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The size and performance of offshore produced water oil-removal technologies for reinjection

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ABSTRACT

Produced water (PW) is wastewater generated from oil exploration, and requires treating for oil and suspended solids removal. The viability of an effluent treatment unit process for this duty is dependent both on its efficacy, in terms of oil removal and – for offshore applications especially – its size, in terms of its area (F_A, m/h) and volume (F_V, h^{-1}) footprint per unit volume flow. The incurred footprint applies to both the individual unit (vessel, column or tank) and the collection (or array) of units/vessels in a skid.

An assessment of unit process footprint based on available information has been conducted, in particular to the case where high-quality treated water is required for reinjection. The analysis encompasses technical data from specific proprietary technologies as well as generic information for process technology types. Technologies considered comprised hydrocyclones (HCs), induced gas flotation (IGF), media (nutshell) filtration (NSF), and crossflow membrane filtration (CMF).

The analysis revealed the HC to incur the smallest area footprint, less than half that of an IGF, notwithstanding only ~0.15% of the total skid volume being used for the actual separation process. The CMF had a slightly smaller area footprint and less than half the volumetric footprint of the NSF, if the requirement for backflushing is considered. The fitting of the modular HC and CMF technologies to a skid incurs a considerable increase in the footprint, particularly for the HC where the volume occupancy is increased by an order of magnitude. It was concluded that spatial efficiency gains could be attained for modular processes if spacing of the HC vessels or membrane modules can be reduced, contributing significantly to the viability of CMF in particular.

1. Introduction

Produced water (PW) generated by the oil and gas industry represents the largest volume by-product of petroleum production, with a water to oil ratio which increases with increasing well age. Current estimates of the average ratio of water:oil globally is ~4:1 [29], with generation of produced water offshore likely to increase more rapidly than that onshore. The latter arises because offshore wells are operated for longer to offset the capital investment, such that the water content is generally higher. Whilst PW contains a number of different chemical species which may be adverse to either environmental impact or oil platform/well operations, the determinant of most importance is the residual oil concentration which is largely present in the suspended form. The threshold suspended oil concentration is limited either by the legislated limit for discharge or, if it is to be considered for reinjection (PWRI), the permeability of the oil reservoir. For PWRI, the concentration of other suspended materials (i.e. the suspended solids, SS) is also of significance.

The technologies selected for PW treatment depend on whether the installation is based onshore or offshore (Fig. 1). For onshore installations footprint is generally a less critical factor than offshore. Simpler, low-energy/high-footprint technologies may therefore be employed, and these may target both the suspended and dissolved oil depending on the target treated water quality. Such treatment processes can potentially include biological-based technologies adapted from those routinely applied to municipal wastewater [16,23], more usually employed for "downstream" refining processes [12]. The large footprint incurred by biological treatment technologies, however, make them untenable on an oil platform even when intensified as a membrane bioreactor (MBR). Aerobic biotreatment also introduces dissolved oxygen, which can be problematic due to the corrosion incurred. Both aerobic treatment and

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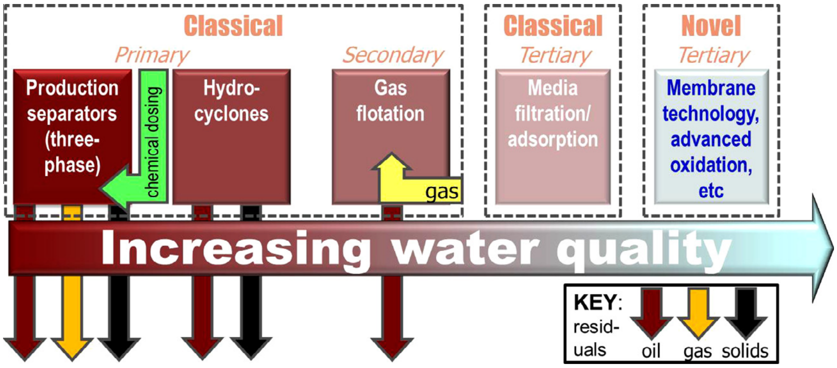

Fig. 1. Offshore produced water treatment.

advanced oxidation processes (AOPs) are therefore only viable for discharge purposes.

Environmental pressures have placed increasing emphasis on PWRI, which is the only viable reuse option offshore and whereby discharge to sea can be avoided. For fractured oil reservoirs, where water can flow more freely without clogging the reservoir pores, the water quality requirements are not onerous and the classical two-stage process of hydrocyclones (HCs) and induced gas flotation (IGF) is normally sufficient (Fig. 1). The IGF may be substituted with a simple degassing vessel in some regions (such as the North Sea), and degassers and/or surge tanks may also be used upstream of the HCs. For "tight" or low permeability reservoirs – normally associated with carbonate strata – removal of particles down to 3–5 μm in size may be necessary, demanding the use of filtration.

It is of interest to appraise the different suspended matter/water separation technologies for PW treatment with specific reference to their incurred footprint with specific reference to offshore duties. These include both the classical primary and secondary technologies along with the tertiary processes of media and membrane filtration. Media filtration, if used, is normally based on nutshell filters (NSFs). The more advanced emerging separation process of crossflow membrane filtration (CMF) provides a more consistent quality effluent, but is generally considered to be comparatively large in footprint.

2. Technologies

2.1. Fundamental parameters

Produced water is normally taken as being the water which exits the production separator (Fig. 1), whose primary purpose is to partition the oil and gas phases. Subsequent processes treating the water phase may recover oil within a concentrate stream, but their primary purpose may be considered as being wastewater purification.

In terms of space occupancy the specific flow capacity is given by:

Capacity by area (flow/area) $F_A = Q_{ave}/A$
Capacity by volume (flow/volume) $F_V = Q_{ave}/V$

where Q_{ave} is the mean flow rate, A is the projected floor area of the technology and V is the technology volume (either the individual unit/vessel or the skid). F_A and F_V thus respectively take units of velocity and inverse time. F_A equates to the approach velocity for column process such as media filtration or the horizontal flow velocity for separator tank, such as an API vessel. F_V is the inverse hydraulic residence time. It is most convenient for F_A and F_V, the difference between which is simply the height of the technology, to take units of m/h and h^{-1} respectively.

Classical primary and secondary technologies normally comprise a combination of gravitation, HC and flotation technologies (Fig. 1); for such technologies the mechanism for oil removal is based at least in part on the droplet buoyancy. The fundamental relationships for the design of these technologies are thus derived from Stokes Law [27], and contain the function $d^2\Delta\rho/\mu$ where d is the oil droplet size, $\Delta\rho$ the density difference between the oil droplet and the water, and μ the water viscosity. It therefore stands to reason that oil removal by such technologies is highly dependent on d, as well as to a lesser extent on the oil fraction (heavy oil being the most dense and thus the least buoyant) and temperature, which affects μ. These factors may then be expected to also influence the values of F_A and F_V. Pretreatment to chemically destabilise the oil droplets (using flocculants) increases their propensity to coalesce, and thus their removal by virtue of their increased buoyancy. Against this, some production chemicals, corrosion inhibitors in particular, tend to stabilise oil droplets making their removal more difficult. Other key factors affecting process efficacy include the presence of suspended solids, which actually determines the operating cycle for some unit processes (Section 3.1).

2.2. Data capture

Very little useful data is available from the peer-reviewed literature. Data were captured largely from grey literature sources (supplier information, internet and papers from specialist conferences) as well as via personal contacts (technology suppliers, consultants, contractors and end users) and text books (Table 1). The technology volume in the analysis was taken to be based on either its single principle component (column, tank, array, etc), or a skid/array comprising normally a number of such units or vessels. The inclusion or exclusion of ancillary equipment (pumps, control panels, etc) was also considered, along with the requirement for duty and standby components (as would be the case for significant periods of downtime). Finally, the sensitivity of sizing, and selection of the unit operation generally, to technology-specific factors was identified.

F_A data for API (American Petroleum Institute) separator and NSF units were obtained directly from design guidelines, reference texts [14,27] or technical papers. For these technologies the maximum horizontal velocity V_h (F_A = height × V_h/length) in the case of the API separator [2] and approach velocity V_a (or hydraulic loading rate, HLR), for the NSF [3] respectively indirectly and directly equate to F_A. Footprint data for all other technologies were calculated from their dimensions and flow capacities, as provided by the various information source types indicated in Table 1. This includes data for skid-mounted technologies, as provided from product brochures and/or end users. Performance data (oil