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

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Content

Motivation

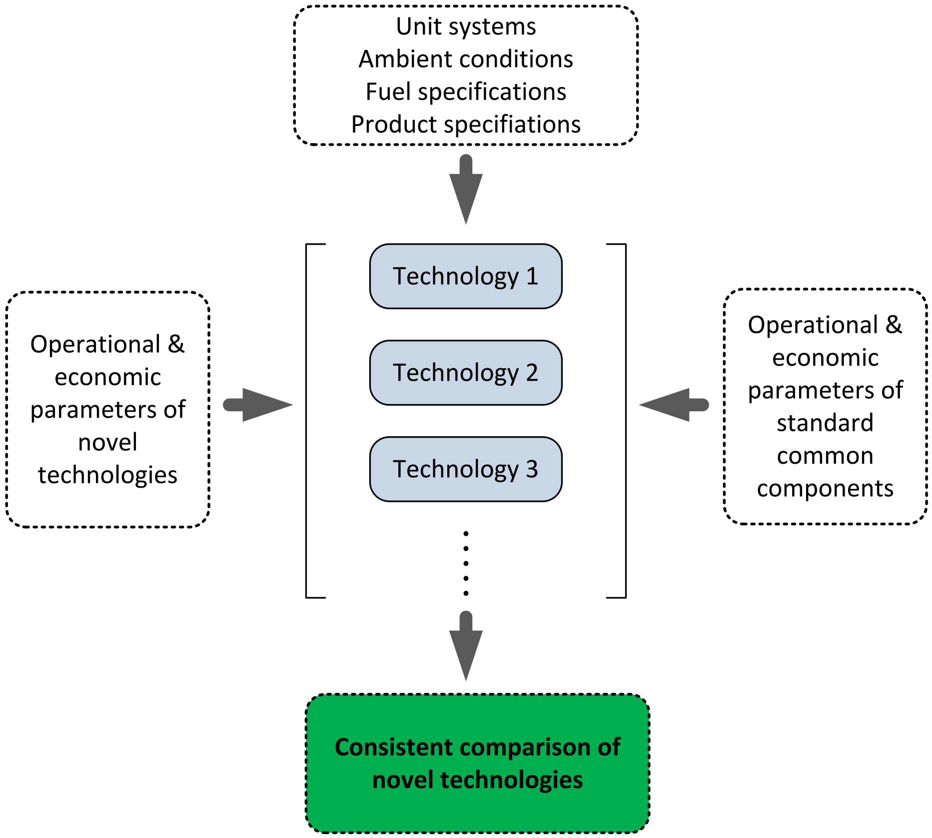
- Natural gas represented 24% of global primary energy consumption in 2012 and is expected to grow by between 1.6 and 1.9% per year until 2035, according to the World Energy Outlook
- Due to the transport requirement, acid gas removal is required is before gas transport (Pipeline ~2-3%$_{CO2}$ and LNG 50-100ppm$_{CO2}$)
- CO_2 removal from natural gas to meet transport specifications can, in principle, be achieved by various acid gas removal technologies
- Chemical solvents are currently the most common method while membrane separation for bulk removal is increasingly used. The low-temperature and adsorption concepts are emerging technologies.
- However, the choice of technology depends on several case-specific criteria (natural gas feed conditions and product specifications, the location and size of the natural gas treatment plant…)

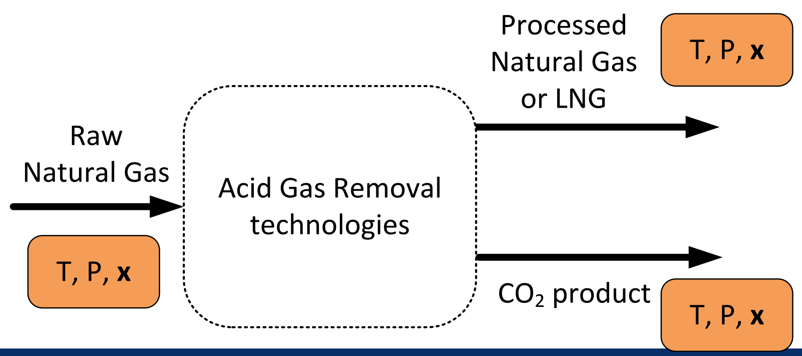
II. Methodology

Methodology

- Aim to evaluate three Acid Gas Removal technologies using a consistent and transparent multi-criteria analysis
  - aMDEA/MDEA
  - Selexol
  - Low-temperature

- Three cases of combinations for specifications for raw natural gas, natural gas product and CO_2 product compositions are considered





Acid gas removal cases

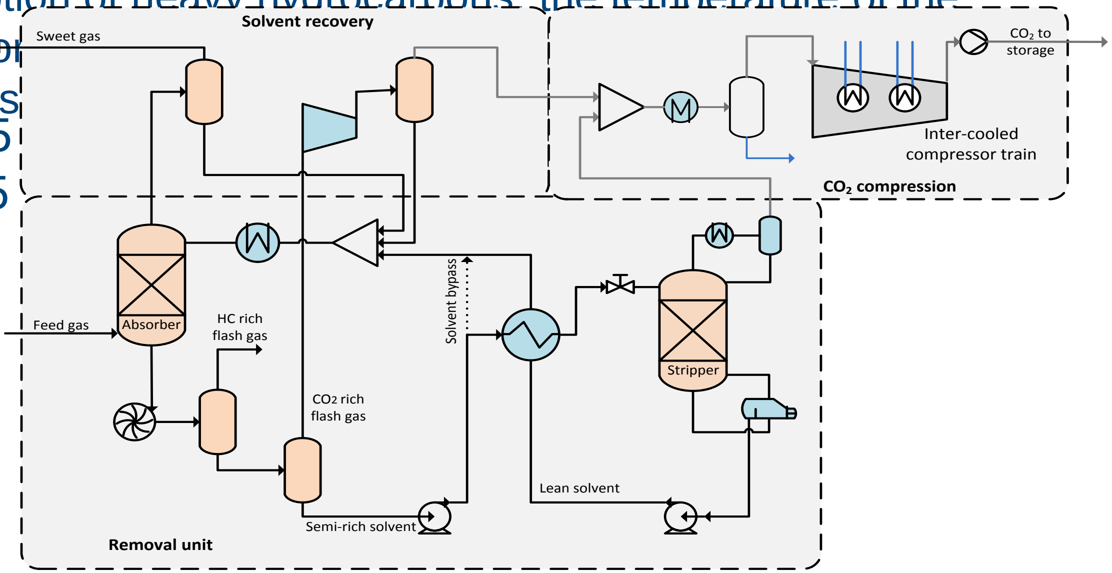
- Acid Gas Removal cases
  - Raw natural gas:
    - RNG1 : 10 $\%_{CO2}$
    - RNG2: 50$\%_{CO2}$
  - Natural Gas Product:
    - Pipe (2.5$\%_{CO2}$)
    - LNG (50ppm_{CO2})
  - CO2 product
    - RNG1: 95% purity
    - RNG2: 70% purity
  - Location
    - RNG1: Onshore
    - RNG2: Offshore

	RNG1 Pipe	**RNG1 LNG**	**RNG2 Pipe**
Raw Natural Gas	RNG1	RNG1	RNG2
Temperature [°C]	40	40	40
Pressure [bar]	70	70	70
Flow rate [Nm^3/hr]	590 000	590 000	590 000
Natural Gas product	NG Pipe	LNG	NG Pipe
Temperature [°C]	40	-162	40
Pressure [bar]	70	1	70
CO_2 content	2.5 *mol%*	50 *ppmv*	2.5 *mol%*
CO_2 product	CP1	CP1	CP2
CO_2 purity [%]	95	95	70
Pressure [bar]	110	110	110
Temperature [°C]	40	40	40
Location	Onshore	Onshore	Offshore

  - Definition of three cases (RNG1 pipe, RNG1 LNG and RNG2 Pipe) with the characteristics given in the Table

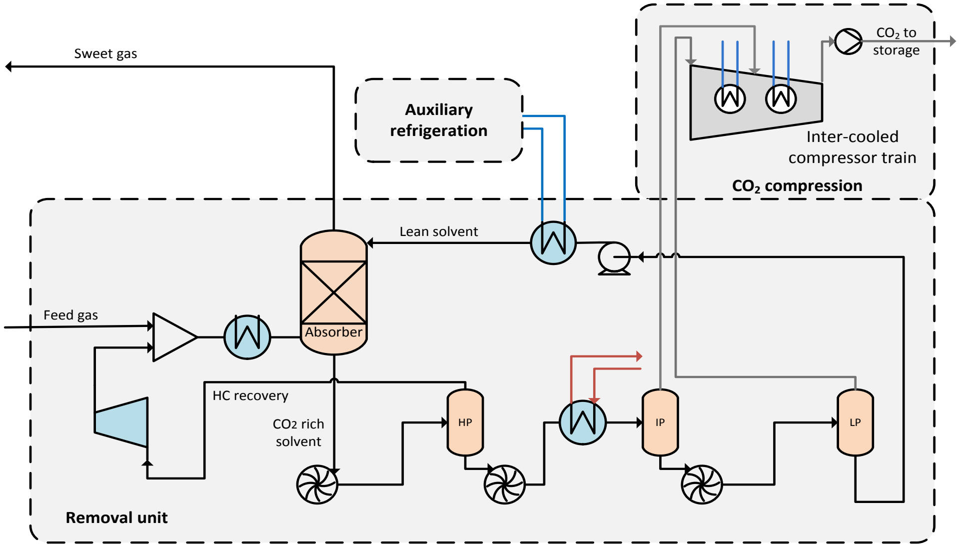
aMDEA/MDEA based solvent concept (reference concepts)

- aMDEA/MDEA process
  - An absorber-stripper configuration with lean-rich solvent heat exchanger
  - Includes flash tanks for partial release of absorbed components through pressure reduction
  - A liquid turbine is used to recover power from the rich solvent stream after leaving the absorber
  - To avoid excessive co-absorption of heavy hydrocarbons, the temperature of the lean solvent entering the absor the dew point of the sweet gas
- Aqueous solution of MDEA (45 wt%) activated by addition of 5 wt% of Piperazine
- Simulations were carried in ProTreat v4.2



Selexol based solvent concepts

- Selexol process
  - A physical solvent based gas sweetening unit using dimethyl ethers of propylene glycol (DMEPG)
  - The chosen configuration relies solely on pressure swing for release of the absorbed species through 3 pressure levels
  - The absorber temperature is significantly lower than the dew point of the feed gas which lead to co-absorption of heavy hydrocarbons (C3+) and released with the acid gas
  - These heavy hydrocarbons can be recovered from the water knock-out steps altough this is not made explicit here



- Simulations were carried in ProTreat v4.2

Low-temperature concepts

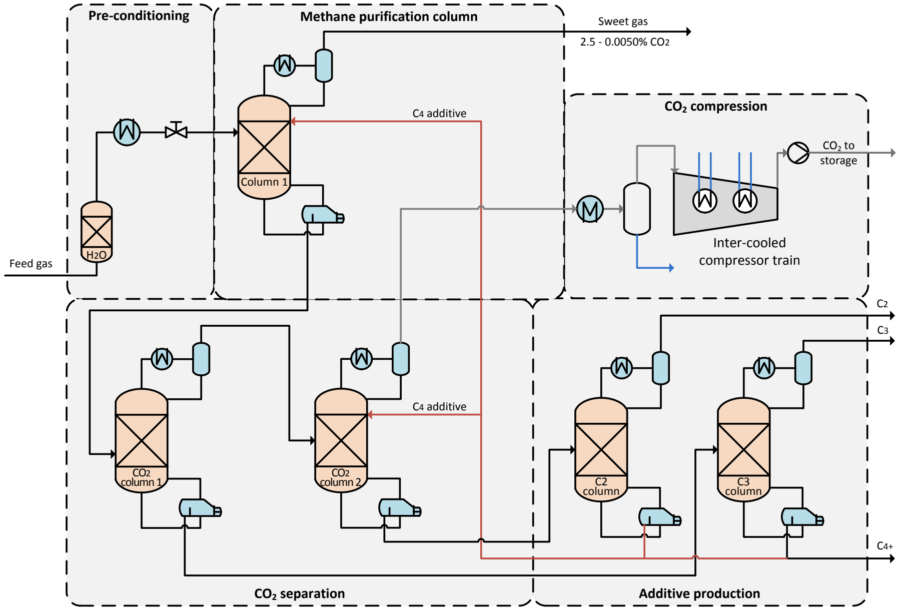
- Low-temperature process
  - A low-temperature separation unit
  - including the main methane column(s), CO_2 purification column(s) and a section producing freeze-out inhibitor for the methane column(s)
  - An auxiliary refrigeration system supplying cooling for the column condensers, not illustrated here, and consisting of a propane-ethylene cascade is also modelled
  - Even if the refrigeration system is not optimized, it is still assumed that the model gives a reasonable estimate of the power consumption required to supply the refrigeration duties.

  - The risk of CO_2 solidification is minimized either by operating a column at temperatures that avoided solidification or by adding a CO_2 solidification inhibitor.

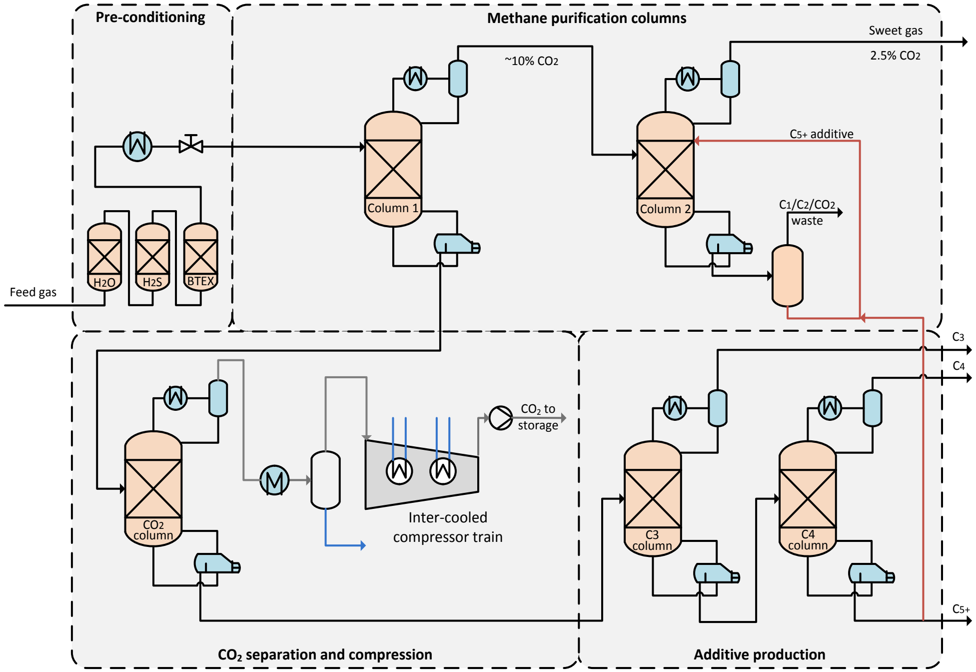
  - Simulations carried in ASPEN HYSYS v8.0

Low-temperature concepts

RNG1 Pipe/LNG



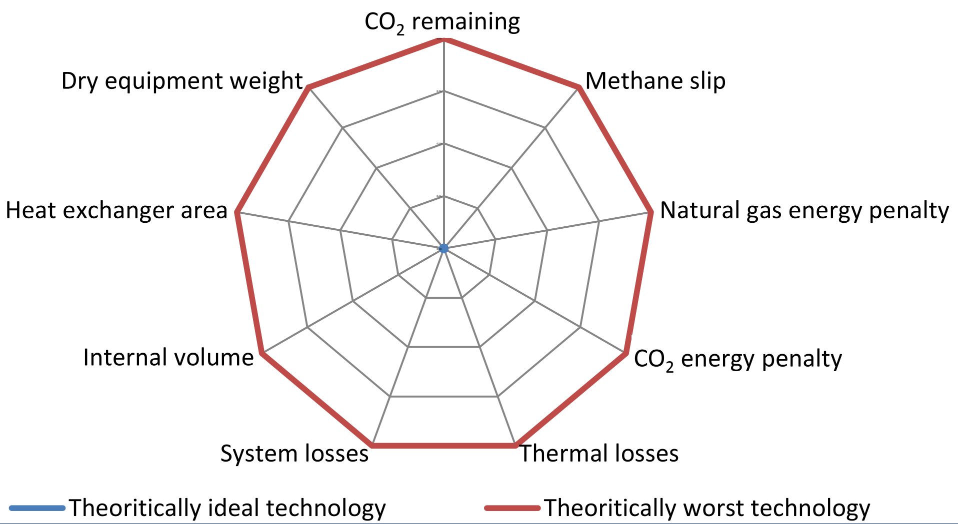
RNG2 Pipe



Multi-criteria analyses

- 9 Key Performance Indicators
  - Quantitative KPIs: Proportion of CO2 not captured (CO2 Remaining), Methane slip, Indicators of overall energy penalty in the process (System penalties), energy losses in the system (System losses)
  - Qualitative KPIs: related to cost and compactness of the process (Weight, volume and heat exchanger area)

- Multi-criteria analyses
  - Pictured on a spider-diagram for each case
  - The closer a KPI value is to the centre the better is the technology and vice versa



III. Results

KPIs evaluation

	CO_2 remaining [%]	Methane slip [%]	Natural gas energy penalty [MW/MW$_{th}$]	CO_2 energy penalty [MJ/kg$_{CO2}$]	Thermal losses [%]	System losses [%]	Concept volume [m^3]	Concept heat exchanger area [10^3 m^2]	Concept weight [t]
aMDEA/MDEA									
RNG1 Pipe	21	0.06	0.004	0.85	0.05	0.38	659	7.5	550
RNG1 LNG	0.04	0.09	0.02	4.08	0.11	2.25	1018	13.8	898
RNG2 Pipe	1.8	0.26	0.04	0.98	1.3	4.0	1884	3.1	1584
Selexol									
RNG1 Pipe	18.5	2.73	0.08	15.76	6.42	7.20	1798	4	1136
RNG1 LNG	X	X	X	X	X	X	X	X	X
RNG2 Pipe	2.5	3.87	0.46	7.87	29.7	31..7	2570	9.7	1669
Low-temperature									
RNG1 Pipe	21.6	0	0.03	5.82	0.64	2.53	974	17.5	1032
RNG1 LNG	0.2	0	0.04	6.77	1.13	3.72	1149	22.6	1177
RNG2 Pipe	2.1	0	0.22	4.50	15.2	18.1	1241	17.6	1125

The technology perspective

- aMDEA/MDEA
  - The KPIs evaluation shows that with rather low methane slip, low energy penalties and high efficiencies performs quite well in terms of energy efficiency.
    - RNG1 LNG: -0.9 efficiency pt due to higher CO_2 energy penalty
    - RNG2 Pipe: -2.6 pt due to higher methane slip in the second
  - Regarding the qualitative KPIs, the aMDEA/MDEA technology is very compact in the RNG1 Pipe case.
    - RNG1 LNG case: volume and weight of the concept rise by 50% and 60%, due to the additional 30% CO_2 removal from the raw natural gas
    - RNG2 Pipe case: weight and volume are almost tripled, while the amount of CO_2 removed from the raw natural gas is approximately six times higher. Increase due the higher solvent flow required however, CO_2 separation from higher concentrations is more efficient

The technology perspective

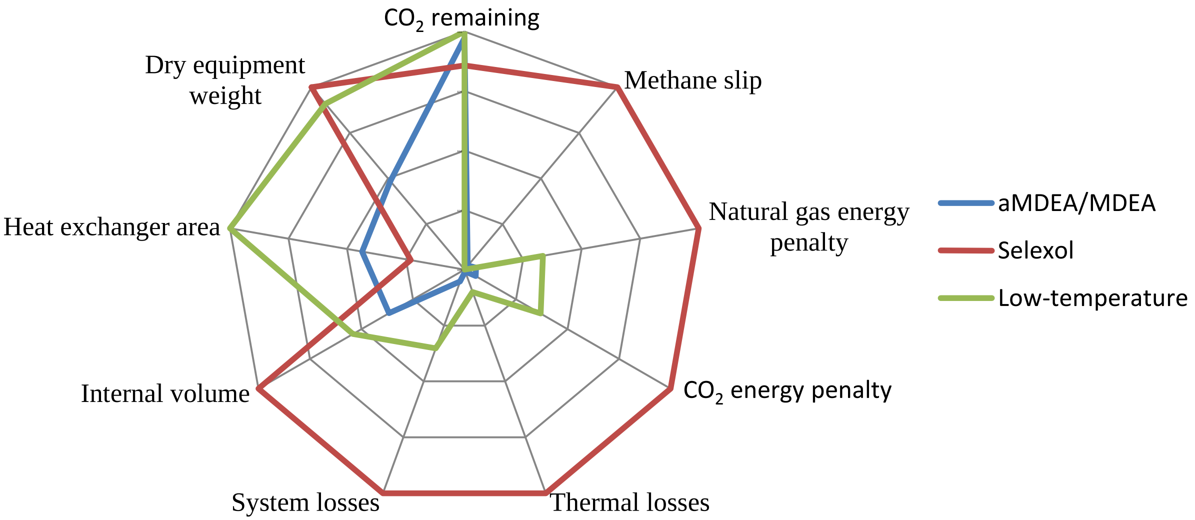
- Selexol
  - The assessment shows that the Selexol concept is not very energy-efficient compared to the other technologies.
    - This is mainly due to to the hydrocarbon slip.
  - Selexol technology is not a compact option for either of the RNG1 and the RNG2 Pipe cases.
    - Due to significantly lower kinetics of absorption and desorption of CO_2 by Selexol
    - The driving force of desorption is mainly pressure-based, while less heat is used than in the chemical solvent case
  - Due to the poor energy and compactness performances of the Selexol technology, the RNG1 LNG case was neither modelled nor evaluated

The technology perspective

- Low-temperature
  - The evaluation demonstrates rather high energy efficiency for the RNG1 cases; this is largely due to the absence of methane slip
    - However the system efficiency of the low-temperature technology drops to 82% in the case of the RNG2 Pipe case as there is a significant loss of hydrocarbons
  - The low-temperature concept shows that it appears to be a quite compact option for acid gas removal.
    - Less compact than aMDEA/MDEA for RNG1 Pipe
    - Approximately 30% more compact for RNG1 LNG and RNG2 Pipe
  - Less affected in terms of weight and volume by an increase in the quantity of CO_2 to be captured (both polishing or bulk removal)
    - RNG2 Pipe compared to RNG1 Pipe: Weight and volume increase by 30 and 10%
    - Lower temperatures can be used in the refrigeration cycles (less freeze-out issue)
    - Two columns are used
      - First column ensure an "easy" bulk removal
      - Second column remove the remaining CO2 starting from a significantly smaller stream than the first one

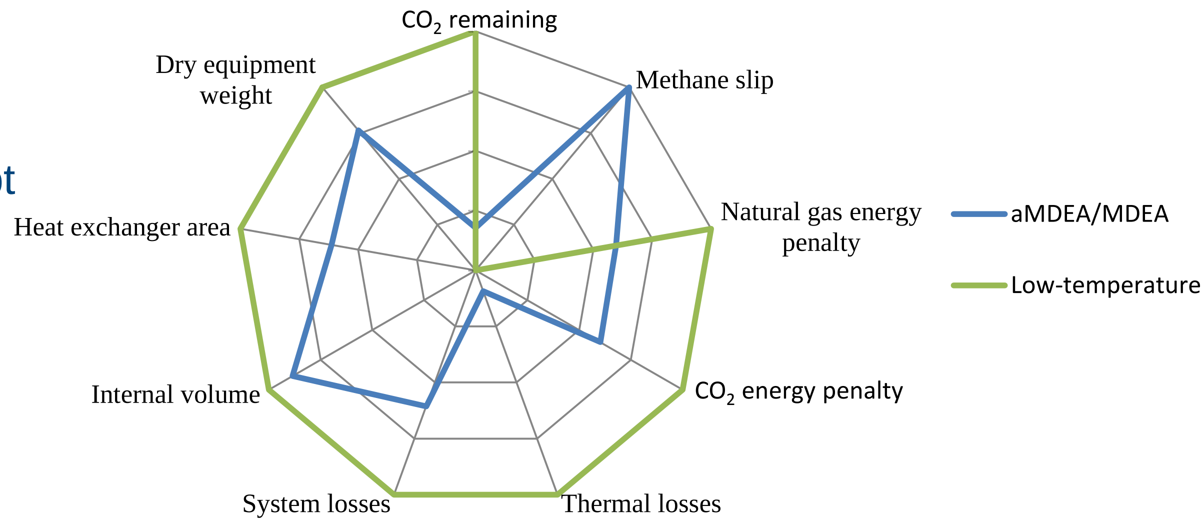
RNG1 Pipe case

- RNG1 Pipe case: 10%$_{CO2}$ to 2.5%$_{CO2}$
- aMDEA/MDEA exhibits the best performances for almost every parameter
- Low-temperature exhibit good energetic performances however its volume and weight are respectively 45 and 85% higher than aMDEA/MDEA
- Selexol exhibit poor performance both for energetic and compactness KPIs



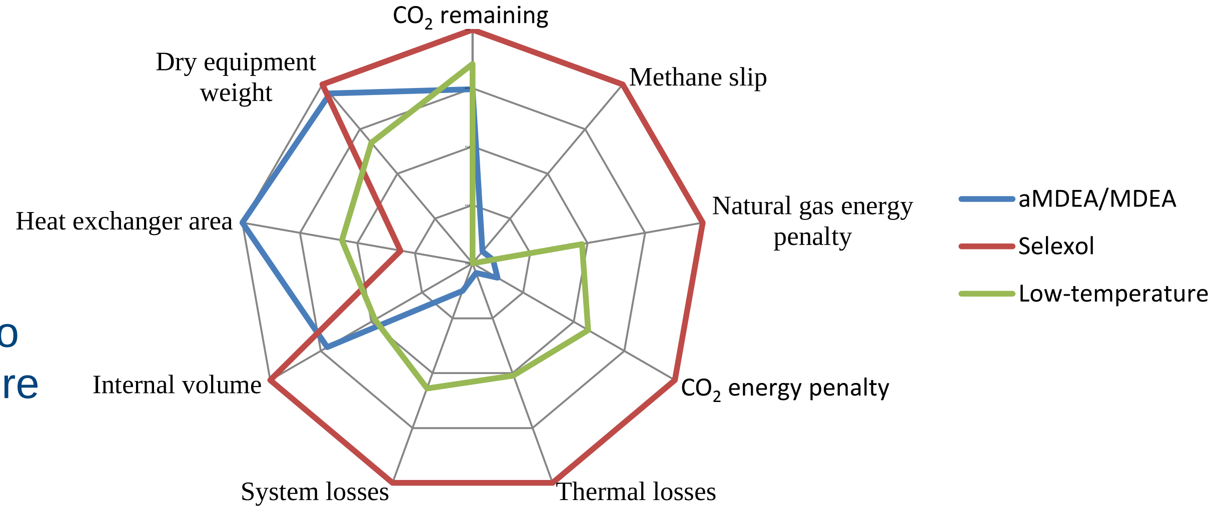
RNG1 LNG

- RNG1 LNG: 10%$_{CO2}$ to 50 ppm$_{CO2}$
- Selexol was not assessed nor evaluated for the RNG1 LNG
- aMDEA/MDEA exhibit the best KPIs except regarding methane slip
- Low-temperature has however similar KPIs:
  - System efficiency 1.4 pt lower
  - Volume +15%
  - Weight +30%



RNG2 Pipe

- RNG2 Pipe case: 50%$_{CO2}$ to 2.5%$_{CO2}$
- Selexol exhibit the worst value for almost all KPIs
- Low-temperature exhibit higher compactness than aMDEA/MDEA however it has less good energetic performances (-14pt of system efficiency)
- Offshore location
  - Importance of compactness
  - aMDEA and MDEA are classified shall be phased out according to the Harmonized Offshore Chemical Notification Format (Norway)



III. Conclusions and further work

Conclusions and further work

- The aMDEA/MDEA technology seems to perform well in terms of energy efficiency, volume and weight for low CO_2 content removal. However for high CO_2 content or strong polishing requirements, it loses efficiency in terms of weight and volume.
- The Selexol concept is an inefficient option for the three cases considered in terms of energy efficiency, volume and weight
- The low-temperature concept shows potential for bulk CO_2 removal, as well as strong polishing requirements especially for offshore application due to compactness and regulation on the use of chemicals.
- Corresponding paper accepted in International Journal of Natural Gas Science and Engineering
- Further work
  - Evaluation of other AGR technologies (membrane, adsorption…)
  - Evaluation of hybrid concepts bringing together two technologies in order to build improved concepts compared to stand-alone technology

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