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Review

Bioelectrochemical approaches for removal of sulfate, hydrocarbon and salinity from produced water

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HIGHLIGHTS

- Conventional treatment strategies for PW treatment have been discussed.
- Electrochemistry based technologies is an emerging field of research.
- New strategy of uniquely integrating bioelectrochemistry with biological system proposed.

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ABSTRACT

Produced water (PW) is the largest liquid waste stream generated during the exploration and drilling process of both the conventional hydrocarbon based resources like crude oil and natural gas, as well as the new fossil resources like shale gas and coal bed methane. Resource management, efficient utilization of the water resources, and water purification protocols are the conventionally used treatment methods applied to either treat or utilize the generated PW. This review provides a comprehensive overview of these conventional PW treatment strategies with special emphasises on electrochemical treatment. Key considerations associated with these approaches for efficient treatment of PW are also discussed. After a thorough assessment of the salient features of these treatment platforms, we propose a new strategy of uniquely integrating bioelectrochemical processes with biological system for more effective PW treatment and management.

Contents

Abbreviations: AEM, anion exchange membrane; BOD, biological oxygen demand; BDD, boron doped diamond; BES, bioelectrochemical system; BTEX, benzene toluene ethylbenzene xylene; BPM, bipolar membrane; CBMPW, coal bed methane produced water; CEM, cation exchange membrane; CMM, charge mosaic membrane; COD, chemical oxygen demand; DSA, dimensionally stable anode; EOR, enhanced oil recovery; HRT, hydraulic retention time; MDC, microbial desalination cell; ME, microbial electrolysis; MEDCC, microbial electrolysis desalination and chemical production cell; NGPW, natural gas produced water; OPW, oil produced water; PW, produced water; SGPW, shale gas produced water; SRB, sulfate reducing bacteria; SS, suspended solids; TDS, total dissolved solids.

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1. Introduction

Water and energy are intrinsically linked and essential for human survival. From a global perspective, the energy sector has been majorly driven by fossil fuels and is expected to remain so for the next few decades (World Energy Resources, 2013). However, along with the benefits, these fuels also adversely impact the environment during its production, distribution and use. As oil and gas are lifted to the surface, a significant amount of water is also brought along with it from the subsurface, which is known as produced water (PW). This is the largest volume of waste stream in the exploration and production process, produced not only during conventional crude oil recovery, but also during the newer forms of fossil energy recovery like shale gas, oil sands and coal bed methane (Fig. 1a and b). The volume of produced water generated from oil and gas production operations does not remain constant over time. The water-to-oil/gas ratio, more commonly known as the “water cut”, increases over the life of a conventional oil or gas well. For crude oil wells, this can account for upto 98% of the extracted fluids during the later stages of production (Veil et al., 2004). Worldwide, production of produced water associated with hydrocarbon recovery is more than 77 billion bbl (oil barrel)per annum (Duraisamy et al., 2013). The oil and gas industry faces two major issues with water management: first, dealing with produced water – a significant by-product of hydrocarbons extraction. And secondly, mature oilfields increasingly require water-based enhanced oil-recovery (EOR) methods and resultantly generate significantly more produced water over time.

Similarly, coalbed methane (CBM) recovery from coal seams results in large quantities of water that are released as by-products of production process (Hamawand et al., 2013). Shale gas, the recent game changer in the energy sector, also significantly use and generate large volumes of water during its production process. Development of shale and tight gas reservoirs require multistage hydraulic fracturing of the wells, a process which requires 2–4 million gallons of water per well (Shaffer et al., 2013). The physical and chemical properties of produced water typically depend on the geographic location of the field, the geological formation and the type of hydrocarbon product produced during operation. PW usually contains high concentrations of dissolved sodium chloride, dissolved hardness (calcium and magnesium carbonates), suspended solids, sulfate, and emulsified oils.

Discharge of such waters into the environment without proper treatment may also result in bioaccumulation in aqueous organisms and subsequent biological sequestration of the harmful chemicals from produced water into the food chain. Furthermore, disposal of such large volumes of contaminated wastewater is a major issue especially with increasingly stringent environmental regulations. Clean water is a precious resource, which is depleting with increasing population and its growing energy needs (World Energy Resources, 2013). It is evident from the above numbers that all these operations related to energy generation are draining the water resources. In addition large space and volume requirement for produced water treatment systems could also have a negative impact on the overall economics of the exploration and extraction processes. Effective treatment and reuse of produced water can thus mitigate scarcity of fresh water, especially in arid areas where oil and gas operations are prevalent (Fig. 1c). Properly applied management techniques and emerging water treatment processes can drastically reduce the water demands of the fossil energy industries, promoting closed loop water recycling and minimizing environmental exposure associated with exploration and processing of various oil and gas resources. The harmful constituents of produced water that can degrade the water potability, its impact on the soil fertility where it is disposed, and the depletion of currently usable water resources can thus act as a driving force for the treatment and management of this source. Thus in this article, while reviewing the conventional treatment techniques that are used in the industry, we discuss the possibility of using bioelectrochemical systems for PW treatment and recycling.

2. Conventional technologies for treatment of produced water

PW is a very complex wastewater stream with a variety of constituents as briefly summarized in Table 1. Traditionally, various strategies have been used by the oil and gas operators for managing PW, including injecting the separated PW into the same formation or another appropriate formation. This can be considered as one of the practical and economical options for the operators as the wastewater so generated in the extraction process is emplaced back underground, which helps in maintaining the reservoir pressure (Arthur et al., 2005). However, there is a requirement for treatment of the injectate to reduce proliferation of sulfate reducing bacteria (SRB). PW from all oil and gas reservoirs inherently contains SRB and when stored after separation for injection, SRB rapidly proliferate due to presence of sulfate in PW (Kaur et al., 2009). This SRB laden PW upon inter mingling with formation water allows rapid and exponential growth of SRBs to thrive under reservoir conditions. This not only also causes reservoir souring and clogging, it also promotes microbially influenced corrosion (MIC) in the pipelines or storage tanks leading to significant economic losses to the industry. Thus, a technology that removes sulfate is desirable if the PW is to be used for re-injection to the reservoirs for enhanced recovery or other purpose by the energy companies.

The second option that is conventionally opted by the operators is surface discharge. However, for discharging this water into the environment, a treatment process which removes organics, sulfate and TDS (total dissolved solids) is important to avoid contamination of soil, surface and groundwater. The PW is hypersaline or brackish and thus cannot be released directly into the environment as it can affect the salinity of soil and thus plant productivity. The PW also contains petroleum hydrocarbons, especially polycyclic aromatic hydrocarbons and these are known to be harmful to the