Novel Water Treatment Technology for Application to Hydraulic Fracturing

Final Report
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Acknowledgements

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Executive Summary

Electrocoagulation (EC) is an emerging technology that combines conventional coagulation, flotation and electrochemistry for the treatment of oily wastewaters. Metals released from the anode during electrolysis cause coagulation of pollutants aiding their separation from water. However, one of the challenges limiting the efficiency of EC is the need for the regular cleanup of the fouled electrodes, which causes shutdowns and restarts of the EC process. The purpose of this project was to overcome this challenge. An ultrasonic system was designed and tested to clean the electrodes effectively during the EC treatment of waste flowback waters from hydraulic fracturing operations.

The prototype of an EC process modified with an ultrasonic process was built by Easwara Origins. The project sourced large quantities of water from the hydraulic fracturing wastewater pond of a large producer in northwestern Alberta. Experiments were conducted at the laboratories of the Department of Chemical and Petroleum Engineering and the Center for Environmental Engineering Research and Education at the University of Calgary, and work witnessed and assessed by the Southern Alberta Institute of Technology, Applied Research and Innovation Services. The objectives were to determine the efficiency of the ultrasound process in reducing electrode fouling during the EC treatment, and to test the EC process for the removal of target contaminants such as total suspended solids, total hardness, heavy metals and total petroleum hydrocarbons from hydraulic fracturing flowback waters. The results were:

- The incorporation of the ultrasonic transducer visually showed a complete removal of scale deposition from the EC anode. Optimal ultrasound settings were determined.
- The EC process was shown to remove up to 90% of suspended solids, oil and hardness from the wastewater.
- The application of a process gas bubbled into the water during the EC process increased the removal of total hardness from 50% to 90%.

The assessment of overall results showed that the Easwara design prototype combining EC and ultrasonic overcame a major drawback associated with electrode fouling. Electrodes may now be cleaned without extraction of electrodes per the current practice, which requires the intermittent stopping of the EC treatment for the extraction, cleanup and reinstallation of the electrodes.

Existing water treatment approaches are not practical, nor cost-effective for hydraulic fracturing because well locations constantly change over wide areas and the requirement for water injection is a one-time event in the life of the well. Other disadvantages of current water treatment solutions include their significant environmental footprint due to the use of chemicals, batch processing, high capital costs, and high operational costs related to transportation of chemicals and the need for skilled operators.

By contrast, EC can be deployed as a practical mobile solution powered by electricity that does not require the transportation of chemicals to field locations. The project demonstrated that EC can effectively reduce target contaminants by over 90% in flowback water from hydraulic fracturing operations. The next step will be the design and packaging of an efficient EC and ultrasonic process into a mobile solution get can be deployed and field-tested at remote locations.

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1. Introduction

This report provides a final account of the project *Novel Water Treatment Technology for Application to Hydraulic Fracturing* undertaken by PTAC Petroleum Technology Alliance Canada (PTAC) in collaboration with Easwara Origins, the Southern Alberta Institute of Technology, the University of Calgary and a large oil and gas producer. The project took place from May 25, 2015 to March 31, 2016.

The purpose of this project was to fill a technology gap with a practical and cost-effective Electrocoagulation (EC) technology solution for treatment and recycling of water in hydraulic fracturing. EC is an emerging technology that combines conventional coagulation, flotation and electrochemistry for the treatment of oily wastewaters. Metals released from the anode during electrolysis cause coagulation of pollutants aiding their separation from water. However, one of the challenges limiting the efficiency of EC is the need for the regular cleanup of the fouled electrodes, which causes shutdowns and restarts of the EC process. The purpose of this project was to overcome this challenge. An ultrasonic system was designed and tested to clean the electrodes effectively during the EC treatment of waste flowback waters from hydraulic fracturing operations.

PTAC Petroleum Technology Alliance Canada (PTAC) is a not-for-profit organization that facilitates collaborative research and technology development to improve the financial, environmental and safety performance of the Canadian hydrocarbon energy industry. PTAC is facilitating this Project through its network of oil and gas operators. PTAC intends to disseminate the opportunity to the industry and facilitate the future demonstration trials that will be required in the next phase of development.

2. Background

Hydraulic fracturing is an oil and gas production technology that has literally revolutionized the industry. While successful, it has raised concerns regarding its environmental impact, particularly concerning water. As a result, the technology has been subject to moratorium in several jurisdictions. The concerns with respect to water focus on: the high volume of water injected into the well, the chemicals added to the water, and the handling of the contaminated water that flows back from the well after fracturing.

Treatment and recycling of flowback water offers an elegant solution to these concerns as treatment removes chemicals and recycling minimizes net water consumption. The technology gap is that no practical, cost-effective technology presently exists for treating and recycling water in hydraulic fracturing applications. Water treatment, as practiced worldwide for municipal and industrial applications (including oil and gas) generally involves fixed assets of substantial size, and high costs that need to be amortized over long periods of time. Existing water treatment approaches are not practical, nor cost-effective for hydraulic fracturing because well locations constantly change over wide areas and the requirement for water injection is a one-time event in the life of the well. Other disadvantages of current water treatment solutions include their significant environmental footprint due to the use of chemicals, batch processing, high capital costs, and excessive operational costs related to transportation of chemicals and the need for skilled operators.

One promising alternative to fixed, chemical-based, batch processing is EC which replaces chemical coagulation and flocculation and operates in a continuous flow. In general, EC removes silica, heavy metals such as oxides, suspended and colloidal solids, breaks emulsions, removes fats, oils and grease, and complex organics, and neutralizes bacteria, viruses and cysts. EC can be deployed as a practical mobile solution powered by electricity that does not require the transportation of chemicals to field locations.

The current problem with EC is fouling of the electrodes by deposition of particulates on the surface of the electrodes. As a result, the process becomes obstructed and efficiency is reduced. A solution to the fouling problem developed by one of the project partners, Easwara, has passed the proof-of concept stage and this project will now focus on developing this proof-of-concept into an in-flow continuous solution with the mobility, ruggedness and reliability required by industry.

3. Objectives

The overall objective of this project is to fill a technology gap with a practical and cost-effective EC solution for treatment and recycling of water in hydraulic fracturing. This will reduce a major environmental impact of hydraulic fracturing by providing a method to treat and recycle flowback water, thereby reducing water consumption. The main benefit of the project is a reduction of environmental impact, which is a goal of governments and industry. The project will also offer economic benefits to operators of hydraulic fracturing operations in the reduction of transportation and management costs for fresh water and wastewater.

3.1. Objective 1 - Efficiency of the Ultrasound Process in Reducing Electrode Fouling

The objective was to determine the efficiency of the ultrasound process in reducing electrode fouling during the EC treatment.

The application of an ultrasound process for the rapid cleanup of the anode during EC treatment was highly effective.

3.2. Objective 2 - Test the EC Process for the Removal of Target Contaminants

The objective was to test the EC process for the removal of target contaminants such as total suspended solids, total hardness, heavy metals and total petroleum hydrocarbons from the wastewater.

The use of EC for treatment of flowback water from hydraulic fracturing operations successfully removed up to 90% of total suspended solids, total hardness and total petroleum hydrocarbons.

4. Combined EC and Ultrasonic Unit Schematics

A laboratory unit was specially designed and constructed, which combined EC and ultrasonic treatment (see Figure 1 below). The ultrasonic transducer is mounted against the EC cell wall. During the application of ultrasounds, it is connected to the ultrasound generator. Both the transducer and the generator are by Blackstone Ney. The transducer is 10” x 12”, it is powered at 480 W and 25 kHz.

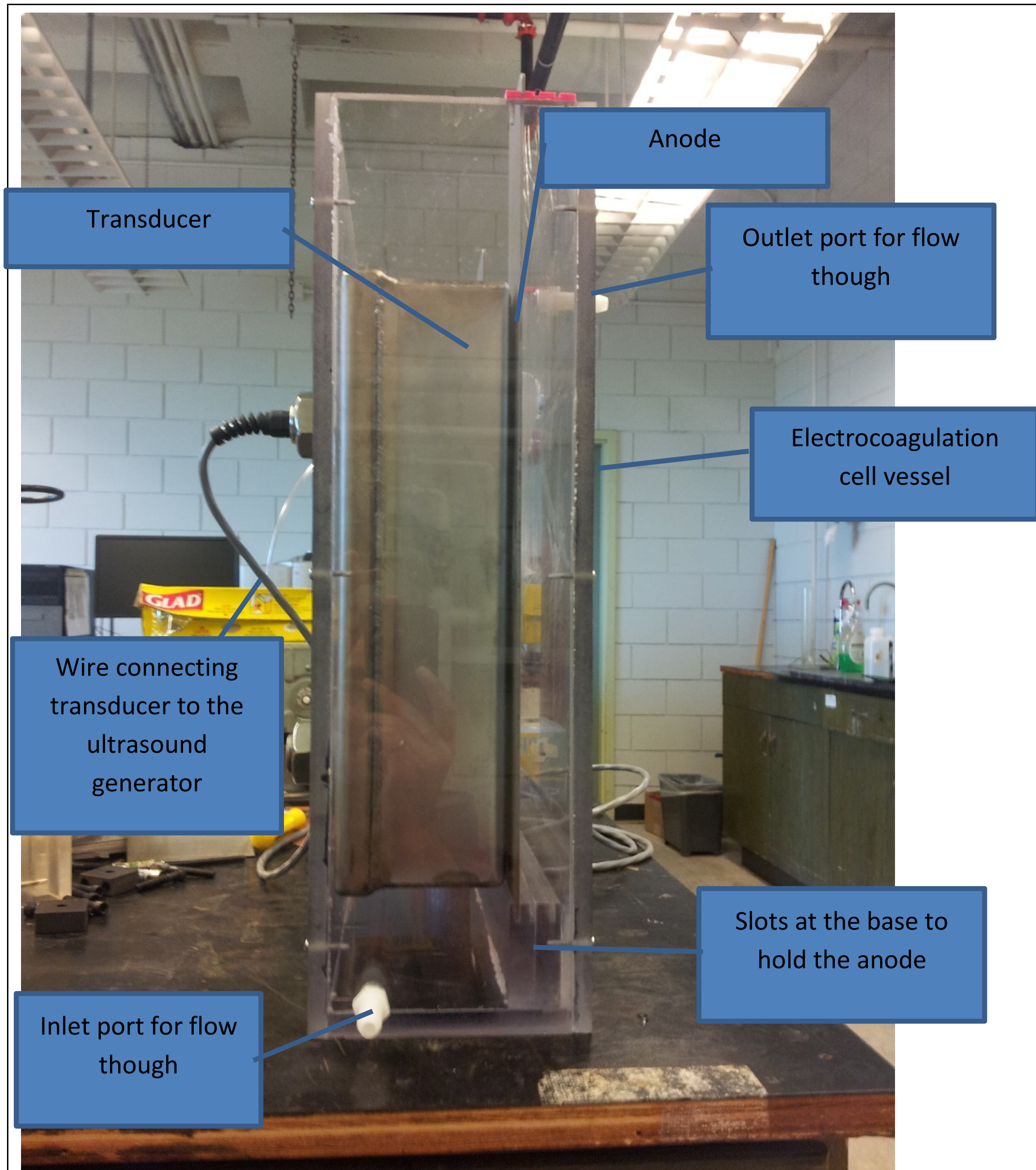

Figure 1. Combined Electrocoagulation and Ultrasound Unit

The transducer consists of piezoelectric drivers and is enclosed in a stainless steel case. Its housings are made of inert gas welded 14 gauge, 316 L stainless steel. The electrical connections in the transducer housing are made using Teflon insulated standard wire and are protected against passive corrosion. The generator is able to produce uniform cavitation, rapid gas removal, and has high performance and reliability cleaning.

5. Project Results

5.1.Methodology

The experimental approach involved two major steps: (1) electrode fouling, which also involved the investigation of the efficiency of the improved EC process in removing target contaminants and (2) electrode de-fouling using the ultrasonic process.

5.2. Electrode Fouling

The first step involves obtaining large volumes of wastewater from the hydraulic fracturing operations of a large producer in northwestern Alberta. Prior to the start of the experiments, the wastewater was analyzed for chemical composition of target contaminants. The results of this analysis showed that the water contained 82,260 ppm of sodium chloride (NaCl), 7560 ppm of calcium chloride ($CaCl_2$) and 3440 ppm of magnesium chloride ($MgCl_2$). The total hardness was 1130 mg/L as $CaCO_3$. The total amount of suspended solids derived from the corresponding turbidity result was 860 NTU and a total petroleum hydrocarbon concentration was 2860 ppm.

This water was pumped into an EC cell and treated by application of the EC process. The average time resulting in heavily fouled electrode was 20 to 30 minutes. EC treatment led to the coagulation of water contaminants and the fouling of the electrode.

The treated water showed a reduction of hardness associated with calcium and magnesium cations. The insoluble products of the oxidation of these and other metals settle at the bottom of the EC treatment device and also accumulate on the electrode surface, thus fouling the electrode.

The precipitates deposited on the electrode were tested for chemical composition. Precipitates from fouled electrodes were scratched out, dried (80°C, for 6 hrs.), crushed and then diffractograms were obtained on Bruker D8 powder X-ray diffractometer. The results indicated that electrode fouling was comprised 90% of iron, 8% magnesium, 2% calcium and approximately 0.1% barium and silicate.

5.3.Electrode De-Fouling

De-fouling was performed with the ultrasonic transducer mounted parallel to the fouled electrode. Ultrasound leads to cavitation bubbles in water, which collapse, creating intense pressure and temperature at the electrode surface, scouring the scale off the electrode. Cleaning was achieved due to sheer forces created by ultrasonic waves on the electrode surface.

Of the conditions tested, the most rapid removal of fouling took place in two minutes. Figure 2 below illustrates the performance of electrode cleaning using ultrasound.

Figure 2. On the left – "fouled" electrode; on the right – plate after 2 min of ultrasound treatment

EC is an effective technology for the rapid removal of total suspended solids, oily sludge and total hardness from wastewater in a variety of industries. According to the results of the experiments, the EC treatment efficiency in removing total hardness, total petroleum hydrocarbons and total suspended solids from flow back water was significantly high at over 90%.

6. Project Achievements

6.1. Achievement 1 - Incorporation of the Ultrasonic Transducer

The incorporation of the ultrasonic transducer visually showed a complete removal of scale deposition from the EC anode. Optimal ultrasound process settings were determined.

6.2. Achievement 2 - Performance of the EC Process

The EC process was shown to remove up to 90% of suspended solids, oil and hardness from the wastewater.

6.3. Achievement 3 - Application of a Process Gas

The application of a process gas bubbled into the water during the EC process increased the removal of total hardness from 50% to 90%.

7. Project Outcomes

7.1. EC Process Efficiency

Hydraulic fracturing is an oil and gas production technology that has literally revolutionized the industry. While successful, it has raised concerns regarding its environmental impact, particularly concerning water. As a result, the technology has been subject to moratorium in several jurisdictions. The concerns with respect to water focus on: the high volume of water injected into the well, the chemicals added to the water, and the handling of the contaminated water that flows back from the well after fracturing.

Treatment and recycling of flowback water offers an elegant solution to these concerns as treatment removes chemicals and recycling minimizes net water consumption. The barrier is that no practical, cost-effective technology presently exists for treating and recycling water in hydraulic fracturing applications.

One promising solution is EC, which replaces chemical coagulation and flocculation and operates in a continuous flow. In general, EC removes silica, heavy metals such as oxides, suspended and colloidal solids, breaks emulsions, removes fats, oils and grease, and complex organics, and neutralizes bacteria, viruses and cysts.

The current barrier with EC is fouling of the electrodes by deposition of precipitates on the surface of the electrodes. As a result, the process becomes obstructed and efficiency is reduced.

A solution to the fouling problem developed by one of the project partners, Easwara, and this project focused on developing the proof-of-concept into an in-flow continuous solution with the mobility, ruggedness and reliability required by industry.

As described earlier, the project demonstrated that the addition of an ultrasonic process to EC resulted in the rapid and efficient removal of electrode fouling which will permit EC to be deployed as an efficient water treatment process in remote areas where hydraulic fracturing operations are practiced.

7.2. Mobile Treatment Solution

Water treatment is practiced worldwide for municipal and industrial applications (including oil and gas) and generally involves fixed assets of substantial size, and high costs that need to be amortized over long periods of time. Existing water treatment approaches are not practical, nor cost-effective for hydraulic fracturing because well locations constantly change over wide areas and the requirement for water is substantially a one-time event in the life of the well. Other disadvantages of current water treatment solutions include their significant environmental footprint due to the use of chemicals, batch processing, high capital costs, and excessive operational costs related to transportation of chemicals and the need for skilled operators.

EC can be deployed as a practical mobile solution powered by electricity that does not require the transportation of chemicals to field locations.

The project demonstrated that EC can effectively reduce target contaminants by over 90% in flowback water from hydraulic fracturing operations. The next step will be to design and packaging of an efficient EC and ultrasonic process into a mobile solution get can be deployed and field-tested at remote locations.

8. Description of Benefits

8.1.Benefit 1 - Efficient EC Process

The project developed a method to cleanup fouled electrodes in a few minutes. This allows for use of the EC as a treatment method in continuous mode (in current practice the process has to be stopped to clean up contaminated electrodes for several hours). The major application of the EC process is to remove total suspended solids (TSS). Worldwide, this method is applied mostly in the construction and mining industry to treat runoff water by removing suspended solids. The project confirmed that the method effectively removes TSS in hydraulic fracturing flowback water.

The project also showed that by applying a process gas during the EC process, up to 90% of heavy metals could be removed. This is significant and the approach, under certain circumstances, could replace currently applied lime softening technology, which is a batch process that generates large amount of waste.

In Canada, the proposed EC technology will lead to manufacturing and service opportunities. Whether to reduce costs or to comply with environmental regulations, the proposed technology will allow oil and gas producers to improve their operations.

8.2.Benefit 2 - Mobile Flow back Water Treatment Process

The improved EC process is a chemical free process which could play an effective and multifunctional role in efficient treatment of flowback water from hydraulic fracturing operations. The improved EC process could be packaged in a mobile system to treat flowback water on site. This will depend on specific situations and the amount of required treatment. The treated water could be recycled/reused or returned to the environment. The mobile solution could be deployed over wide areas and reused for a large number of wells as required. Most of the existing water treatment technologies are simply not suitable as mobile solutions.

The mobile wastewater treatment solution, based on the improved and efficient EC process, will benefit Easwara Origins as the technology developer, as well as well oil and gas operators who will have access to this new technology option for their operations in Western Canada.

8.3.Benefit 3 - Proprietary Technology for Canadian Small Enterprise

Easwara had applied and received a provisional patent for the technology from the United States Patent Office. Preparations for the patent application are underway and it will be filed in 2016.

8.4. Benefit 4 - Canadian Technology Exports

The technology would also create a promising opportunity for export of Canadian technology and equipment. Hydraulic fracturing is widely practiced in North America but it is only emerging in the rest of the world. International jurisdictions will need effective Canadian technologies to manage their water challenges.

9. Conclusion

The focus of this project was to pilot and demonstrate the performance of a prototype EC and ultrasonic process for the treatment of flowback water in hydraulic fracturing operations. The technology was developed by Easwara Origins.

The results of this project demonstrated that EC provides an effective method of treatment for flowback water from hydraulic fracturing operations. Easwara Origins developed an advancement to electrocoagulation that allows the cleaning of fouled electrodes in a matter of minutes, allowing EC to be used continuously. Prior to this advancement, EC had to be stopped for several hours in order to clean contaminated electrodes using current practices.

The project also demonstrated that the EC process is capable of removing over 90% of targeted contaminants in flowback water from hydraulic fracturing. During this project, Easwara Origins also discovered that by applying a process gas during the electrocoagulation process, up to 90% of heavy metals could be removed.

The project progressed the technology from TRL 3 to 4.

This project was performed in the context of PTAC's Tight Oil and Shale Gas Innovation Network (TOGIN) and it is expected that the project will lead to follow-on projects to progress the technology beyond TRL 5 to full commercialization and industrial deployment.