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Membrane applications and opportunities for water management in the oil & gas industry

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ABSTRACT

Water touches most segments of the petroleum industry and thus cost-effective water management is a key part of oil & gas industry operations. The water to be managed is either co-produced with the hydrocarbons, generated as a by-product from oil/gas processing, and/or utilized to support production operations. While a majority of the water usually receives basic treatment, there are multiple recent drivers for advanced treatment that should facilitate beneficial water reuse. Hence, a toolbox of advanced technologies needs to be considered to ensure that fit for purpose treatment is deployed. Membrane processes are key components of the technology toolbox since they include some of the best available technologies. This paper provides an overview of the various case studies from ConocoPhillips global projects portfolio, which covered various operations such as gas fields, oil fields, oil sands & shale plays. In these case studies, a wide spectrum of membrane processes, including membrane bioreactors, reverse osmosis, microfiltration, ultrafiltration, nanofiltration, ceramic membranes, forward osmosis, membrane distillation, pressure retarded osmosis, membrane contactors, and/or new innovative membrane materials were either installed at full scale capacity, evaluated via field/lab testing, or investigated through desktop studies. The information presented demonstrates that reverse osmosis and nanofiltration are widely utilized by the industry for water desalination and desulfating, respectively. In addition, membrane filtration and bioreactors are frequently applied as standalone treatments for inorganics and organics removal, respectively; or as pretreatment to desalination membranes. Novel membrane technologies and materials are also being developed by the industry for niche applications.

1. Background and introduction

Oil and gas (O&G) resources can be extracted via both conventional and unconventional means. The conventional way of hydrocarbon extraction, after well drilling, is by the natural pressure of the well supported with pumping or compression operations. After depletion of the well's natural pressure, different methods can be applied to boost production, mainly water and gas injection or other depletion compression techniques, but the O&G reservoir is still considered a conventional resource. Beyond the use of the above traditional methods to increase oil recovery or artificial lift, the O&G reservoir will be classified as unconventional resource. The primary sources of unconventional oil typically found in low-permeability rock are heavy oil, oil sands, and oil shale [1–5].

1.1. Water and the petroleum industry

1.1.1. Conventional operations

Water touches most segments of the petroleum industry (see Fig. 1). For conventional upstream operations, whether it is a gas field producing natural gas (NG), liquefied natural gas (LNG), or gas to liquid (GTL); or an oil field with an onshore or offshore platform, all facilities will have to manage water. Typically, the water to be managed is either co-produced with the hydrocarbons, generated as a by-product from oil/gas processing, and/or water utilized at the facility to support production operations. For downstream facilities supporting conventional oil production, all refineries also utilize water primarily for cooling purposes and oil processing. Global oil, natural gas & LNG consumptions are approximately 95 million barrels per day, 320 billion ft^3 per day & 258 million tonnes per annum, respectively [6,7]. It should be noted that seawater, groundwater and/or surface water usually play important roles for the upstream & downstream operations as these sources can provide cooling water, process water, desalinated water for boiler feed, or just supply potable water for onshore or offshore platforms. Thus, cost-effective water management is an integral part of the O&G industry to ensure optimized sustainable operations and obtain license to operate in many parts around the world.

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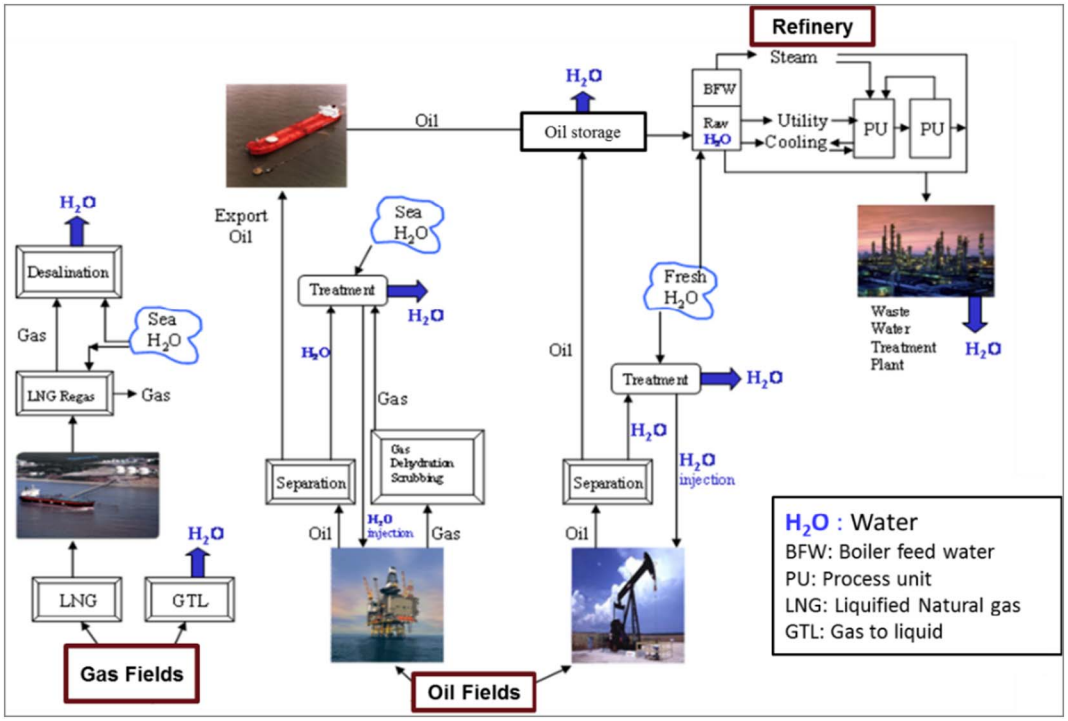

Fig. 1. Water in conventional petroleum industry.

For upstream operations, most of the water being managed is called produced water, which is the water extracted with hydrocarbons from the O&G reservoirs. For downstream operations, the majority of the water being utilized is cooling water, which is obtained from saline (e.g. seawater, brackish groundwater, etc.) and/or non-saline water sources (e.g. lakes, rivers, fresh groundwater, etc.). Both upstream and downstream operations also manage process water, which is the by-product water generated during hydrocarbon processing. The industry may also utilize municipal water sources, including desalination plants, to generate feedwater for boilers, potable supply, and/or other beneficial uses within the facility.

1.1.2. Unconventional operations

Within the past couple of decades, the O&G production has undergone significant evolution, which expanded the global oil production, especially from unconventional sources. In mid to late-1990s, the Canadian oil sands/bitumen production, which is primarily extracted through the steam assisted gravity drainage (SAGD) process, became a major focus of the O&G industry [1]. The SAGD process converts water to steam and injects the steam into upper reservoir (injector well) in the oil sand deposit to melt the bitumen. The oil and condensed water collect in a parallel lower channel of the reservoir (producer well) and are extracted to the surface (Fig. 2a). A major portion of this heavy oil resource was discovered in Alberta region and this discovery resulted in dramatic changes in proven reserves for the oil industry. Hence, many international oil companies invested in major capital programs in pursuit of this relatively new resource.

More recently, there was a major focus by the industry on unconventional shale reservoirs, primarily in the North America. The extraction process (Fig. 2b) was made more feasible through new developments in the field of horizontal drilling and hydraulic fracturing procedures [2]. This made shale plays, which can be gas or liquid-rich reservoirs, attractive for hydrocarbon extraction and transformed the hydrocarbon reserves portfolio in the United States, making it one of the world's leading countries in O&G production. The hydraulic fracturing procedure requires water to be mixed with proponent (sand) and injected to the horizontal reservoirs under very high pressures.

The above demonstrates that water is also very important for unconventional resources production. Both saline and non-saline water sources can be used, after adequate pretreatment, for injection into the unconventional reservoirs and the water extracted with oil production is also referred to as produced water. The water extracted immediately after fracturing shale play reservoirs until oil production is stabilized can also be called flowback water. This review paper focuses on the water managed primarily by upstream operations namely; produced water, process water, and saline water.

1.2. Produced water

1.2.1. Production volume

On average, for every barrel of conventional oil barrel extracted, 3 to 4 barrels of water are usually produced [8]. This ratio will vary with subsurface geology for hydrocarbon reservoirs around the world. Also, as the production reservoir ages with years of extraction, the oil-to-water ratio can increase reaching 1 to 10 or even higher [8]. These estimates illustrate that petroleum companies handle more water than oil on a daily basis [9].

Data published in 2011 estimated the global annual produced water volume from conventional sources at approximately 100 billion barrels [10,11]. Other newer survey, which included conventional and non-conventional sources, estimated the annual global produced water volumes at 202 billion barrels in 2014 and projected it to increase to 340 billion barrels by 2020 [12] (Fig. 3).

Rising unconventional shale oil/gas production will always be an important factor in increasing the global produced water volumes. The estimated produced water volume from shale reservoirs ranges between 1.7 and 14.3 million L per well over the first 5–10 years of production [13]. The estimated annual US production is 20 billion barrels of produced water [10,11].

1.2.2. Chemical characteristics

While seawater characteristics are reasonably consistent around the world [14,15], this is not the case for produced water as it varies significantly due to various factors including: geographical location, type