

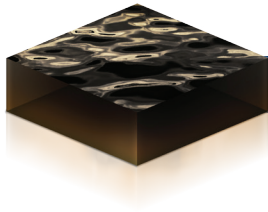
WHITE PAPER

Electro Water Separation as applied to the Oil & Gas Industry

EWS Petro

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An Overview

The oil industry is essentially a water industry, which delivers oil as a by-product of produced water.

Introduction

Hydraulic fracturing (“fracking”) is the injection of about two million gallons of water and chemicals at a time into a well, to open up the gas or oil trapped in shale deep below. This one-time injection is called a “frac job”. A well may require up to 40 frac jobs. But while “fracking” gets all the headlines for its massive use of water and chemicals, it is an intermittent process.

Produced Water

Meanwhile, oil and gas wells all over the world inject water continuously to improve productivity. What comes back up, along with natural water from deep aquifers, is a flood of “produced” water that must be managed.

Over the life of a well, about eight barrels of this produced water are brought to the surface for every barrel of oil, and in the United States this Water-To-Oil Ratio (WOR) can reach 50-1.

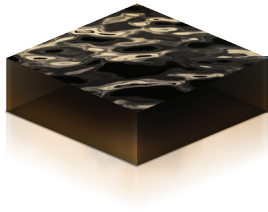
The oil industry is essentially a water industry, which delivers oil as a by-product of produced water.

Frac Flowback

On the other hand, “frac flowback” water is the 15 to 30 percent of injected frac water that flows back to the wellhead in the few weeks following a frac job. This frac flowback water is often more contaminated than produced water because of the chemicals added to the frac water before it is injected.

For economic and environmental reasons, recycling of produced and frac flowback water is the trend of the future. The industry practice of disposal is becoming less tenable as regulatory issues increase and water treatment technologies become more effective and less expensive.

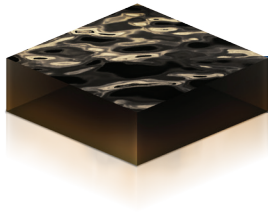
These are fast-growing markets: the frac water cleanup market is forecast to grow nine-fold to \$9 billion in 2020, a 28% annual growth rate ([Lux Research](#)), and the market for equipment for produced water treatment market, now at \$693 million is forecast to go to \$2.9 billion in 2025 ([Global Water Intelligence](#)).



A New Generation

An innovative entry into this market of opportunity, OriginOil's process, EWS Petro™, represents a new generation of water treatment that is chemical free, low energy and beneficial to the environment:

- EWS Petro not only generates significant cost savings by minimizing new water purchasing and reducing transportation and disposal expenses, but it also addresses sustainability concerns.
- EWS Petro allows for a giant reduction in the quantity of disposed material and usage of our scarce water resources.
- OriginOil's EWS Petro technology is the most effective process available for the removal of oil, suspended solids, insoluble organics and bacteria from frac or produced water.
- EWS Petro is an integrated, continuous, high-speed and chemical free process.
- EWS Petro synergistically combines electro-coagulation and electro-flocculation to create the most effective and efficient treatment system available.
- The EWS Petro system can be used as the first stage of a multi-stage process to achieve water reuse for water flooding, or new frac water or simply as a high-speed, chemical-free way to recover oil and organics prior to recycling or disposal.



Electro-Coagulation

History

Electrolytic processes to separate oil in wastewater were described in the patent literature as early as 1903. The process was used to treat condensed water from steam engines, before it entered the steam boiler as feed water. The unit used iron sheets as the anode material; the iron was oxidized during the process, and had to be replaced after a while.

Since then, both electro-coagulation and electro-flotation processes have been used to clean waste water streams from various industries, such as the textiles, oil production, metal finishing, domestic sewage, mining and many more. Today's electro-coagulation and electro-flotation technologies have progressed alongside the development of materials and electrical power systems.

Technology

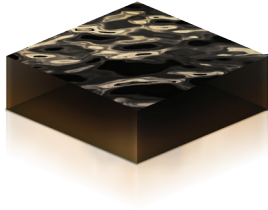
Underlying the technology are actually four subsets: chemical coagulation, electro-coagulation, electrolytic coagulation and electro-flocculation. In basic terms, the differences are fairly simple once the coagulation process is understood.

Coagulation is a critical physio-chemical operation used in water treatment. The process is used to cause the destabilization and subsequent aggregation of smaller particles into larger complexes. Water contaminants such as ions (heavy metals) and colloids (organic and inorganic) are primarily held in solution by electrical charges. Colloidal systems could be destabilized by the addition of ions of the charge opposite to that of the colloid. The destabilized colloids can then aggregate and subsequently be separated from the wastewater.

Chemical coagulation or flocculation is a process whereby colloids come out of [suspension](#) in the form of a floc or flake due to the addition of and reaction with a [clarifying or flocculating agent](#), such as: alum, aluminum sulfate, calcium oxide, calcium hydroxide, ferrous sulfate, ferric chloride or polyacrylamide.

On the other hand, electro-coagulation is a process of destabilizing suspended, emulsified or dissolved contaminants in an aqueous medium by introducing electrical current into the medium. The electrical current provides the electromotive force causing the chemical reactions. The electrical current is introduced into the water via parallel electrodes constructed of various metals generally selected to optimize the removal process.

Underlying the technology are actually four subsets: chemical coagulation, electro-coagulation, electrolytic



The two most common electrode materials are Iron (Fe) and Aluminum (Al). Metal ions will be split off or sacrificed into the liquid medium. This will form a nucleus, which will attract the contaminants into a precipitate that will be removed from the treated fluid. These metal ions tend to form metal oxide or hydroxide nuclei that are an electro-coagulation attractant to the contaminants, which have been destabilized.

Several distinct electrochemical processes occur during the electro-coagulation process independently. These include:

1. Seeding resulting from the anode reduction of metal ions that become new centers for larger, stable, insoluble complexes;
2. Emulsion breaking resulting from oxygen and hydrogen ions reacting with emulsified substances and forming water insoluble material;
3. Halogen completing as the metal ions bind themselves to halogens;
4. Bleaching by oxygen species produced in the reaction chamber and providing oxidation of chemical substances reducing bio-hazards through oxidation of bacteria and viruses;
5. Electron flooding of the water affects the polarity of water, allowing colloidal materials to precipitate;
6. Pulsed electrons create osmotic pressure rupturing cell walls of bacteria, cysts, and viruses.

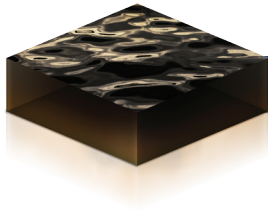
Oxidation and reduction reactions are forced to their natural end point. Electro-coagulation can speed up the natural processes occurring in wet chemistry.

Electrolytic coagulation, a form of electro-coagulation, achieves similar results without the seeding of metal ions from sacrificial anodes. In this case the electrode materials are inert materials, such as: carbon or coated titanium.

Electro-flotation is an electrolysis process where hydrogen gas bubbles are generated from the cathode and oxygen gas bubbles are generated from the anode. As these bubbles rise to the surface of the water, the bubbles attach themselves to the agglomerated particles generated from the electro-coagulation process. The coagulated pollutants are then floated to the surface where they are raked or skimmed off.

The Water Treatment Challenge

Produced water is water from underground formations that is brought to the surface during oil or gas production, either as a result of injection or originating in those formations.



Because the water has been in contact with hydrocarbon-bearing formations, it contains some of the chemical characteristics of the formations and other constituents that were added to enhance production. It may include water from the reservoir, water previously injected into the formation, and any chemicals added during the production processes.

The physical and chemical properties of produced water vary considerably depending on the geographic location of the field, the geologic formation, and the type of hydrocarbon product being produced. Produced water properties and volume also vary throughout the lifetime of a reservoir.

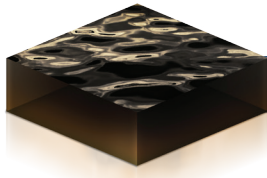
Additional water is often needed to maintain sufficient pressure in a reservoir for oil production. Produced water may be reused for this purpose, but the water may also be supplied from additional sources including groundwater and seawater. These additional water sources may contain additional solids and microorganisms. To combat scaling and maintain production efficiency, chemical additives such as corrosion and scale inhibitors, emulsion breakers, coagulants, and solvents may be used in drilling operations, production operations, and separations processing. The production of a well can be improved by utilizing the appropriate scale inhibitor and well-treatment chemicals according to the characteristics of the formation. However, these additives can become part of the produced water and can affect its overall toxicity.

Hydraulic Fracturing

In unconventional gas and oil sources associated with shale formations, horizontal drilling and hydraulic fracturing may be used to initiate production or to enhance ongoing production. Hydraulic fracturing is the propagation of fractures in a rock layer caused by the presence of a pressurized fluid. Hydraulic fractures form naturally, as in the case of veins or dikes, and is one means by which gas and petroleum from source rocks may migrate to reservoir rocks.

This process is used to release petroleum, natural gas (including shale gas, tight gas and coal seam gas), via a technique called induced hydraulic fracturing, often shortened to fracking hydro-fracking. This type of fracturing, known colloquially as a 'frac job', creates fractures from a wellbore drilled into reservoir rock formations.

A distinction can be made between low-volume hydraulic fracturing used to stimulate high-permeability reservoirs, which may consume typically 20,000 to 80,000 US gallons of fluid per well, and high-volume hydraulic fracturing, used in the completion of tight gas and shale gas wells, which can use as much as 2 to 3 million US gallons of fluid per well.



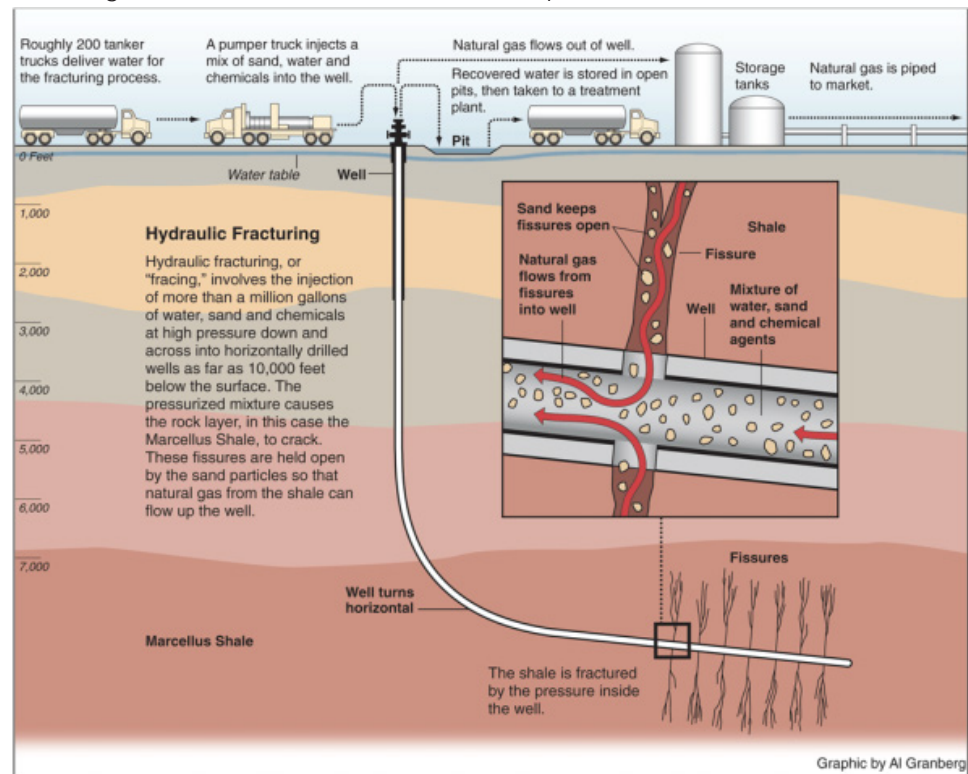
Because of these environmental reasons and cost of disposal, recycling of produced and frac flowback water is the trend of the future.

The water used for hydraulic fracturing, frac water, is treated with up to a dozen different chemicals to enhance the operation. Chemicals can include: proppants like sand, acids, friction reducers, biocides, coagulants, solvents and surfactants. Although they amount to a small percentage, they do add to the treatment challenge.

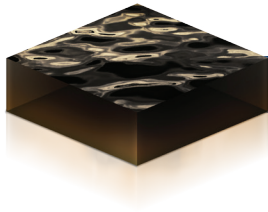
When a hydraulic fracturing job is completed, 20 to 30% for the frac water flows back, frac flowback water, to the surface and must be disposed of or treated. Likewise, produced water must be treated for recycling or disposed of, usually in injection wells. Both frac flowback water and produced water are of environmental concern due to the contamination of ground water, risks to air quality, the migration of gases and hydraulic fracturing chemicals to the surface, surface contamination from spills and the health effects of these. In addition, these issues are on top of the demand for water for other industrial applications, agriculture and domestic uses.

Recycling is the Trend of the Future

Because of these environmental reasons and cost of disposal, recycling of produced and frac flowback water is the trend of the future. The industry practice of disposal is becoming less tenable as regulatory issues increase and water treatment technologies become more effective and less expensive.



Hydrofracturing, from "Sustainable Water Management for Marcellus Shale Development", Radisav D. Vidic



Less conservatively, if the frac flowback water is remediated at \$0.21 per gallon, the market size is \$2.94 billion.

The level of water treatment is dependent upon the amount and type of contamination and, as importantly, the planned reuse of the water. The treated water for industrial purposes include water for hydraulic fracturing at oil and gas sites, water could be used for water flooding, enhanced oil recovery, future fracking jobs, power generation, dust control, irrigation, fire control and even drinking water. Frac flowback water and produced water will typically have high COD from hydrocarbons, VOCs, iron, sulfides, calcium/magnesium/sodium salts, chlorides, sulfates and bicarbonates. High COD is the largest and most troublesome issue.

Produced and Frac Flowback Water Market Size

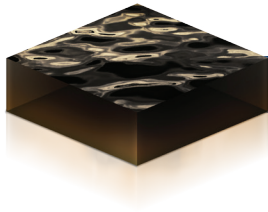
According to a 2012 study, “Produced Water Market” by Global Water Intelligence, “Produced water is a \$5 billion market now, going to \$10 billion by 2025 (4.7% growth).” Further, “Equipment for produced water treatment is a \$693 million market now, going to \$2.9 billion by 2025 (10.1%).”

The market data for frac water treatment, which is a subset of produced water, is more limited. The most definitive is from Lux Research, “Frack Water Market to Grow Nine-fold to \$9 Billion in 2020... offering 28% annual growth in water treatment”. Backing the 2020 \$9 billion market to the present would indicate that the 2012 market is \$1.25 billion.

The current estimate of cost to remediate this water to class B status is roughly \$0.21-0.26 per gallon or \$0.11 per gallon for disposal in deep wells. Assuming that only 20% of the 70 billion gallons of frac water is returned to the surface as frac flowback water, and it is disposed of at \$0.11 per gallon, the treatment of frac flowback water is \$1.54 billion. Less conservatively, if the frac flowback water is remediated at \$0.21 per gallon, the market size is \$2.94 billion.

[Greentech Media](#) reports that “current market for treating produced water is estimated to exceed \$4.3 billion for the next five years, and that market will expand whether or not regulations increase.”

In any case, the frac flowback water treatment market in 2012 is \$1.5 billion at a minimum with a 28% growth rate.



Current State of Technology

Water treatment of frac flow back and produced water is done in many ways. It is very dependent on the contamination present, as well as the final water quality desired.

The general objectives of process water treatment are:

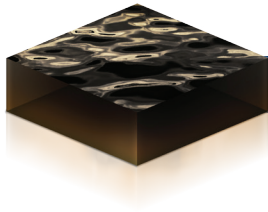
1. De-oiling – Removal of free and dispersed oil and grease present in produced water.
2. Soluble organics removal – Removal of dissolved organics.
3. Disinfection – Removal of bacteria, microorganisms, algae, etc.
4. Suspended solids removal – Removal of suspended particles, sand, turbidity, etc.
5. Dissolved gas removal – Removal of light hydrocarbon gases, carbon dioxide, hydrogen sulfide, etc.
6. Desalination or demineralization – Removal of dissolved salts, sulfates, nitrates, contaminants, scaling agents, etc.
7. Softening – Removal of excess water hardness.
8. Sodium Adsorption Ratio (SAR) adjustment – Addition of calcium or magnesium ions into the produced water to adjust sodicity levels prior to irrigation.
9. Miscellaneous – Naturally occurring radioactive materials (NORM) removal.

The First Stage

In any case, the first step in the water treatment is usually the removal of oil, organics and suspended solids. Historically, some form of gravity clarifier or filter media or chemical coagulants with dissolved air flotation or induced air flotation systems have been used in this first step. Each has its own limitations and drawbacks.

As a first stage process, electro-coagulation is a relatively new method for this application, but is becoming the technology of choice for this first phase. Its performance is significantly more effective than historical methods, with lower Operating Expense (Opex) and Capital Expense (Capex).

There are six competitors offering some form of electro-coagulation. Some of these competitors still rely on additional chemical coagulants. With one exception, all use large parallel steel plates as the electrodes. The use of these parallel plates results in high system resistance to current flow and therefore high power consumption. All of the six competitors also rely on downstream flotation equipment, such as: gravity clarifiers, vacuum clarifiers, dissolved air flotation systems or skimmers.



OriginOil's EWS Petro technology evolved from a technology developed to solve the challenge of harvesting algae, which has been compared to taking the Kool-Aid out of the Kool-Aid or harvesting the algae from your swimming pool. So it is very good at removing small amounts of organic contaminants from very large volumes of water.

How EWS Petro Manages the First Stage

To achieve an integrated, continuous, high-speed and chemical free process, EWS Petro synergistically combines electro-coagulation and electro-flotation in one piece of equipment.

Stage One: Electro-Coagulation

In the first stage, the process water passes through OriginOil's patent-pending Single Step Extraction™ (SSE) tubes, where electrical pulses are applied to the electrodes. The SSE design, which uses long tubes with a concentric anode/cathode layout, is the key to the system's high throughput and efficient power usage without "hot spots".

Different electrode materials are available and are predetermined by the inlet water contamination anticipated. The electrical pulses are controlled by proprietary algorithms developed to optimize efficiency by monitoring inlet and outlet water parameters.

This electro-coagulation process causes three basic effects:

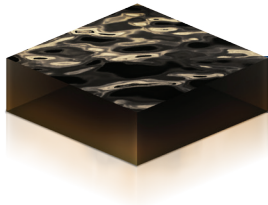
1. Breaks the oil and water emulsion to separate oil into droplets;
2. Neutralizes the repulsive charge on the suspended solids and oil droplets, allowing the particles and droplets to coalesce;
3. Kills bacteria.

The coalesced droplets and solids exit the SSE reactor tubes as agglomerated particles. They are then pumped into the flotation chamber.

Stage Two: Electro-Flotation

The second stage of the process, electro-flotation, occurs in the flotation chamber, which utilizes electrolysis between the anodes and cathodes.

Again, pulsed electrical charges are applied to the anodes and cathodes for maximum efficiency. The electrolysis of the water generates a cloud of micro-bubbles of hydrogen and oxygen. These bubbles attach themselves to lift organic material to the surface of the water.



The configuration of the anodes and cathodes within the chamber minimizes the power requirements and maximizes the exposure of the agglomerated particles to the micro-bubbles.

The mechanical design of the chamber allows heavy material to fall to the bottom to be removed, while the hydrocarbons and other organics are raked from the surface onto a dewatering belt minimizing water content. The clear effluent of treated process water exits through a weir, or dam, at the end of the chamber.

Test Results

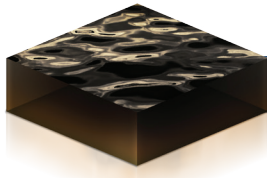
Testing of frac flowback and produced water processed with EWS Petro has been conducted in the lab with samples supplied from various regions of the country, as well as in the field at Lost Hills, California, Eagle Ford, Texas, and Delta, Colorado.

Before and after samples were tested for Chemical Oxygen Demand (COD), a measurement of the amount of [organic \(hydrocarbons\) compounds](#) in [water](#), and Total Suspended Solids (TSS), a measurement of non-dissolved particulate in the water.

Samples were also tested on the PetroCAM, which optically analyzes the water for free oil and suspended solids. Results have varied because of different source waters, but the reduction in oil or hydrocarbon is as high as 99% and the reduction in suspended solids is as high as 99.5%.

Tests are now being conducted on the amount of bacteria in the water before and after processing. A 99% reduction is expected based upon outside lab testing done on algae water.

Results have varied because of different source waters, but the reduction in oil or hydrocarbon is as high as 99% and the reduction in suspended solids is as high as 99.5%.

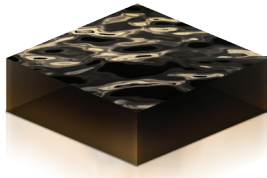


The EWS Petro Difference

OriginOil's EWS Petro offers significant advantages over the competitors. Those include:

1. Open architecture which allows for an integrated design or a modular design. This allows EWS Petro systems adaptable to existing infrastructure, such as placement in frac tanks, thereby lowering Capex.
2. The integrated EWS Petro system integrates electro-coagulation and electro-flotation on a continuous flow basis that scales well. Others go through electro-coagulation then must be processed through batch processes, such as decanters or skimmers that can be costly to scale.
3. EWS Petro's electro-coagulation step employs a proprietary electrode assembly and low voltage electrical pulses. These pulses are tuned to be very effective at neutralizing repellent charges on organics particles, at breaking oil and water emulsions which results in agglomerated organic material, and at killing bacteria. These low voltage pulses result in low energy and low Opex.
4. The EWS Petro concentration step employs its own proprietary electrode array with low voltage electrical pulses causing the generation of angstrom size bubbles which attach themselves to the agglomerated particles and float the particles to the surface for separation from the water. The system is not only very effective, it reduces both time to separation of oil/chemicals and water and reduces the footprint of settling tanks for the operator. The key components of the technology are the electrode array and power application.
5. The electrical pulses for both stages are controlled by algorithms that utilize the measurement of certain input and output water quality parameters for real time control. These algorithms can be updated from OriginOil's central server, potentially providing security and tracking for the operator through authentication and sensor metering.
6. OriginOil's electrode array design eliminates tight flow channels and fouling. Electrical pulses minimize electrode passivation.

In some cases, the electrodes utilize a Mixed Metal Oxide (MMO) coating that reduces power required, eliminates sacrificial metal loss which can cause downstream issues and, most importantly, results in electrode life of a minimum of two years. The MMO coating is a catalyst in a sense, but is not part of the reaction and does not have to be regenerated. The MMO coating allows for the production of micro-bubbles of gasses by making their production more thermodynamically and kinetically favorable without itself being consumed.



The oil and gas industry produces approximately 14 billion barrels of water annually.

Water's Beneficial Reuse

Water produced during oil and gas extraction operations constitutes the industry's most important waste stream on the basis of volume. The oil and gas industry produces approximately 14 billion barrels of water annually. The water varies greatly in quality and quantity from region to region and over the life of a well. In some cases the water can be a useful by-product or even a salable commodity. Produced water and frac flowback water is most often considered a waste, but the industry is beginning to consider the beneficial reuse of the water and the potential profit stream.

The degree of contamination in the produced or frac flowback water, and the water quality requirement for beneficial reuse dictate the additional stages beyond EWS Petro; such as nanofiltration, reverse osmosis membranes, etc. Typically, frac flowback is more challenging than produced water to clean to a particular standard, due to the added chemicals.

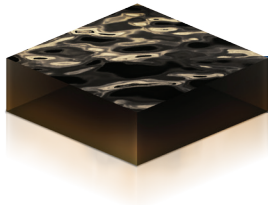
Contaminants

Produced water is the water phase that is separated from the oil as it is first processed from the wellhead through some variation of a decanting process or 'gun barrel'. This process removes almost all of the oil and BS&W (Basic Sediment & Water or mud). However, the produced water is still contaminated with some small level of hydrocarbons ([crude oil](#), [resins](#), [aromatic hydrocarbons](#), and [alkanes](#)), suspended solids, heavy metals, and dissolved salts.

Frac flowback water has all the same contaminants as produced water, but also can contain additives from the fracking process. Those include: proppants¹ like sand, acids, friction reducers, biocides, coagulants, solvents and surfactants.

There are a number of beneficial reuses of this process water. Each use has a water quality standard that must be met either from a practical or regulatory standpoint. The most prevalent reuse with the least requirements is water injection or water flooding in the same or adjacent wells. Optimally, water used for flooding should have minimum residual hydrocarbon, suspended solids, and bacteria. Once the oil has been pumped from the reservoir of oil in the ground, why inject it back into the reservoir? Suspended solids and bacteria will only cause plugging. It is probably not necessary to remove the divalent ions of: calcium, magnesium, barium and strontium, which contribute to the hardness of the water.

¹Proppant: A contraction of "propping" and "agent", used to hold open cracks in the formation so that energy has a pathway to access the wellbore. Sand is most commonly used; in some cases, man-made materials are used instead ([source](#)).



Reuse for Enhanced Oil Recovery

Another beneficial reuse is for enhanced oil recovery (EOR). EOR processes fall into three categories: thermal, chemical or miscible gas. Thermal is usually done via steam flooding. Steam flooding is normally done via a once-through steam generator (OTSG). Chemical EOR makes use of surfactants, alkaline or microbes to decrease interfacial tensions and reduce viscosity. Miscible gas flooding utilizes gases like CO₂, N₂ and hydrocarbon gases that are miscible with the oil to flush the remaining oil.

Water quality standards for OTSG feed water requires that the organics and suspended solids be removed. In addition, the divalent ions of: calcium, magnesium, barium and strontium must be removed to prevent hardness or scaling. Salinity from the monovalent ions (such as sodium and chloride) is not a significant problem since those salts will typically remain in solution in the 30% of the water that is not turned into steam.

Water quality standards for chemical EOR are more similar to the standards required for water flooding. In chemical EOR, thickeners are added to the water. Thickeners are available in various formulations and one can be chosen which is compatible with the salinity of the processed water.

Recycling for Frac Water

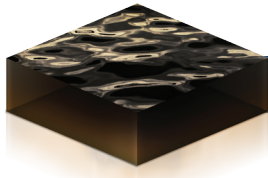
Recycling frac flowback water as “new” frac water is another beneficial reuse. Since wells generating significant produced water are usually not near the wells that are being fracked, recycling produced water as “new” frac water is unlikely.

“New” frac water has higher standards than other oil well related reuses. Hydrocarbons should be at an absolute minimum to prevent interference with the frac chemicals. Suspended solids should be reduced to < 1 mg/L. Bacteria should be < 10 to the fifth per ml. Hardness should be decreased to < 1,000 mg/liter. Iron should be < 1 mg/l. Alkalinity should be < 500 mg/l. New frac chemicals, such as Halliburton’s friction reducers, are compatible with high salinity water allowing high levels on monovalent ions, such as sodium and chlorides.

Tailing Pond Water Reuse

The potential beneficial reuse of tailing pond water from the tar sand operations as new feed water for their steam generators will have two benefits.

First, is the benefit to treat the water in the tailing ponds to some acceptable standard or to treat the water prior to the water entering the tailing ponds.



Beneficial reuses not related to the oil & gas industry include: power generation, dust control, irrigation, and even drinking water.

Second, fresh water is currently used for feed water, but if tailing pond water could be recycled back as feed water, fresh water usage could be minimized. The water quality for this reuse would be similar to that needed for steam flooding.

Other Beneficial Reuses

Beneficial reuses not related to the oil & gas industry include: power generation, dust control, irrigation, and even drinking water. Power generation requirements are the same as other steam generating applications. Dust control requirements are dependent upon local regulations. Achieving irrigation water standards is a major opportunity in regions where water is scarce, like Texas and California. Water quality standards are similar but less rigorous than for OTSG feed water. Achieving water quality standards is obviously the most stringent and includes reducing the salinity levels to freshwater levels. It is achievable but expensive.

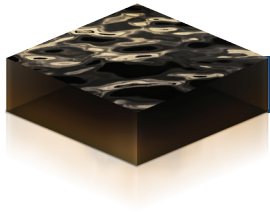
Environmental Impacts

The environment is impacted in a variety of ways by produced and frac flowback water in the oil & gas industry. First, the water cycle of the fracking operations historically has necessitated the use of fresh water for each fracking operation. Each frack job can use up to two to three million gallons of fresh water, and a well can have up to 40 frac jobs. The potential benefit of recycling water for use as “new” frac water would be good news for what is a scarce resource in many regions.

Second, estimated truck traffic for a single frac job is between 300 to 1,300 truckloads. Trucking of fresh water to well sites, and the disposal of well site output to disposal wells impacts air emissions and damages the roads used by these trucks, which in turn has caused local governments to demand payment for road repairs. Again, recycling these process waters could minimize the truck traffic.

Third, injecting these contaminated waters into deep disposal wells raises the concern of potential near and long term contamination of drinking water resources. Although disposal wells are much deeper than natural aquifers and there are significant layers of rock between them, there is still a concern. Trace chemicals are being used to study the possible migration of contamination into natural aquifers. Again, recycling of treated waters would minimize the quantity of water being injected into disposal wells.

Fourth, potential spills are a concern. Good management practices will minimize this particular environmental danger, and recycling will not be a factor here.



Treatment Economics

Disposal

Historically, the least expensive alternative was the disposal of produced and frac flowback water in deep injection wells. That disposal cost includes both the expense of hauling the water to the disposal site of \$0.075 per gallon and the charge for using the disposal site of \$0.035 per gallon.

The national average disposal cost is believed to be \$0.11 per gallon. These costs vary widely. For instance, there are only four permitted wells in Pennsylvania and the process water must be trucked to Ohio's disposal wells. On the other hand, there are many disposal wells in Texas bringing the disposal costs down considerably. However, fewer and fewer regions are permitting new disposal wells. Once permitted, a substantial capital investment (\$1M to \$2M) is required.

Settling Ponds

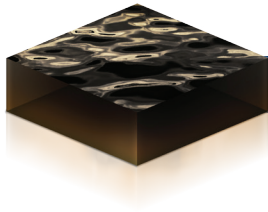
Another inexpensive process is simple vaporization of the frac water in settling ponds. In this case, the water may have to be hauled to the settling ponds, which averages \$0.075 per gallon. The high salinity of frac water results in poor evaporation. This approach still leaves the operator with a solids disposal issue.

Wastewater Plant Treatment

Another process option is hauling the frac flowback water to a municipal or privately owned water treatment plant. Again hauling expenses are likely to be more than the \$0.075 per gallon due to the distance of the treatment plants. The treatment plant will also add a significant treatment charge per gallon. Most treatment plants are unwilling to process the water due to high salinity or the naturally occurring radioactive materials (NORM) present.

Treatment for Reuse

Produced and frac flowback water can also be treated prior to reuse. There are a number of processes that can be used depending upon the contaminants in the process water feed and desired properties of the "clean" water.



Some of these processes are: crystallizer, membrane distillation, evaporation, reverse osmosis, electro-dialysis, electro-dialysis reversal, chemical flocculation, capacitive deionization and electro-coagulation. These are listed in the order of decreasing energy cost per barrel of water.

Most of these processes must be combined with other processes to complete a “clean water” standard. Overall treatment costs between \$0.025 and \$0.26 per gallon.

Evaporation

One of the more expensive processes from the above list is evaporation. Evaporators are expensive to build and operate since the water must be evaporated. Heat of vaporization alone is about \$0.24 per gallon. Alternatively, vapor recompression evaporation reclaims part of the heat of vaporization lowering the operating cost but significantly increases the capital cost.

Chemical Flocculation

Another process that is used in the treatment of most waste waters is the use of chemical flocculants in conjunction with dissolved air flotation or gravity clarifiers. The chemical flocculation systems combined with flotation systems only remove about 70% of the COD. The water must still be processed to remove the balance of the hydrocarbon and the dissolved solids.

Electro-Coagulation

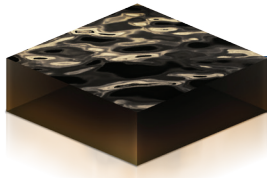
Some configuration of electro-coagulation (EC) can be used to replace the chemical flocculation.

In typical EC systems, once the water passes through the electro-coagulation, the water enters a skimmer or dissolved air flotation system or gravity clarifier. The water must still be processed to remove the dissolved solids and other contaminants. Costs are estimated to be about \$0.10 per gallon.

By comparison, OriginOil's EWS Petro system costs about \$0.0125 per gallon to achieve a 99% reduction of organic contaminants; and energy costs are very low at 0.02 kWh per gallon or a one half cent per gallon.

PEARLBLUE has combined the EWS Petro system with a nano-filter in their Frack-Back™ system for recycling water as new frac water. The projected operating cost is about \$0.025 per gallon.

Obviously, an average operating cost of \$0.025 per gallon is a major advantage even over disposal, let alone traditional treatment costs.



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Competition

Since OriginOil’s EWS Petro process offers an alternative or precursor water treatment solution, many “competitors” are also potential OEMs licensing OriginOil technology.

Competitors fall into two classes: those offering technology different other than electro-coagulation or those offering some form of electro-coagulation. Those offering technology different from electro-coagulation are typically offering equipment whose operation could be enhanced by using OriginOil’s EWS Petro system – therefore are the most likely potential OEM accounts.

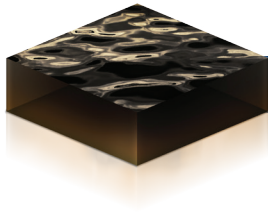
There are six key competitors offering some form of electro-coagulation. Some of these competitors still rely on additional chemical coagulants. With one exception, all use large parallel steel plates as the electrodes. The use of these parallel plates results in high system resistance to current flow and therefore high power consumption. All of the six competitors also rely on downstream flotation equipment, such as: gravity clarifiers, vacuum clarifiers, dissolved air flotation systems or skimmers. Those competitors include: Halliburton, Kaelco, Water Vision, Quantum-Ionics, Ecolotron, and Bosque.

The Halliburton Comparison

How does OriginOil’s EWS Petro technology compare to the largest player, Halliburton?

	Kaelco	Water Vision	Quantum-Ionics	Ecolotron	Bosque ECR	Halliburton WaterTectonics Clean-Wave	OriginOil CLEAN-FRAC
Pretreatment	Prefilter	Prefilter	Prefilter	Prefilter	Prefilter & Chemical Flocculants	Prefilter	Prefilter
Anode Cathode Configuration	Parallel Flat Plates	Thin Cells	Parallel Flat Plates	Parallel Flat Plates	Parallel Flat Plates	Parallel Flat Plates	Proprietary Tube & Plates
Electrode Fouling	None	Less than 1 Month	1-2 Months	1-2 Months	1-2 Months	1-2 Months	None
Electrode Life	Medium	Low	Medium	Medium	Low	Medium	2-5 Years
System Configuration	Fixed No Integration	Fixed No Integration	Fixed No Integration	Fixed No Integration	Fixed No Integration	Fixed No Integration	Modular Immersion in Frac Tank
OPEX	High	Medium	High	High	High	High	Low
Oil/Water Separation	Gravity Clarifier	Dissolved Air Flotation	Vacuum Clarifier	Gravity Clarifier	Gravity Clarifier	Skimmer	Integrated Concentrator

The competitive advantages of OriginOil’s EWS Petro



The Halliburton System

Halliburton's frac flowback water treatment system appears to be based on a system licensed from WaterTectonics. The Halliburton system encompasses three separate pieces of equipment. The first stage, called CleanWave, uses a set of electrode plates to destabilize and coagulate the suspended colloidal matter in water. When contaminated water passes through the electro-coagulation cells, the anodic process releases positively charged ions, which bind onto the negatively charged colloidal particles in water resulting in coagulation.

At the same time, gas bubbles, produced at the cathode, attach to the coagulated matter. The water then passes into a conventional skimmer where the coagulated matter is floated to the surface by the gas bubbles and skimmed from the surface. Heavier particles sink to the bottom. The water then flows through a third process, CleanStream. CleanStream exposes the process water to ultra-violet light that kills most of the bacteria.

The EWS Petro System

By contrast, EWS Petro accomplishes all three processes of coagulation, flotation and bactericide in one piece of equipment.

1. As the frac flowback or produced water flows through the EWS Petro system it passes through SSE reactor tubes where the pulsed electrical current breaks the oil/water emulsion, neutralizes the charge on the colloidal matter allowing the particles to coagulate and kills most of the bacteria.
2. The process water then flows into the flotation chamber where pulsed electrical current in the electrodes generate microscopic bubbles that float the coagulated particles and oil to the surface where it is raked onto a dewatering belt. Clear water flows under and over a weir to the discharge. Oil and contamination are removed into a hopper by a 'doctor' blade on the dewatering belt.

In short, all the same processes are accomplished in one piece of equipment with much less power and a smaller footprint.

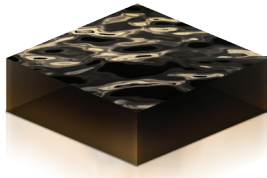
Cost Comparison

How does the cost of OriginOil's EWS Petro process compare to Halliburton's Clean Wave?

Halliburton

According to published Halliburton costs from 2011, a specific project processed 1,110,000 barrels of produced water at a cost of \$1,692,000.

Therefore, the cost per barrel is \$1.52 or the cost per gallon is \$0.04.



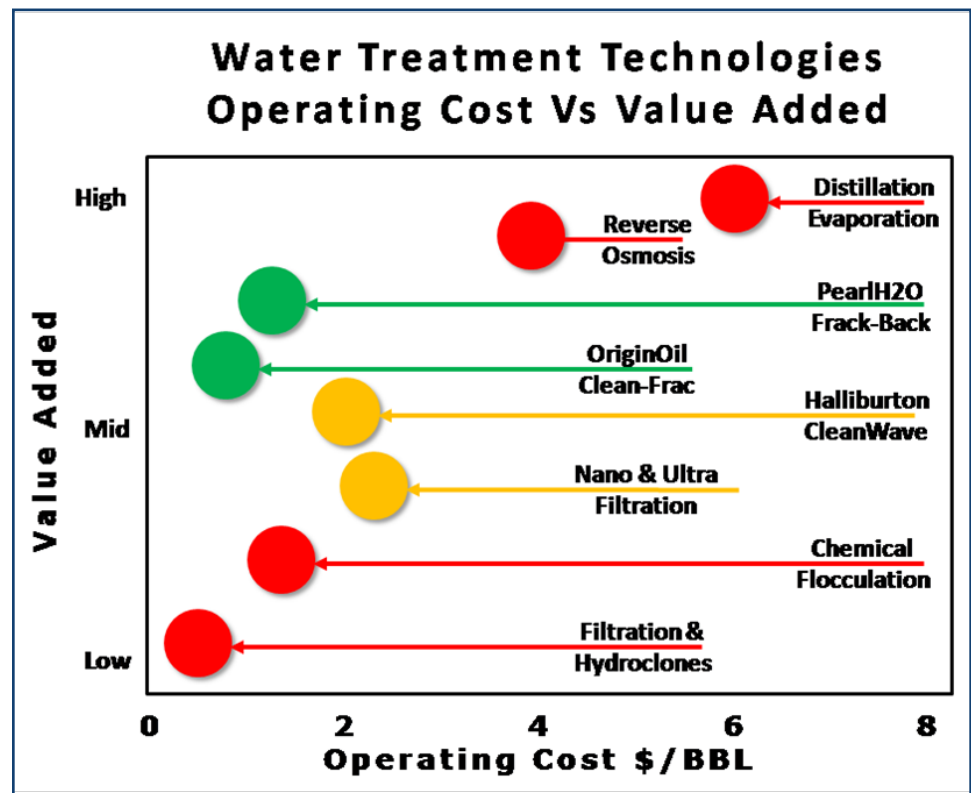
OriginOil

Based on cost projections prepared by Pacific Advanced Civil Engineering, the EWS Petro operating costs are projected to be \$0.43 per barrel or \$0.01 per gallon.

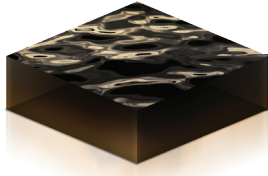
Going a step further, compare the Frack-Back system by PEARLBLUE to Halliburton's system. PEARLBLUE's FRACK-BACK system utilizes the EWS Petro system as first stage treatment and a proprietary nano-filter system as a second stage. The nano-filters remove hardness to prevent scaling, which goes beyond what the Halliburton system is designed to achieve. The operating cost of the FRACK-BACK system, which includes EWS Petro, is projected to be \$1.00 per barrel or \$0.024 per gallon; still 40% lower than Halliburton's Clean-Wave.

The final argument in favor of OriginOil is that its system can be readily licensed or integrated into any other process, and is available without requiring ancillary services. This is a major benefit to service companies and operators alike.

Perhaps this graphic provides the best demonstration of value versus operating costs (EWS Petro powered technologies in green):



Value Comparison of Water Treatment Technologies.



Electro-Coagulation (EC) is emerging as the leading method for cleaning frac flowback and produced water, and of all the EC systems, The EWS Petro design is the most scalable and efficient.

Conclusion

Electro-Coagulation (EC) is emerging as the leading method for cleaning frac flowback and produced water, and of all the EC systems, The EWS Petro design is the most scalable and efficient.

Integrating EWS Petro into any clean water system will return better operating profits and require lower capital investment.

Unlike other brands which require commitments to other products and services, EWS Petro is freely available for integration into any system.

EWS Petro is the high-speed, chemical-free process that responds to the oil and gas industry's need for scalable and cost-efficient water cleanup systems.

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