Evolution of Best Management Practices and Water Treatment in High Volume Hydraulic Fracturing Operations

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Abstract: Best water management practices (BMPs) and water treatment technologies in unconventional oil and gas development operations have been evolving since the late 1990's. That evolution underwent two major accelerations the first starting around 1999 when coal bed natural gas water production was climbing and disposal options in several western states was limited and the second starting in 2005 with the growing adoption of high volume hydraulic fracturing (HVHF). Well drilling, completions and production operations of modern horizontal drilled unconventional plays require large volumes of water during the well lifecycle. The lifecycle cost of water alone for a Marcellus Shale well can exceed $1 million (Shauk, 2012). Economic and environmental concerns have provided impetus for a "paradigm shift" toward the development of pre-planned water management programs that cover the full lifecycle of a field. The goal of such programs is to minimize fresh water use, optimize environmental and safety effects, and reduce costs. This paper will focus on trends in water management programs, water treatment technologies, and water best management practices.

Introduction

Best practices in water management are evolving into an essential component of a cost-effective, environmentally friendly hydraulic fracturing program. In fact, industry and government work groups have set forth general best water management practices that have in some cases become part of the rapidly evolving regulations for HVHF operations (API n.d.).

Treatment of produced water from fracturing operations is frequently being performed onsite or in nearby plants in high-flow-through, lower-energy facilities which remove and dispose of the solids. While the initial focus of treatment for HVHF was desalination, desalination is now performed less frequently, as effective fracturing fluids can be designed with salinities over 100,000 ppm. (Halliburton n.d.) Rather, treatment processes once considered pretreatment for desalination are evolving and new treatment technologies and techniques are being developed.

Water tanks staged for a hydraulic fracturing job in the Marcellus Shale region.

Treatment systems typically involve removal of solids such as organics and fines, the deactivation/removal of scale-forming multi-valent ions, and the neutralization of bacteria. Technology improvements range from equipment to manage the higher salinity fluids to new applications of existing water treatment technologies.

Fracturing fluid makeup technology is also advancing, including source water mixing modeling (ALL Consulting, 2010), the use of "greener" treatment chemicals to support advanced fracturing technologies to optimize production (Fisher, 2012), and the overall reduction in the number of chemical additives used and chemical volumes.

Shale gas has become economically producible principally due to advancements in two technologies: horizontal drilling and high volume hydraulic fracturing (HVHF). The amount of water needed to drill and fracture a horizontal shale gas well generally ranges from about two million to 10 million gallons, depending on the formation characteristics. With potentially hundreds of wells to be drilled each year as development proceeds, these water demands can be significant.

Water management issues are associated with every stage of shale gas development and can impact operator's costs and ability to get permits. High volume hydraulic fracturing is typically done in 20-30 consecutive stages, with source water (fresh water, treated produced fluids or untreated produced fluids) coming from various sources either by truck or pipeline. Source water can be delivered on demand or stored for future use, requiring large tanks or centralized impoundments.

Water management issues include identifying the volume of water needed, procuring that water, transporting it to the well pad, providing on-site storage, treatment or conditioning the water as necessary, and eventually disposing of produced water. In addition to actual management of the water, potential environmental and community concerns create public trepidation. These concerns can be directly related to water resources and some are more indirectly related to water management, (e.g., potential traffic and roadway impacts that may result from the trucks used to haul water).

Benchmarking

Water management strategies are best formed when using historic data, current operations, and planned future development. Establishing baseline water quality conditions ahead of development is critical. Pre-drill baseline water sampling is a first step.

Establishing baseline water quality conditions before drilling is becoming standard industry practice to defend against groundwater or surface water contamination claims (Leatherbury and Denson, 2013). Understanding the source of methane in groundwater can be complex. Water sampling helps establish a baseline or “Pre-Drill” water quality data. Water sampling can be used to “fingerprint” water sources and compare them to historical state and federal data sets to establish regional and localized groundwater and surface water trends.

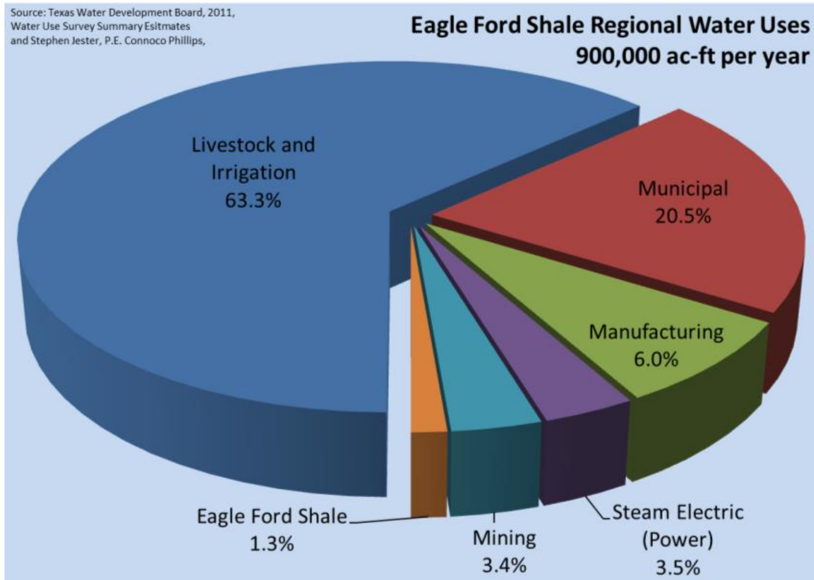
States across the country are starting to require baseline water quality sampling.

Some states are beginning to require baseline water sampling. For example, Ohio requires E&P (exploration and production) companies to collect water samples from water sources on properties that are within a 1,500 foot radius of a proposed well location prior to commencement of drilling (ODNR, 2012). Colorado requires collection of baseline surface water data consisting of a pre-drilling surface water sample collected immediately downgradient of the oil and gas location and follow-up surface water data consisting of a sample collected at the same location three months after the conclusion of any drilling activities, operations, or completion (COGCC, 2013). In Pennsylvania, a well operator who wants to prove that pollution of a water supply existed prior to the drilling of the well must conduct a pre-drilling survey . Michigan is also considering proposed rules that would require operators to collect baseline samples from available water sources within a ¼ mile radius of the well location

Water Management Planning

When planning a shale development project, water management planning considerations include issues related to water sourcing, well drilling, well completions, how to deal with flowback water and produced water, and water requirements for production operations.

In the pre-completion stage, the focus is on the withdrawal source, transport and storage of water. Options available to meet water needs for drilling and fracturing include surface water, groundwater, municipal water, recycled produced water, collected water (e.g., precipitation, top-hole water), and private water purchases.



Water withdrawals for high volume hydraulic fracturing are often seen as a concern for both communities and the environment. For many individuals, talk of "millions of gallons" of water being withdrawn sounds ominous because they are not aware of the size of other large volume withdrawals such as for municipal public water distribution systems, agricultural, recreational, industrial, or power generation needs. Shale gas production at the height of development activity is generally less than 1.5% of total withdrawals on a regional basis.

However, impacts from surface water withdrawals, either individual or cumulative, can occur if not properly planned. Withdrawals from small rivers and streams can significantly affect stream flow and harm aquatic life and local recreation. Withdrawals from larger rivers can create these same impacts if taken during periods of low flow such as late summer or in periods of prolonged drought, therefore, planning is essential and having more than one source is advantageous.

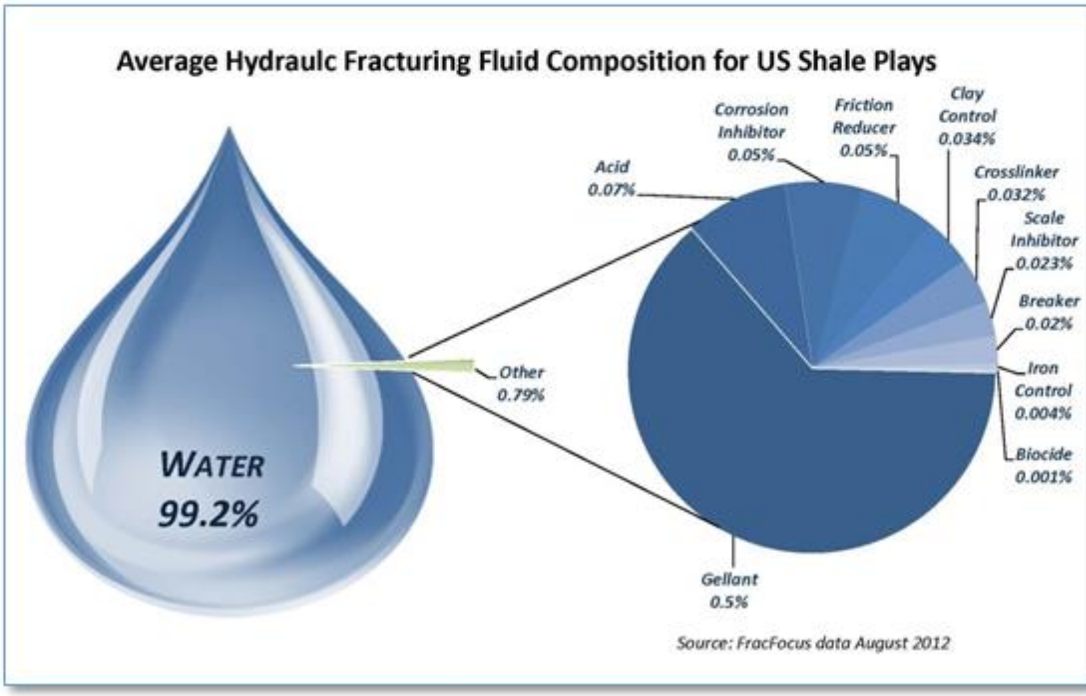
For E&P companies, in addition to avoiding adverse environmental impacts, operational concerns are access to the water, the timing of that access, and the various regulatory permits required. The cost of transportation and potential road and community impacts also have to be considered.

Water for fracturing operations must be stored prior to the fracture operation. This can occur at well-specific impoundments or at centralized impoundments. Centralized impoundments that feed multiple wells on a single well pad or multiple well-pads can be used to store large volumes of water, thus allowing for withdrawals in wetter periods, smaller, more frequent withdrawals, and withdrawals from multiple watersheds.

Storage of produced water must be planned and managed to prevent release of high TDS (total dissolved solids) water onto land surfaces or into surface water bodies. Some have also voiced a concern that produced water stored in surface impoundments may result in air emissions of fracture chemicals or other constituents that could affect human health.

HVHF Fracture Fluid Chemicals

Chemicals used for hydraulic fracturing have been a focus for environmentalists, and public pressure has resulted in regulators developing new regulations related to hydraulic fracturing chemical disclosure. The public has focused on the potential for water contamination during fracturing operations, but regulators and industry have focused on what they consider larger concerns for industry, including the potential for surface water contamination from spills during handling and transportation of chemicals for fracturing, spills of produced water that may contain some residual fracture fluid chemicals, and well equipment failures that could result in surface discharges of chemicals and produced water.



One point of contention that has remained relative to the chemical composition of fracture fluid mixtures are the chemical additives that are considered proprietary, especially instances were emergency responders or the public may have come into contact with the chemicals as a result of an accidental exposure.

To address regulatory requirements and in an effort to try to alleviate the public's concerns related to the composition of hydraulic fracturing fluids, the oil & gas industry funded the development of a national chemical disclosure registry, FracFocus. Today, 14 states require that companies use the website to publicly disclose the chemicals used in each new well that is hydraulically fractured. The registry currently provides public access to disclosure of hydraulic fracturing chemical additives used in more than 55,000 wells by over 600 companies for hydraulic fracturing treatments in the United States completed since April 2011.

As of October 2013, operators had entered close to 1.5 million individual ingredients into FracFocus. Of those, approximately 200,000, or 13 percent, were labeled as proprietary.

Companies have also been implementing "greener" alternatives for select processes that were previously achieved by chemical additives for hydraulic fracturing. One example is Halliburton, which has invested considerable resources to develop greener fracturing systems. Halliburton's CleanStim® Formulation is a line of chemical additives comprised of materials sourced entirely from the food industry. The company is also using UltraViolet (UV) light instead of chemical additives for bacteria control with a system that treats wastewater at the well pad location during the fracture stimulation. This treatment allows produced water from flowback operations to be reused and recycled by the operator, thus significantly reducing the need for freshwater (Halliburton n.d.).

As another example, Chesapeake Energy Corporation has a Green Frac initiative that evaluates each chemical additive to determine its environmental friendliness. This initiative and others similar are being used by industry to assess the necessity of additives relative to their overall usefulness in facilitating and improving well production. To date, Chesapeake has eliminated 10–25% of the additives previously used in its hydraulic fracturing fluids (Chesapeake n.d.). Review of FracFocus data from individual plays over time shows that Chesapeake and other companies continue to search for ways to reduce chemical additives in fracture stimulations even further.

Produced Water Management and Disposal

Concerns with produced water include on-site management of the water brought to the surface as well as how the water is ultimately disposed.

When pressure in the well is released after a fracturing operation, hydraulic fracturing fluid, formation water, and natural gas begin to flow back up the well. This "produced water" contains a mix of hydraulic fracturing chemical additives and naturally occurring substances. Depending on the formation, produced water may range in volume from 15 to 50% (or more) of the volume of the fracture fluid (ALL Consulting and GWPC, 2009).

Shale gas produced water in the United States is generally disposed of through underground injection or treated. Underground injection through brine disposal wells is the most common disposal method, but local geology does not always provide formations suitable for large scale disposal. Disposal wells in many plays are a combination of commercial disposal wells or company owned and operated.

Public concerns about the amount of fresh water used for HVHF operations, coupled with the lack of disposal options, have resulted in operators increasingly turning to treating and/or re-using produced water. Treatment of produced water has evolved from treatment to near freshwater quality for discharge to treatment for re-use in subsequent drilling and fracture operations.

Treatment typically utilizes several technologies with the exact technologies selected depending on the intended use of the treated water. In the early years of shale related produced water treatment, water had been sent to municipal treatment plants and then discharged to surface water bodies (C&EN n.d.). Concern over the effectiveness of this treatment has resulted in this practice being discouraged in most states or outlawed in many areas because the treatment process may not adequately address treatment needs beyond the removal of salts or solids in the produced water.

Assessment of this treatment indicates POTWs may not have truly treated the water but merely diluted the produced water before release. Many operators are reusing produced water of varied quality from one well in the fracture fluid at another well. With minimal treatment, most produced waters can be blended with fresh water and reused. This approach to reuse helps operators to address water availability concerns by reducing the overall volume of fresh water that must be acquired. As an added benefit, reuse can also reduce transportation and disposal costs.

Water Reuse & Recycling

Many people in the industry believe reuse/ recycling of water is key to the future of unconventional oil and gas production. The overriding goal of water management is to minimize freshwater use, protect water resources, and maximize the recycling of produced water. In order to reduce current and future freshwater demands, produced water return volumes can be analyzed to determine available volumes for reuse and recycling.

Many operators reuse produced water by blending it with fresh water for subsequent fracturing operations. Benefits of recycling are the reduced cost for water withdrawals and the reduced volume of produced water for disposal. It also can lower transportation costs, truck traffic and associated community concerns.

Recycling can help reduce the amount of truck traffic required for a hydraulic fracturing operation.

There are several things to take into consideration when attempting to recycle produced water including the volume of produced water available, the quality and characteristics of the water, treated effluent requirements, storage requirements and site specific considerations.

Where water is plentiful, treatment costs can greatly exceed the cost of sourcing fresh water. Blended water must be suitable for fracture fluid; high TDS concentrations may affect friction reducing additives. Some friction reducers can work with higher TDS water, but this raises chemical costs. Operators also have to consider scale tendencies and the risk of bio-fouling with recycled waters.

Recycling produced water also typically requires separate storage facilities, since produced and fresh water should be stored separately. Some states have different requirements for ponds that hold low quality water. Lower quality water also may require additional site controls, depending on the location. Those controls might include berms, lined pits, lined pads, tanks, leak prevention, spill control and cleanup measures. Additional containment may be required in case of berm failure, and additional monitoring that may be required for permit compliance.

Water Treatment

Treatment of produced water from fracturing operations is frequently performed onsite or in nearby plants in high-flow-through, lower energy facilities which remove and dispose of the solids. Recent advances in water treatment technologies allow for higher volume water recycling and use of higher salinity fluids for hydraulic fracturing operations.

Traditionally TDS levels needed to be <20,000 ppm to insure compatibility with fracturing fluid chemical additives. Efforts have been made across the industry to expand the compatibility of fracturing chemical additives to a broader range of source water qualities (Seth, et. al, 2013).

Water Treatment Process	Organics	Suspended Solids	Biologics (bacteria & algae)	Low TDS <10,000 mg/L)	Med TDS <50,000 mg/L	High TDS >50,000 mg/L	Metals
Thermal Distillation/ Evaporation	X		X	X	X	X	X
Crystallization	X		X	X	X	X	X
Reverse Osmosis		X		X	X		X
UV Sterilization	X		X				
Ozone			X				
Ultrasound		X	X				X

Typical water treatment systems and the constituents they remove.

During the early days of treatment, when efforts to achieve high quality treated water, there were three primary treatment needs for produced water: reducing TDS (desalination) for discharge, beneficial use, or reuse; reducing the volume for disposal; and removing suspended solids and reducing scaling and bio-fouling potential in reuse applications (Parker, et. al, 2003; Arthur, et. al. 2009, Gaudlip, et.al, 2008).

Produced water quality varies between shale plays and within shale plays and over time (ALL Consulting and GWPC, 2009). High TDS concentrations had limited not only the potential uses but also dictated the treatment options (Kuijenhoven, et al, 2013).

For high TDS concentration waters, Reverse Osmosis (RO) and thermal distillation/evaporation were considered the only treatment technologies applicable to shale gas produced water. RO, which forces water through an osmotic membrane, is generally limited to those produced waters where TDS concentrations are below 40,000 ppm (parts per million). Membrane fouling and replacement is a costly concern. Thermal evaporation using Mechanical Vapor Recompression (MVR) is currently the most common treatment process for TDS removal. MVR can be effective, but concerns with corrosion and scale can be a problem for the process. Still, MVR can handle TDS values up to about 200,000 mg/L.

Crystallization has also be used successfully and can be cost effective with sale of commodity chemical byproducts. It benefits from no limit on TDS and is a zero liquid discharge systems. However, crystallization does require disposal of the resultant solids that can't be sold. Typical commodity byproducts include distilled water, calcium chloride liquid and sodium chloride dry salt (NYWEA n.d.).

Generally, as the TDS of the produced water increases, the volume of useable treated water decreases and waste increases.

Depending on the primary treatment system, pretreatment or condition may be needed. Pretreatment can include flocculation for removal of suspended solids, scale inhibitors and pH adjustments. Biocides may also be needed (Platt, et. al., 2011 and Geza, et. al, 2013). Typical biocides are Liquid chemical biocides (Glutaraldehyde being one of the most commonly used), but can also be non-liquid chemicals such as; Ozone, Ultraviolet light or ultrasound. However each of these has limitations.

- Ozone
    - Affected by the Chemical Oxygen Demand (COD) of the water being treated
    - Limited residual kill (has a short half-life about a half hour in the atmosphere).
- Ultraviolet Light
    - No residual kill (only effective when the light is being applied).
- Ultrasound
    - Reduces biological growth.
    - Can reduce concentrations of heavy metals, Total Suspended Solids (TSS) and turbidity levels
    - More effective when it is applied with ultraviolet light or ozone

The disposal of treatment process reject water and solids, plus transportation costs, must factor in to the cost of treatment. In areas where NORM is a concern, solids may need to be tested prior to disposal in a landfill. If NORM exceeds state standards, special disposal options may be required.

To be economic, the cost of produced water treatment for reuse must be less than the cost to dispose of the water via underground injection plus the cost of sourcing and transporting an equal volume of fresh water.

Conclusion

Shale Gas is going to remaining an important source of energy and large volumes of water are necessary for production. Treatment can conserve source water and reduce waste streams, but treatment is more than simple desalination. Reuse is an important option and is seen by many as the future of the industry. Treatment technologies are advancing and changing, but treatment for shale gas water remains in its infancy. The migration away from trying to treat to fresh water standards opens up options for treatment that previously were limited by the poor quality of produced water from many shale plays. As industry develops hydraulic fracturing treatment designs and identifies fracturing additives that are more tolerant and still efficient when used with higher TDS fluids, the options for treatment will continue to open up and expand. As such it could be expected that the service industry of water treatment for shale gas produced water will also expand and those companies with successful treatment technologies will grow.

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