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Multi-criteria analyses of two solvent and one low-temperature concepts for acid gas removal from natural gas

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This paper evaluates three acid gas removal concepts studied in the project "A Green Sea". Two solvent concepts (aMDEA/MDEA and Selexol) and a low-temperature concept are modelled and assessed, taking different raw natural gases and natural gas product requirements into consideration. The analyses and comparisons of the concepts and cases consider nine criteria in order to include both energy efficiencies and compactness.

The assessment shows that acid gas removal using aMDEA/MDEA technology seems to perform well in terms of energy efficiency, volume and weight for low CO_2 removal. However, for high CO_2 content or strong polishing requirements, the chemical solvent technology loses its efficiency in terms of weight and volume. The assessment shows that the Selexol concept is an inefficient option in terms of energy efficiency, volume and weight, especially when large quantities of CO_2 have to be removed from the gas stream. The assessment also shows that the low-temperature technology can be a compact and energy-efficient option, both in the case of strong polishing requirements and high bulk removal of CO_2. However, the higher the amount of CO_2 to be removed, the less energy efficient is the low-temperature technology.

The case evaluation underlines the fact that the aMDEA/MDEA solvent concept exhibits the best or close to the best key performance indicators (KPIs) for all parameters for the RNG1Pipe case (raw natural gas specification 1 to pipeline quality specification) and therefore appears to be the best technology option. For this case, the two other technologies are slightly less energy efficient than the aMDEA/MDEA, but both are significantly less compact. For the RNG1 LNG (raw natural gas specification 1 to LNG quality specification) case, the aMDEA/MDEA and low-temperature concepts have similar KPIs. The chemical solvent technology, however, is slightly more energy efficient and compact and would therefore be preferred for the RNG1 LNG case. Finally, the RNG2 Pipe (raw natural gas specification 2 to pipeline quality specification) case shows that the low-temperature technology can be a compact option for acid gas removal, which is a critical factor in the case of offshore applications for both the equipment costs and the weight constraints on the platform. Despite its lower energy efficiency, it is therefore likely that the low-temperature technology will be selected in the RNG2 Pipe case. This choice is strengthened by some regulations which recommend that solvents such as MDEA and aMDEA should be phased out for offshore applications, as is seen, e.g. in Norway. In addition, if stricter regulations are also enforced for onshore applications, this might also argue in favour of the low-temperature technology or other chemical solvents that are otherwise less efficient than aMDEA/MDEA.

Finally, the potential of hybrid concepts is discussed and suggested for future works, in order to combine the advantages of the different technologies, such as the energy-efficient performances of the aMDEA/MDEA concept and the compactness of the low-temperature concept.

1. Introduction

Natural gas represented 24% of global primary energy consumption in 2012 (BP Stastical Review, 2013) and is expected to grow by between 1.6 and 1.9% per year until 2035, according to the World Energy Outlook (IE Agency, 2012). However, as illustrated in Table 1, natural gas resources are often not located close

Abbreviations: AGR, acid gas removal; aMDEA, activated *N*,*N*-dimethylethanolamine; BTEX, benzene, toluene, ethylbenzene and xylenes; CCS, CO_2 capture; transport and storage, CP; CO_2 products, CR; CO_2 remaining, DMEPG; dimethyl ethers of propylene glycol, DMMEA,N,N-dimethylethanolamine; FPSO, floating production storage and offloading; HOCNF, harmonized offshore chemical notification format; LNG, liquified natural gas; MDEA, *N*-methyl-diethanolamine; MS, methane slip; PSA, pressure swing absorption; Pipe, pipeline; RNG, raw natural gas.

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Table 1
Volumes of natural gas produced and consumed (in billions of cubic metres) by respectively top natural gas producing and consuming countries in 2012[a].

Top 10 natural gas producers			Top 10 natural gas consumers		
Rank	Country	Annual production	Rank	Country	Annual consumption
1	United States	681.4	1	United states	722.1
2	Russian federation	592.3	2	Russian Federation	416.2
3	Iran	160.5	3	Iran	156.1
4	Qatar	157	4	China	143.8
5	Canada	156.5	5	Japan	116.7
6	Norway	114.9	6	Saudi Arabia	102.8
7	China	107.2	7	Canada	100.7
8	Saudi Arabia	102.8	8	Mexico	83.7
9	Algeria	81.5	9	United Kingdom	78.3
10	Indonesia	71.1	10	Germany	75.2

[a] BP Statistical Review (2013).

to markets, and large-scale transport of natural gas is required between countries. Furthermore, to meet the growing demand, new natural gas fields with higher CO_2 and H_2S content will also be developed (Table 2). Natural gas product quality specifications for pipelines are typically 2–3% CO_2, and 50–100 ppmCO_2 for Liquified Natural Gas (LNG) (Coyle et al., 2003). For fields with CO_2 concentrations in natural gas greater than these limits, Acid Gas Removal (AGR) is therefore a requirement, rather than an option.

CO_2 removal from natural gas to meet transport specifications can, in principle, be achieved by various acid gas removal technologies (Rufford et al., 2012) such as chemical and physical absorption (Kohl and Nielsen, 1997), membrane separation (Bernardo et al., 2009), pressure swing adsorption (PSA) (Tagliabue et al., 2009; Grande and Blom, 2012), membrane contactors (Faiz and Al-Marzouqi, 2011), cryogenic/low-temperature separation (Berstad et al., 2012) or separation by hydrates (Van Denderen et al., 2009). Chemical solvents are currently the most common for acid gas removal from natural gas, and these are expected to remain important in the near future for large-scale gas processing applications (Rufford et al., 2012). Membrane separation for bulk CO_2 removal from natural gas is increasingly used (Olajire, 2010). The low-temperature and adsorption concepts are emerging technologies that are expected to become alternatives to solvents for natural gases with high CO_2 content (Rufford et al., 2012). However, the choice of technology depends on several case-specific criteria such as natural gas feed conditions and product specifications, the location and size of the natural gas treatment plant, plant economics, ambient conditions and environmental aspects, and process control and operation.

Table 2
Example of natural gas reservoirs compositions (in %vol)[a,b].

Component	Reservoir				
	Groningen (Netherlands)	Ardjuna (Indonesia)	Uthmaniyah (Saudi Arabia)	Lacq (France)	Uch (Pakistan)
CH_4	81.3	65.7	55.5	69	27.3
C_2H_6	2.9	8.5	18	3	0.7
C_3H_8	0.4	14.5	9.8	0.9	0.3
C_4H_{10}	0.1	5.1	4.5	0.5	0.3
C_{5+}	0.1	0.8	1.6	0.5	–
N_2	14.3	1.3	0.2	1.5	25.2
H_2S	–	–	1.5	15.3	–
CO_2	0.9	4.1	8.9	9.3	46.2

[a] Rojey (1997).
[b] Shimekit and Mukhtar (2011).

The most widely used technologies for CO_2 removal from natural gas are chemical and physical absorption. However, most of the amine-based solvents used for acid gas removal have significant environmental impacts and are expected to be phased out in the near future, for example, under the Harmonized Offshore Chemical Notification Format (HOCNF) implementation in Norway. Furthermore, the handling of acid gases like CO_2 and H_2S needs to be integrated into the process in order to avoid their emission to air. The objective of the project "A Green Sea" is therefore to identify and evaluate mature as well as new technologies and concepts for acid gas removal to achieve required product specifications and also prevent the use of chemicals that are harmful to the environment.

This paper presents the evaluation of three acid gas removal concepts studied in the project "A Green Sea". Two solvent concepts (aMDEA/MDEA and Selexol) and a low-temperature concept are modelled and assessed, considering a range of raw natural gases, and natural gas product requirements. The analyses and comparisons of the concepts and cases are performed using multi-criteria analyses (Jakobsen et al., 2011; Roussanaly et al., 2013) in order to include different Key Performance Indicators (KPIs) ranging from energy efficiencies to the compactness of the processes under consideration.

The methodology, including the cases considered in this study, and an overview of acid gas removal technologies and the KPIs for the concept evaluation is presented. The cases are evaluated for each of the AGR technologies and compared using the KPIs described in the methodology section. The assessment results are then discussed from the technology point of view and the case perspective in order to provide recommendations. The potential impact of current and future regulations is finally discussed before concluding.

2. Methodology

To ensure a consistent and transparent evaluation of the different technologies, a systematic methodology for evaluation is required. An overview of the technology evaluation methodology is shown in Fig. 1 below. The framework for the methodology can be divided into three part.

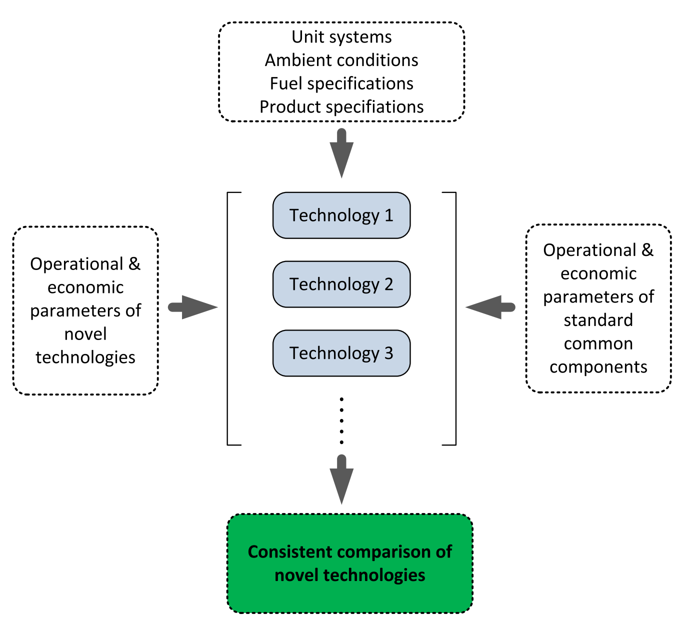

Fig. 1. Methodology for technology assessment.