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Challenges and Opportunities in Produced Water and Drilling Waste Treatment Techniques to Mitigate the Adverse Environmental Impacts

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Introduction

In 2012, the oil and gas wells in the United States generated 21.2 billion barrels of produced water (PW) [1]. The PW is the aqueous liquid phase of the mixture of oil and/or gas drilled from producing wells, which contains a number of contaminants, typically BTEX (benzene, toluene, ethyl benzene, xylenes). The Water-to-Oil Ratio (WOR) in the mixture is about three on average globally, significantly varying over the lifetime of a field, increasing from a small portion to more than ten. The composition of the PW is complex and site-specific and a function of the geological formation, the oil and water chemistry, rock/fluid interactions, the type of production, and required additives for oil-production-related activities [2]. The PW has become the most waste stream from oil and gas industry. Ninety-seven percent of the PW is generated by the onshore wells and only three percent by offshore platforms. The oil and gas wells in the State of Texas contribute to more than one third of the total PW in the United States. Meanwhile, a considerable amount of waste has been co-produced during drilling, mainly excavated material or cuttings from the borehole and added drilling fluids.

Both of PW and drilling waste (DW) are comprised of serval thousand compounds, the improper treatment of which poses a threat to public health and environment. The major toxicants include monocyclic aromatic hydrocarbons, polycyclic aromatic hydrocarbons (PATH), and related heterocyclic aromatic compounds. Dispersed oil, aromatic hydrocarbons and alkylphenols (AP), heavy metals, and naturally occurring radioactive material (NORM) raise major environmental concerns in the public [3]. Some of the toxicants are acutely toxic, some are carcinogenic, and others are endocrine-disruptor [4-7] for microorganisms as well as human beings in the ecosystem system.

Enormous technologies have been developed to address the adverse environmental impacts of the PW and DW by improving treatment process and technologies for disposal and reuse purposes. This commentary is intended to remark the challenges in mitigating the environmental impacts by the PW and DW treatments and the opportunities in the resource recovery from the PW and DW.

Challenges in Mitigating the Environmental Impacts by Produced Water Treatments

The selection of PW treatment process and technologies is usually determined by the contaminant concentration levels in its destination. For instance, if the treated PW is proposed to inject to the underground serving in a hydraulic fracturing operation, only the coarse particles, small hydrocarbon droplets, and small particles removal are designed in the treatment process. For lawn watering, desalination process is inevitable.

However, the chemical complex substance contamination and stable emulsion system in the PW challenges the treatment processes and technologies. For instance, flow back water is injected into the well with trace chemical additives, which are mostly anti-microbial, anti-coagulants, corrosion and scale inhibitors, emulsion breakers and solvents. The flow back water with the chemical additives could contaminate underground drinking water supplies or surface water. The presence of iodide and bromide potentially form disinfection byproducts (DBPs), which is much more toxic than chlorinated DBPs [8]. The efficient removal techniques of the iodide and bromide have been rarely reported. Moreover, the PW contains large amounts of dissolved grease and other organic compounds, as well as salts and radioactive substances. Traditional physico-chemical methods, such as hydrocyclones, membrane filtration and coagulation and flocculation cannot efficiently remove dissolved hydrocarbon components [9].

Further, the formation water is extreme salty, the salinity level of which is highly greater than seawater's (3.5%). Salinity is an abiotic stress, which imposes ion toxicity, nutrient deficiency, osmotic stress, and oxidative stress on plants during any phase of their life cycle [10]. Likewise, the high concentration of salt changes the availability of water and nutrients for microorganisms [11]. As a result, most bacteria in traditional activated sludge are not able to tolerate high salinity (greater than 1%) [12]. The high level of salinity in PW limits conventional bioremediation process and its application in agriculture and power plants for its nature of corrosion. A recent study by Sharghi et al. [13] designed a membrane bioreactor to biodegrade high salinity synthetic oilfield produced, which achieves 89.2% and 95.5% oil and gas removal efficiency, respectively. The effluent of the membrane bioreactor is consistently below international standards for disposal to sea or re-injection to oil wells. However, the bioremediation process requires eighty days for sludge retention time, which is not competitive for other physical treatments, such as hydrocyclones and centrifuges, for the same quality effluent. Further, the high membrane fouling rate from the bioreactor is still a concern.

Challenges in Mitigating the Environmental Impacts by Drilling Waste Treatments

The cuttings from a drilling process are the broken bits of solid material removed from a borehole. Meanwhile, drilling fluids, also known as drilling mud, are used to facilitate the drilling process by suspending cuttings, controlling pressure, stabilizing exposed rock, providing buoyancy, cooling, and lubricating (Arnold, et al., 2004).

Efforts have been exerted to seek the most environmentally acceptable

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techniques to reduce DW production. Directional drilling, synthetic-based muds (SBMs), and pneumatic drilling are typically developed to reduce cuttings and frilling fluid production, particularly suitable for an environmentally sensitive area. Directional drilling uses steerable or directional down whole tools that allow the driller to direct the wellbore in any angle to reach the target [14]. In this way, a reservoir could be completed by a single horizontal well, instead of three conventional vertical wells. The associated waste with the single well is much less than the ones with the three well. One of the directional and horizontal drillings, is drilled across an oil and gas formation with any wellbore that exceeds 80 degrees, which produces up to 20 times more than that of its vertical counterpart. The SBM is less toxic and more biodegradable mud, compared to traditional oil-based muds (OBMs), which helps drillers in stabilizing water sensitive shales and provides lubricity for coring operations and minimized reservoir damages. The cuttings coated with the SBMs could be buried and discharged to the sea or remediated by a biological process, such as biostimulation and bioaugmentation. Fan et al. [15] reported that the bioaugmented system can achieve 95.2% of total organic carbon degradation (TOC) and 91.2% of total petroleum hydrocarbon (TPH) within 120 h, while the biostimulation removes 82.9% and 58.3% of TOC and TPH, respectively. The functional or species diversity within bacterial communities in the bioremediation are subject to the complex combination of numerous components in the drilling fluids. Besides, the pneumatic drilling technique is to use air or other forms of gases to circulate cuttings from the well, which does not require large surface to reserve pits. In some cases, such as hard and dry underlying formation and no subsurface pressure required in shallow locations, the air drilling is considerably faster and less expensive than the one using water-based or oil-base fluids [14].

Among other methods, cuttings reinjection (CRI) and RECLAIM technology effectively facilitate minimization of environmental impacts by reducing the volume. While the CRI is practiced in environmentally disposed oily-waste, the RECLAIM technology can chemically enhance solids-removal process to maintain higher fluid's performance and stability. Cuttings can be grinded with seawater to form a stable viscous slurry, which either pumped to a disposal well or through the annulus between casing strings on a drilling well, forcing under pressure into formations. This process generates hydraulic fracture in the formation. The CRI is the only environmentally acceptable disposal method for some remote or environmental sensitive areas, such as extreme northern and southern areas, where harsh winter weather excludes the most onshore treatments [16]. However, there is a risk that the CRI operations could be shut down for being blocked down either casing or an annulus. Further, it is challenging to accurately estimate the settling velocity and maximum allowable residence time that the slurry is left in the injection tubing without solids dropping and potentially plugging the disposal well.

On the other hand, most of the cuttings and fine solids are extracted from muds continuously when they return to the surface, and a small portion of the solids is left in the mud. Accumulatively, the concentration of the ultrafine solids or low-gravity solids (LGS) in the mud becomes higher, leading to the decrease in the fluid's performance and general stability. Conventionally, the LGS concentration is lowered by either dilution or building new mud, which increases waste and disposal loads as well. RECLAIM technology is capable of eliminating the majority of the fine solids from the muds and decrease the WOR of the drilling fluid, with no significant change in the volume of fluid.

Further, barite is one of the most important additives to drilling muds, consisting of barium sulphate, which improves the technical performance of the mud by stabilizing the borehole. The barite is a primary source of toxic heavy metals in DW discharges [17]. Besides, there is correlation between cadmium and mercury concentrations, and the concentrations of some other trace metals in the barite [18]. Though physically the barite could be recovered by decanter centrifuges, it is challenging to achieve high efficiency of the barite recovery goal when the centrifuges also serve to reduce the content of drilled fines, specifically colloidal solids, for different range of particle sizes [19].

Opportunities in Resource Recovery from Produced Water and Drilling Waste

High concentrations of commercially useful iodide trace elements and radionuclides, such as radium and strontium formed by the decay of uranium and thorium naturally, are found in PW as well. The iodide recovery from the PW in Oklahoma has become the largest source of iodine in the United States. Likewise, the PW is a plentiful reservoir of radionuclides, which has not been extensively exploited. Nevertheless, in some states in Northeast and Midwest of the United States, including New York, Pennsylvania, Ohio, and Michigan, the PW with radionuclides has been used to spread on roads to suppress dust in summer and de-ice in winter [20].

Since the extensive application of hydraulic fracturing, the PW production significantly increases from formation as well as from flow back. In the hydraulic fracturing operation, water is injected under pressure into the rock formation to create fractures as paths for more oil or gas flows, which will return back to the surface through the wellbore. The PW is daily substantially produced with around between 60 million and 70 million barrels every day in the United States, which is potential to be reused in the regions with shortage of freshwater [21]. For instance, New Mexico State University explores revegetation of pipeline right-of-ways and wells sites using selected grasses irrigated by water produced to mitigate the drier conditions [22]. Texas A&M University in College Station, works with the Texas Water Research Institute to build a prototype mobile PW treatment unit, the effluent of which is used to irrigate rangeland [23]. Another example is using PW to irrigate special salt-tolerant crops and trees planted in desert. Plant's tolerance to the salt is susceptible to RSA3/MUR3/KAM1 along with other cell wall-associated proteins, found by Li et al. [10]. However, so far, only small amount of the PW is treated and reused in irrigating crops, watering livestock, de-icing roads, and in aquaculture, power plants, dust suppression and fire prevention [21]. More than 92% of the PW is reinjected underground to maintain pressure in the reservoir or be disposed.

Most DW is eventually disposed by an onshore treatment facility using techniques, such as land farming, bioremediation, and composting. The vermi-culture was developed in New Zealand to use earthworms to enhance the bioremediation process and convert the drill cuttings into organic fertilizer, a valuable resource. Though this process is proven successful only in certain synthetic-based wastes, the cuttings could be a source of organic fertilizers.

Moreover, DW has been largely used in road spreading and construction materials, such as fill material, aggregate or filler in concrete, brick or block manufacturing, which considerably reduce the landfill disposal, thereby minimizing the ecological damages caused by the landfill construction. An opportunity could lie in the difference between the treatment technique costs and the finished product costs.

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Conclusion

Substantial PW as well as DW streams pose a threat to public health and environment, the complex and toxic chemical substances of which play a significant role in the challenges in waste reduction by volume and detoxification process. The challenges in the removal or recovery of iodide, bromide, dissolved hydrocarbon, radionuclide, and barite, reuse DW, desalination, and reducing PW production, were remarked. Meanwhile, the challenges also provide opportunities to relieve resource shortage, including freshwater, iodide trace elements, radionuclides and construction materials.

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