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Review

Offshore produced water management: A review of current practice and challenges in harsh/Arctic environments

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ABSTRACT

Increasing offshore oil and gas exploration and development in harsh/Arctic environments require more effective offshore produced water management, as these environments are much more sensitive to changes in water quality than more temperate climates. However, the number and scope of studies of offshore produced water management in harsh/Arctic environments are limited. This paper reviews the current state of offshore produced water management, impacts, and policies, as well as the vulnerability, implications and operational challenges in harsh/Arctic environments. The findings show that the primary contaminant(s) of concern are contained in both the dissolved oil and the dispersed oil. The application of emerging technologies that can tackle this issue is significantly limited by the challenges of offshore operations in harsh/Arctic environments. Therefore, there is a need to develop more efficient and suitable management systems since more stringent policies are being implemented due to the increased vulnerability of harsh/Arctic environments.

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1. Introduction

Global energy demand continues to grow (Chu and Majumdar, 2012; Davidson et al., 2014; Han et al., 2009); and with it, oil and gas production experiences rapid increases to meet increased energy consumption. Offshore oil and gas production began in the 1940s in Louisiana's offshore region. Due to the development over the last six decades, big offshore reservoirs such as the offshore Alaska, Gulf of Mexico, the North Sea and the North Atlantic have been explored and well developed for production (Fraser, 2014). Offshore production accounts for 30% of the world's oil and gas production and is expected to increase in the future (Fakhru'l-Razi et al., 2009). It is now moving to deeper waters and harsher environments such as the Arctic, which

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represents a new set of challenges for safe and environmentally sound operations (Gautier et al., 2009; Harsem et al., 2011).

Produced water is the largest volume of the waste stream from oil and gas production (Clark and Veil, 2009; dos Santos et al., 2014; Nadim, 2010; Ranck et al., 2005; Tellez et al., 2002; Veil et al., 2004) and is a mixture of formation water, re-injected water and treatment chemicals during drilling, stimulation, production, and oil–water separation processes (Igunnu and Chen, 2012; Neff et al., 2011). The effluent usually contains various pollutants such as petroleum hydrocarbons, metals, heavy metals, and toxic treatment chemicals, which may result in unexpected environmental issues (Barker and Jones, 2013; Fakhru'l-Razi et al., 2009; Igunnu and Chen, 2012; Shpiner et al., 2009; Stephenson, 1992a). Since tens of millions of barrels of offshore produced water are generated daily worldwide (Fakhru'l-Razi et al., 2009), the environmental impact brought by the contaminants in the effluent has become a major concern for the oil and gas industry and government, thus, promoting the significance of offshore produced water management. The major strategies for offshore produced water management include water minimization, water reuse and water disposal (Veil, 2011). Both water reuse and disposal require a treatment processes to meet certain regulatory standards or technical requirements. Only a small part of the water is reused by re-injection in offshore production and most offshore produced water is surface discharged for disposal. For instance, only 8.3% of offshore produced water generated in the United States was re-injected for enhancing recovery and 91.5% of water was surface discharged to the ocean in 2007 (Clark and Veil, 2009). Weight and space are the most critical constraints in current offshore treatment practices; thus, only compact technologies with low water retention are appropriate for offshore platforms.

Harsh environments refer to warm and cold climatic conditions that are difficult for people to work in and for process plants to be operated (Khan et al., 2015). The Arctic and sub-Arctic region is in one of the harshest environmental conditions in the world. Considerable offshore oil and gas production is in harsh, and/or Arctic environments which can bring cold temperatures, fragile ecosystems, and in some cases require unmanned operations adding further complexity to produced water management (Jing et al., 2012). In such environments, more stringent contaminant reduction is necessary (Noble et al., 2013). Various emerging technologies which can be applied onshore, however, can raise installation and operation issues offshore and thus limit their applicability in harsh/Arctic environments.

Currently, there are very few studies dedicated to offshore produced water management and specifically for harsh/Arctic environments. Thus, management of offshore produced water and reduction of environmental impacts that efficiently tackles the challenges in such highly vulnerable environments has become urgent tasks. Therefore, in this review, we outline produced water status and its characteristics from offshore oil and gas production. This review also summarizes current management policies for offshore produced water. The current offshore produced water treatment technologies were discussed to show their feasibilities and potentials, especially for application in harsh/Arctic environments. The major challenges for management in harsh/Arctic environments are also demonstrated. This review represents a comprehensive study of offshore produced water management and its challenges in harsh/Arctic environments. The priorities for future research and development for offshore produced water management in harsh/Arctic environments are also highlighted.

2. Offshore produced water production status

Offshore produced water is generated through the production of oil and gas from offshore wells. The major source of offshore produced water is formation water. For offshore wells, formation water is usually the seawater that has been trapped with oil and gas in an offshore reservoir (Kharaka, 1977), so the salinity of the produced water may reach a level higher than seawater (Table 2). It may contain the flows from above or below the hydrocarbon as well as the flow from within the hydrocarbon zone (Fakhru'l-Razi et al., 2009); therefore, the offshore produced water always contains significant amount of petroleum hydrocarbons and related organic pollutants. In addition, surface water and production chemicals are sometimes injected into the reservoir to enhance production. These injected waters can also penetrate the production zone and get produced with oil and gas (Neff, 2002; Veil et al., 2004). The topsides are designed to separate produced water from the petroleum fluids (Ekins et al., 2007). After separation, a small amount of dispersed and dissolved oil may retain in the water that requires further treatment for re-injection or discharge.

2.1. Production volume

Produced water represents the largest waste effluent volume for most offshore platforms (Krause, 1995; Stephenson, 1992a). On a global scale, the water to oil ratio is approximately 3:1 for oil producing wells, and is higher for gas wells (Neff et al., 2011). As shown in Fig. 1, offshore production volumes are significant but currently lower than onshore. However, the fraction of offshore production volume is increasing, indicating the increased importance for handling offshore produced water. Volumes of produced waters vary from site to site. The differences in volume as well as the characteristics of produced water depend on many parameters including age of field, geographic location, reservoir type and production technologies. As shown in Fig. 1, the volume of produced water typically increases as production ages (Clark and Veil, 2009). With maturing fields and new fields, water volume tends to increase each year leading to a higher volume of wastes to be handled (Henderson et al., 1999). Some data on offshore oil and water production for some large oilfields in harsh environments are summarized in Table 1. From this table, it can be seen that the water/oil ratios are around 3:1 but different from site to site. The high production rates of produced water discharged offshore can result in significant environmental risks. As exploration expands to colder environments such as the Arctic, the discharge of such amounts of produced water from platforms will bring greater concerns for the receiving environment and therefore, reduction in volume and managing environmental impacts has become even more crucial (Casper, 2009). Therefore, more stringent environmental policies have been proposed such as "zero discharge" policies due to the higher vulnerability (Smit et al., 2011).

2.2. Contaminants and toxicity

Offshore produced water contains various organic and inorganic substances from geologic formations. Stephenson (1992b) categorized produced water constituents into oil (organic compounds), salt, dissolved oxygen, heavy metals, radionuclides, and treatment chemicals. Other contaminants, such as production solids and dissolved gases are also present (Fakhru'l-Razi et al., 2009; Hansen and Davies, 1994). The produced water also contains bacteria (Yeung et al., 2011). In general, the properties of produced water have larger variability than those of seawater, raising significant environmental concerns (Table 2). These properties depend on the nature and condition of the reservoir, type and condition of the production process, and environmental conditions.

The major groups of oil compounds in produced water include aliphatic hydrocarbons, less soluble aromatic hydrocarbons, organic acids and phenols. Depending on the solubility and partition, the majority of aromatic hydrocarbons and aliphatic hydrocarbons are in the dispersed oil. The majority of contaminants in dissolved oil are water soluble organic compounds such as organic acids and phenols. It should be noted that, although most petroleum hydrocarbons are in dispersed oil, the dissolved oil still contains a considerable amount of toxic organic petroleum hydrocarbons such as BTEX, polycyclic aromatic hydrocarbons (PAHs) and alkyl phenols (APs) (Dórea et al., 2007). Concentration of these compound groups in offshore produced water also depends on parameters such as the volume of water produced, the production