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Invited Review

Potential applications of membrane separation for subsea natural gas processing: A review

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A B S T R A C T

The petroleum industry is receiving increased interest in subsea oil and gas processing as it is running out of easily accessible oil and gas reservoirs. Membrane processes fulfill subsea design requirements with a simple and compact design. However, today no application has been used subsea. This paper reviews the advances in membrane separation to date in view of the industrial needs for subsea separation. Some potential applications of membranes and membrane processes in subsea processing are proposed based on the topside experience. Two subsea natural gas treatment processes, namely natural gas dehydration and acid gas removal, are discussed in details with respect to the advantages and challenges in the implementation of membrane technology subsea, including future research perspectives. This study can be a starting point in connecting the two research areas (subsea separation and membrane technology) together.

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1. Introduction

As more than 70% of the Earth's surface is water, large amounts of oil and gas are located in underwater reservoirs. This leads to the need for a platform or subsea installation to produce oil and gas. After a century of exploration, the petroleum industry is running out of easily accessible reservoirs. It is receiving increased interest in subsea oil and gas processing. Subsea to shore could be favorable when an oil reservoir is far away from the coast, in deep waters or

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in arctic regions where the use of a platform is not an option due to safety reasons or as a tie-in to existing infrastructure and platforms (Albuquerque et al., 2013). An example of subsea process illustrated as "Statoil Subsea Factory" by Norway's largest oil company is given in Fig. 1 (Ramberg et al., 2013).

The ultimate vision for subsea processing is to transport produced hydrocarbons directly from the reservoir to the market and to avoid further topside treatment (Ruud et al., 2015). The driving force for subsea processing is to maximize the recovery, to increase the production from existing fields and to reduce capital expenditure and operating costs for new installations. In addition, subsea processing can enable the development of new fields that have been left undeveloped due to technical and/or economical limitations, as well as production in harsh environments where platform constructions are not possible (Ramberg et al., 2013; Ruud et al., 2015). Existing platforms often have a limitation in gas capacity, which makes the tie-in of additional fields challenging. Subsea processing of the gas directly into the export pipelines remove such limitations. Subsea processing also improves safety due to less personal risk compared to a platform, especially regarding fire and explosions (Albuquerque et al., 2013; da Silva et al., 2013). There is no need for fire protection or detection, or fire-fighting systems to protect the personnel.

For the design of subsea processing systems several aspects are critical. As the process will take place at a remote location, a design for unmanned operations is important without the requirements for rapidly periodical maintenance. High accessibility and retrievability is another important aspect for subsea processing, which favors high modularization of the units. In addition, limited moving parts are preferable to reduce the periodical maintenance of the equipment (Daigle et al., 2012; Jahnsen et al., 2011). Due to crane limitations for installation and retrieval (Albuquerque et al., 2013; Orlowski et al., 2012), the subsea equipment must be compact in size and weight. Another aspect that should be taken into consideration is that the process should be flexible in order to deal with changes in the flow rates and composition during the production lifetime of the reservoir. Furthermore, operations at high pressure should be possible for the subsea equipment, as high pressure is preferable to minimize the boosting and energy requirements (Gyllenhammar et al., 2015).

1.1. The subsea oil and gas production process

Oil and gas production consists of several processing steps from the well to sale products, as illustrated in Fig. 2.

As a pretreatment step for the bulk separator, the feed from subsea wells might be cooled down. The cooling step has a significant influence on the following processing steps, as it will change the feed properties and affect the amount of water removed in the bulk separator. The bulk separator separates the feed stream into gas, oil, sand and water. The bulk separation in topside processing normally consists of several steps at different pressures. However, for the currently installed subsea separation systems, one stage is used. The outlet of a bulk separator might be routed to four different branch processes, namely gas treatment, oil treatment, sand handling and produced water treatment. Due to the scope of

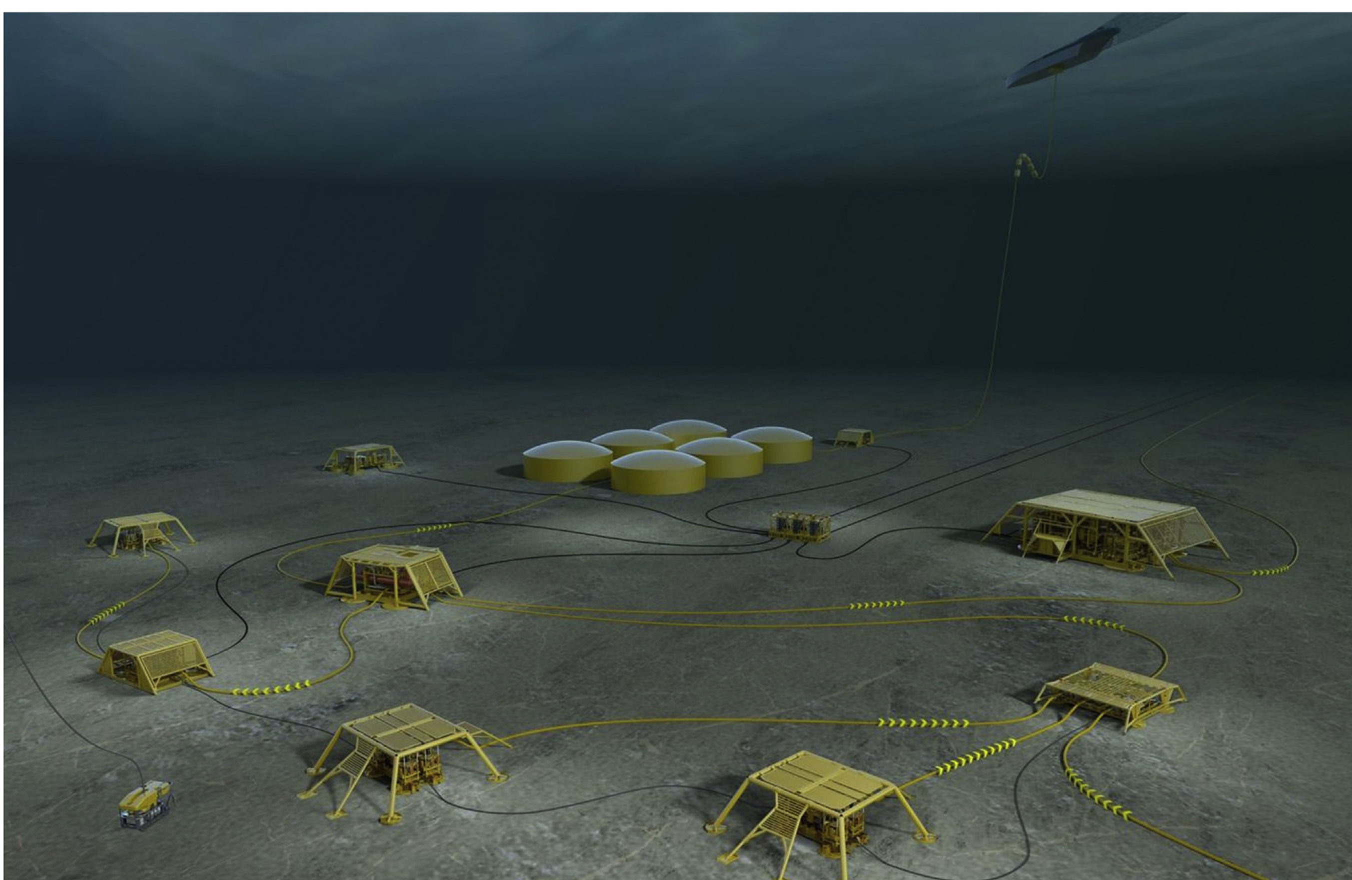

Fig. 1. The Statoil Subsea Factory™ illustration (Ramberg et al., 2013).