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Co-treatment of residential and oil and gas production wastewater with a hybrid sequencing batch reactor-membrane bioreactor process

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ABSTRACT

Exploration and production of oil and gas (O&G) generates large volumes of wastewater. High salinity and the presence of both dissolved constituents and suspended solids require complex and expensive treatment of O&G produced waters for beneficial reuse (e.g., fracking, irrigation, surface water discharge). Nearly 90% of wastewater produced during the lifetime of O&G wells is currently disposed of due to the high cost of treatment; thus, simple and inexpensive treatment technologies and approaches must be developed to promote water reuse in the O&G industry. In this study we investigated the potential for publicly owned wastewater treatment plants to co-treat produced water and residential wastewater. The removal of organic compounds, nutrients, metals, trace organic compounds, and suspended solids from the combined stream was investigated using a pilot-scale hybrid sequencing batch reactor-membrane bioreactor system. Produced water was initially dosed at 6% by volume, and comparable removal of primary (i.e., chemical oxygen demand, ammonia) and secondary constituents (i.e., trace organic compounds, inorganic contaminants) to control conditions was achieved. When produced water was increased to 20% of the influent by volume, nitrification was lost; however, the dominant biological communities in the bioreactors remained stable, providing evidence of an adaptive system and reliance on non-dominant microorganisms to achieve optimal treatment.

1. Introduction

Competition for water resources is partially driven by increased industrial activities such as agriculture, energy production, and resource extraction [1]. For example, water for mining operations, including coal and petroleum, constitutes one percent (approximately 7.6 million m^3 (two billion gallons) annually) of the total water demand in the United States (US) [2–4]. Unlike other industrial applications, oil and gas (O&G) extraction generates wastewater streams that are primarily disposed of through deep-well injection, rather than being treated and reused [5–7]. Deep-well injection has been found to enhance fault lines, leading to injection-induced earthquakes [8]. The occurrence of injection-induced earthquakes has led to a heightened awareness of O&G wastewater disposal, and several states seeking to ban deep-well disposal [9–11]. Technologies to treat O&G wastewater are available, but currently in most regions of the US they cannot compete economically with disposal [12]. A possible solution to this economic imbalance is to utilize existing treatment facilities at publicly owned treatment works (POTWs) to co-treat O&G waste streams with domestic wastewater, enabling reuse of the combined effluent or conditioning the water ahead of desalination.

The amount of water used for a single well drilling and completion operation widely varies and reportedly ranges from 200 to 50,000 m^3 (50,000 to 13 million gallons) per well [4,13,14]; this water is commonly acquired from fresh water sources such as groundwater, lakes, and streams [14–19]. Produced water is the largest (by volume) waste stream generated by upstream O&G operations [20]. Produced water contains a broad range of organic constituents, including volatile organic compounds, free oil and grease, and total petroleum hydrocarbons [15]. Produced water chemical oxygen demand (COD) concentration may range from 150 to 9300 mg/L [15]. Produced water also contains many inorganic compounds. The concentration of total dissolved solids (TDS) has been reported to be as high as 285,000 mg/L [21]; yet, most wells generate produced water at much lower salinity. High concentrations of barium, boron, bromide, chloride, iron, magnesium, manganese, nitrogen, potassium, sodium, sulfate, zinc, and nat-

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urally occurring radionuclides can be found in produced water [6,22–24]. Other contaminants in produced water include microorganisms and total suspended solids (TSS). Thus, it is clear that produced waters are very complex streams and require unique treatment approaches.

Produced water generated in the Denver-Julesburg (D-J) basin (Colorado, US) is of particular interest in this study due to its location in a water stressed region and the prevalence of deep-well disposal facilities in the area [14]. The D-J basin is located in northeastern Colorado and contains O&G from tight oil and shale gas reserves in the Niobrara formation. Over 30 million m^3 (8.1 billion gallons) of water have been used in the D-J basin for drilling and completion operations, only 50% of which is returned to the surface [25]. The economics of managing O&G waste streams—treatment or disposal—varies substantially with geographic location. In the D-J basin, deep-well injection is inexpensive and in close proximity to drilling operations. Still, wastewater treatment and reuse in the basin will be highly beneficial to balance regional water supplies and demands.

1.1. Biological treatment of wastewater

Due to highly variable concentrations of organic and inorganic constituents, produced water treatment requires robust, durable, versatile, redundant, and economical systems that can tolerate variation in influent quality and quantity. Pretreatment of produced water is often employed to reduce TSS and the concentration of major constituents. Biological treatment is of particular interest as a pretreatment method due to the high biodegradable organic matter content in produced water. It also allows for the implementation of secondary treatment to minimize fouling and increase the treatment efficiency of desalination technologies such as nanofiltration (NF) and reverse osmosis (RO) [12]. While biological processes can efficiently be used for removal of organic constituents in waste streams, high salt concentration, as expected in produced water and produced water co-treated with domestic wastewater, may negatively impact the performance of the microorganisms in the treatment system. Furthermore, when considering co-treatment of produced water with residential wastewater, it is necessary to ensure that salinity and other constituents present in produced water do not negatively impact removal of constituents present in residential wastewater such as COD, ammonia, phosphate, and trace organic compounds (TOrCs).

Various biological treatment processes dominate the residential wastewater treatment industry. Biological processes are designed to accomplish a similar goal: to remove organic matter, nutrients, and TSS from waste streams and to allow safe discharge of plant effluent to the environment [26]. Common biological treatment trains include conventional activated sludge, sequencing batch reactor (SBR), and membrane bioreactor (MBR) systems. SBRs operate in cycles using precise timing of dosing, aeration, settling, and decanting to achieve nitrification, denitrification, biochemical oxygen demand (BOD) removal, biological phosphorus uptake, and clarification. In SBR systems, equalization, biological treatment, and clarification take place in one bioreactor (BR), thus reducing the physical footprint of the treatment facility. Due to the flexibility in timing, SBRs are capable of handling variable organic and nutrient loading rates common to both residential wastewater and produced water [27].

In MBRs, high concentration of mixed liquor suspended solids (MLSS) is used to achieve high BOD removal, nitrification, and denitrification. Rather than settling the MLSS by gravity to decant the clarified water, an ultrafiltration (UF) or microfiltration membrane is used to physically separate the suspended solids from the treated stream. Using an MBR reduces the need for high-footprint floc formation and gravity clarification. Combining the benefits of both processes, the biological treatment configuration used in this study was a pilot-scale hybrid sequencing batch reactor-membrane bioreactor (SBR-MBR).

1.2. Co-treatment of produced water with residential wastewater

One option for treatment and reuse of produced water could involve conveyance to nearby POTWs employing biological treatment processes. There are numerous advantages for this option. First, biological treatment processes contain microorganisms capable of reducing the high concentrations of organic carbon present in produced water [28–30]. Second, the abundance of POTWs throughout the country, and thus short hauling distances, would likely keep transportation and/or pipeline costs low. Third, utilizing existing facilities would minimize capital costs, making it an economically competitive treatment alternative. Above all, treating O&G wastewater, rather than sequestering it in the subsurface, would mean availability to use the water for future applications with the added environmental benefit of decreased, man-made seismic activity. While studies have been conducted to address the feasibility of treating produced water with activated sludge, data pertaining to the impacts on nitrogen and phosphorus removal is insufficient [28–31].

In order for an industrial wastewater to be considered for treatment at a POTW, it must pass several criteria based on federal, state, and local regulations. The US Environmental Protection Agency (EPA) Clean Water Act (CWA) 40 CFR Part 403, commonly referred to as the National Pretreatment Program, establishes requirements for accepting industrial wastewaters at POTWs based on the quality of the industrial wastewater submitted for treatment [22]. In order to comply, industrial wastewaters cannot interfere with the overall operation of the POTW, cause a hazardous work environment for employees (i.e., explosives/fire hazard, radiation, toxic gases, etc.), or introduce pollutants that will pass through the process without treatment. Additionally, industrial wastewaters may not contain constituents (i.e., heavy metals) that have been demonstrated to negatively influence sludge reuse applications (i.e., land application) [22]. At the state and local levels, states and individual POTWs have the ability to ban produced water from entering their headworks [13]. Regulations pertaining to other methods of O&G wastewater treatment and disposal can be found in CWA 40 CFR Part 435, Subpart C and the Safe Drinking Water Act (Section 1421). Biosolids are regulated under CWA 40 CFR Part 503 [32]—this regulation establishes maximum allowable pollutant limits in order to use biosolids for land application. Nine key inorganic metals are regulated under this code and include arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc with ceiling concentrations of 75, 85, 4300, 840, 57, 75, 420, 100, and 7500 mg/kg, respectively.

A limited number of studies have evaluated whether or not accepting produced water at POTWs will influence the ability of the treatment process to adhere to the expectations outlined by the National Pretreatment Program [22]. These studies—primarily based on reports from POTWs in Pennsylvania that accepted produced water in the past—have been included in a June 2015 US EPA rule that bans POTWs from accepting produced water. The volume fraction of produced water mixed with the residential wastewater stream in these POTWs ranged from 0.04% to 21% [22]. However, it is important to note that basin waters typically have their own specific chemistries and what applies at one location may not apply at another, though it is difficult for law and regulation to be basin specific.

Possible concerns related to the co-treatment of produced water with residential wastewater using biological treatment processes include salinity and dissolved metals present in produced water. Salinity in produced water and other waste streams has