TRIMMING RESIDUE CO$_2$
WITH MEMBRANE TECHNOLOGY
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INTRO

• The Problem (Opportunity)
• The Hunt for the Best Answer
• The Solution
DEFS Mewbourn Plant

- Weld County Colorado
- 60 -70 MMscfd Inlet Gas Rate
- 2 Refrigerated JT Trains
- EG Dehydration
- DJ Basin/Wattenberg Gas
The Problem

• Residue Sales Gas Exceeding 3 Mole % CO$_2$
• 6 Month Deadline to Remedy
• Minimize Capital and Operating Costs
Possible Solutions

• Amine Treating
• Blending
• Deep Liquids Recovery
• Membrane Separation
Amine Treating

- Tried and True
- Capital Cost
- Operating Cost
- Complexity
Amine Treating

- Control of Treating Target
- Permitting
- Waste Streams
- DEA, MDEA, Blends
Typical Amine Process

Where does this vent go?
HYDROCARBON SOLUBILITY IN AMINE

• Flash Tank 85 – 90% Hydrocarbon
  – TOX
  – Fuel
  – Recycle/Re-process
  – Flare
  – Vent to atmosphere
HYDROCARBON SOLUBILITY IN AMINE

• Stripper/Still 0.1% – 0.3% Hydrocarbon
  – TOX
  – SRU
  – Further processing
  – Flare
  – Vent to atmosphere
Blending

- Dilution of CO$_2$
- Sweet Gas Not Conveniently Available
- Costs to Lay Pipe for Supply
Deep Liquids Recovery

- Incremental Refrigeration
- Cryogenic Expansion
- NGL Infrastructure
- Defers Treating to Liquid Sales
- Costs
Membrane Separation

- Technology Step Out for DEFS
- Capital Cost
- Operating Cost
- Simplicity
- Project Schedule
Membrane Separation

- Control of Treating Target
- Permitting
- No Waste Streams
- Cellulose Acetate, Hollow Fiber, …
Membrane Application Drivers

- Water “Dry” Feed
- Hydrocarbon “Dry” Feed
- High Pressure Feed
- Low Pressure Permeate
- Temperature Control
Membrane Design Objectives

• Trim CO2 to Under 3.0 Mole %
• Consume all Permeate as Fuel
• Ensure Flexibility to Meet Target
### Gas Compositions (Mole%)

<table>
<thead>
<tr>
<th>Plant Inlet</th>
<th>Membrane Feed</th>
<th>Membrane Residue</th>
<th>Blended Residue</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_1</td>
<td>C_1</td>
<td>C_1</td>
<td>C_1</td>
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<tr>
<td>82.3</td>
<td>82.37</td>
<td>82.69</td>
<td>83.0</td>
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<tr>
<td>C_2</td>
<td>C_2</td>
<td>C_2</td>
<td>C_2</td>
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<tr>
<td>11.9</td>
<td>11.53</td>
<td>11.96</td>
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<tr>
<td>C_3</td>
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<td>C_3</td>
<td>C_3</td>
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<tr>
<td>2.2</td>
<td>2.22</td>
<td>2.34</td>
<td>2.29</td>
</tr>
<tr>
<td>C_4’s</td>
<td>C_4’s</td>
<td>C_4’s</td>
<td>C_4’s</td>
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<tr>
<td>0.4</td>
<td>0.46</td>
<td>0.47</td>
<td>0.46</td>
</tr>
<tr>
<td>C_5’s</td>
<td>C_5’s</td>
<td>C_5’s</td>
<td>C_5’s</td>
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<tr>
<td>0.03</td>
<td>0.00</td>
<td>0.04</td>
<td>0.05</td>
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<tr>
<td>C_6+</td>
<td>C_6+</td>
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<td>0.01</td>
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<td>CO_2</td>
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<td>CO_2</td>
<td>CO_2</td>
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<tr>
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<td>2.85</td>
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<tr>
<td>N_2</td>
<td>N_2</td>
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<tr>
<td>0.28</td>
<td>0.29</td>
<td>0.29</td>
<td>0.28</td>
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</tbody>
</table>
Feed Pretreatment

- Solids
- Aerosols
- Free Liquids
- BTEX & Other Aromatics
Membranes

- Grace – KPS USA
- Spiral Wound Cellulose Acetate
- 16 Tubes
- 4 Banks
- 4 Tubes per Bank
- 7 Membrane Modules per Tube
Membrane Modules

- 8.26” I.D. x 10” Pipe Tubes
- 42” Long Modules/Sections
- Spiral Wound
- About 45 pounds per Module
Grace Cellulose Acetate Spiral Wound Module

• Manufactured By Grace Since 1984

• Used In Over 220 Natural Gas Applications

• Robust Design – 1800 PSI Differential Pressure

• Light Weight/Easy To Handle – 8.25” (Diameter) x 42” (Long) - < 45 Lbs.
Flat Sheet Cellulose Acetate Membrane

**Asymmetric Membrane**

- **Dense Active Layer** (0.1 – 1 micron)
- **Porous Membrane Sublayer** (200 micron)
- **Open Support Material** (for flat sheet membranes)
Flat Sheet Cellulose Acetate Membrane

The photo above is an electron microscopic image of a typical flat sheet membrane.
Initial Membrane Loading

• 84 Membrane Modules
• 21 Modules per Bank
• 50% of Area in Service
• 2 Banks on Line
## Permeate – Fuel Blend (Mole%)

<table>
<thead>
<tr>
<th>Permeate</th>
<th>Blended Fuel</th>
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</thead>
<tbody>
<tr>
<td>C(_1)</td>
<td>C(_1)</td>
</tr>
<tr>
<td>77.27</td>
<td>76.7</td>
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<tr>
<td>C(_2)</td>
<td>C(_2)</td>
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<tr>
<td>6.70</td>
<td>11.89</td>
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<tr>
<td>C(_3)</td>
<td>C(_3)</td>
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<tr>
<td>0.85</td>
<td>2.09</td>
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<tr>
<td>C(_4’s)</td>
<td>C(_4’s)</td>
</tr>
<tr>
<td>0.17</td>
<td>0.32</td>
</tr>
<tr>
<td>C(_5’s)</td>
<td>C(_5’s)</td>
</tr>
<tr>
<td>0.00</td>
<td>0.03</td>
</tr>
<tr>
<td>C(_6^+)</td>
<td>C(_6^+)</td>
</tr>
<tr>
<td>0.00</td>
<td>0.06</td>
</tr>
<tr>
<td>CO(_2)</td>
<td>CO(_2)</td>
</tr>
<tr>
<td>14.68</td>
<td>8.71</td>
</tr>
<tr>
<td>N(_2)</td>
<td>N(_2)</td>
</tr>
<tr>
<td>0.33</td>
<td>0.20</td>
</tr>
</tbody>
</table>
Fuel Requirements

- Engine Performance
- Lower Btu – Higher Flow
- Emissions Performance
- “Contaminant” Content
- Air Fuel Ratio Controllers
- Variability
Residue Sales Quality

- CO$_2$ on Spec (<3%)
- Wobbe on Spec
- Btu on Spec
- S.G. on Spec
- Less Water
- Less H$_2$S
Conclusion

- Cost Effective
- Rapid Deployment
- Flexible
- Simple
- No Waste
- Easy to Redeploy
General Utilization Curve

Public Service Company of Colorado
General Utilization Curve

1140
1120
1100
1080
1060
1040
1020
1000
980
960
940

0.54 0.56 0.58 0.60 0.62 0.64 0.66 0.68 0.70 0.72 0.74 0.76

Specific Gravity

Heating Value (Btu/scf)

1279 maximum Wobbe
1326 target Wobbe
1273 minimum Wobbe
0.59 min SG

Wobbe = Hv / (SG^(1/2))
Hv = Heating Value
SG = Specific Gravity

14.73 psia, 60°F
Gross, Dry

0.74 max SG

131 Btu/scf maximum

The Utilization Curve is a general representation of the natural gas quality that is acceptable from a utilization standpoint. However, the gas composition must be known to determine if a supply is acceptable and can be interchanged with supplies in Company's system. Company reserves the right in all instances to evaluate gas composition to determine system compatibility and to refuse any gas that is unacceptable from a utilization basis.
CA Spiral Wound Membrane Loading
CO2 FLUX & SELECTIVITY VS. TIME
DEFS MEWBOURN MEMBRANE PLANT

Note 1.0 Equals Design Values
Start Up - 4/15/04
KPS US – DEFS Mewbourn Membrane Plant

ACTUAL CASE - 42 ELEMENTS - 16 APR 04
KPS US – DEFS Mewbourn Membrane Plant

DESIGN CASE - 46 ELEMENTS
CA Spiral Wound Membrane Housing Design
Grace Spiral Wound Membrane Construction

A
- Sealed Edges
- Membrane
- Permeate Flow through Spacer
- Permeate Flow
- Membrane

B
- Membrane Leaf
- Permeate Flow into Collector Tube
- Perforated Collector Tube
- Flow from Collector Tube to Process Piping
- Feed Flow Across Membranes

C
- Feed Spacer
- Membrane Leaf and Feed Spacer Rolled Around Collector Tube
- Feed Flow Through Spacer
Grace Spiral Wound Membrane Construction

GRACE Cellulose Acetate
Spiral Wound Membrane

FEED
PERMEATE
FEED SPACER
MEMBRANE
PERMEATE SPACER
MEMBRANE
FEED SPACER
RESIDUE
RESIDUE