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# Biologically active filtration for fracturing flowback and produced water treatment

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ABSTRACT

Reclamation of fracturing flowback and produced water associated with unconventional oil and gas resource development is becoming a more widely applied management practice because it protects freshwater resources through elimination of surface discharge and by reducing demand for high quality water sources. Reduction of organic matter has been a notable wastewater treatment challenge and has limited practical opportunities for reuse of these waste streams. This research focuses on harnessing the ability of microorganisms to biodegrade organic carbon present at high concentrations in flowback and produced water. Bench-scale and lab-scale biofiltration systems were investigated to determine adaptability of biofilms and measure biodegradation of organic carbon under different operating conditions. Microorganisms associated with biologically active carbon filters were initially acclimated to a produced water stream from the Piceance Basin. Following successful acclimation, the bench-scale system consistently achieved more than 90% dissolved organic carbon removal ($C_o$ ~ 240 mg/L). Similar performance was observed for the lab-scale system, demonstrating system scalability. After treating distinct wastewater feeds (produced water [$C_o$ ~ 350 mg/L] and flowback water [$C_o$ ~ 2150 mg/L] from the Denver-Julesburg Basin), the system further demonstrated robustness and flexibility. Results from the performance evaluation validated the ability of the system to maintain treatment efficiency under variable operating conditions, including different pretreatment, aeration rates, temperatures, and empty-bed contact times.

## 1. Introduction

The abundance of technically recoverable oil and gas (O & G) reserves in the U.S. has resulted in rapid development of unconventional resources [1]. However, this rapid exploitation of resources has not been without scrutiny. The economic, energy security, and climate change benefits are often countered by the potential environmental impacts [2], including contamination of drinking water aquifers [3–6], leakage of methane to the atmosphere [7], and depletion of freshwater resources [8,9]. Of these, water-related environmental issues have emerged as some of the greatest concerns resulting from unconventional O & G development—both water quantity and quality management are critical to the sustainability of the industry [10].

The primary uses of water in O & G development are for drilling and well completion activities. Drilling operations require large volumes of water to circulate the drilling fluid that cools the drill bit and carries the rock cutting out of the borehole [11]. Following drilling in unconventional reservoirs, the well undergoes a completion stage using a stimulation technique known as hydraulic fracturing (a.k.a., frac or fracking). In this process, water mixed with chemical additives is injected at high pressures into the low permeability formations to fracture the rock and allow higher recovery of hydrocarbons from the well [12,13]. The hydraulic fracturing process is the most water-intensive operation in unconventional O & G development [14,15], requiring volumes that typically range between 7 and 19 megaliters (ML) (2 and 5 million gallons) per well [1,9,11].

Following hydraulic fracturing, the pumping pressure is released and the injected frac fluid returns to the surface in the form of flowback water. Over time, the flowback water gradually mixes with formation water, generating the waste stream commonly referred to as produced water. The volume of produced water generated from a given well depends on the formation characteristics, geographic location of the well, the type of hydrocarbon produced, and the method of production [13]. In 2007, U.S. onshore O & G production operations generated over

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8700 ML/day (2.3 billion gallons/day) of produced water [16]. This represents the largest waste stream generated by the O & G industry [17], and its management is often referred to as one of the biggest challenges in sustainable unconventional resource development [11,18,19].

### 1.1. Wastewater management practices

Current management practices for frac flowback and produced water include temporary on-site storage followed by transportation for off-site disposal, either via deep well injection or treatment prior to reuse or surface water discharge [12,20]. In most areas, deep well injection is the primary disposal method because it requires little or no treatment, and it is often the least expensive option [12,13]. However, reclamation and reuse of fracturing flowback and produced waters within the upstream O & G sector is becoming a more attractive option [21–23]. This alternative protects freshwater resources by eliminating discharge to the environment and reducing demand on high-quality source waters. Reuse applications within the industry include well drilling, hydraulic fracturing, enhanced oil recovery, and water flooding [24].

A major hindrance to most water reuse applications is the high salinity of some O & G waste streams, measured as total dissolved solids (TDS). High TDS can be managed through the use of desalination processes such as membrane separation, evaporative crystallizers, or mechanical vapor compression [19,25]. However, substantial pretreatment to reduce fouling and scaling potential is required before fracturing flowback and produced water can be desalinated using membrane technologies [19,26].

Chemical pretreatment is often sufficient for removal of inorganic scalants, but the removal of organic foulants requires different pretreatment approaches. The very high concentrations of organic matter in O & G wastewater streams, relative to typical surface water, groundwater, or domestic wastewater, present challenges in identifying cost-effective treatment processes. The addition of coagulants, oxidants, and/or adsorbents (e.g., powder activated carbon) can be employed for such an application [27], but the high quantities required will often render the treatment cost-prohibitive [17]. Alternatively, a cost-effective pretreatment method for removal of organic constituents is the application of biological treatment processes [28], which may have the potential to increase economic viability of treatment for reuse in the oilfield. Yet, the low tolerance of many microorganisms to high salinity must be overcome before these processes are adopted by the industry.

### 1.2. Biologically active filtration (BAF)

Biological treatment processes are designed to remove biodegradable compounds while fostering the growth of microorganisms. Such processes are classified into two categories: suspended-growth and attached-growth processes. The most common suspended-growth process used for municipal wastewater treatment is the activated-sludge process [29]. Limited research has been conducted to evaluate the effectiveness of this process for treatment of oilfield produced or fracturing flowback waters [30–33].

In attached-growth processes, the microorganisms are attached to a medium that serves as a surface on which the biomass is grown and retained (i.e., biofilm). Media used in these processes include sand, gravel, wood, anthracite coal, granular activated carbon (GAC), and other synthetic plastic materials. Biofilms have better ability to adapt to sudden variations in ecosystem conditions such as pH, temperature, salinity, and substrate type or availability. In addition, attached-growth processes generally require simpler operation, less maintenance, and less energy than suspended-growth processes. Attached-growth systems have also been found to contain biomass in higher concentrations than in suspended-growth systems [28]. For these reasons, attached-growth biological systems present a promising solution for O & G wastewater treatment and were identified in this research for further investigation.

Biologically active filtration (BAF), or biofiltration, was selected for evaluation in this study, because of its widely successful application for treatment of drinking water and municipal wastewater [34–36]. In BAF, removal of contaminants can be accomplished in several ways: colloidal and suspended particles are physically separated by filtration, dissolved material is adsorbed to the filter media or to the biomass, and the predominant removal mechanism is through biodegradation [34–36]. In this manner, the constituents are incorporated into the biomass or used as energy sources through biological oxidation.

A number of studies have been conducted to evaluate biofiltration for treatment of drinking water and domestic wastewater [28,34–47], but very few have been reported for applications in the O & G industry [48–51]. This presented an opportunity to evaluate a cost-effective and potentially robust treatment process for a new, challenging application: treatment of wastewater generated during well completion and production of O & G. The potential benefits include pretreatment for membrane processes through rejection of colloidal and suspended solids, adsorption of organic compounds, and enhanced biological stability of the filtered effluent; each of which can reduce the fouling potential of the feed water, leading to more sustainable and economical membrane system operations.

The primary objective of this research was to determine the efficacy and technical feasibility of a bench-scale biological filtration system for treatment of produced water and fracturing flowback. The evaluation followed an experimental plan with several specific steps, including (1) acclimate a pre-existing biofilm to a new water type (i.e., produced water), (2) investigate the benefits of pretreatment, and (3) investigate system flexibility. Following performance verification of the bench-scale system, further objectives were established for a lab-scale system evaluation including investigation of scalability, flexibility, and impacts of variable operating conditions on performance. The testing included verifying comparable system performance and the necessity of biofilm acclimation. Specific operating conditions evaluated include level of pretreatment, presence/absence of aeration, variable temperatures, and empty-bed contact time.

## 2. Materials and methods

### 2.1. Feed streams

Bench-scale and lab-scale tests were conducted with produced water from the Piceance Basin, acquired from a centralized produced water treatment facility in Rifle, CO, and stored in 200 L (55 gal) drums. The water was vigorously mixed prior to drawing of batches for each experiment to ensure a representative and consistent water quality. Additional bench-scale and lab-scale tests were conducted with produced water and fracturing flowback from the Denver-Julesburg (DJ) Basin (Niobrara Formation), acquired from a centralized collection facility in Ft. Lupton, CO. The fracturing flowback stream was acquired from the operator 20 days after completion of hydraulic fracturing [52]. Baseline water quality is summarized in Table 1.

### 2.2. Bench-scale filtration system

A bench-scale system (Fig. 1a) consisting of four 1.27 cm (0.5 inch) diameter clear PVC filtration columns was utilized to conduct preliminary experiments. Each column was connected via neoprene tubing to a dedicated 1 L feed tank. A peristaltic pump (Cole-Parmer, Court Vernon Hills, IL) was used to draw water from the feed tanks to the columns. Each column contained 30 cm (12 in.) of filter media. One column was designated an *abiotic control* by adding sodium azide (0.1% by wt. $NaN_3$) to the feed water to limit microbial activity. Aeration was applied by submerging stone diffusers in the feed tanks and supplying air with a 45 L/min compressor (Hydrofarm, Inc., Broomfield, CO); a control valve/rotameter was used to regulate airflow to approximately