KGS OFR 2008-33

Plant flow process and data analysis to optimize low-BTU gas upgradation using a PSA-based micro-scale plant at Elmdale field, Chase County, KS

Saibal Bhattacharya,
Dave Newell
Lynn Watney

PROBLEM STATEMENT

U.S. natural gas reserves around 204 tcf (Energy Information Administration, 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)

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

Sub-quality gas due to N_2 contamination

- 15% N_2 or more in natural gas reduces heat value to less than 950 BTU/cu ft
- N_2 is the primary cause in Mid-continent (Beebe, 1968; Jenden & others, 1988)
- 17% of gas (> 32 tcf) nationwide (Lokhandwala and Zammerille, 2006)
- Significant volumes in modest/small fields (Lokhandwala and Zammerille, 2006)
    - isolated location, low pressure & flow rates, rapid declines

How to upgrade marginal low-BTU gas within resource reach of small producers?

PROPOSED SOLUTION

Build and operate a low-cost, 2-tower, micro-scale N2 rejection plant to upgrade low-BTU gas

- **Use non-patented processes & inexpensive adsorption beds, off-the-shelf components**
- **Mobile and scalable skid-mounted units (assembled and reassembled with feed volume fluctuations)**
- **Few moving parts and low maintenance**
- **Limited environmental footprint**

MICRO-SCALE LOW-BTU UPGRADATION PLANT, ELMDALE FIELD

CHASE COUNTY, KANSAS

Plant layout with a footprint of around 400 sq ft. Low-BTU feed enters the plant by a 2-inch line. The upgraded gas flows by a 3-inch line into the scrubber and then on to the compressor. The N_2-rich vent gas flows through a 2-inch line to the flare tower. The plant was pressure-tested to 105 psi and held 28 inches of Hg vacuum. Expected volumes of feed to be processed ≈150 mcf/d.

MICRO-SCALE LOW-BTU UPGRADATION PLANT, ELMDALE FIELD

CHASE COUNTY, KANSAS

Front side of towers showing feed lines and solenoid valves.

Rear side of towers showing evacuation lines and solenoid valves.

MICRO-SCALE LOW-BTU UPGRADATION PLANT, ELMDALE FIELD
CHASE COUNTY, KANSAS

Surge tank (25 feet long and 5 feet diameter) provides 1 hour holding time to desorbed gas to attain uniform composition before passing through the sales meter and on to the pipeline.

MICRO-SCALE LOW-BTU UPGRADATION PLANT, ELMDALE FIELD

CHASE COUNTY, KANSAS

6-cylinder 50 HP VGG-330 gas-fired engine operates on low-BTU feed and drives the Ingersoll-Rand compressor designed for vacuum service for desorption.

MICRO-SCALE LOW-BTU UPGRADATION PLANT, ELMDALE FIELD

CHASE COUNTY, KANSAS

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

MICRO-SCALE LOW-BTU UPGRADATION PLANT, ELMDALE FIELD

CHASE COUNTY, KANSAS

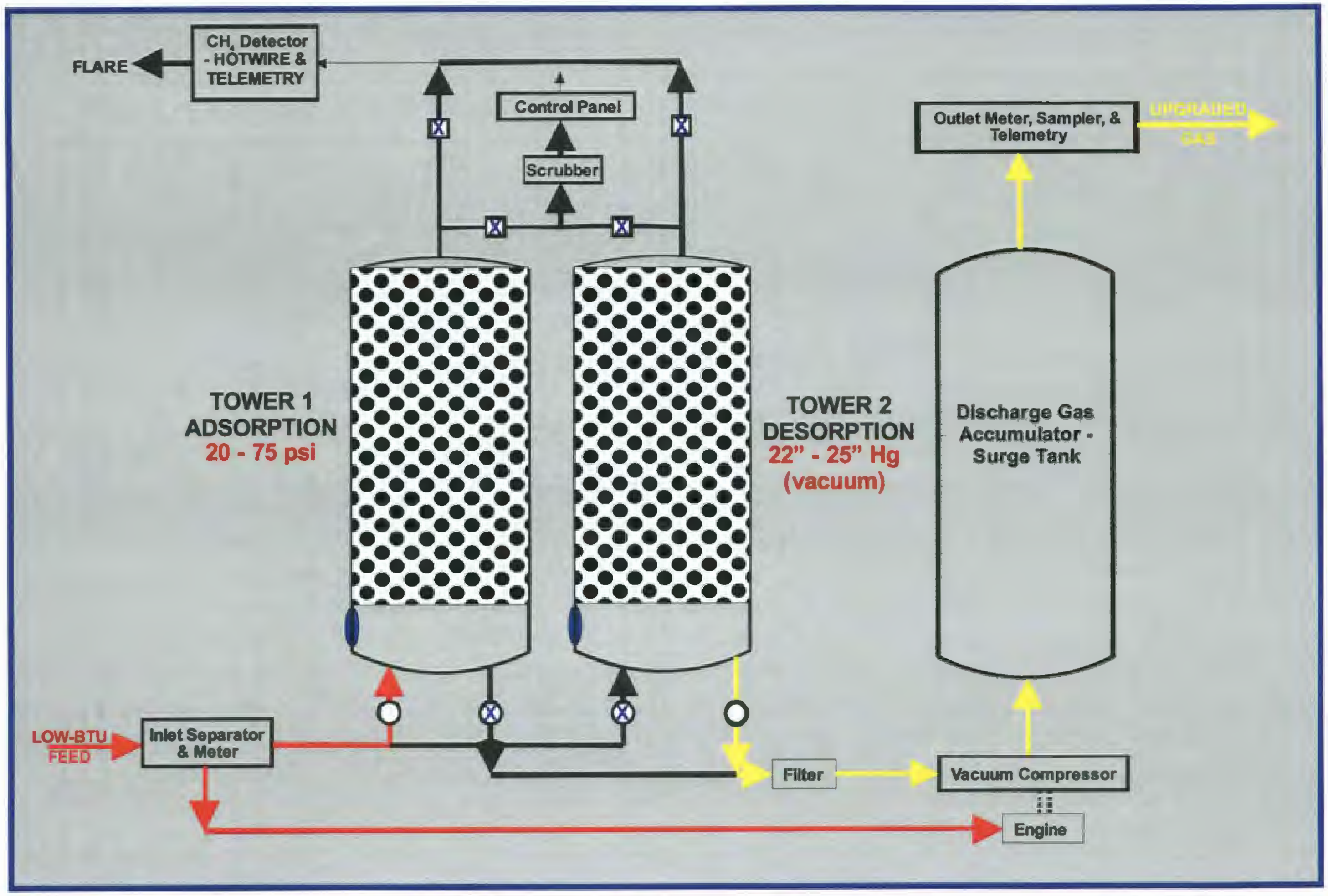
Activated carbon was purchased in 1100 lb bags and costs around 7 cents/lb.

MICRO-SCALE LOW-BTU UPGRADATION PLANT, ELMDALE FIELD

CHASE COUNTY, KANSAS

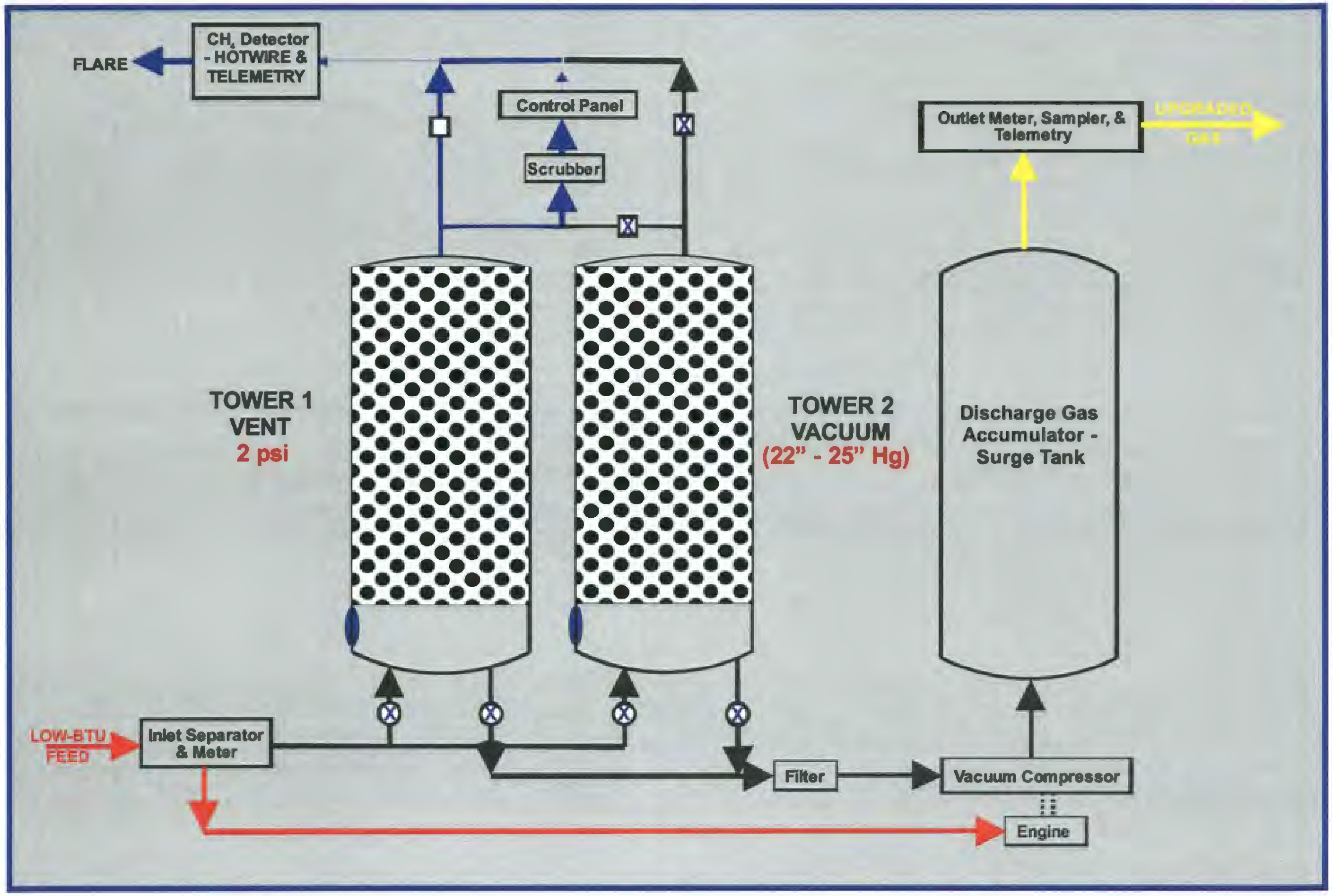
Each tower was charged with 2200 lb of carbon.

STEP 1 - Tower 1 Adsorption, Tower 2 Desorption



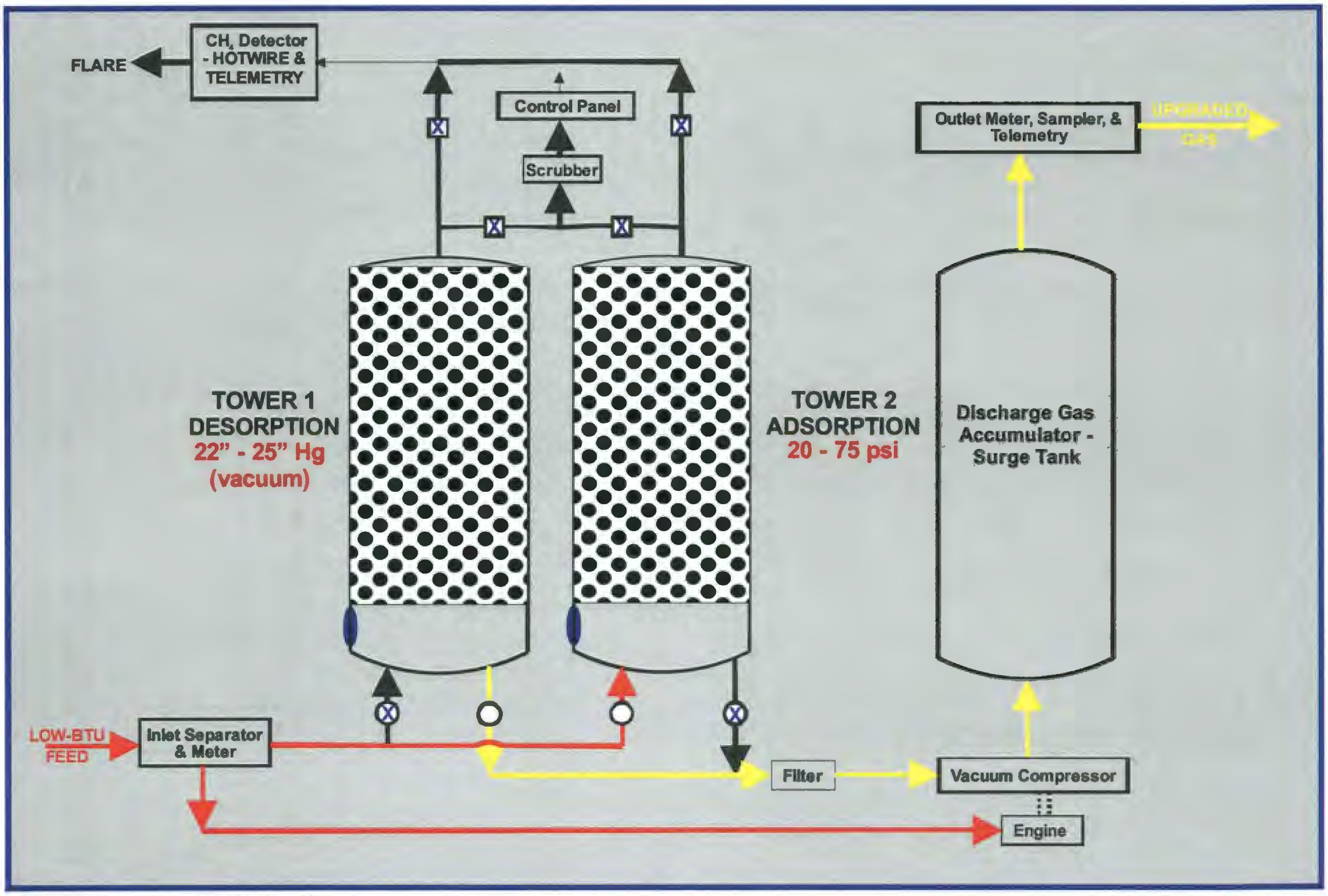
In the 1st step, the feed gas charges up the evacuated Tower 1 to the set pressure (between 25 to 75 psi) depending on the plant settings determined by the feed gas quality, while Tower 2 is going through the evacuation process to vacuum ranging between 22 to 25 inches of Hg.

STEP 2 - Tower 1 Venting, Tower 2 in Vacuum



In the 2nd step, the Tower 1 is vented to 2 psi after having been charged to the set pressure thus allowing the removal of N_2-rich unadsorbed gas from the tower. This venting results in some loss of CH_4 but also prevents the unadsorbed N_2 from ending up in the surge tank during the desorption process. The vent period is very short (less than a minute for a plant of this size) and Tower 2 remains under vacuum during this time.

STEP 3 - Tower 1 Desorption, Tower 2 Adsorption



In the 3rd stage, Tower 1 (after completion of the venting) is put under vacuum to evacuate the CH_4-rich gas adsorbed in the activated bed while Tower 2 is connected to the feed line and gets charged.

BTU CONTENT

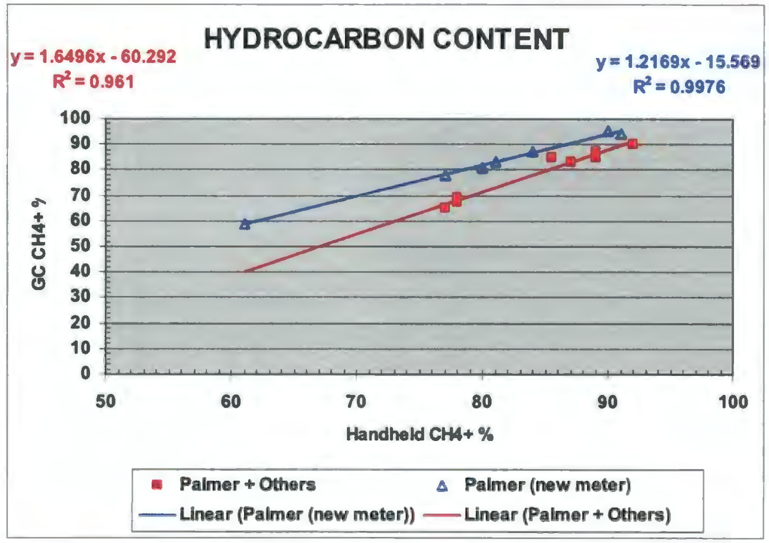
	BTU/cu ft
Methane	1010
Ethane	1770
Propane	2516
i-Butane	3253
n-Butane	3264
i-Pentane	4000
n-Pentane	4006
n-Hexane	4722
n-Heptane	5500

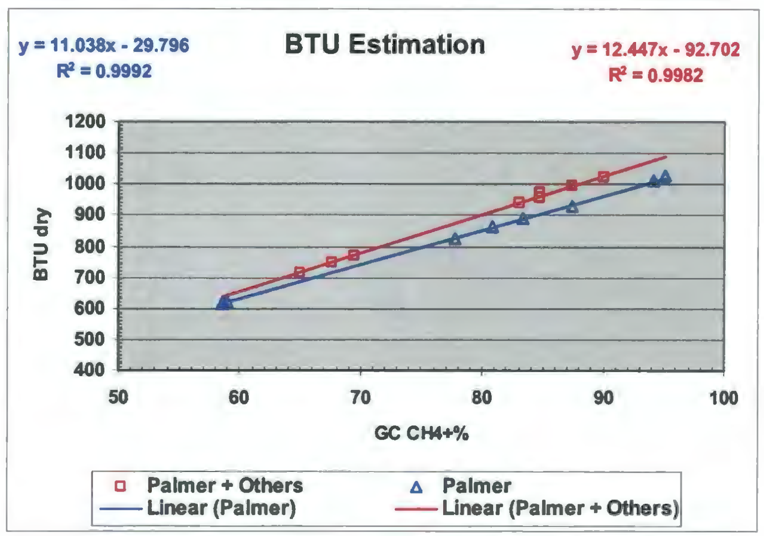
Heavier hydrocarbons significantly contribute to the BTU content of natural gas. Thus, optimum plant settings will change for near constant feed BTU but different C_2H_6+/CH_4+ ratios.

GAS ANALYSIS – PORTABLE GAS CHROMATOGRAPH

Portable handheld hydrocarbon (CH4+) detector.

Sampling feed stream using portable detector





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

RESULTS - FEED 700 BTU/cu ft, avg C_2H_6+/CH_4+ = 7.9%, Vent from top

Tower Charge Pr	Vent to psi	Corrected Avg Feed CH4+, fr	Corrected Avg Sales CH4+, fr	Sales/Feed	Efficiency N2 stripping	Efficiency CH4+ Rec	N2 % in Vent Gas	BTU feed	BTU sales	BTU rec %
34	2	0.63	0.84	0.54	76.7	73.2	63.1	687	953	75.7
20	2	0.65	0.85	0.60	73.8	77.4	63.2	722	964	79.7

Pipeline quality

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 - increase tower charge pressure (more HCs adsorbed in the bed)
- LOW - decrease tower charge pressure (less HCs adsorbed in the bed)

CH_4+ Recovery Efficiency - % of feed HCs that are captured for sales

- HIGH - low tower charge pressure (greater volume of HCs lost during vent)
- LOW - high tower charge pressure (lesser volume of HCs lost during vent)

BTU Recovery Efficiency - (Sales BTU*Sales mcf)/(Feed BTU*Feed mcf)

- Follows CH_4 recovery efficiency - HCs determine BTU content

BED ADSORPTION

Sample date	30-May-08	
Sample No.	KGS 1	
Sample description	Feed gas	
Component	Mole %	BTU/scf
Hydrogen	0.0000	0.00
Helium	0.6495	0.00
CO2	0.2135	0.00
Neopentane	0.0014	0.00
Nitrogen	33.7049	0.00
Argon	0.1748	0.00
Methane	60.3800	609.84
Ethane	2.8948	51.23
Propane	1.3320	33.52
i-Butane	0.1826	5.94
n-Butane	0.3161	10.31
i-Pentane	0.0664	2.66
n-Pentane	0.0665	2.67
n-Hexane	0.0135	0.64
n-Heptane	0.0040	0.22

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

Sample date	6-Jun-08	
Sample No.	KGS 5	
Sample description	Sales gas	
Component	Mole %	BTU/scf
Hydrogen	0.0000	0.00
Helium	0.1225	0.00
CO2	0.1820	0.00
Neopentane	0.0000	0.00
Nitrogen	14.5400	0.00
Argon	0.3692	0.00
Methane	75.3267	760.80
Ethane	5.2381	92.70
Propane	2.7426	69.01
i-Butane	0.3890	12.65
n-Butane	0.7116	23.22
i-Pentane	0.1574	6.30
n-Pentane	0.1640	6.58
n-Hexane	0.0363	1.73
n-Heptane	0.0205	1.13

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

Sample date	3-Jun-08	
Sample No.	KGS 2	
Sample description	Vent gas	
Component	Mole %	BTU/scf
Hydrogen	0.0000	0.00
Helium	1.0348	0.00
CO2	0.1317	0.00
Neopentane	0.0000	0.00
Nitrogen	60.7047	0.00
Argon	0.0000	0.00
Methane	37.1535	375.25
Ethane	0.6415	11.35
Propane	0.3337	8.40
i-Butane	0.0000	0.00
n-Butane	0.0000	0.00
i-Pentane	0.0000	0.00
n-Pentane	0.0000	0.00
n-Hexane	0.0000	0.00
n-Heptane	0.0000	0.00

CH4+	38.1287
C2H6+	0.9752
C2H6+/CH4+	0.026

GC analysis of vent gas shows that most of the heavy hydrocarbons (HCs) are adsorbed in the activated carbon. This 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 FEED CAN THE PLANT UPGRADE?

FEED 615 BTU/cu ft, avg C_2H_6+/CH_4+ = 3.8%

Sample date	20-Aug-08	
Sample No.	KGS 3	
Sample description	Palmer Feed gas	
Component	**Mole %**	**BTU/scf**
Hydrogen	0.0000	0.00
Helium	0.7238	0.00
CO2	0.0954	0.00
Neopentane	0.0010	0.00
Nitrogen	40.0308	0.00
Argon	0.0008	0.00
Methane	56.4955	570.60
Ethane	1.7401	30.79
Propane	0.6295	15.84
i-Butane	0.0974	3.17
n-Butane	0.1301	4.25
i-Pentane	0.0271	1.08
n-Pentane	0.0238	0.95
n-Hexane	0.0048	0.23
n-Heptane	0.0000	0.00

CH4+	59.1
C2H6+	2.7
C2H6+/CH4+	0.045

Sample date	20-Aug-08	
Sample No.	KGS 4	
Sample description	Sales gas	
Component	**Mole %**	**BTU/scf**
Hydrogen	0.0000	0.00
Helium	0.0640	0.00
CO2	0.1786	0.00
Neopentane	0.0024	0.00
Nitrogen	10.6556	0.00
Argon	0.0429	0.00
Methane	83.6332	760.80
Ethane	3.7091	92.70
Propane	1.2250	69.01
i-Butane	0.1903	12.65
n-Butane	0.2102	23.22
i-Pentane	0.0450	6.30
n-Pentane	0.0347	6.58
n-Hexane	0.0072	1.73
n-Heptane	0.0020	1.13

CH4+	89.1
C2H6+	5.4
C2H6+/CH4+	0.061

Pipeline quality

As feed quality changed, lower BTU and lower C_2H_6+/CH_4+ ratio, the plant settings had to be changed dramatically to achieve pipeline quality output at lower sales/feed ratios.

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

Tower Charge Pr	Vent to psi	Corrected Avg Feed CH4+ %	Corrected Avg Sales CH4+ %	Sales/Feed	Efficiency N2 stripping	Efficiency CH4+ Rec	N2 % in Vent Gas	BTU feed	BTU sales	BTU rec %
15	2 T*	59	78	0.64	66	85	75	619	831	86
30	2 T*	59	82	0.49	79	69	64	622	881	70
70	13 T*	59	86	0.45	85	66	63	621	920	67
66	9.5 T*	59	84	0.49	84	73	68	618	923	74
66	4 T&B**	58	88	0.42	88	64	64	607	940	65
69	3 T&B**	60	89	0.39	90	58	59	633	958	59
72	4 T&B**	60	89	0.40	89	59	59	634	956	60

SIMULTANEOUS VENTING - TOP & BOTTOM OF THE TOWER

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.

PERFORMANCE COMPARISON WITH COMMERCIAL PLANT

Daily Feed, mcf	Seller's %
1,300 to 1,750	72
1,100 to 1,299	70
900 to 1,099	68
650 to 899	64
550 to 649	59
450 to 549	55
< 450	51

ADDITIONAL DETAILS

Feed: < 28% N_2

Transportation costs: 13%

Pipeline availability from well to commercial plant

SELL TO COMMERCIAL PLANT (if feed qualifies, i.e. feed N_2 < 28%)

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% N_2)

Feed 100 mcf/d - Transportation costs zero

Seller's revenue - 40 mcf/d (Feed - 40% N_2, 615 BTU/cu ft, C_2H_6+/CH_4+ = 3.8%)

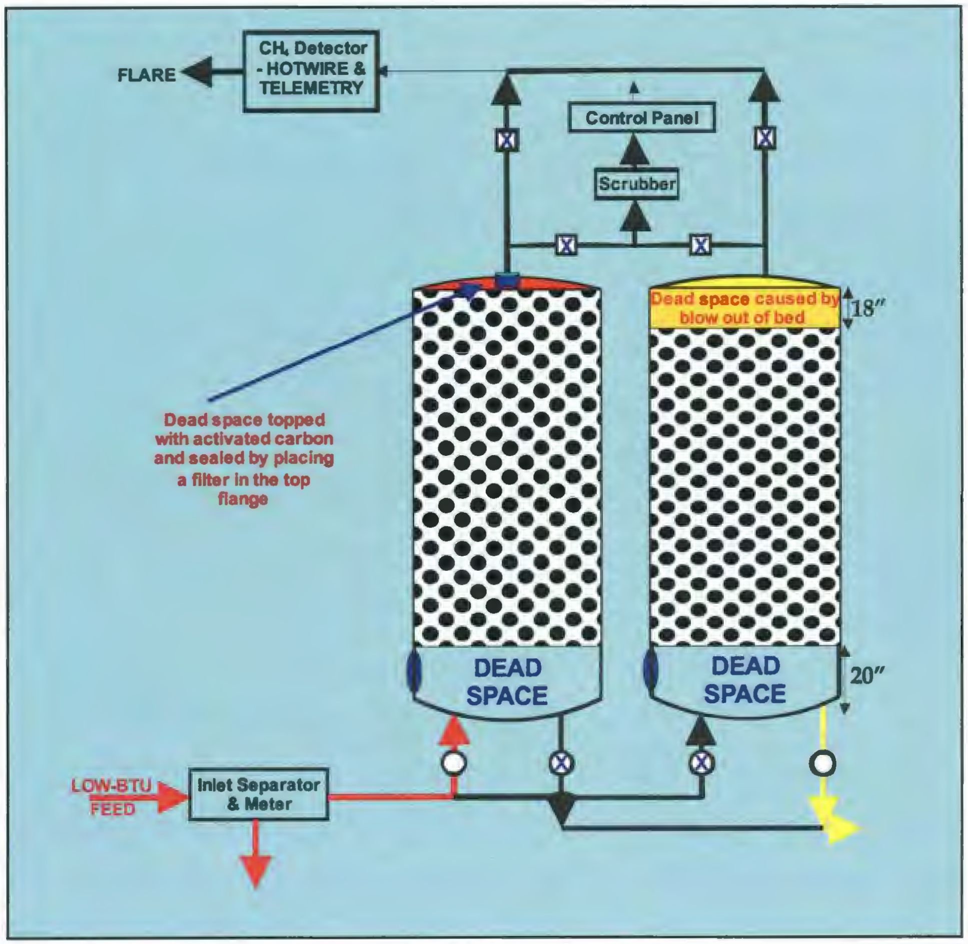
Seller's revenue - 60 mcf/d (Feed - 35% N_2, 700 BTU/cu ft, C_2H_6+/CH_4+ = 7.9%)

BED BLOWOUT

2008		Reported	Reported			
		Next day	Next day		Corrected	Corrected
Date	Time	Input, mcf	Sales, mcf	Sales/Input	Feed CH4, fr	Sales CH4, fr
		Old CH4 meter. Changed settings to charge towers to 34 psi. Vent from top to 2 psi. Desorb to 22 inHg.				
31-May	AM	117	61	0.52	0.60	0.83
	PM	117	61	0.52	0.65	0.85
1-Jun	AM	117	65	0.56	0.60	0.85
	PM	117	65	0.56	0.60	0.83
2-Jun	AM	117	65	0.56	0.65	0.83
	PM	117	65	0.56	0.65	0.85
3-Jun	AM	103	54	0.52	0.67	0.83
	PM	Old CH4 meter. Changed settings to charge towers to 20 psi. Vent from top to 2 psi. Desorb to 22 inHg.				
4-Jun	AM	85	50	0.59	0.67	0.83
	PM	85	50	0.59	0.60	0.83
5-Jun	AM	86	52	0.60	0.67	0.88
	PM	86	52	0.60	0.68	0.85
6-Jun	AM	69	34	0.49	0.68	0.83
	PM	Old CH4 meter. New settings: Vent from top and bottom to 2 psi. Tower charge to 20 psi. Desorb to 2 inch Hg.				
7-Jun	AM	88	40	0.45	0.68	0.85
	PM	88	40	0.45	0.68	0.82
8-Jun	AM	90	47	0.52	0.68	0.82
	PM	90	47	0.52	0.68	0.82
9-Jun	AM	91	48	0.53	0.72	0.83
	PM	91	48	0.53	0.70	0.85
10-Jun	AM	108	58	0.54	0.60	0.85
	PM	Old CH4 meter. New settings: Vent from top and bottom to 2 psi. Tower charge to 30 psi. Desorb to 2 inch Hg.				
11-Jun	AM	105	48	0.46	0.67	0.85
	PM	105	48	0.46	0.68	0.87
12-Jun	AM	106	48	0.45	0.70	0.87
	PM	106	48	0.45	0.70	0.85
13-Jun	AM	114	48	0.42	0.63	0.85
	PM	114	48	0.42	0.63	0.83
14-Jun	AM	114	47	0.41	0.70	0.87
	PM	114	47	0.41	0.52	0.72

Sudden decrease in the sales/input ratio without significant changes in the plant settings is indicative of bed blow-out.

BED BLOWOUT



Bed blow out was suspected as sales/feed ratio declined despite near constant feed and unchanging operating conditions. Reduction in bed mass results in reduced desorbed volumes and lower sales/feed ratios. Upon opening the bull-plug atop the tower, it was found that about 18 inches of bed had blown out from the top of the tower as a result of repeated venting. This dead space was filled with new activated carbon and sealed by placing a filter in the top flange.

PLANT ECONOMICS - Feed 150 mcf/d, $7/mcf gas

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 38 to 42 psi (well deliverability limitations)

Feed = 696.6 BTU/cu ft, Sales = 954.9 BTU/cu ft

Sales/Feed ratio = 0.5 to 0.52

3. Complete building 2nd set of towers

- Height = 20 ft, Diameter = 6 ft

- Designed to minimize dead space (relative to tower volume)

4. American Energies Corporation plans to build, install, and sell many more plants

REFERENCES

Energy Information Administration, Sep 2006, U.S. Crude oil, natural gas, and natural gas liquids reserves, 2005 Annual Report, available at:

http://www.eia.doe.gov/pub/oil_gas/natural_gas/data_publications/advanced_summary/current/adsum.pdf

Lokhandwala, K., Zammerilli, A., 2006, New Nitrogen-rejection membrane technology commercialized, GasTIPS, v. 12, no. 4, p 16-20

Beebe, B.W., (ed.), 1968, Natural Gases of North America: American Association of Petroleum Geologists, Memoir 9, 2457 p.

Hugman, R.H., Vidas, E.H., and Springer, P.S., 1990, Chemical composition of discovered and undiscovered natural gas in the lower-48 United States: Gas Research Institute, Chicago, IL, Publication GRI 90/0248, 69 p., plus appendices.

Newell, K.D., 2007, Geochemical trends in gas quality in Kansas: Kansas Geological Survey Open-File Report 2007-08 (poster presented for 2007 Annual Convention of the American Association of Petroleum Geologists, Long Beach, CA; available online at www.kgs.ku.edu).

Jenden, P.D., Newell, K.D., Kaplan, I.R., and Watney, W.L., 1988, Composition and stable-isotope geochemistry of natural gases from Kansas, Midcontinent, U.S.A.: Chemical Geology, v. 71. p. 117-147.