Advanced Sulfur Technologies for Mega Size Sulfur Complexes in Arid Environments

Presented by Thomas Chow
Presentation Agenda

- Introduction
- Fluor Patented Air Demand Feedback Control Systems
- Fluor/GAA Patented Oxygen Enrichment Claus Technology
- Fluor Proprietary Claus Tail Gas Treating Technology
  - Fluor Patented Low Energy Direct Contact Condenser Design
  - Absorber Solvent: Flexsorb® versus MDEA
- Fluor/GAA Patented Liquid Sulfur Degassing Technology
INTRODUCTION
SRU/TGTU Design Challenges for Mega Size Gas Development Projects in Desert Environment

- **Feedstock**
  - Sour gas (low % H₂S, say 20 – 40 mole % H₂S)
  - High levels of CO₂ (~30 mole %): Weak acid gas feed

- **Capacity**
  - World’s Largest SRU/TGTU Single Train Complex (25,000 MTD)
  - Limitations on size of equipment that can be shop fabricated

- **Strict Environmental Regulations**
  - Recover 99.9+% sulfur
  - Achieve < 500 mg/Nm³ SO₂ in Incinerator stack gas

- **Climate**
  - Extremely high ambient temperatures
  - No cooling water for process applications – must use refrigerant
Modified Claus Sulfur Recovery Unit
Hydrogenation/Amine Tail Gas Treating

HYDROGENATION SECTION OF TGTU

TAIL GAS

HYDROGENATED TAIL GAS

CONDENSED WATER

STEAM

AMINE SECTION OF TGTU

VENT TO ATMOS

FILTER

LEAN AMINE PUMP

RICH AMINE PUMP

ACID GAS

RECYCLE TO SRU

SOUR WATER

HYDROGENATED TAIL GAS

STEAM

CONDENSED WATER

FLUOR®
FLUOR PATENTED AIR DEMAND FEEDBACK CONTROL SYSTEMS
SRU Process and Control Overview

ACID GASES

AIR

FUEL GAS

SULFUR VENT GASES

No. 1 CLAUS THERMAL STAGE

CLAUS CATALYTIC STAGES

No. 2 CLAUS THERMAL STAGE

TGTU HYDROGENATION SECTION

TGTU SOLVENT SECTION

ACID GASES

AIR

FUEL GAS

LIQUID SULFUR

LIQUID SULFUR
SRU Air Demand Feedback Control System

[Diagram of SRU Air Demand Feedback Control System]

- ACID GASES
- FUEL GASES
- SULFUR GASES
- AIR

No. 1 THERMAL STAGE

No. 2 THERMAL STAGE

No. 1 TAIL GAS ANALYZER

No. 2 TAIL GAS ANALYZER

COMMON TAIL GASES ANALYZER

TO TGTU

F(x)
Fluor’s patented Air Demand Feedback Control System to ensure the desired H$_2$S to SO$_2$ ratio is attained in the effluent stream of each thermal stage.

Separate gas analyzers are provided at the outlet of each thermal stage in addition to the gas analyzer at the outlet of the Last Sulfur Condenser.
FLUOR / GAA PATENTED
OXYGEN ENRICHMENT
CLAUS TECHNOLOGY
Fluor’s Advanced Sulfur Technology

Oxygen Enrichment Technology

For

Processing Capacity Expansion

&

Reducing Equipment Sizes of New Plants
## Claus Chemistry

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{H}_2\text{S} + \frac{3}{2}\text{O}_2$</td>
<td>$\rightarrow \text{SO}_2 + \text{H}_2\text{O}$</td>
</tr>
<tr>
<td>$2\text{H}_2\text{S} + \text{SO}_2$</td>
<td>$\leftrightarrow 3\text{S} + 2\text{H}_2\text{O}$</td>
</tr>
<tr>
<td>$3\text{H}_2\text{S} + \frac{3}{2}\text{O}_2$</td>
<td>$\rightarrow 3\text{S} + 3\text{H}_2\text{O}$ (Overall)</td>
</tr>
</tbody>
</table>

- Nitrogen does not participate
Fluor Oxygen Enrichment Technology -- Principle for SRU Capacity Expansion

The principle for SRU capacity expansion is based on the chemical reaction:

\[ \text{H}_2\text{S} + \frac{1}{2} \text{O}_2 + x \text{N}_2 \rightarrow \text{H}_2\text{O} + \text{S} + x \text{N}_2 \]  

(Condensed)

<table>
<thead>
<tr>
<th>O\textsubscript{2} %</th>
<th>x</th>
<th>Tail Gas Flow Rate</th>
<th>Capacity Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>2</td>
<td>1 + 2 = 3</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>0.5</td>
<td>1 + 0.5 = 1.5</td>
<td>100</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
<td>1</td>
<td>200</td>
</tr>
</tbody>
</table>
Three Levels of Oxygen Enrichment

Adiabatic Flame Temperature

% Oxygen

Capacity Increase

Refractory Limit

1760°C 3200°F
1649°C 3000°F
1538°C 2800°F
1427°C 2600°F
1316°C 2400°F
1204°C 2200°F

21 28 45

250 200 150 100

% of Design Capacity

Low Medium High

1204°C 2200°F
1316°C 2400°F
1427°C 2600°F
1538°C 2800°F
1649°C 3000°F
1760°C 3200°F
Low Level Oxygen Enrichment

- Oxygen Stream Introduced to Air Stream
- Limited to 28-30% Oxygen Enrichment
Three Levels of Oxygen Enrichment
Oxygen Stream Introduced Directly to High Intensity Oxygen Burner

Oxygen Enrichment Limited by Working Temperature of the Refractory
Three Levels of Oxygen Enrichment

Adiabatic Flame Temperature

% Oxygen

Capacity Increase

Refractory Limit

Low
Medium
High

% of Design Capacity
Fluor/GAA Patented COPE II Oxygen Enrichment Claus Technology

**Diagram Description:**
- **NH₃** flows into the burner.
- **H₂S** and **Air** enter the burner along with **O₂**.
- The **Eductor** is connected to the burner.
- **Air / Steam** are added to the system.
- The mixture goes through the **Reheater** and the **Converter**.
- The process continues through various stages until it reaches the **Condenser**.
- The final output is the **Sulfur Pit**.
- Recycle Stream Added to Moderate Flame Temperature to Desired Set Point
- Enrichment up to 100% Oxygen; Potentially Yields up to 150% SRU Capacity Increase
Process Benefits

- Facilitate contaminant destruction
- Enhance SRU sulfur recovery efficiency
- Accommodate process fluctuations
- Enhance operational flexibility and operability
- Relieve tight pressure profile
- Increase plant processing capacity; provide spare plant capacity; or smaller equipment
Economic Benefits

- Reduced Equipment Sizes in Grassroots Facilities
- Incremental Capacity Increase for Revamps
- Spare Capacity
- Short Implementation Schedule for Revamps
- Improved Logistics of Equipment Transportation and Procurement - For Mega Size Facilities
- Compact Footprint
Relative Costs Associated with Incremental Capacity

- Cost effective alternative to construction of new SRU/TGTU

<table>
<thead>
<tr>
<th>Increase in SRU Capacity</th>
<th>Est. Cost for New SRU/TGTU, $MMUSD(^1)</th>
<th>Est. Cost for Revamp w/ O(_2) Enrich., $MMUSD(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 – 30%</td>
<td>18</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>70 – 80%</td>
<td>32</td>
<td>2</td>
</tr>
<tr>
<td>150 – 160%</td>
<td>45</td>
<td>7</td>
</tr>
</tbody>
</table>

Notes:

1. Based on US Gulf Coast, 2nd Quarter 2010 US dollars excluding site preparation, contingency, escalation, owner’s cost, license fees, catalysts and chemicals cost.
2. Does not include any oxygen supply cost.
# Example of Economic Benefits O2 Enrichment Technology for New SRU/TGTU

## 5,000 MTPD CAPACITY SRU/TGTU

<table>
<thead>
<tr>
<th></th>
<th>Air Only Four SRU Trains</th>
<th>O₂ Enrichment¹ Two SRU Trains</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Differential Total Installed Cost²</strong></td>
<td>Base</td>
<td>Base – 50%</td>
</tr>
<tr>
<td><strong>Differential Net Capital Cost³</strong></td>
<td>Base</td>
<td>Base – 44%</td>
</tr>
<tr>
<td><strong>Differential Operating Cost (NPV)⁴,⁵</strong></td>
<td>Base</td>
<td>Base + 21%</td>
</tr>
<tr>
<td><strong>NPV of Total Savings for 20 Year Life Cycle⁶</strong></td>
<td>Base</td>
<td>Base – 40%</td>
</tr>
</tbody>
</table>

**Notes:**

1. Oxygen Enrichment level is above 85% to provide the 5,000 MTPD processing capacity.
2. Does not include cost of an oxygen supply system.
3. Considers cost of new, dedicated oxygen supply system.
4. Operating cost based on steam cost of $6.17/tonne, power cost of $24.50/MWh, and 8000 operating hours per year.
5. NPV based on a 20 year plant life, an 8% discount rate, and 2% per year escalation.
6. Considers capital cost and operating costs for a 20 year plant life cycle.
# Economic Benefits associated with Spare Train Capacity via Oxygen Enrichment Technology

<table>
<thead>
<tr>
<th>Achieving Spare Capacity Via Oxygen Enrichment</th>
<th>4 Operating + 1 Spare</th>
<th>4 Operating w/ $O_2$ Enrichment Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration</td>
<td>4 Operating + 1 Spare</td>
<td>4 Operating w/ $O_2$ Enrichment Capability</td>
</tr>
<tr>
<td>Total Units</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Capacity</td>
<td>5000 MTPD</td>
<td>5000 MTPD</td>
</tr>
<tr>
<td>$O_2$ Enrichment Level</td>
<td>N/A</td>
<td>Medium Level (~33%)</td>
</tr>
<tr>
<td>Required Equipment</td>
<td>1 spare SRU/TGTU train</td>
<td>Implement $O_2$ Burners</td>
</tr>
<tr>
<td>Effect on Capital Cost</td>
<td>Cost of 1 SRU/TGTU train</td>
<td>$O_2$ Burners + $O_2$ Supply System</td>
</tr>
</tbody>
</table>
## Choosing The Right O₂ Supply Mode

<table>
<thead>
<tr>
<th>Supply Features</th>
<th>LOx</th>
<th>VSA</th>
<th>Cryo</th>
<th>Pipeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Range T/D</td>
<td>0-50</td>
<td>50-300</td>
<td>100+</td>
<td>100+</td>
</tr>
<tr>
<td>Relative Price Range $/T</td>
<td>60-110</td>
<td>35-50</td>
<td>30-45</td>
<td>25-45</td>
</tr>
<tr>
<td>Commitment</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Coproduct N₂</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Maybe</td>
</tr>
<tr>
<td>Time to Implement</td>
<td>1-2 Months</td>
<td>10-12 Months</td>
<td>12-14 Months</td>
<td>6-8 Months</td>
</tr>
<tr>
<td>Location Limitations</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Application - Best Fit</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Use Pattern</td>
<td>Variable</td>
<td>Steady</td>
<td>Steady</td>
<td>Variable</td>
</tr>
</tbody>
</table>

**LOX** = Liquid Oxygen  
**VSA** = Vacuum Swing Adsorber  
**Cryo** = Cryogenic Air Separation Plant  
**Pipeline** = Gas Piped in from Remote Air Separation Plant
FLUOR PROPRIETARY CLAUS TAIL GAS TREATING TECHNOLOGY
Fluor’s Conventional Claus Tail Gas Hydrogenation/Amine Technology

HYDROGENATION SECTION OF TGTU → AMINE SECTION OF TGTU

TAIL GAS
AIR
FUEL GAS
STEAM

HYDROGENATED TAIL GAS

CONDENSED WATER
LEAN AMINE PUMP
RICH AMINE PUMP

VENT TO ATMOS

ACID GAS RECYCLE TO SRU

SOUR WATER

AMINE SECTION OF TGTU

HYDROGENATION SECTION OF TGTU

STEAM
AIR
FUEL GAS

CONDENSED WATER
LEAN AMINE PUMP
RICH AMINE PUMP

FILTER

SOUR WATER

ACID GAS RECYCLE TO SRU
Reducing Gas Generation Reaction

Basic chemistry for generation of reducing gases is described by the following reaction:

- \( \text{CH}_4 + \frac{1}{2} \text{O}_2 \rightleftharpoons \text{CO} + 2 \text{H}_2 \)
Hydrogenation Reactions

Hydrogenation and hydrolysis reactions for the four primary sulfur constituents are as follows:

- $S + H_2 \rightarrow H_2S \quad (1)$
- $SO_2 + 3 H_2 \rightarrow H_2S + 2 H_2O \quad (2)$
- $CS_2 + 2 H_2O \rightarrow 2 H_2S + CO_2 \quad (3)$
- $COS + H_2O \rightarrow H_2S + CO_2 \quad (4)$
Hydrogenation Technology

- Conventional CoMo Catalyst
  - Feed Temperature
    - 274°C - 285°C (525°F - 545°F)
  - Achievable COS Conversion
    - Higher

- Low Temperature CoMo Catalyst
  - Feed Temperature
    - 232°C - 246°C (450°F - 475°F)
  - Achievable COS Conversion
    - Lower
Fluor Advanced Low Temperature Claus Tail Gas Hydrogenation/Amine Technology

HYDROGENATION SECTION OF TGTU

TAIL GAS

HYDROGENATED TAIL GAS

STEAM

CONDENSED WATER

FLUOR

RICH AMINE PUMP

LEAN AMINE PUMP

AMINE SECTION OF TGTU

VENT TO ATMOS

FILTER

ACID GAS

RECYCLE TO SRU

SOUR WATER

HYDROGENATED TAIL GAS

STEAM

CONDENSED WATER

RICH AMINE PUMP

LEAN AMINE PUMP
Hydrogenation/Amine Tail Gas Treating

Hydrogenation/Hydrolysis Section
- Sulfur vapor, SO$_2$, CS$_2$, and COS converted to H$_2$S
- CoMo catalyst

Contact Condensing/Desuperheating Section
- Reactor effluent cooled by generation of LP steam
- Desuperheating section with circulating alkaline solution
  - Protects downstream solvent from degradation due to potential SO$_2$ slip
- Contact condensing section removes water vapor from tail gas
FLUOR PATENTED LOW ENERGY DIRECT CONTACT CONDENSER DESIGN
Fluor Advanced Low Temperature Claus Tail Gas Hydrogenation/Amine Technology

Hydrogenation Section of TGTU

- Tail Gas
- Steam

Amine Section of TGTU

- Condensed Water
- Hydrogenated Tail Gas
- Lean Amine Pump
- Rich Amine Pump
- Filter
- VENT TO ATMOS
- Acid Gas Recycle to SRU
- Sour Water
Conventional DCC Process

- Hot tail gas desuperheated
- Tail gas further cooled
- Excess water rejected
- PA cooled by air, then trim cooling
- Cooled gas to absorber
Economic Incentive to Minimize DCC Effluent Gas Temp.

HIGHER GAS EFFlUENT TEMPERATURE…

- Reduces H$_2$S removal by solvent
- Often requires expensive solvent
- Carries more water that dilutes the solvent
Economic Incentive to Minimize DCC Effluent Gas Temp.

HIGHER GAS EFFLUENT TEMPERATURE...

- Reduces $H_2S$ removal by solvent
- Often requires expensive solvent
- Carries more water that dilutes the solvent

TO MINIMIZE...

- Target 2.8 °C (5°F) approach between effluent gas and process water inlet
- Target 35 – 46 °C (95 - 115°F) for process water inlet
DCC Optimization: Maximize Air Cooling

- Maximize air cooler size, duty
- But limited by air/process water approach, target 8 - 11°C
- Smaller approaches escalate air cooler size and cost with diminishing benefits
- For 50°C air, process water cooled to 58°C – 61°C
- Rest of cooling by refrigeration ------ Expensive!

Expensive!
DCC Optimization: Minimizing PA Rate

- Hotter process water
- Higher portion of duty can be removed by air
- Water T out of bed gets closer to gas T in
- Requires taller bed, expensive distributors
- More prone to mal-distribution problems!
- Good practice: Keep \((\text{gas in}) – (\text{water out}) \geq 10^\circ F\)
- Close approach situation: “Pinch” at the bed inlet
Condenser Packed Bed Operation

4 Stages

Pinch

$T_{vap}, F$

$T_{liq}, F$
** Improved DCC Process

- Splits DCC bed into two, with separate PA circuits
- Bottom circuit air cooled
- Top circuit refrigerant or water-cooled

**Refrieg duty minimized!**
Comparison: Conventional vs. Patented Design

**Conventional Design**

- **DESUPERHEATING SECTION**
  - HOT TAIL GAS: 620 Mb/h
  - 167°F
  - 1,400 Mb/h

- **DIRECT CONTACT CONDENSER SECTION**
  - GAS TO ABSORBER: 120°F
    - WATER: 85 Mb/h
    - 167°F

- **Make-up Water**
  - 32 Mb/h

**Improved Design**

- **Upper Direct Contact Condenser Section**
  - GAS TO ABSORBER: 120°F
    - WATER: 35 Mb/h
    - 143°F

- **Lower Direct Contact Condenser Section**
  - GAS TO ABSORBER: 120°F
    - WATER: 50 Mb/h
    - 154°F

- **Make-up Water**
  - 32 Mb/h

**Key Values**

- **Desuperheating Section**
  - HOT TAIL GAS: 620 Mb/h
  - 167°F
  - 1,400 Mb/h

- **Conventional Design**
  - Desuperheating: 70 MMBtu/h
  - Direct Contact Condenser: 55 MMBtu/h

- **Improved Design**
  - Desuperheating: 39 MMBtu/h
  - Upper Direct Contact Condenser: 86 MMBtu/h

**Additional Values**

- **GAS TO ABSORBER**
  - 2,900 Mb/h
  - 390°F

- **Make-up Water**
  - 1,400 Mb/h
  - 32 Mb/h

- **Additional Temperatures**
  - 115°F
  - 138°F
  - 157°F
Upper Bed Operation

T_{\text{liq}}, F

2 Stages

F_{\text{vap}}, F
Lower Bed Operation

2 Stages

T_{\text{vap}, F}, T_{\text{liq}, F}

135
140
145
150
155
160
165
170

135 140 145 150 155 160 165 170

F, F

1

2
Advantages of Smaller Beds

- Smaller bed LMTDs higher than single bed LMTD
- Less packing is needed for the Improved Design
- Shorter beds eliminate need for expensive liquid distributors
# Economic Benefits of Patented DCC Process Scheme

<table>
<thead>
<tr>
<th></th>
<th>Conventional Design</th>
<th>Patented Design</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capacity</strong></td>
<td>Large Scale Plant</td>
<td>Large Scale Plant</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>Middle East</td>
<td>Middle East</td>
</tr>
<tr>
<td><strong>Gas Rate</strong></td>
<td>Base</td>
<td>Base</td>
</tr>
<tr>
<td><strong>Gas Inlet/Outlet Temp.</strong></td>
<td>Base</td>
<td>Base</td>
</tr>
<tr>
<td><strong>Cooling Medium</strong></td>
<td>Air + Propane Refrig</td>
<td>Air + Propane Refrig</td>
</tr>
<tr>
<td><strong>Temperature Approach on Top of Bed</strong></td>
<td>5°F (2.7°C)</td>
<td>5°F (2.7°C)</td>
</tr>
<tr>
<td><strong>Temperature Approach on Bottom of Bed</strong></td>
<td>10°F (5.4°C)</td>
<td>15°F (8.3°C)</td>
</tr>
<tr>
<td><strong>Total Packing Height</strong></td>
<td>Base</td>
<td>Slightly &lt; Base</td>
</tr>
</tbody>
</table>
## Economic Benefits of Patented DCC Process Scheme

<table>
<thead>
<tr>
<th></th>
<th>Conventional Design</th>
<th>Patented Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column Internals Costs</td>
<td>Base</td>
<td>Slightly &lt; Base</td>
</tr>
<tr>
<td>Tower Height &amp; Diameter</td>
<td>Base</td>
<td>Base</td>
</tr>
<tr>
<td><strong>Trim Cooler Duty</strong></td>
<td>70 MMBtu/h</td>
<td>39 MMBtu/h</td>
</tr>
<tr>
<td>Air Cooler Duty</td>
<td>55 MMBtu/h</td>
<td>86 MMBtu/h</td>
</tr>
<tr>
<td>Power Savings NPV&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Base</td>
<td>$13 MM</td>
</tr>
<tr>
<td>Capital Cost Savings</td>
<td>Base</td>
<td>$40 MM</td>
</tr>
<tr>
<td>Total Savings</td>
<td>Base</td>
<td>$53 MM</td>
</tr>
</tbody>
</table>

**Notes:**

1. NPV (net present value) based on 8% discount rate, $24.5/MWh and 20 year plant life
Summary

- Single PA DCCs in hot and arid regions require excessive capital and energy costs in trim cooling.
- Fluor’s Patented DCC technology transfers ≈ 50% of trim cooling duty to air coolers by using two PA loops instead of one.
- Resulting power / capital cost savings can be large.
- As added benefit, two small packed beds are more reliable and robust than one large packed bed.
- Good process optimization can save energy and capital.
ABSORBER SOLVENT
FLEXSORB® VERSUS MDEA
**Amine Section**

- **Absorber:** Solvent preferentially absorbs \( \text{H}_2\text{S} \)
  - Treated vapor to Incinerator
  - Rich solvent to Regenerator

- **Regenerator:** Stripping with LP steam to remove \( \text{H}_2\text{S} \) from solvent
  - \( \text{H}_2\text{S} \) rich vapor recycled to SRU
  - Lean solvent circulated back to Absorber

- **Solvent Options**
  - MethylDiEthanolAmine (MDEA): Generic, Selective, and Formulated
  - Proprietary Amine: FLEXSORB® SE and FLEXSORB® SE Plus
Selection of Tail Gas Treating Solvent

◆ Formulated MDEA
  – Study investigated 45 wt. % MDEA with proprietary additives
  – Tertiary amine → natural selectivity for H₂S over CO₂

◆ FLEXSORB® SE Plus
  – Sterically-hindered amine licensed by ExxonMobil
  – Bulky side group inhibits reaction with CO₂ → selective for H₂S
  – Primary and secondary amines = stronger bases, enabling higher amine loadings at same H₂S partial pressure
  – Lower amine circulation rate → decreased capital & operating costs
Selection of Tail Gas Treating Solvent

- Required Absorber temperature to meet environmental specifications
  - Based on commercial operating experience
    - Formulated MDEA = 38°C
    - FLEXSORB® SE Plus = 49°C

- Middle East Region maximum summer ambient temperature = 50°C
  - No cooling water available for process cooling
  - All cooling accomplished via air cooling followed by trim cooling using propane refrigeration
  - Decrease in required cooling duty results in substantial equipment, utility, and plot space savings
Process Advantages of FLEXSORB® SE Plus

- **High performance**
  - Ensures compliance with Middle East environmental regulations

- **Decreased foaming tendency relative to MDEA**

- **Higher tolerance to heat stable salts (HSS)**
  - TGTUs using FLEXSORB® SE Plus tolerate 10-12 wt% HSS
  - MDEA maximum allowable HSS concentration = 4-5 wt%

- **Proven to have higher reliability, flexibility, and operational simplicity**
Economic Advantages of FLEXSORB® SE Plus

- **Lower capital investment**
  - Circulation rate decreased ~50% → Smaller equipment

- **Lower operating expenses**
  - Reboiler duty decreased → Annual steam consumption decreased 65%
  - Higher Absorber operating temperature → Smaller refrigeration unit
  - Lower circulation rate → Decreased electric power consumption for pumps
  - Total annual power consumption decreased 50%

- **Lower plot space requirement**
  - Smaller equipment & smaller refrigeration unit → Decreased footprint

- **Higher solvent cost & license fee offset by savings in other areas**
Advantages of FLEXSORB® SE Plus vs MDEA

<table>
<thead>
<tr>
<th>Feature</th>
<th>Formulated MDEA</th>
<th>FLEXSORB® SE Plus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance, mg/Nm$^3$ SO$_2$ in stack gas</td>
<td>&lt; 500</td>
<td>&lt; 500</td>
</tr>
<tr>
<td>Absorber Operating Temperature, °C</td>
<td>38</td>
<td>49</td>
</tr>
<tr>
<td>Gas and Lean Amine Cooling Requirement</td>
<td>Air Cooling + Large Propane Refrigeration</td>
<td>Air Cooling + Small Propane Refrigeration</td>
</tr>
<tr>
<td>Plot Space Requirement</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Equipment Transportation Logistic</td>
<td>Equipment Size outside Logistic Limits</td>
<td>Equipment Size within Logistic Limits</td>
</tr>
<tr>
<td>Robustness</td>
<td>High</td>
<td>Very High</td>
</tr>
</tbody>
</table>
## Magnitude of Savings

**FLEXSORB® SE Plus** offers an overall savings of ~30% (net present value) over Formulated MDEA based on 20 year plant life.

<table>
<thead>
<tr>
<th>Differential Capital Cost</th>
<th>Formulated MDEA</th>
<th>FLEXSORB® SE Plus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment, MM$</td>
<td>Base</td>
<td>Base – 10%</td>
</tr>
<tr>
<td>Solvent Initial Fill, MM$</td>
<td>Base</td>
<td>Base + 150%</td>
</tr>
<tr>
<td>Total, MM$</td>
<td>Base</td>
<td>Base – 6%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Differential Operating Cost</th>
<th>Formulated MDEA</th>
<th>FLEXSORB® SE Plus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam, MM$/yr</td>
<td>Base</td>
<td>Base – 65%</td>
</tr>
<tr>
<td>Solvent Make-up, MM$/yr</td>
<td>Base</td>
<td>Base + 70%</td>
</tr>
<tr>
<td>Power, MM$/yr</td>
<td>Base</td>
<td>Base – 50%</td>
</tr>
<tr>
<td>Total, MM$/yr</td>
<td>Base</td>
<td>Base – 60%</td>
</tr>
<tr>
<td>Net Present Value, MM$</td>
<td>Base</td>
<td>Base – 57%</td>
</tr>
</tbody>
</table>
Summary

- Hydrogenation/Amine TGTU required to meet $\text{SO}_2$ emission limits

- **FLEXSORB® SE Plus** offers numerous advantages over MDEA
  - Decreased capital investment
  - Decreased operating expenses
  - Decreased plot space requirement
  - Enhanced Equipment Delivery Logistics
  - Increased reliability, flexibility, and simplicity of operation

- Overall savings of ~30% over 20 year plant life
Benefits of Fluor Hydrogenation/Amine Tail Gas Treating Technology

- Highest Sulfur Recovery Efficiency Ever Achievable
  - Up to 99.99+% 
  - Design with No Incinerator -- Savings in Capital Cost and Fuel Gas Operating Cost 
  - New Patented Technology with Zero Emission
FLUOR/GAA PATENTED “D’GAASS” LIQUID SULFUR DEGASSING TECHNOLOGY
Sulphur Degassing Technology

“In-pit” versus “Out-of-pit”

Sulphur Degassing Technologies
Sulphur Degassing Process

- **In-Pit Technology**
  - Fluor
  - Shell
  - Lurgi / Elf Aquitain / SNEA

- **Out-of-Pit Technology**
  - GAA
In-Pit Sulphur Degassing Process

- **Vent Air**
- **Liquid Sulphur**
- **Stripping Air**
- **Atomized Sulphur Spray Nozzles**
- **Degassing Compartments**
- **Sweep Air**

**Sulphur Pit / Vessel**
Out-of-Pit Sulphur Degassing Process
Include Contactor, cooler, & major controls
GAA D’GAASS “Out-of-Pit” Liquid Sulfur Degassing Technology

◆ The only Patented “Out-of-Pit” Liquid Sulfur Degassing Technology with Proven Commercial Experience

◆ A Fast Degassing Process Capable of Achieving Degassed Liquid Sulfur Specification of Less than 10 ppmw $\text{H}_2\text{S}/\text{H}_2\text{S}_x$ within One Hour -- Compare to 24 hours Requirement by Most Competing Sulfur Degassing Technologies

◆ This Technology allows the Replacement of A Normal 3 days Size Sulfur Pit with a 1 to 4 hours Capacity Sulfur Receiving Vessel -- Significant Reduces Plot Plan Size and Minimizes Undesired Sulfur Pit Corrosion Issues.
THANK YOU FOR YOUR ATTENTION