the equipment during operations. Data evaluation and reporting will be completed through a joint effort of these two participants.

Over the course of operations, strategic soil and groundwater samples will be collected to determine the effectiveness of the system. At a minimum, every October, prior to winter shutdown, the samples will be collected and evaluated. Decisions concerning operations will be made based on the data. Adjustments to the future operation of the system may also be made at that time. During the active operating periods, operating parameters such as voltage, current and soil temperature will be monitored continuously. This data will allow us to calculate power usage and estimate the chloride and sodium migration rates based on our computer models. The soil and groundwater samples mentioned above will help us calibrate these models.

TIMETABLE

Installation is anticipated for spring of 2018. The system will operate spring to fall, during the non-freezing season. The system will be shut down for the winter due to water lines freezing and site access. To reach mass removal target, the system will most likely need 3 summer seasons. Each fall after evaluating the season's end soil and groundwater sample data, the project effectiveness will be assessed and operations adjusted accordingly or terminated.

BUDGET

Project Associated Expense	NDIC's Share	Applicant's Share (Cash)	Applicant's Share (In-Kind)	Other Project Sponsor's Share
Site Investigation and Prep - Direct	$0		$0	
Investigation and Prep - Labor	$0		$0	
System Design - Labor	$0		$0	
Equipment/Materials	$102,960			
Installation - Direct	$0		$68,000	
Installation - Labor	$12,000		$38,160	
Operations - Direct	$0		$30,000	
Operations -Labor	$30,000		$0	
Monitoring - Direct	$0		$40,000	
Monitoring - Labor	$5,000		$0	
Demobilization - Direct	$0		$20,000	
Demobilization - Labor	$0		$0	
TOTALS	$149,960		$196,160	

The costs above are based on previous experience taking into account size, depth and design of the EKSD system. The submitting partners have already contributed significantly to the site prep and investigations. Not including the actual remediation activities undertaken thus far, Oasis has provided soil and contamination information needed to baseline the current conditions and establish the basis for design. A majority of the site investigation and prep costs will be borne by the submitting partners. Terran has evaluated available information to develop the initial design, which in turn is used to generate the cost estimates for the project.

The equipment and materials for the project includes the electrode wells (well pipe, DSA wire, backfill material), conductors, plumbing, pumps, shed, totes, data acquisition system, communication system, and power system (solar power).

The installation costs include several weeks of subcontracting direct-push equipment and operators and support as well as general laborers. It also includes surveying, the system hookup, and shakeout. The installation should take approximately 4 weeks to complete.

Operations include the on-going data management, maintenance, waste management, and general oversight. The system is expected to operate for at least 2 summer seasons with winter shut-downs. A third summer will most likely be beneficial.

Monitoring includes periodic soil and groundwater sampling as well as seasonal reports on operating conditions and remediation progress.

Demobilization consists of removing the power source from the site and pulling the electrode wells from the ground. Depending on their condition, the electrode wells may be set aside for reuse at another site, or discarded (recycling any possible components).

CONFIDENTIAL INFORMATION

At this time, there is no confidential information in this grant application.

PATENTS/RIGHTS TO TECHNICAL DATA

Terran Corporation has received a patent for the basis of this work. The title is *Electrokinetic Desalinization System and Method*, US Patent #9,545,651. Any enhancements to the system developed during this demonstration, including the solar aspects, that are deemed patentable will be pursued by Terran Corporation.

STATUS OF ONGOING PROJECTS (IF ANY)

If the applicant is a recipient of previous funding from the Commission, a statement must be provided regarding the current status of the project.

Terran Corporation has no past or current projects with the Commission.

Oasis Petroleum has no past or current projects with the Commission.

APPLICATION CHECKLIST

Use this checklist as a tool to ensure that you have all of the components of the application package. Please note, this checklist is for your use only and does not need to be included in the package.

☒	Application
☒	Transmittal Letter
☒	$100 Application Contribution
☒	Tax Liability Statement
☒	Letters of Support (If Applicable)
☐	Other Appendices (If Applicable)

When the package is completed, send an electronic version to Ms. Karlene Fine at kfine@nd.gov, and 2 hard copies by mail to:

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For more information on the application process please visit:
http://www.nd.gov/ndic/ogrp/info/ogrcsubgrant-app.pdf

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