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Application of forward osmosis for reducing volume of produced/Process water from oil and gas operations

Joel Minier-Matar [a], Altaf Hussain [a], Arnold Janson [a], Rong Wang [b], Anthony G. Fane [b], Samer Adham [a,*]

[a] ConocoPhillips Global Water Sustainability Centre, Qatar Science & Technology Park, Doha, Qatar
[b] Singapore Membrane Technology Centre, Nanyang Technological University, Singapore

HIGHLIGHTS

- A novel FO process was evaluated to reduce produced & process water disposal volumes.
- Pretreatment is key for the implementation of FO to treat produced and process water.
- Temperature and draw solution concentration influenced FO process performance.

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ABSTRACT

Produced water management is one of the key challenges faced by the oil and gas industry globally. Specifically, the gas industry in Qatar is challenged to minimize the produced/process water (PPW) volumes injected into disposal wells to ensure long term sustainability of the reservoirs. This research evaluated a novel application of forward osmosis (FO) to reduce the volumes of PPW disposed of by deep well injection using brine from thermal desalination plants or seawater as draw solutions. In the case of brines, this process also provides some environmentally beneficial dilution before discharge.

In order to verify the PPW volume reduction concept, bench-scale FO experiments were carried out using commercial flat sheet membranes. FO performance was evaluated using PPW with and without pretreatment and results confirm that pretreatment is key to the successful implementation of FO for the treatment of PPW. Experimental results indicate that FO is effective in achieving 50% volume reduction of pretreated PPW with stable flux of 12 LMH. Lab analyses show that the TOC in the diluted draw solution was below the detection limit indicating that the TOC from the feed did not appear in the draw solution and hence would not be discharged to the environment.

1. Introduction

Reports published in 2007 and 2011 indicate that globally, between 70 and 100 billion barrels of produced water (PW) was generated by the petroleum industry in 2007 [1,2]. The reports also projected a steady increase in PW generated in the US until 2025. According to the International Energy Agency (IEA), both oil & gas will still represent a significant fraction of the energy consumption by 2035. This means that the trend is for PW volumes to continue to increase in the long term.

The number of oil & gas production facilities where PW is being treated, recycled and/or reused is increasing. For instance:

- In the US shale plays, fracturing operations are extremely water intensive and a single well may require up to 15,000 m^3 of either fresh or brackish water. Currently, the emphasis has been on treating and recycling/reusing flowback and produced waters for frac fluids to reduce water consumption [3,4];
- In Australian coal bed methane (CBM) operations, the number of production facilities that are reusing treated PW for aquifer recharge and/or crop irrigation has increased considerably [4]. Recently, Plumlee et al. [5] provided an excellent review of the produced water treatment technologies for coal bed methane process.
- In the Middle East, projects involving recycling and/or reuse of PW are currently growing due to water scarcity and concerns related to environmental impact of injecting PW into disposal wells. Special emphasis is given on the treatment of gas field produced water due to their lower salinities.

These trends show the global need of PW management which includes development and implementation of treatment technologies to reuse and recycle PW [6–8]. Specifically in Qatar, there is a

* Corresponding author.

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need to reduce PW disposal volumes, from gas field operations, to ensure long term sustainability of the reservoirs. This paper highlights a novel application of FO to minimize PW volumes injected into disposal wells with a relevant impact in Qatar and worldwide.

1.1. Forward osmosis (FO)

Forward osmosis (FO) is an emerging membrane technology for water treatment that typically involves two steps:

Step 1 Filtration: Water flows by simple diffusion through a semi-permeable membrane from the feed solution (at lower osmotic pressure due to lower salinity) into a draw solution (at higher osmotic pressure due to higher salinity); other contaminants in the feed water, including dissolved ions, are rejected by the membrane and are concentrated in the feed. The draw solution is diluted by the water that has passed through the membrane (Fig. 1).

Step 2 Water recovery: If required, water is separated (recovered) from draw solution restoring the draw solution back to its original condition and permitting it to be reused in Step 1. The recovery of water from the draw solution can be done by any of a variety of means including evaporation of the water or the draw solution.

In Step 1, the driving force to achieve filtration is the osmotic pressure gradient caused by the difference in solute concentrations [9]. The greater the difference in solute concentrations, the higher the membrane flux. In Step 2, an input of energy is required to remove the water and restore the original osmotic pressure of the draw solution.

This work proposes a novel "single-step" FO process concept wherein reject brine from thermal desalination plants serves as the draw solution to remove water from the produced/process water (PPW) thereby reducing its volume. No "second step" of water recovery from the "draw" solution is planned and therefore no external energy is needed other than that required to pump the water through the system. The process operates in osmotic dilution mode which ensures low energy consumption [10,11]. It is important to clarify that PPW is a mixture of offshore PW and process water from onshore gas liquefaction operations. More details about PPW are provided in Section 2.7. Fig. 2 highlights our proposed application.

In this application, the key advantages of the FO process over RO are its potentially lower capital and operating cost. This process does not need high pressure pumps which reduces electrical energy

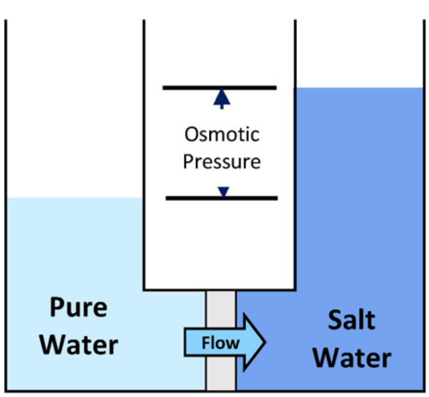

Fig. 1. FO process.

consumption. Also, FO membranes are claimed to be less prone to irreversible fouling and the foulants can be removed by simple flushing with clean water [10–12].

Following a comprehensive literature review, only a few relevant references were identified on FO being applied in the field to treat wastewaters generated from oil & gas operations. One refers to collaboration between Bear Creek Services and Hydration Technology Innovations, LLC (HTI) to assess the feasibility of using FO to treat drilling fluids from shale gas operations, achieving a recovery of 90% [13]. Another relevant study is the project developed by Oasys Water Inc. where FO was evaluated to treat flow back water from shale gas operations using ammonium carbonate as draw solution and achieving 62% volume reduction [14]. At a bench scale level, significant work has been done in recent years on FO but relatively few involved PW. A rare example is the work carried out by Hickenbottom et al. [15] on drilling fluids in shale gas operation in which the membrane flux, TOC rejection and volume reduction observed were 15 LMH, 99% and 80% respectively.

There are potential challenges in implementing FO systems; the main one is the limited experience on produced water treatment [4], pretreatment [16] and its fouling propensity [16,17]. The other challenges are towards the optimization of proper membrane chemistries and modules for produced water application.

The main objective of this research is to investigate the application of the FO process to reduce the PPW volumes from gas operations by a target of 50%. Various bench scale FO experiments were conducted using commercial flat sheet membranes to understand the influence draw solution concentration and temperature on permeate flux. Experiments were also conducted using real PPW to evaluate the FO performance to reduce disposal volumes from gas operations. Hollow fiber (HF) membrane chemistries, their pretreatment needs and chemical cleaning are currently under investigation [18–20].

2. Materials and methods

2.1. Bench scale forward osmosis unit

The FO system used in the experiments consisted of a custom-built cross-flow membrane cell with equally structured rectangular channels on both sides of the membrane. The dimensions of the channels are 146 mm long, 95 mm wide, and 2 mm deep and plastic spacers were used inside feed and draw solution channels. The active membrane area was 0.014 m^2. Two variable speed air pumps (Wilden, USA) were used to generate the cross-flow, creating two separate closed counter-current loops for the feed and draw solutions. The feed solution tank was placed on a digital balance (Meter Toledo, USA) and weight changes were monitored by a data acquisition system (National Instruments) to record the water flux. A constant feed and draw solution temperature of 25 $\pm$ 1 °C was maintained by a water bath (Julabo, Germany). Temperature and pressure were constantly monitored through the experiments. The draw solution osmotic pressure was maintained constant by adding concentrated draw solution into the draw solution tank. Fig. 3 shows a picture and schematic of the FO system.

2.2. Membranes

Commercial flat sheet thin film composite membranes were used throughout the testing program. Table 1 provides data on membrane specifications provided by the manufacturer.

2.3. Draw and feed solutions

The thermodynamic properties of the solutions such as osmotic pressure and viscosity were calculated using OLI Stream Analyzer 9.0