New Challenges & Solutions in Designing Large Sour Gas Projects

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1. Introduction

Sour Gas Processing Routes

Sulphur Recovery Route

Acid Gas Injection Route
1. Introduction

Topics

1. Introduction
2. Background Information
3. Flowscheme Development
4. Evaluation of Options
5. Technological Development Trends
6. Summary
2. Background Information
2. Background Information

Why are sour gas projects important?

40% of remaining reserves are sour*

Reserves with 10% H_{2}S: over 350 Tcf
Reserves with 10% CO_{2}: over 650 Tcf

2. Background Information

Why are sour gas & acid gas different?

- **Sour natural gas**
  - Contains more than 10 or 20 ppm sulphur compounds
  - The most important sulphur compound is H$_2$S

- **Acid gas**
  - Product of treating sour gas
  - Predominantly carbon dioxide or a mixture of CO$_2$ & H$_2$S
  - Traces of hydrocarbons

- **Major differences to handling sweet natural gas**
  - H$_2$S has significant physiological effects on humans and other animals
  - Sour gas and acid gas (CO$_2$ & H$_2$S) require special attention to materials of construction
2. Background Information

Why are sour gas & acid gas different?

Relative Hazards of Sweet Gas, Sour Gas and Acid Gas

<table>
<thead>
<tr>
<th></th>
<th>Sweet Gas</th>
<th>Sour Gas</th>
<th>Acid Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂S &amp; CO₂</td>
<td>“0%”</td>
<td>100 ppm</td>
<td>“100%”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>to 60%</td>
<td></td>
</tr>
<tr>
<td>Explosion/Fire Hazard</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Toxicity</td>
<td>Minimal</td>
<td>Increasing with H₂S</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Asphyxiant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrosive</td>
<td>Minimal</td>
<td>Significant</td>
<td>High</td>
</tr>
<tr>
<td>Hydrate Formation</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Flammability of Main Gas Components in Sweet Gas, Sour Gas and Acid Gas

<table>
<thead>
<tr>
<th>Component</th>
<th>Flammable Limit in Air, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower Limit</td>
</tr>
<tr>
<td>Methane</td>
<td>5</td>
</tr>
<tr>
<td>Ethane</td>
<td>3</td>
</tr>
<tr>
<td>H₂S</td>
<td>4</td>
</tr>
<tr>
<td>CO₂</td>
<td>Non - combustible</td>
</tr>
</tbody>
</table>
2. Background Information

Why are sour gas & acid gas different?

Toxicity of $\text{H}_2\text{S}$ (general effects)

<table>
<thead>
<tr>
<th>Hydrogen Sulphide Concentration (ppm)</th>
<th>Physiological Effect (dependent on health &amp; susceptibility of individuals)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Detectable by smell similar to rotten eggs</td>
</tr>
<tr>
<td>10</td>
<td>Allowable exposure 8 hours but cannot rely on sense of smell. Increasingly irritant.</td>
</tr>
<tr>
<td>100</td>
<td>Kills sense of smell immediately</td>
</tr>
<tr>
<td>500</td>
<td>Causes loss of reasoning and balance</td>
</tr>
<tr>
<td>700</td>
<td>Causes unconsciousness and breathing stops</td>
</tr>
<tr>
<td>1000</td>
<td>Brief exposure may result in permanent brain damage</td>
</tr>
</tbody>
</table>

- What if we burn $\text{H}_2\text{S}$ to sulphur oxides:
  - $\text{H}_2\text{S}$ turns to $\text{SO}_2$ with limited quantities of $\text{SO}_3$
  - $\text{SO}_x$ can acidify the local environment via acid rain
  - $\text{SO}_2$ is an irritant which causes respiratory problems at very low levels
  - $\text{SO}_2$ has the same toxicity classification as $\text{H}_2\text{S}$
  - Burning $\text{H}_2\text{S}$ may increase dispersion but does not eliminate toxicity problem
2. Background Information

What basic data are important in project definition?

- Sour gas field
  - Rates and compositions
  - Operating cases
- Environmental constraints
- Acid gas injection
  - Reservoir pressure/Temperature
  - Depth of injection zone
  - Tubing diameter
  - Injectivity has been considered by the geologist
- Facility locations – pipelines
- Meteorological data
- Population distribution
3. Flowscheme Development
3. Flowscheme Development

Gas Processing Block Flow Diagram

Sulphur Recovery Route

Well Streams → Gas/Oil Separation → Acid Gas Removal → Gas Dehydration → NGL Recovery → LPG Separation

- Liquid → Condensate Stabilisation
- CO₂ → TGCU/TGTU → Sulphur Storage → Export Sulphur

Sales Gas → C₂ → To Treatment
C₃ → To Treatment
C₄ → To Treatment

Condensate Product → To Treatment
3. Flowscheme Development

**Sour Gas Wells & Flowlines**

- **Gas/Oil Separation**
  - Well Streams
  - Sour Gas
  - Acid Gas

- **Acid Gas Removal**
  - Acid Gas

- **Sulphur Recovery Route**
  - CO₂
  - TGCU/TGTU
  - Sulphur Storage
  - Export Sulphur

- **Sour Gas Wells & Flowlines**
  - Acid gas fraction and CO2/H₂S ratio
  - Sour gas health and safety aspects
  - Potential for elemental sulphur in feed
3. Flowscheme Development

**Impact of Acid Gas Fraction & CO$_2$/H$_2$S Ratio**

Impact of Acid Gas Fraction & CO$_2$/H$_2$S Ratio on Sulphur and CO$_2$ Production

**Raw Gas 1 Billion scfd**

<table>
<thead>
<tr>
<th>Acid Gas Fraction (%)</th>
<th>4</th>
<th>7</th>
<th>10</th>
<th>20</th>
<th>40</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$/H$_2$S Ratio</td>
<td>3</td>
<td>2.5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.33</td>
</tr>
<tr>
<td>H2S (%)</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Sulphur (tonnes/d)</td>
<td>400</td>
<td>800</td>
<td>2000</td>
<td>4000</td>
<td>8000</td>
<td>12000</td>
</tr>
<tr>
<td>CO2 (tonnes/d)</td>
<td>1500</td>
<td>2500</td>
<td>2500</td>
<td>5000</td>
<td>10000</td>
<td>5000</td>
</tr>
</tbody>
</table>

(excluding heat and power)

More than 1.5 million tpa

More than 4 million tpa
3. Flowscheme Development

**Acid Gas Removal Unit**

- **Acid Gas Removal Unit**
  - Acid gas fraction in feed
  - Efficient removal of acid gas
  - Reliable, subsequent acid gas processing

**Sulphur Recovery Route**

- **Gas/Oil Separation**
  - Well Streams

- **Acid Gas Removal**

- **Sulphur Recovery Unit**
  - CO₂

- **TGCU/TGTU**

- **Sulphur Storage**

- **Export Sulphur**
3. Flowscheme Development

**Acid Gas Removal Unit**

Efficient acid gas removal technologies
- High acid gas loading required to minimise circulation rate
- Options
  - Amine based solvents
    - Generic MDEA, DGA™ agent
    - Proprietary/Licensed MDEA
    - Easily tailored to bulk vs deep acid gas removal
    - Very high loadings achievable
  - Physical solvents
    - DMPEG, PC, NMP, refrigerated methanol
    - Low regeneration heat if treat spec is relaxed
    - Removal of more organic sulphur
    - Hydrocarbon coabsorption increased
  - Mixed solvents
3. Flowscheme Development

**Sulphur Recovery Unit**

**Sulphur Recovery Route**

- **Well Streams** → **Gas/Oil Separation** → **Acid Gas Removal** → **Acid Gas** → **Sulphur Recovery Unit** → **CO₂** → **Export Sulphur** → **Sulphur Storage**

**Sulphur Recovery Unit CO₂ /H₂S ratio**
- ≥ 50% H₂S
- < 50% H₂S
- Reliable SRU operation

**Acid Gas Removal**

- **Sour Gas** → **Acid Gas Removal**
3. Flowscheme Development

**Sulphur Recovery Unit**

- **Reliable SRU Operation**

<table>
<thead>
<tr>
<th>CO₂/H₂S ratio in feed</th>
<th>≤ 1</th>
<th>&gt; 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂S in acid gas to SRU</td>
<td>≥ 50%</td>
<td>&lt; 50%</td>
</tr>
<tr>
<td>Reliability</td>
<td>Good</td>
<td>?</td>
</tr>
<tr>
<td>Design</td>
<td>Straight through reaction furnace, high intensity burner</td>
<td>AVOID</td>
</tr>
</tbody>
</table>

**AVOID**
- AG bypass
- Co-firing fuel or sales gas

**PREFER**
- Feed air and acid gas preheat
- Enriched acid gas

**Diagram:**
- BTEX
- Acid Gas
- Air
- Reaction Furnace
- Zone 1
- Zone 2
- Acid Gas Bypass
- Catalytic Claus Conversion
3. Flowscheme Development

**Sulphur Recovery Unit**

**Acid Gas Enrichment Unit**
- < 50% H₂S
- Acid gas enrichment unit
- CO₂ slip to 75% or greater
3. Flowscheme Development

**Tail Gas Clean-up/Treating Unit**

**Sulphur Recovery Route**

- **Well Streams** → **Gas/Oil Separation** → **Acid Gas Removal** → **Sulphur Recovery Unit** → **TGCU/TGTU** → **Sulphur Storage** → **Export Sulphur**

<table>
<thead>
<tr>
<th>Process Type</th>
<th>Sulphur Recovery, %</th>
<th>Sulphur Emission, tpy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selective direct oxidation Sub-dewpoint</td>
<td>99</td>
<td>40,000</td>
</tr>
<tr>
<td>Hydrogenation/amine treating</td>
<td>99.9+</td>
<td>4,000</td>
</tr>
</tbody>
</table>

**TGCU/TGTU**
3. Flowscheme Development

**Sulphur Storage and Export**

- **Sulphur Recovery Route**
  - **Gas/Oil Separation**
  - **Acid Gas Removal**
  - **Sour Gas**
  - **Acid Gas**
  - **Sulphur Recovery Unit**
  - **CO₂**
  - **TGCU/TGTU**
  - **Sulphur Storage**
  - **Export Sulphur**

**Scale:** 1 Bscfd 30% H₂S = 12,000 tpd sulphur

**Sulphur Export**
- Liquid export via pipeline 10”/12” Size
- Solid export via trucks 300 to 400 Trucks/d

**Sulphur Storage On Site**
- Storage in blocks on site 15 Hectares/y
- Weathering, acidification, environmental concerns
- Makes AGI look very attractive!
Sulphur Storage and Export
3. Flowscheme Development

Acid Gas Injection Route – Acid Gas Properties

<table>
<thead>
<tr>
<th>Acid Gas Injection Route</th>
<th>Acid Gas Dehydration</th>
<th>Pipeline</th>
<th>Injection Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid Gas Removal</td>
<td>Acid Gas Compression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sour Gas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas/Oil Separation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well Streams</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Acid gas properties – From AGRU
- Pressure, bara: 1.5
- $\text{H}_2\text{S}\%$: 70
- $\text{CO}_2\%$: 20
- $\text{H}_2\text{O} \text{g/Sm}^3$: 75

Acid gas properties – Wellhead
- Pressure, bara: 150 to 300
- $\text{H}_2\text{S}\%$: 77
- $\text{CO}_2\%$: 22
- $\text{H}_2\text{O} \text{g/Sm}^3$: 4
- $\text{H}_2\text{O} \text{g/Sm}^3$ (with dehydration): 0.3
3. Flowscheme Development

**Acid Gas Injection Route - Phase Envelopes**

- Phase envelope is unique to acid gas case
- Constructed using process simulation software with carefully selected thermodynamic model
3. Flowscheme Development

**Acid Gas Injection Route – AG Compression I**

**Acid Gas Compression**
- Large, multistage, barrel compressor
- One or two casings
- Gas turbine driven
- Typical base train machine - GE Frame 5
  - PGT 25
3. Flowscheme Development

**Acid Gas Injection Route – AG Compression II**

**Typical four stage compression train**
- Train capacity dictated by GT frame size & gas composition
- Stage compression limited by maximum discharge temperature and design phase envelope
- Compressor casing and rotor materials are critical
- Seal materials/ design is critical
- Seal gas must exclude oxygen

[Diagram of Acid Gas Injection Route – AG Compression II]
3. Flowscheme Development

**Acid Gas Injection Route – Hydrate Formation**

**Effect of Water Content on Hydrate Formation Temperature**

![Graph showing the effect of water content on hydrate formation temperature.](image)
3. Flowscheme Development

**Injection wells**

**Acid Gas Injection Route**

- **Gas/Oil Separation**
  - **Sour Gas**
  - **Well Streams**

- **Acid Gas Removal**

- **Acid Gas Dehydration**

- **Acid Gas Compression**

- **Pipeline**

- **Injection Wells**

**Pipeline & Injection well**

- **Hydraulic Capacity**
  - Depth
  - Pressure
  - Well bore size

- **Geology**
3. Flowscheme Development

Acid Gas Injection Route – Compression and Injection Diagram

Phase Diagram Representation of Compression & Injection Scheme
4. Evaluation of Options
4. Evaluation

- Health & Safety
- Environmental Impact
- Technical Aspects
- Economics
- Synergies
4. Evaluation

Health & Safety - I a

- Credible leak orifice size
- Process conditions (T & P)
- Process fluid composition (H2S%)
- Base meteorological conditions/range of met cases
- Geography (hills, valleys etc)
- Duration of event/inventory
- Limit concentration for assessing hazard potential and emergency response planning

---

Emergency Response Level

<table>
<thead>
<tr>
<th>H2S ppm</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERPG – 2</td>
<td>1 hour</td>
</tr>
<tr>
<td>ERPG – 3</td>
<td>1 hour</td>
</tr>
</tbody>
</table>
4. Evaluation

Health & Safety - 1 b

Relative hazard of leak sources

Area within limit H$_2$S concentration (Not to Scale)

- 1% H$_2$S, Sour Gas
- 10% H$_2$S, Sour Gas
- 75% H$_2$S, Acid Gas

Distance downwind to limit H$_2$S concentration

1000~5000
25~75
4. Evaluation

Health & Safety - Ic

Relative hazard of leak sources (semi quantitative)

Area within limit H$_2$S concentration

- 1

100

1000~5000

Distance downwind to limit H$_2$S concentration

1% H$_2$S, Sour Gas
10% H$_2$S, Sour Gas
75% H$_2$S, Acid Gas
Relative hazards of SRU & AGI Processing Routes (Qualitative only)

<table>
<thead>
<tr>
<th>Route</th>
<th>SRU</th>
<th>AGI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sour Gas wells &amp; Gathering system</td>
<td>● ●</td>
<td>● ●</td>
</tr>
<tr>
<td>On Plant areas</td>
<td>● ●</td>
<td>● ● ● ● ●</td>
</tr>
<tr>
<td>Acid gas pipelines &amp; wellsites</td>
<td>● ● ● ●</td>
<td>● ● ● ●</td>
</tr>
<tr>
<td>Offsite Areas</td>
<td>● ●</td>
<td>● ● ● ●</td>
</tr>
</tbody>
</table>

- Subject to population distribution
4. Evaluation

Health & Safety - III

Hazard mitigation – managing the risks

• Design & Systems
  – Plant layout
  – High mechanical integrity
    - Materials selection
    - Minimise leak sources (flanges, small bore, seals etc.)
  – Gas detectors, personal monitors, windsocks, and safe havens/PPE

• Operations and maintenance
  – Training of staff
  – Minimum Manning

• Design safety – continuing commitment
  – HAZID/HAZOP
  – Risk assessment
  – Consequence modelling of major hazards
  – Demonstrate that risk is ALARP
  – Emergency planning zones
  – Emergency response planning
4. Evaluation

**Environmental Evaluation - Emissions**

- Sulphur & greenhouse gas from hydrocarbon stream

<table>
<thead>
<tr>
<th>Processing Route</th>
<th>Emissions*</th>
<th>SO$_2$ tpy</th>
<th>CO$_2$ tpy</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRU 99% Recovery</td>
<td></td>
<td>80,000</td>
<td>1,500,000</td>
</tr>
<tr>
<td>SRU 99.9% Recovery</td>
<td></td>
<td>8,000</td>
<td>1,500,000</td>
</tr>
<tr>
<td>AGI</td>
<td>&quot;0&quot;</td>
<td>&quot;0&quot;</td>
<td></td>
</tr>
</tbody>
</table>

* Excluding emissions from heat and power generation
4. Evaluation

Technical Evaluation

- Reliability of equipment, flowschemes
- Reliability of acid gas disposal routes
4. Evaluation

Economics – Relative Capital Contributions

SRU Route

AGR: 34%
BOP: 31%
SRU: 35%

AGI Route
(remote injection)

AGR: 35%
BOP: 31%
AGI: 33%

AGI Route
(local injection)

AGR: 38%
BOP: 34%
AGI: 28%

- AGR: Acid Gas Removal
- SRU: Sulphur Recovery
- AGI: Acid Gas Injection
- BOP: Balance of Plant/Utilities
4. Evaluation

**Economics - Relative Capital Cost of Options**

![Relative Capital Cost Chart]

- SRU + TGTU
- SRU + TGCU
- AGI + Remote Injection
- AGI + Local Injection

The chart illustrates the relative capital cost of different options, with AGI + Local Injection being the least expensive and SRU + TGTU being the most expensive.
4. Evaluation

### Economics - Variable Costs

- **Product Values**
  - Sales gas
  - LPGs
  - Condensate

- **Sulphur Value/Cost**
  - Currently: Very High
  - Medium to long term: ?
  - Supply: ?
  - Markets: ?
  - Freight cost: ?

- **CO₂ Value/Cost**
  - Value: Greenhouse gas?
  - Enhanced oil recovery?
  - Cost: Greenhouse gas?

- **Utilities**
  - Fuel gas
  - Electrical power
4. Evaluation

Synergies

- Incremental development
  - Existing site
- New site close to acid gas storage or sulphur export
- Integration, e.g. integrate with gas to liquids plant, $O_2$ for SRU
5. Technological Development Trends
5. Technological Development Trends

Cryogenic Pre-extraction Processes

- **Acid Gas Injection Route**
  - **Acid Gas Dehydration**
  - **Acid Gas Compression**
  - **Pump**
  - **Pipeline**
  - **Injection Wells**

**Cryogenic Acid Gas Pre-extraction**
- Removes an H$_2$S liquid rich stream
- -30 degC or less
- H$_2$S stream contains water and most of C3+
- CO$_2$ removal and H$_2$S polishing required
- Light component stripping
5. Technological Development Trends

Membrane Processes

Membranes
- Membrane must be resistant to H₂S
- Protect from heavy hydrocarbons
- Loss of product
- Future – more selective membranes
5. Technological Development Trends

**SO\textsubscript{2} Injection**

- **Acid Gas Injection Route**
  - Gas sweetening in reservoir;
  - Sulphur surplus deposited in the formation;
  - Possibly influence the reservoir production?
5. Technological Development Trends

**Sulphur Storage Technology**

- **Above ground sulphur storage**
  - Acid run-off, dust generation
  - Operation & maintenance

- **Long term storage improvements**
  - Surface treatment
    - Limestone
    - Applied chemical treatment
  - Burial
    - Above ground
    - Below ground
    - Use natural geography
      - Valleys
      - Underground cavities
      - Man-made cavities
6. Conclusions
6. Conclusions

- Establishing a good basis of design, especially acid gas storage feasibility is critical.
- Highly sour gases will benefit from cheaper processing options to enable development.
- Economics will be aided by:
  - EOR credits using CO2 or potentially mixed acid gas.
  - Potentially carbon credits or saving charges on CO2 emissions.
  - Other drivers: Strategic, future resource values.
- Evaluation of schemes featuring high pressure acid gas handling is strongly influenced by safety considerations for both current and developing technologies.
- The reliability of economic AGI processes will be strongly dependent on developing technology:
  - Large GT driven centrifugal AG compressors.
  - New separation processes.
The end

Thank you for your attention