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Review

Treatment modalities for the reuse of produced waste from oil and gas development

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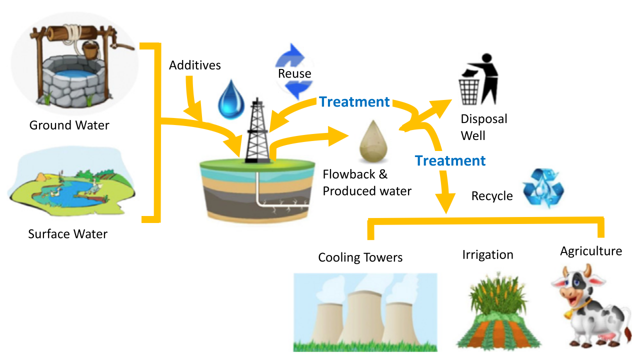
HIGHLIGHTS

- Challenges associated reusing produced water for hydraulic fracturing.
- Produced water is considered one of the most complex water matrices.
- Produced water has a highly variable biogeochemical composition.
- Recycling technology is pivotal to maintain environmentally responsible practices.
- A single technology is not an effective option for treating produced water.

GRAPHICAL ABSTRACT



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ABSTRACT

Unconventional oil and gas development is achieved through a series of sub-processes, which utilize large amounts of water, proppant, and chemical additives to retrieve sequestered hydrocarbons from low permeability petroliferous strata. As a result, a large amount of wastewater is produced, which is traditionally disposed of via subsurface injection into non-productive stratum throughout the country. However, this method of waste management has been linked to the induction of seismic events in a number of regions across North America, calling into question the environmental stewardship and sustainability of subsurface waste disposal. Advancements in water treatment technologies have improved the efficacy and financial viability of produced water recycling for beneficial reuse in the oil and gas sector. This review will cover the various treatment options that are currently being utilized in shale energy basins to remove organic, inorganic, and biological constituents, as well as some emerging technologies that are designed to remove pertinent contaminants that would otherwise preclude the reuse of produced water for production well stimulation.

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1. Introduction

The American economy relies upon oil and natural gas acquired through conventional and unconventional exploration of petroliferous strata to meet the growing domestic energy needs (Kim et al., 2016; Mobilia and Comstock, 2017; U.S. Department of Energy, 2015; U.S. Energy Information Administration, 2017a). Until the turn of the century, pockets of hydrocarbons, referred to as conventional resources, were the principle source of oil and natural gas. This commodity was sequestered in subsurface strata comprised primarily of sand and limestone formations that were porous enough to allow the oil, gas, and natural formation water to migrate to the wellhead with minimal aid (Sinclair, 2012; U.S. Department of Energy, 2015). In contrast, unconventional oil and gas resources, which are on the rise today, are found in low porosity tight-sands and shale formations, which require more advanced technologies and processes to achieve hydrocarbon extraction. These include horizontal drilling and hydraulic fracturing (HF) stimulation, (U.S. Energy Information Administration, 2017b), which have contributed to a 39% increase in unconventional natural gas production between 2000 and 2007 in the United States. Moreover, by 2015, two-thirds of the natural gas output came from hydraulically-fractured production wells, (Ground Water Protection Council, All Consulting, 2009; Perrin and Cook, 2016; Wang et al., 2014) with 92% of production growth being derived from unconventional resources in seven key oil and gas basins: Bakken (North Dakota and Montana), Niobrara (Colorado), Marcellus and Utica (Pennsylvania, Ohio and West Virginia), Haynesville (Louisiana and East Texas), Eagle Ford (South Texas), and the Permian Basin (West Texas and Southeast New Mexico).

In this review, our discussion begins with an overview of the water cycle for unconventional oil and gas development (UD). We also address the common chemicals used and the roles that they play during the HF process, followed by an analysis of the composition of the wastewater, which includes organics, inorganics, as well as microbial contaminants. Current disposal practices are also discussed as well as contemporary treatment modalities and challenges associated with reuse of produced water for future oil and gas operations or use in other anthropological activities.

1.1. Water use in the unconventional oil and gas production process

Unconventional oil and gas development (UD) is comprised of three primary phases: Drilling, completion, and production. Water plays a pivotal role in each step during the process, as shown in Fig. 1. Therefore, the success of UD relies heavily on accessibility to large volumes of water, which can be acquired from a variety of sources such as surface- or groundwater.

The first step in the well development process, drilling, only consumes approximately 1–12% of the overall water used throughout UD (Mantell, 2011). During this phase, drilling fluid, also known as drilling mud, is required to prevent a collapse of the borehole, bringing cuttings (rock particles), and other matter from the formation, back to the surface, as well as to lubricate the drill bit and to keep it cool (King and Durham, 2017; The Editors of Encyclopedia Britannica, 2014; US Government Accountability Office, 2012). Drilling mud is typically a salt solution from sodium or potassium chloride that matches the formation fluid's salinity to minimize clay reactions when the drilling fluid is introduced to the formation. Common additives in drilling mud include bentonite clay to increase viscosity, weighting agents such as barite, and polymers from xanthan gum or cellulose derivatives to stabilize the formation (King and Durham, 2017). At the completion of the drilling process, the drilling mud is typically disposed of either on-site or at a solid waste facility.

The completion process, referred to as HF or 'fracking', uses the majority of the water required throughout UD. This process is used to enhance productivity by increasing permeability of the formation near the wellbore (Tayal et al., 1997). It is during the completion process that well stimulation is performed using HF fluid, which is typically a viscous water-based slurry, referred to as slick water, gelled fracturing fluids, or hybrid mixtures of the two (King and Durham, 2017). The primary considerations when preparing the stimulation fluid are fracture conductivity (flow capacity) (Chapman and Palisch, 2014), proppant transport, and preventing damage to the formation during the fracturing operation that would limit permeability (Kim et al., 2016). Proppants are hard solid particles, such as resin-coated silica sand, which are used to prop open the fractures formed during HF, so that the oil and gas can flow up the wellbore to the surface (Fu et al., 2016; Ground Water Protection Council, All Consulting, 2009; Wang et al., 2014). The well performance is largely dependent on how efficiently the proppant is transported down the wellbore and how long the proppant remains suspended in the fracturing fluid.

The stimulation fluid is prepared by mixing additives to help the stimulation process, which can vary in complexity from 1 to 2 or up to 30 chemicals. Additives for slickwater fracturing fluids include friction reducers, biocides, scale inhibitors, surfactants, clay control agents, and acids (Fracline, 2012). Gelled fracturing fluids will also incorporate gellants, crosslinkers, and gel breakers. Friction reducers help reduce friction generated as the fluid is pumped down the wellbore. Four primary friction reducers used are polyacrylic acid (PAAc), polyacrylamide (PAAm), partially hydrolyzed polyacrylamide (PHPA), which is the most common friction reducer used, and acrylamido methyl propane sulfonate (AMPS) (Montgomery, 2013). Biocides are used to kill bacteria in the water to prevent the production of corrosive hydrogen sulfide gas (H_2S) and to limit biofouling, which can hinder production (Liden