Water Associated with Oil and Gas Production – Produced Water Management and Water Needs

John Veil

Veil Environmental, LLC, 1081 Carriage Hill Ct., Annapolis, MD 21401, USA, john@veilenvironmental.com

Abstract Water plays an integral role in oil and gas production as a needed input and as a byproduct. Water is required to make up drilling fluids and hydraulic fracturing fluids, and in many fields is needed for water or steam flooding to produce more oil. Most wells generate produced water during production. This paper describes how water is a part of oil and gas production, with an emphasis on management of produced water.

Keywords produced water, oil and gas, hydraulic fracturing

Introduction

Oil and gas can be produced in a variety of ways. Each of these production methods has its own profile for water needs and wastewater (produced water) generation. Produced water is not a single, consistent commodity. In reality, it is quite variable, not only in its chemical/physical characteristics, but also in the volume of produced water generated by a single well and whether that volume increases or decreases over time. Table 1 shows a summary of how the water needs and the produced water

Type of Oil and Gas Production	Water Needs for Production	Produced Water Generated
Conventional Oil and Gas	• Modest needs for hydraulic fracturing • More needed for enhanced recovery later on	• Low volume initially • Increased volume over time • High lifetime pw production
Coalbed Methane	• Modest needs for hydraulic fracturing	• High volume initially • Decreases over time
Shale Gas	• Large needs for hydraulic fracturing	• Initial flow rate is high, but quickly drops to very low • Low lifetime flowback and produced water production
Heavy Crude	• Steam flood to help move heavy oil to production wells	• Much of the water results from the injected steam used in steam flooding
Oil/Tar Sands	• Steam (or water) injection used in large volumes	• In-situ production methods: some water is formation water, but much is from the injected steam • Oil sand mining production methods and subsequent processing steps also generate wastewater

***Table 1** Variations in Water Needs and Generation by Production Method*

outputs vary based on the hydrocarbon production method used.

What Is Produced Water?

Produced water is water brought to the surface along with oil or gas. In most cases, the water is natural water that was present in the formation for a long time, but it can also include water that was introduced to the formation by the oil and gas company for production purposes (*e.g.* water flood, steam flood, hydraulic fracturing). Produced water may also be referred to as “brine” or “salt water” (Veil *et al.* 2004).

The individual concentrations vary from well-to-well and over time, but the major constituents of concern in produced water are:

- Salt content (salinity, total dissolved solids [TDS], electrical conductivity) – TDS concentrations range from < 5,000 mg/L to > 250,000 mg/L.
- Oil and grease (this is not a single compound – rather it is an analytical method that measures the presence of many families of organic chemical compounds). Oil and grease is typically quite low in gas wells but is much higher in oil wells. Oil may be in separate state or may be emulsified.
- Various natural inorganic and organic compounds that are part of the rock from which the produced water originated, the hydrocarbon which was in contact with the produced water for centuries, or chemical additives that are used in drilling and operating the well. There can be hundreds of potential compounds in produced water, but most are present in low concentration. Some of the volatile organic compounds can lead to air emissions when produced water is stored in open ponds.
- Naturally occurring radioactive material (NORM). NORM ranges from extremely low levels in some formations to relatively higher levels in formations like the Marcellus Shale. Generally the concentration of NORM in produced water is below any public health concern levels, although if produced water is treated, any resulting sludges or concentrated brines will have higher concentrations.

Produced Water Volume

It is challenging to make a comprehensive and accurate estimate of the produced water volume generated in the entire United States over a year (there are nearly 1 million producing oil and gas wells in the country). The most recent detailed estimate was published in 2009 – it represents water volumes from the 2007 calendar year (Clark and Veil 2009). The total 2007 produced water volume, including onshore and offshore wells, was approximately $21 \cdot 10^9$ US bbl ($882 \cdot 10^9$ US gal; $3.3 \cdot 10^9$ m^3).

Water production profiles and lifetime total volumes vary depending on the method used to produce oil and gas. These differences are shown in Table 1.

Another important statistic is the water-to-oil ratio (WOR). Clark and Veil (2009), using data from only 14 states, found WOR values from 5.3 to 1 to 7.6 to 1. However, the data provided by several of the states with the largest number of wells could not be used for WOR calculation (water production was not separated by gas wells *vs.* oil wells). The authors noted that if data from those states with large numbers of older wells with presumably high WORs had been available and included, the actual national average WOR would most likely be greater than 10 to 1. Higher WOR values mean that the operator must devote more effort and cost to manage the water from those wells. Typically, wells with higher WOR are older, more mature wells.

Since 2007, many new wells have been drilled to produce oil and gas from tight shale formations. Some people believe this will cause the national produced water volume to increase dramatically. Typically, these wells require a significant volume of water for hydraulic fracturing, but once the well begins production, there is only a small ongoing volume of water produced. The newly abundant shale gas wells contribute far less produced water to the national total that other more conventional oil and gas wells. The national produced water total is unlikely to rise rapidly from its 2007 level.

Produced Water Management

Produced water management technologies and strategies can be described in terms of a three-tiered water management or pollution prevention hierarchy (*i.e.* minimization, recycle/reuse, and disposal). Companies are encouraged to first evaluate practices that reduce the volumes of produced water entering the well or being handled at the surface. In this water minimization tier, processes are modified, technologies are adapted, or products are substituted so that less water is generated. When feasible, water minimization can often save money for operators and results in greater protection of the environment. Examples of technologies followed include:

- Reduce the volume of water entering the wells using mechanical blocking devices (*e.g.* packers, plugs, cement jobs) or water shut-off chemicals.
- Reduce the volume of water managed at the surface by remote separation (*e.g.* downhole separation or sea floor separation).

For the water that is still produced following water minimization, operators move next to the second tier, in which water is reused in a beneficial manner or recycled. Examples of reuse include injection for enhanced oil recovery, irrigation water, industrial water supply, and even drinking water.

In some situations, these more desirable management options may not be practical, cost-effective, or permitted by the regulatory agencies. Then water must be disposed of by injection, discharge, evaporation, or removal offsite to a commercial water disposal facility.

Prior to reusing or disposing produced water, companies often must first treat the produced water. Many technologies are available that can be used to treat different components of the produced water. For removing inorganics and salinity the following technologies have been used:

- pH adjustment, flocculation, and clarification,
- Electrocoagulation,
- Membrane filtration (micro filtration, ultrafiltration, nanofiltration, reverse osmosis),
- Thermal treatment,
- Ion exchange, and
- Capacitive deionization.

For removing organics and oil and grease, the following technologies have been used:

- Physical separation (gravity separators, hydrocyclones, filters, centrifuges),
- Coalescence,
- Flotation,
- Combined physical and extraction processes,
- Solvent extraction,
- Adsorption, and
- Oxidation.

A detailed written description of technologies and practices is available at Veil (2011). A more readily available version of this information can be found on the Produced Water Management Information System (PWMIS) website, developed by the author and his former colleagues (PWMIS 2007).

Costs for produced water management vary widely from a few cents per barrel (1 barrel or bbl = 42 U.S. gallons = 0.16 m^3) to more than $10/barrel. They are very site-specific. The true cost includes many cost components (Table 2).

U.S. Regulations Concerning Produced Water

In 1988 and 1993 the U.S. Environmental Protection Agency (EPA) published notices stating

Category	Cost Component (Some or all may be applicable)
Prior to Operations	• Prepare feasibility study to select option (in-house costs and outside consultants) • Obtain financing • Obtain necessary permits • Prepare site (grading; construction of facilities for treatment and storage; pipe installation) • Purchase and install equipment • Ensure utilities are available
During Operations	• Utilities • Chemicals and other consumable supplies • Transportation • Debt service • Maintenance • Disposal fees • Management of residuals removed or generated during treatment • Monitoring and reporting • Down time due to component failure or repair • Clean up of spills
After Operations	• Removal of facilities • Long-term liability • Site remediation and restoration

Table 2 *Components Contributing to Total Cost of Wastewater Management*

that wastes resulting from oil and gas exploration and production (including produced water) would not be regulated as hazardous wastes under the Resource Conservation and Recovery Act. The notices clarified that most oversight of these wastes would be handled by state agencies.

The most common ways for managing produced water are discharge and injection. The EPA published national discharge standards (effluent limitations guidelines) for the oil and gas industry. Offshore platforms can discharge in conformance with the requirements of National Pollutant Discharge Elimination System (NPDES) permits. Nearly all offshore wells treat produced water on the platform then discharge it back to the ocean.

Most onshore wells, however, are prohibited from discharging produced water. This led most operators to inject their produced water. Clark and Veil (2009) report that more than 90 % of onshore produced water is injected into underground formations. Slightly more than half is injected into producing formations for enhanced recovery. The remainder is injected into non-hydrocarbon bearing formations for disposal. Injection wells are regulated by the Underground Injection Control (UIC) program. The EPA has primary authority for this program, but has delegated UIC authority to many states.

In a few locations, the salinity level of produced water is low enough that it can be economically treated and discharged. In these situations, the state NPDES permitting agencies would issue permits to control the discharges.

When there is an opportunity for beneficial reuse of produced water, there may or may not be regulatory requirements. Usually the level of treatment prior to reuse is set not by regulatory standards, but rather by the operational water quality needs of the end user.

Conclusions

Sizeable volumes of water are needed to drill and hydraulically fracture many wells. Produced water is generated at many U.S. locations in high volume. Various options are available for managing that water. The presentation provides more detail on how water is used to produce oil and gas, qualitative estimates of the water volume needed, how produced water is managed, and some discussion of hydraulic fracturing and flowback water.

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