A MICRO-SCALE N₂ REJECTION PLANT TO UPGRADE LOW-BTU MARGINAL GAS

Saibal Bhattacharya¹, K. David Newell¹, W. Lynn Watney¹, and Michael Sigel²

1) Kansas Geological Survey, Lawrence, KS;
2) American Energies Corp, Wichita, KS

Project Funding: Stripper Well Consortium
(The Pennsylvania State University)

Steve Moore: Proposed the initial plant design and the idea behind cost-effective low-BTU upgradation

Alan DeGood: Financial Support, Encouragement, and Patience
U.S. natural gas reserves around 204 tcf (EIA, 2006)

Sub pipeline quality gas - CO$_2$ and/or N$_2$ contaminated

- 17.5 tcf in Midcontinent region (Hugman and others, 1990)
- 9 tcf in Rocky Mountain region (Hugman and others, 1990)
- 60 tcf in the U.S. (Lokhandwala and Zammerille, 2006)

Kansas - 33% (of 1253 samples) tested low-BTU (Newell, 2007)

Sub-quality - due to N$_2$ contamination

- 15+% N$_2$ reduces heat value to less than 950 BTU/cu ft
- Mid-continent - N$_2$ primary cause (Beebe, 1968; Jenden et al., 1988)
- 17% of gas (> 32 tcf) nationwide (Lokhandwala and Zammerille, 2006)
  - Significantly in modest/small fields
  - Isolated location, low pressure & flow rates, rapid declines

How to upgrade marginal low-BTU gas within resource reach of small producers?
Low-BTU gas is widely prevalent in Kansas. 33% of 1253 samples collected and tested were found to be of low-BTU.

Centralized upgradation plants
- Cryogenic (>5 mmcf/d)
- Conventional PSA/TSA (0.5 - 20 mmcf/d)
Low-BTU in Elmdale Field

Most of the wells produce pipeline quality gas from deeper Lansing horizon.

Lansing production declining between 15 to 20% annually.

Low-BTU gas has been tested in shallower intervals (Ireland, Tecumseh, Douglas) at several wells.

Currently, limited low-BTU gas produced by blending with higher BTU

What happens when Lansing gas runs out?

NOTE: Complex geology – gas pockets and compositional variation within a zone
Plant Layout

Footprint - around 400 sq ft.
Low-BTU feed to plant – 2” line
Upgraded gas to the scrubber and compressor – 3” line
$N_2$-rich vent gas to flare tower – 2” line
Plant tested - 105 psi and held 28” of Hg vacuum
Expected to process - 150 mcf/d feed
Process Towers

Diameter = 48”
Height = 8’

Feed line

Upgraded gas line
Surge Tank – 25’ long and 5’ feet diameter
Holding time = 1 hour
- Desorbed gas attains uniform composition
Engine - 6-cylinder 50 HP VGG-330 gas-fired engine
- operates on low-BTU feed
Compressor - Ingersoll-Rand compressor designed for vacuum service
Adsorption Bed

Commonly available activated carbon made from coconut husks was used as adsorption bed.

Activated carbon was purchased in 1100 lb bags and costs around 7 cents/lb.

Each tower was charged with 2200 lb of carbon.
STEP 1 - Tower 1 Adsorption, Tower 2 Desorption
STEP 2 - Tower 1 Venting, Tower 2 in Vacuum
STEP 3 - Tower 1 Desorption, Tower 2 Adsorption
CRITICAL FACT ABOUT LOW-BTU UPGRADEATION

<table>
<thead>
<tr>
<th></th>
<th>BTU/cu ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>1010</td>
</tr>
<tr>
<td>Ethane</td>
<td>1770</td>
</tr>
<tr>
<td>Propane</td>
<td>2516</td>
</tr>
<tr>
<td>i-Butane</td>
<td>3253</td>
</tr>
<tr>
<td>n-Butane</td>
<td>3264</td>
</tr>
<tr>
<td>i-Pentane</td>
<td>4000</td>
</tr>
<tr>
<td>n-Pentane</td>
<td>4006</td>
</tr>
<tr>
<td>n-Hexane</td>
<td>4722</td>
</tr>
<tr>
<td>n-Heptane</td>
<td>5500</td>
</tr>
</tbody>
</table>

Heavy HCs ($C_2H_6+$) significantly contribute to the BTU content of natural gas.

Low-BTU upgraded to pipeline quality if process captures and recovers maximum $C_2H_6+$ content.

Also, success of upgradation depends on how rich low-BTU feed is in terms of its $C_2H_6+$ content.
CALIBRATION FOR GAS ANALYSIS

Correlations are dependent on both the feed BTU and gas composition (ratio of heavy hydrocarbons to total hydrocarbons, $C_2H_6+/CH_4+$).

**HYDROCARBON CONTENT**

```
y = 1.6496x - 60.292
R^2 = 0.961
```

```
y = 1.2169x - 15.569
R^2 = 0.9976
```

**BTU Estimation**

```
y = 11.038x - 29.796
R^2 = 0.9992
```

```
y = 12.447x - 92.702
R^2 = 0.9982
```

**FEED 615 BTU/cu ft, avg C2H6+/CH4+ = 3.8%**

**FEED 700 BTU/cu ft, avg C2H6+/CH4+ = 7.9%**
### Sales/Feed ratio
- Indicative of gas (CH$_4^+$ & N$_2$) lost from the system
  - **HIGH** - tower charge pressure low, dead space volume minimized
  - **LOW** - tower charge pressure high, dead space volume significant

### N$_2$ Stripping Efficiency
- **%** of feed N$_2$ volume that is rejected (vented)
  - **HIGH** - high tower charge pressure (more HCs adsorbed)
  - **LOW** - low tower charge pressure (less HCs adsorbed)

### CH$_4^+$ Recovery Efficiency
- **%** of feed HC captured for sales
  - **HIGH** - low tower charge pressure (less HCs lost during vent)
  - **LOW** - high tower charge pressure (more HCs lost during vent)

### BTU Recovery Efficiency
- (Sales BTU*Sales mcf)/(Feed BTU*Feed mcf)
- Follows CH$_4$ recovery efficiency - HCs determine BTU content

---

<table>
<thead>
<tr>
<th>Tower Charge Pr</th>
<th>Vent to Avg Feed</th>
<th>Corrected CH$_4^+$, fr</th>
<th>Corrected CH$_4^+$, fr</th>
<th>Sales/Feed</th>
<th>Efficiency N2 stripping</th>
<th>Efficiency CH$_4^+$ Rec</th>
<th>Vent Gas</th>
<th>BTU feed</th>
<th>BTU sales</th>
<th>BTU rec %</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>2</td>
<td>0.63</td>
<td>0.84</td>
<td>0.54</td>
<td>76.7</td>
<td>73.2</td>
<td>63.1</td>
<td>687</td>
<td>953</td>
<td>75.7</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
<td>0.65</td>
<td>0.85</td>
<td>0.60</td>
<td>73.8</td>
<td>77.4</td>
<td>63.2</td>
<td>722</td>
<td>964</td>
<td>79.7</td>
</tr>
</tbody>
</table>

---

**Feed @ 700 BTU/cu ft, C$_2$H$_6^+$/CH$_4^+=$7.9%**
**GAS ANALYSIS**

### Sample 1:
- **Sample date:** 30-May-08
- **Sample No.:** KGS 1
- **Sample description:** Feed gas

<table>
<thead>
<tr>
<th>Component</th>
<th>Mole %</th>
<th>BTU/scf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>0.0000</td>
<td>0.00</td>
</tr>
<tr>
<td>Helium</td>
<td>0.6495</td>
<td>0.00</td>
</tr>
<tr>
<td>CO2</td>
<td>0.0040</td>
<td>0.00</td>
</tr>
<tr>
<td>Neopentane</td>
<td>0.0014</td>
<td>0.00</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>33.7049</td>
<td>0.00</td>
</tr>
<tr>
<td>Argon</td>
<td>0.1748</td>
<td>0.00</td>
</tr>
<tr>
<td>Methane</td>
<td>60.3800</td>
<td>609.84</td>
</tr>
<tr>
<td>Ethane</td>
<td>2.8948</td>
<td>51.23</td>
</tr>
<tr>
<td>Propane</td>
<td>1.3320</td>
<td>33.52</td>
</tr>
<tr>
<td>i-Butane</td>
<td>0.1826</td>
<td>5.94</td>
</tr>
<tr>
<td>n-Butane</td>
<td>0.3161</td>
<td>10.31</td>
</tr>
<tr>
<td>i-Pentane</td>
<td>0.0664</td>
<td>2.66</td>
</tr>
<tr>
<td>n-Pentane</td>
<td>0.0665</td>
<td>2.67</td>
</tr>
<tr>
<td>n-Hexane</td>
<td>0.0135</td>
<td>0.64</td>
</tr>
<tr>
<td>n-Heptane</td>
<td>0.0040</td>
<td>0.22</td>
</tr>
</tbody>
</table>

**CH4+** 65.3  
**C2H6+** 4.9  
**C2H6+/CH4+** 0.075

### Sample 2:
- **Sample date:** 6-Jun-08
- **Sample No.:** KGS 5
- **Sample description:** Sales gas

<table>
<thead>
<tr>
<th>Component</th>
<th>Mole %</th>
<th>BTU/scf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>0.0000</td>
<td>0.00</td>
</tr>
<tr>
<td>Helium</td>
<td>0.1225</td>
<td>0.00</td>
</tr>
<tr>
<td>CO2</td>
<td>0.1820</td>
<td>0.00</td>
</tr>
<tr>
<td>Neopentane</td>
<td>0.0000</td>
<td>0.00</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>14.5400</td>
<td>0.00</td>
</tr>
<tr>
<td>Argon</td>
<td>0.3692</td>
<td>0.00</td>
</tr>
<tr>
<td>Methane</td>
<td>75.3267</td>
<td>760.80</td>
</tr>
<tr>
<td>Ethane</td>
<td>5.2381</td>
<td>92.70</td>
</tr>
<tr>
<td>Propane</td>
<td>2.7426</td>
<td>69.01</td>
</tr>
<tr>
<td>i-Butane</td>
<td>0.3890</td>
<td>12.65</td>
</tr>
<tr>
<td>n-Butane</td>
<td>0.7116</td>
<td>23.22</td>
</tr>
<tr>
<td>i-Pentane</td>
<td>0.1574</td>
<td>6.30</td>
</tr>
<tr>
<td>n-Pentane</td>
<td>0.1640</td>
<td>6.58</td>
</tr>
<tr>
<td>n-Hexane</td>
<td>0.0363</td>
<td>1.73</td>
</tr>
<tr>
<td>n-Heptane</td>
<td>0.0205</td>
<td>1.13</td>
</tr>
</tbody>
</table>

**CH4+** 84.8  
**C2H6+** 9.5  
**C2H6+/CH4+** 0.112

Most heavy HCs are adsorbed by the activated carbon and subsequently recovered.

Calls in question the feasibility of capturing vent gas for secondary upgradation given that it lacks heavy HCs that significantly add to the BTU of the upgraded gas.
HOW POOR A GAS CAN BE UPGRADED? Feed 615 BTU/cu ft, HHC = 3.8%

<table>
<thead>
<tr>
<th>Tower</th>
<th>Vent to</th>
<th>Corrected Avg Feed</th>
<th>Corrected Avg Sales</th>
<th>Efficiency N2 stripping</th>
<th>Efficiency CH4+ Rec</th>
<th>N2 % in Vent Gas</th>
<th>BTU feed</th>
<th>BTU sales</th>
<th>BTU rec %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charge Pr</td>
<td>psi</td>
<td>CH4+ %</td>
<td>CH4+ %</td>
<td>Sales/Feed</td>
<td>BTU feed</td>
<td>BTU sales</td>
<td>BTU rec %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>2 T*</td>
<td>59</td>
<td>78</td>
<td>0.64</td>
<td>66</td>
<td>85</td>
<td>75</td>
<td>619</td>
<td>831</td>
</tr>
<tr>
<td>30</td>
<td>2 T*</td>
<td>59</td>
<td>82</td>
<td>0.49</td>
<td>79</td>
<td>69</td>
<td>64</td>
<td>622</td>
<td>881</td>
</tr>
<tr>
<td>70</td>
<td>13 T*</td>
<td>59</td>
<td>86</td>
<td>0.45</td>
<td>85</td>
<td>66</td>
<td>63</td>
<td>621</td>
<td>920</td>
</tr>
<tr>
<td>66</td>
<td>9.5 T*</td>
<td>59</td>
<td>84</td>
<td>0.49</td>
<td>84</td>
<td>73</td>
<td>68</td>
<td>618</td>
<td>923</td>
</tr>
<tr>
<td>66</td>
<td>4 T&amp;B**</td>
<td>58</td>
<td>88</td>
<td>0.42</td>
<td>88</td>
<td>64</td>
<td>64</td>
<td>607</td>
<td>940</td>
</tr>
<tr>
<td>69</td>
<td>3 T&amp;B**</td>
<td>60</td>
<td>89</td>
<td>0.39</td>
<td>90</td>
<td>58</td>
<td>59</td>
<td>633</td>
<td>958</td>
</tr>
<tr>
<td>72</td>
<td>4 T&amp;B**</td>
<td>60</td>
<td>89</td>
<td>0.40</td>
<td>89</td>
<td>59</td>
<td>59</td>
<td>634</td>
<td>956</td>
</tr>
</tbody>
</table>

T* - vent from top; T&B** - vent from top and bottom of the tower

As feed quality changed, lower BTU and lower C₂H₆+/CH₄+ ratio, the plant settings had to be changed dramatically to achieve pipeline quality output that resulted in lower sales/feed ratios.

SIMULTANEOUS VENTING FROM TOP & BOTTOM

Dead space remains at the bottom of each tower and this is filled with N₂-rich feed gas after the vent phase. Upon desorption, this remaining feed gas enters the surge tank and lowers the BTU of the sales gas.

Attempts were made to flush out much of this feed gas in the bottom dead space by simultaneously venting from both the top and bottom of the tower.
Minimize dead space in tower especially relative to the tower volume.

Higher bed mass, increases volume of adsorbed gas and therefore results in higher sales/feed ratios.

Dead space topped with activated carbon and sealed by placing a filter in the top flange.

Minimize dead space in tower especially relative to the tower volume.

Higher bed mass, increases volume of adsorbed gas and therefore results in higher sales/feed ratios.

Minimize dead space in tower especially relative to the tower volume.

Higher bed mass, increases volume of adsorbed gas and therefore results in higher sales/feed ratios.

Minimize dead space in tower especially relative to the tower volume.

Higher bed mass, increases volume of adsorbed gas and therefore results in higher sales/feed ratios.

Minimize dead space in tower especially relative to the tower volume.

Higher bed mass, increases volume of adsorbed gas and therefore results in higher sales/feed ratios.

Minimize dead space in tower especially relative to the tower volume.

Higher bed mass, increases volume of adsorbed gas and therefore results in higher sales/feed ratios.

Minimize dead space in tower especially relative to the tower volume.

Higher bed mass, increases volume of adsorbed gas and therefore results in higher sales/feed ratios.

Minimize dead space in tower especially relative to the tower volume.

Higher bed mass, increases volume of adsorbed gas and therefore results in higher sales/feed ratios.

Minimize dead space in tower especially relative to the tower volume.

Higher bed mass, increases volume of adsorbed gas and therefore results in higher sales/feed ratios.

Minimize dead space in tower especially relative to the tower volume.

Higher bed mass, increases volume of adsorbed gas and therefore results in higher sales/feed ratios.

Minimize dead space in tower especially relative to the tower volume.

Higher bed mass, increases volume of adsorbed gas and therefore results in higher sales/feed ratios.

Minimize dead space in tower especially relative to the tower volume.

Higher bed mass, increases volume of adsorbed gas and therefore results in higher sales/feed ratios.
PERFORMANCE COMPARISON WITH COMMERCIAL PLANT

<table>
<thead>
<tr>
<th>Daily Feed, mcf</th>
<th>Seller’s %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,300 to 1,750</td>
<td>72</td>
</tr>
<tr>
<td>1,100 to 1,299</td>
<td>70</td>
</tr>
<tr>
<td>900 to 1,099</td>
<td>68</td>
</tr>
<tr>
<td>650 to 899</td>
<td>64</td>
</tr>
<tr>
<td>550 to 649</td>
<td>59</td>
</tr>
<tr>
<td>450 to 549</td>
<td>55</td>
</tr>
<tr>
<td>&lt; 450</td>
<td>51</td>
</tr>
</tbody>
</table>

ADDITIONAL DETAILS

Feed limitations: Often can't have too high N₂ (< 28% N₂) concentration

Transportation costs if pipeline is available to connect source to plant (would additionally cost 13% of volume transported in this case)

SELL TO COMMERCIAL PLANT (if feed qualifies??)

Feed 100 mcf/d - Seller paid 51 mcf/d, Transportation costs 13 mcf/d
Seller’s revenue - 36 mcf/d

USE OUR PLANT (feed with as high as 40% N₂)

Feed 100 mcf/d - Transportation costs zero
Seller’s revenue - 40 mcf/d (Feed - 40% N₂, 615 BTU/ cu ft, C₂H₆+/CH₄+ = 3.8%)
Seller’s revenue - 60 mcf/d (Feed - 35% N₂, 700 BTU/ cu ft, C₂H₆+/CH₄+ = 7.9%)
PLANT ECONOMICS
Feed 150 mcf/d, Gas Price = $7/mcf

Plant Construction Costs = $120,000

@ 615 BTU/cu ft feed, Sales = 60 mcf/d, Revenue = $420/daily,
Pay out = 9.5 months

@ 700 BTU/cu ft feed, Sales = 90 mcf/d, Revenue = $630/daily,
Pay out = 6.5 months
FUTURE PLANS

1. Fill-up towers to reduce dead space (at the bottom).

2. Test Towers - Feed at 615 BTU/cu ft. Optimize charge and vent pressures to maximize sales/feed at pipeline quality.

3. Complete building 2nd set of towers where dead space is insignificant to tower volume and operationalize tower at an American Energies (Corp) field.

4. American Energies (Corp) plans to build, install, and sell many more plants.

Height = 20’, Diameter = 6’
CONCLUSIONS

“YES, WE CAN” – it is possible to upgrade low-BTU gas to pipeline quality using a simple cost-effective plant.

Approximating plant construction costs at $120,000 and assuming a feed of 150 mcf/d, payout is estimated at 9.5 months for 615 BTU/cu ft feed and 6.5 months for 700 BTU/cu ft feed.

Minimize dead space relative to tower volume. Greater the bed mass, more HCs adsorbed and better the sales/feed ratio.

Need to evacuate (desorb) towers to maximum vacuum (≈25” Hg) quickly to recover heavy HCs adsorbed and increase plant throughput. This improves bed life and BTU of desorbed gas.

SO DO NOT GO CHEAP ON THE COMPRESSOR.

Optimum plant settings will change as per feed composition (BTU and C₂H₆+/CH₄+ ratios).