Performance of Dehydration Units for CO$_2$ Capture

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Dehydration Study Approach

Study comprises of 4 main elements:
- Evaluation and characterisation of dehydration process
- Guidance on dehydration process selection
- Evaluation of moisture monitoring methods
- Analysis of future drying technology developments

3 different moisture levels investigated:
- 550 ppmv
- 50 ppmv
- > 10 ppmv

2 different CO₂ flow rates considered:
- 2.0 Mt/yr
- 4.5 Mt/yr
Background Issues

Several vendors assisted in this study but most others have been unable/unwilling:

- Booming oil & gas market → low engagement in CCS
- Large number of cancelled CCS projects
- Issues surrounding DECC competition & NER300

Presence of inerts & impurities:

- Changes in physical properties → modified/new EOS needed
- Changes in corrosion rates & hydrate formation

Wide range of dry CO\(_2\) moisture specifications

Some technologies cannot achieve required low moisture levels but are straightforward & low cost → offloading

Extent of cooling limited by hydrates/water ice/liquid CO\(_2\)
Background Issues

**Indication of Limiting Conditions for Wet CO2**

- **Pressure (bara)**
- **Temperature (°C)**

- **Water ice**
- **CO2 Hydrate**
- **Liquid CO2**

The graph shows the relationship between pressure and temperature, indicating the limiting conditions for wet CO2.
Extremely important to know and adequately consider the impurities during design
Additional upstream treatment may be required

**Background Issues**

- Additional amounts (make-up) of desiccant
- Acid resistant desiccants
- Protective guard layers (activated alumina, silica gel)
  - Regenerable
  - Sacrificial
- Remove solids with inline filtration
- Use of anti-foam & high-efficiency internals to minimise carry-over
- Corrosion & degradation

**Impurities in solid desiccant systems**

- Additional amounts (make-up) of desiccant
- Acid resistant desiccants
- Protective guard layers (activated alumina, silica gel)
- Regenerable
- Sacrificial

**Impurities in liquid desiccant systems**

- Remove solids with inline filtration
- Use of anti-foam & high-efficiency internals to minimise carry-over
- Corrosion & degradation
Technologies

**Post-combustion**
Gas is delivered water-saturated at atmospheric pressure

**Pre-combustion**

- **Rectisol**
  - Delivers dry gas > 1 ppmv → no additional drying required
  - Small carryover of MeOH

- **Selexol**
  - Gas is water-saturated → 500-1000 ppmv when p > 10 bar → but CO₂ purity at these conditions < 98%
  - If S removal not required → pure PEGDME → lower water content
  - Minimal contamination with PEGDME

**Oxyfuel combustion**
Gas stream is water-saturated, H₂O/NOₓ/SOₓ content can vary
Technologies

Selection of dehydration technologies

- Focus on TEG & molecular sieve at 30 bara & 30 C
- Low pressure operation requires large diameter beds
- Typical media life for both technologies ~ 3 years

Maximum train size

- Molecular sieve → 300-600 t/hr
- TEG preliminary estimate → 3,500 t/hr (multiple contactors)

Limitations:
- Maximum vessel diameter
- Capital cost of vessel
- Maximum number of parallel beds
- Adsorption time / size of each bed
- Regeneration rate

If considered at point of design → future capacity expansion possible
Costs – Molecular Sieves

Molecular Sieve Package
Maximum and Minimum Equipment Cost Indicator

- Equipment Capital Cost Indicator vs. CO2 rate (te/hr)
Costs – Molecular Sieves

Wide spread in capital cost from different vendors (for fixed operating pressure)

Differences due to:

- Regeneration techniques
- Use of CO₂ compression facility for regeneration gas
- Materials of construction
- Number and size of adsorption bed(s)
- Number of parallel dehydration trains possible

No difference in CAPEX for the different target moistures

Equipment CAPEX minimum location depends upon:

- Equipment design pressure
- Type of regeneration and extent of regeneration equipment
Costs – Molecular Sieves

Equipment Capital Cost vs Operating Pressure

Operating Pressure [bara]

Equipment Capital Cost
Costs - TEG

- Data on liquid desiccant systems lacking from vendors
- Product moisture is 50 ppmv
- Stripping gas used to increase TEG concentration
- Higher levels of target product moisture (> 150 ppmv)
  - Only basic equipment needed
  - Stripper not required
Costs - TEG

TEG Package
Maximum Equipment Cost Indicator for 50 ppmv Product

[Graph showing the relationship between CO2 rate (te/hr) and Equipment Capital Cost Indicator]
**Costs**

**High impurities:**

**Molecular sieve**
- Increased O₂ levels (300 ppmv) have no effect
- Presence of NOₓ, SOₓ & H₂S:
  - Acid resistant molecular sieve → 5% higher media volume → 15% higher media cost
  - 7% increase in molecular sieve equipment CAPEX

**TEG**
- O₂ degrades TEG → acceptable limits & effect on costs unknown
- Effect of NOₓ, SOₓ & H₂S cannot be evaluated

**Equipment CAPEX higher for both TEG & molecular sieve**
- Increased gas volume → larger diameter for TEG contactor and molecular sieve bed
- Higher water content → larger TEG circulation rate and larger molecular sieve volume required

**High inerts:**
- Equipment CAPEX higher for both TEG & molecular sieve
OPEX Estimates

Molecular sieve at 265 t/h

- Minimum CAPEX case:
  - Low pressure regeneration with atmospheric air
- Maximum CAPEX case:
  - Regeneration with CO\textsubscript{2} at pressure

TEG at 265 t/h

- Only maximum CAPEX case due to lack of vendor data

Further indications

- OPEX depends on operating pressure
- Effect of impurities on molecular sieve OPEX considered negligible
OPEX Estimates

- Mol. sieve, min CAPEX
- Mol. sieve, max CAPEX
- TEG, max CAPEX

OPEX [M€/year]
Selection

Consider series of multiple dehydration techniques

Cheaper to offload the final system with basic techniques
- Minimises the moisture fed to the final dehydration package
- Reduces the gas volume that has to be processed → smaller equipment

Molecular sieves can be protected with guard layers
- Silica gel or activated alumina
- Can better deal with the impurities
- Regenerable or sacrificial
Selection

![Graph showing the selection of methods based on water content in dry and wet gas.

- **Silica Gel and Mol Sieve**
- **Silica Gel and enhanced glycols**
- **Glycol, refrigerant, Joule Thompson/twister**
- **Glycol, refrigerant, Joule Thompson/twister and compression & cooling**
- **Compression & cooling**
- **Refrigerant drier, Joule Thompson and Twister**
- **Glycols and methanol**
- **Silica gel and activated alumina**
- **Molecular Sieve**]
Operation & Monitoring

Continuous automated sampling is required

Available analysis techniques:

• Laser absorption spectroscopy
• Phosphorous pentoxide cell
• Quartz crystal cell
• Silicon sensor

Maintenance frequency depends on gas quality

• Impurities
• Particulates

Min. 2 moisture analysis points recommended

• Immediately after dehydration
• Further downstream (e.g. after compression)
Further Work

Effect of inerts & impurities on physical properties
- Significant changes in phase envelop
- Increased/decreased saturated water content of CO₂

Improve models for physical properties estimation

Investigate & quantify the issue of hydrate formation

(Re-)Engagement of vendors

Membranes for dehydration of supercritical CO₂

Development of acid resistant solid desiccants
Conclusions & Recommendations

- Examined the characteristics of the various dehydration processes & their CCS integration
- A number of suitable technologies already exists
- Due to lack of vendor support information on costs and operation is preliminary, fragmentary & uncertain
- Follow up research & activities in this area needed
- (Re-)Engagement of vendors, also in IEAGHG networks
Thank you, any Questions?

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