DEMONSTRATION OF A LOW COST 2-TOWER MICRO SCALE N_2 REJECTION SYSTEM TO UPGRADE LOW-BTU GAS FROM STRIPPER WELLS

Type of Report: Quarterly
Reporting Period Start Date: 5/1/2008
Reporting Period End Date: 7/31/2008

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Date Report was issued: April 2009
DOE Award No: DE-FC26-04NT42098
[Subaward No: 3447-UK-DOE-2098]

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ABSTRACT

Natural gas is marketed on the basis of its heat content (950 BTU/cu ft or higher). U.S. pipeline specifications vary but generally require nitrogen (N_2) to be less than 5% resulting in 32 tcf (17% of known reserves) to be categorized as low-BTU "sub quality". N_2 is thus a major target for removal to upgrade natural gas to pipeline quality. A significant portion of the nation's N_2-rich low-BTU gas is trapped in modest to small fields owned by stripper operators, or isolated behind pipe. These small fields are not amenable to upgrading technologies such as cryogenic separation and conventional pressure swing adsorption (PSA) because these fields cannot usually deliver the large feed volumes necessary for profitable operations of these types of technologies.

In an attempt to encourage economically viable upgrading of low-BTU gas from stripper wells, a demonstration project that encompasses the planning, design, construction, operation, and optimization of an easily built, low-cost, 2-tower micro-scale PSA (pressure swing adsorption) plant for N_2-rejection using non-patented processes and commonly available equipment was proposed as a joint project between the Kansas Geological Survey (KGS) and American Energies Corporation (AEC), Wichita, Kansas.

During the current reporting period, the N_2 rejection plant was run with two types of low-BTU feed gas with a) an average heat content of 715 BTU/cu ft, and b) an average heat content of 630 BTU/cu ft. The plant was run at different settings and results analyzed to determine the optimum settings where the feed gas could be upgraded to pipeline quality (> 950 BTU/cu ft). Under optimum running conditions, the plant operator could sell at least 54% and 39% of feed gas volumes as upgraded pipeline quality gas for feed gas compositions having as much as 37% and 40% nitrogen

respectively. The sales/feed ratio varied significantly (from 54% to 39%) despite small changes in the nitrogen composition (from 37% to 40%) because of variation in the ratio of heavy to total hydrocarbons (from 7.9% to 3.9%) in the feed. Thus, both nitrogen content and the fraction of heavy hydrocarbons in the feed control the optimum plant settings and determine its efficiency. The bed of readily available activated carbon was found to be effective in adsorbing and desorbing the heavy hydrocarbons (C_2H_6+) entrained in the feed leaving the vent stream stripped of any component with any significant heat content other than methane. This puts in question the viability of upgrading part of the vent gas to pipeline quality by a secondary tower. A commonly available screen filter placed within the top flange of each tower (i.e., the mouth of the vent stream) proved effective in preventing bed blow-out due to repeated tower pressurization and venting. A flaw was found in the current design where significant dead space volume existed at the bottom of each tower because the grate supporting the bed of activated carbon was placed above the tower access hole. This dead space always remained filled with low-BTU feed gas even after the vent phase, and this untreated feed gas ended up in the surge tank (sales stream) thus lowering its average heat content. Minimizing the dead space volume, with respect to the tower volume, results in a) minimal volume of feed gas entering the sales stream, and b) greater bed volume with increased adsorption capacity. When compared to the costs of and conditions for using a local commercial low-BTU upgradation plant, this micro-plant was found to be more economic to producers of low-volume, low-BTU gas from isolated gas fields/wells. Assuming a gas price of $4/mcf and feed volumes of 150 mcf/d, the calculated pay out time for the micro-plant was 17 and 12 months when the feed gas was rated at 615 and 715 BTU/cu ft, respectively.

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INTRODUCTION

Natural gas is marketed on the basis of its heat content (950 BTU/cu ft or higher). U.S. pipeline specifications vary but generally require nitrogen (N_2) to be less than 5% resulting in 32 tcf (17% of known reserves) to be categorized as low-BTU "sub quality". N_2 is thus a major target for removal to upgrade natural gas to pipeline quality. A significant portion of the nation's N_2-rich low-BTU gas is trapped in modest to small fields owned by stripper operators, or isolated behind pipe. These small fields are not amenable to upgrading technologies such as cryogenic separation and conventional pressure swing adsorption (PSA) because these fields cannot usually deliver the large feed volumes necessary for profitable operations of these technologies.

The objective of this project is to design, construct, operate, and optimize a micro-scale N_2 rejection plant to economically upgrade low-BTU gas from stripper wells. Our goals were to build a low-cost, 2-tower micro-scale PSA (pressure swing adsorption) plant using readily available activated carbon (made from coconut husks) as adsorbent bed to adsorb methane and heavier hydrocarbons under pressure while rejecting the N_2 followed by desorption of the hydrocarbons under vacuum.

EXECUTIVE SUMMARY

This project is a joint effort by the Kansas Geological Survey (University of Kansas) and American Energies Corporation (AEC), a company that primarily operates stripper wells in Kansas). In this reporting quarter, the plant was run with two different feed gas compositions. The plant parameters were modified in each case to attain pipeline quality sales stream. For a feed gas with (an average) 35% N_2 (i.e., around 715 BTU/cu ft and C_2H_6+/CH_4+ = 7.9%), the plant was able to deliver about 57% (on average) of the feed volume as pipeline quality sales gas (at 950 BTU/cu ft). When the feed composition deteriorated to an average of 40% N_2 (i.e., around 630 BTU/cu ft and C_2H_6+/CH_4+ = 3.9%), the plant was optimized to deliver 39% of the feed volume as pipeline quality sales gas (at 950 BTU/cu ft). The sales/feed ratio was critically influenced by the amount of heavy hydrocarbons (C_2H_6+/CH_4+) in the feed stream. The commonly available activated carbon (made from coconut husks) was effective in removing high BTU content heavy hydrocarbons (C_2H_6+) from the feed stream for later recovery into the sales stream. This effective removal of heavy hydrocarbons strips the vent stream of most of the components with significant heat content except methane, and thus puts in question the feasibility of upgrading the vent gas to pipeline quality. An appropriately sized screen filter placed in the vent stream successfully stopped bed blowout during repeated venting. Finally, a flaw was discovered in the current design which resulted in unnecessary dead space volume at the base of each tower that remained filled with low-BTU feed at the end of the vent phase, which finally ended in the sales stream to lower its heat content.

The project web-site, which can be accessed at http://www.kgs.ku.edu/PRS/Microscale/index.html, was updated with results obtained from these plant optimization tests. Technology transfer of project results was carried out by oral presentations at the fall meeting of the Stripper Well Consortium on September 8-9, 2008, Oklahoma Oil & Gas Trade Expo on October 16, 2008, and at the Kansas Geological Society meeting on November 10, 2008. A technical manuscript summarizing the plant design and optimization and lessons learnt is currently under preparation for publication in a trade journal that has wide circulation in the small producer community. Publication is expected to be in the fall of 2009.

EXPERIMENTAL OBSERVATIONS & DISCUSSION

PLANT OPERATION - STAGES

STAGE 1 - Figures 1 to 3 show the current flow of operations at the low-BTU upgradation plant which in the succeeding text will be referred as the NRU (nitrogen rejection unit). The first step in the sequence of operation is depicted in Figure 1. The low-BTU feed gas travels (by the line shown in red) to Tower 1 and charges it up from the bottom to the requisite pressure. The optimum tower charge pressure is primarily dependent on the feed composition (i.e., N_2 and heavy hydrocarbon content) and requirements of heat content by the pipeline company, and is determined by a process of trial and error. The plant is run by charging up Tower 1 to different pressure settings, and the pressure at which the sales stream achieves pipeline quality is deemed as the requisite tower pressure. During this first step, Tower 2 is under desorption, i.e., its bed is desorbed under vacuum (22 to 25 inch of mercury). The compressor that pulls this vacuum is run by an engine that operates on the low-BTU feed gas. The time taken to charge Tower 1 to requisite pressure depends on the flow rate and pressure of the incoming feed gas and the fill-up volume of the tower. During this charging period, hydrocarbons are preferentially adsorbed in the bed of activated carbon inside Tower 1, while gas in the free space (existing between the carbon particles and in the dead space) is made up primarily of nitrogen for which the activated bed has significantly less adsorption affinity.

STAGE 2 - The second step is shown in Figure 2, where Tower 1 is vented from the top to atmosphere till the pressure inside it reaches 2 psi while Tower 2 is kept under vacuum. The length of the venting period is proportionate to the magnitude of the Tower 1 charge pressure. During this period, the nitrogen-rich gas in the free space (inside Tower 1) is vented to atmosphere, thus preventing its entry into the sales stream and resultant dilution of its heat content.

STAGE 3 - During the third stage (Figure 3), the Tower 1 is connected to the compressor which pulls a vacuum (of 22 to 25 inch mercury) while the desorbed Tower 2 is connected to the low-BTU feed stream for charge up to the same pressure as Tower 1 (and described in stage one). During the counter current desorption stage, the pressure in Tower 1 is reduced from 2 psi to 22 to 25 inch mercury, and this results in extraction (desorption) of hydrocarbons that had been adsorbed in the bed of activated carbon (during the 1st stage one). The desorbed gas is rich in hydrocarbons and leaves Tower 1 from the bottom, and it will be of pipeline quality when the plant settings (i.e., charge-up pressure and final vent pressure) are optimally set for the feed (composition). The sales stream coming out of the NRU is made up of this desorbed gas, and it is minimally contaminated with unadsorbed N_2 when the tower design is such that the dead space is minimized with respect to the tower volume because the N_2-rich unabsorbed (feed) gas pervading in the dead space ends up in the sales stream during the desorption process.

PLANT THROUGHPUT BOTTLENECK

The bottleneck affecting the NRU sales (volume) throughput is primarily the time taken to desorb a tower from vent pressure (of 2 psi as in this case) to 22 to 25 inches of (mercury) vacuum. The tower evacuation time depends on the tower (or bed) volume and the compressor capacity, and is normally longer than the tower charge up time given sufficient pressure and rate in the feed line. Thus, the tower charging process has to be often adjusted (slowed) to make the charge time equal to the evacuation time for continuous operation of the NTU. Thus, one of the critical lessons from this project is that the operator should employ a strong compressor that is capable of evacuating the tower (volume) in as short a time as possible so that the process cycle time is reduced and the plant throughput is maximized assuming that the feed line pressure and rate is sufficient for quick charging of the towers.

GAS ANALYSES

A potable gas meter (Figure 4A) that detected total hydrocarbon concentration (CH_4+ %) was used to take readings from the feed, vent, and sales streams entering and exiting the plant. The portable meter played an indispensible role in taking quick readings (Figure 4B) of gas compositions from different parts of the plant under various field operating conditions. Recordings from this portable gas meter (referred as handheld-CH_4+ %) were calibrated (Figure 4C) with the total hydrocarbon content determined from gas-chromatographic (GC) analyses (referred as GC-CH_4+ %) of the same samples. Furthermore, these GC-analyses of gas samples taken from the plant helped to establish correlations (Figure 4D) between hydrocarbon content (GC-CH_4+ %) and the heat content of the gas (BTU dry). Equations encapsulating these correlations proved useful for quick determination of N_2 (% composition) and BTU content in any gas stream into and out of the NRU under different operational settings. It is critical to note, however, that these correlations are dependent on the specific handheld (portable) gas meter and its calibration. The red filled squares and the blue triangles (Figures 4C and 4D) represent two sets of data each representing feed gas of different composition and measurements carried out using two different handheld gas meters.

BED BLOWOUT

Initial testing at the NRU commenced on May 31, 2008, after both towers were topped with activated carbon and respective top flanges sealed. Results from the series of tests carried out at the NRU are summarized in Figure 5. The first test was carried out between from May 31 and June 3, 2008, when the towers were charged to 34 psi and then vented (to 2 psi) from the top. The average feed entering the plant had 63% hydrocarbons (CH_4+) which the plant was able to upgrade to 84% (CH_4+), and the corresponding sales/feed ratio (i.e., the ratio between the sales to feed volumes) was 0.54 (i.e., 54% of the feed gas by volume was upgraded by the plant). The sales/feed ratio critically affects the volume of saleable gas from the plant, or inversely the volume of gas lost during the venting process. The volume of gas lost during the venting process depends on the pressure differential between the tower charge pressure and the vent pressure (here set at 2 psi) and the N_2 (%) content of the feed. The greater the nitrogen content in the feed, the greater the volume of unabsorbed gas inside the tower, and the plant controls need to be optimized to efficiently reject most of this gas during the venting process.

With minor fluctuations in the feed stream composition, a second test was carried out (from June 4 to June 6, 2008) with the towers charged to 20 psi followed by venting to 2 psi in order to reduce the pressure differential between charge and vent pressures. The feed and sales gas during this second test contained (on average) about 66% and 85% hydrocarbons, both of which were slightly higher than that observed during the first test.

The sales/feed ratio during the second test was around 58%, a value slightly higher (and therefore better) than the first test. However due to feed quality improvement (from 63% to 66% hydrocarbons), it is difficult to know if this increase in the sales/feed ratio (from 0.54 to 0.58) is solely due to reduced vent volumes as a result of lower differential between charge and vent pressures. Under real-life operating conditions in marginal environments where the feed stream is a mixture of production from different wells, it is not uncommon for the feed composition to fluctuate over time.

Another factor that affected plant performance is the dead-space volume that was inadvertently left at the base of each tower (Figure 6A) as a result of improper design. The gas remaining in the dead space is the low-Btu feed gas that never contacted the bed even after the end of the vent phase. Upon desorption (i.e., tower evacuation to vacuum) this nitrogen-rich low-BTU feed gas (with as much as 35 to 37% nitrogen) ended up in the surge tank, where it lowered the heat content of the sales stream. To better vent this feed gas accumulating at the base of each tower, the plant was run by simultaneously venting the towers from both the top and bottom during the vent phase under the assumption that such dual venting might improve the purging of N_2-rich gas and as a result improve the BTU content of the gas desorbed from the bed and stored in the surge tank for sales.

During the third test period (i.e., from 7 to June 10, 2008), the towers were alternatively charged to 20 psi with feed gas, the composition of which showed minor variation from the previous two tests, and then vented simultaneously from top and bottom to 2 psi before being desorbed under vacuum. Though the feed composition changed slightly from the second test, i.e. average total hydrocarbons increased from

66% to 68%, the sales stream showed a small reduction in the hydrocarbon content (from 85% to 83%). Contrary to expectations, the sales/feed ratio decreased between the second and third tests, from 0.58 to 0.51, especially when the tower charge pressure remained unchanged at 20 psi and the feed had slightly higher hydrocarbon content. It is counter-intuitive for the average hydrocarbon content in the sales stream to decline as a result of simultaneous venting from top and bottom of the towers because it was assumed that such dual venting would be more effective in purging unadsorbed low-BTU feed gas from the tower and thus increase the heat content (or CH_4+ %) in the sales stream.

The decline in the sales/feed ratio was exacerbated during the fourth test period (i.e., from 11 to June 14, 2008), when the towers were charged to 30 psi followed by venting to 2 psi from top and bottom and desorption under vacuum. The feed composition was very similar to that during the third test (i.e. contained 67% hydrocarbons as compared to 68%). However, the sales/feed ratio decreased significantly from 0.51 to 0.44 during this test. Also, the tower charge pressure (i.e., 30 psi) during the fourth test was close to that of the first test (i.e., 34 psi). However, the sales/feed ratio in the 4th test (i.e., 44%) was significantly lower than that obtained during the 1st test (i.e., 54%) despite similar differential between the tower charge and vent pressures.

Other interesting data include the near constant hydrocarbon content (varying between 83 to 85%) in the upgraded sales gas (extracted from the bed under vacuum) despite slight changes in the feed hydrocarbon content and major variations in the sales/feed ratio recorded during these four tests. The near constancy of the sales hydrocarbon content may indicate of the unchanging effectiveness of the bed in adsorbing the hydrocarbons from the feed stream. The decline in the sale/feed ratio over time may indicate bed blow-out during the venting process, especially because it was visually evident that carbon particles were ejected from the vent tower during each vent phases. Lacking any screen filter placed inside the vent valve located inside the top flange, it is reasonable to expect the small grained activated carbon particles were ejected during the vent process when the charged tower is suddenly allowed to expand against atmospheric pressure. With bed material blown out, the dead-space increased inside each tower and this resulted in poorer performance of the plant.

The flange atop each tower was opened to visually check for bed blowout, and each of the towers was found to have lost about 18 inches of bed from the top of the column (Figure 6A). The towers were refilled (topped) with fresh activated carbon (Figure 6B), and an appropriately sized screen filter was set below the top flange to prevent future bed blowouts.

PLANT PERFORMANCE – Average feed: 715 BTU/cu ft & C_2H_6+/CH_4+ = 7.9%

Initial optimization of the plant was carried out using a feed gas consisting of commingled production from a number of wells. Some wells were on pump and were prone to producing slugs of water along with gas. These varying production conditions at the different wells resulted in changes in the gas composition feeding to the plant. Also the valves in the production lines, carrying gas from different wells to a central manifold downstream to the plant, had to be adjusted to maintain feed flow rate and pressure within a range, and these changes in the valve settings resulted in variation in the feed compositions.

At first, the low-BTU feed gas averaged around 687 BTU/cu ft with the ratio of the heavy to total hydrocarbons (C_2H_6+/CH_4+) around 7.9%. Under this feed condition, the plant was optimized to output pipeline quality gas (> 950 BTU/ cu ft) by charging the towers to 34 psi and then venting (from the top) to 2 psi to remove the unabsorbed N_2-rich gas from the tower followed by desorption of the bed to around 25 inch of Hg (vacuum). These settings (Figure 7) resulted in a sales/feed ratio of 0.54, i.e., 54% of the low-BTU feed gas (by volume) was upgraded to pipeline quality. Thus a feed gas with an average hydrocarbon content of 63% (CH_4+ % mole) was upgraded to a saleable stream containing around 84% of CH_4+ (% mole), thus resulting in 73.2% of hydrocarbon recovery and 75.7 % BTU recovery. The BTU recovery was calculated as the ratio of the product of total BTU coming into the plant (i.e., feed volume times feed BTU/cu ft) and that recovered in the sales stream (i.e., sales volume times sales BTU/cu ft). Under these settings, the vented gas contained about 63.1% N_2 (% mole) resulting in an average N_2 rejection efficiency of 76.7%.

The sales/feed ratio critically determines the plant economics. Given similar feed compositions, higher sales/feed ratios result in greater recovery of the hydrocarbons entrained in the feed and higher volumes of pipeline quality gas for sale. Conversely, it represents the volume and amount of hydrocarbons lost from the system as a result of the venting process. Given unchanging feed composition and bed adsorption characteristics, the sales/feed ratio depends on the differential between the tower charge pressure (34 psi as stated earlier) and the vent pressure (2 psi), the volume of dead space within each tower, and volume of gas desorbed from the beds during the venting process. The dead space in each tower consists of the volume between the carbon particles in the bed and any other unfilled space within the tower.

To increase the sales/feed ratio, the pressure differential between tower charge pressure and vent pressure was reduced. As mentioned earlier, it was difficult to maintain a constant feed gas composition because of commingling production from different wells. Thus by the time the plant could be operated under lower tower charge pressure, the feed gas composition had changed to an average of 743 BTU/cu ft. The plant produced pipeline quality gas (964 BTU/cu ft) at a higher sales/feed ratio of 0.60 (i.e., sales volume was 60% of the feed, refer to Figure 7) when its towers were charged to 20 psi and then vented to 2 psi (from the top of the tower). It is difficult to determine if the lower tower charge pressure resulted in slightly higher CH_4 recovery efficiencies (of 75.4%) and slightly lower N_2 stripping efficiency (of 72.6%), or if these were the result of better quality feed gas coming into the plant.

PLANT PERFORMANCE – Average feed: 630 BTU/cu ft & C_2H_6+/CH_4+ = 3.9%

To maintain sufficient feed rate and pressure, the plant was connected to a different combination of wells including Palmer 1 - the major contributor. This resulted in a feed that was poorer in heat content with an average of around 615 BTU/cu ft as compared to 715 BTU/cu ft that was previously discussed. Also, the ratio of the heavy hydrocarbons to total hydrocarbons in the feed decreased to 3.8% from 7.9%. However, this change (deterioration) in the feed gas composition provided an opportunity to fine tune the plant settings to see if this plant could upgrade a poorer quality of feed gas than that discussed earlier.

Figure 8 tabulates the BTU content of different kinds of hydrocarbons, it is evident that small increases in heavy hydrocarbons result in significant increases in the BTU content of the gas. Thus, the reduction in BTU content and halving of heavy hydrocarbon fraction (C_2H_6+/CH_4+) in the feed necessitated dramatic changes in the plant settings to produce pipeline quality gas.

The plant was run under different settings and the results are tabulated in Figure 9. The variation in BTU content of the feed gas was less than 5% during this plant optimization study. When the plant was run with tower charge pressures of 15 and 30 psi and vent pressure of 2 psi, values close to settings that resulted in pipeline quality sales stream (of 950 BTU/cu ft) for a feed with heat content of 715 BTU/cu ft and heavy hydrocarbon component fraction of 7.9%, the desorbed gas from the NRU was found to be of sub-pipeline quality, i.e., 831 and 881 BTU/cu ft, respectively. Raising the tower charge pressure to 70 and 65 psi, followed by venting to 13 and 9.5 psi, increased the heat content of the desorbed gas to around 920 BTU/cu ft but also resulted in lower sales/feed ratios, i.e., 45 and 49%, respectively. At the time of these tests, the feed gas had a heat content and heavy hydrocarbon fraction that was 12% and 50% lower than the earlier discussed feed. This deterioration (change) in the feed composition was the main reason for requiring higher tower charge pressures in order for the desorbed gas to come close to pipeline quality, i.e., 950 BTU/cu ft. Higher tower charge pressures result in greater pressure differential during the vent process, and therefore greater loss of hydrocarbons and lower sales/feed ratios. Thus, the vent pressures were set higher (to 13 and 9.5 psi) when the towers were charged to 70 and 66 psi, respectively, to reduce the pressure differential during the vent process, and thus to reduce the adverse impact on the sale/feed ratio. However, these settings failed to produce pipeline quality gas with the heat content of the desorbed gas hovering around 920 BTU/cu ft.

In the current tower design (Figure 6A), an unfilled space about 20 inches from the bottom of the (8 foot) tower remains unfilled by the bed of activated carbon because the grate supporting the bed was incorrectly designed to be located above the tower access hole. This dead (space) volume at the bottom of each tower remains filled with N_2-rich feed gas (at 2 psi) after the vent phase when the venting took place solely from the tower top. Thus during the desorption stage, this feed gas remaining in the dead space entered the surge tank and lowered the BTU of the sales gas. Hence, attempts were made to see if simultaneously venting from both the top and bottom of the tower would help improve the purging of this (untreated) feed gas present in the bottom dead space.

The sales gas from the plant was found to be of pipeline quality (at 958 BTU/cu ft) when the tower charge pressure was set at 69 psi and vent pressure to 3 psi with venting occurring from both the top and bottom of the tower. This setting resulted in a sales/feed ratio of 0.39. The sales/feed ratio was improved slightly to 0.40 when the tower charge pressure was set to 72 psi and the vent pressure was set at 4 psi with minor variations in the feed gas heat content.

It is apparent from the above results that this plant can upgrade a feed with as low a heat-content as 630 BTU/cu ft and with a heavy hydrocarbon fraction of 3.8%. Thus, it is critical to note that both the heat content and the amount of heavy hydrocarbons present in the feed stream dictate the operational settings for the plant to attain pipeline quality sales gas. Needless to say, any deterioration in the quality of the feed will result in a concatenate reduction in the sales/feed ratio. This is expected because poorer quality of feed gas will naturally contain increasingly higher amounts of non-hydrocarbon components (such as nitrogen), and any upgradation process, such as this plant, is effective only if it can successfully reject most of this increasing volume of non-hydrocarbon impurities in the feed, and thus naturally result in lower sales/feed ratios. Also as feed quality deteriorates, the towers must be charged to higher pressures and this results in higher pressure differentials during the venting process, leading to greater volumes of gas lost and lower sales/feed ratios. Also for this poorer quality feed, the BTU-recovery efficiency decreased to around 59% as compared to 75% obtained with a superior feed having an average of 715 BTU/cu ft.

HEAVY HYDROCARBONS ADSORPTION

Figures 10A to 10B display the analyses of gas samples taken from the feed and the upgraded sales stream for a feed gas with heat content of around 746 BTU/cu ft and heavy hydrocarbon fraction of 7.7%. A mass balance on the heavy hydrocarbons (C_2H_6+) made on the feed and the upgraded sales gas shows that about 98% of the heavy hydrocarbons entrained in the feed are recovered in the sales stream. Thus, the bed of activated carbon was found efficient in capturing the incoming heavy hydrocarbons and the desorption process was equally effective in recovering these adsorbed hydrocarbons. Also, the mass balance calculations show that about 67.7% of the total hydrocarbons (CH_4+) have been recovered at the NRU. Therefore, the vent stream is mostly made up of unadsorbed nitrogen and some methane because most of the heavy hydrocarbons are recovered in the sales stream.

Figures 11A and 11B show the gas analyses of the feed (at 601 BTU/cu ft and heavy hydrocarbon fraction of 3.7%) and the respective upgraded (sales) gas from the plant. As compared to the previous case, the feed gas composition has deteriorated both in terms of heat content and heavy hydrocarbon fraction. Mass balance calculations on this poorer quality feed gas show that the plant is able to trap and recover around 98.2% of the entrained heavy hydrocarbons (C_2H_6+). The associated total hydrocarbon recovery (CH_4+) is lower (at 58.6%) for this poorer quality feed.

The above results clearly indicate that an unpatented off-the-shelf bed of activated carbon (made from coconut husks) is effective in adsorbing and then desorbing 98% of the entrained heavy hydrocarbons (C_2H_6+) from a feed stream of low-BTU gas. This effective capture and recovery of the heavy hydrocarbons, where each component has significant heat content, plays a critical role for the plant to be able to upgrade low-BTU gas to pipeline standards. However, the adsorption effectiveness of the bed means that the vent gas contains little to no heavy hydrocarbons, and therefore the only component in the vent gas that has any heat content is CH_4. This calls in question the economic feasibility of upgrading the vent gas to pipeline quality in order to improve the total hydrocarbon recovery from the plant.

PERFORMANCE COMPARISON WITH COMMERCIAL PLANT

Figure 12A tabulates the price, in terms percentage of sales volume, that American Energies Corporation (AEC) was offered by a local commercial plant to upgrade its low-BTU gas. This micro-scale NRU was designed to handle around 250 mcf/d of low-BTU feed gas. The appropriate seller’s percentage offered to AEC for such low volume sales (i.e., less than 450 mcf/d) was 51% of the total volume of gas sold to the commercial upgradation plant. Thus for every 100 mcf of low-BTU gas that AEC sells to the plant, it gets paid for 51 mcf. Also, the sales contract carried additional constraints (Figure 12B), important among which was that the feed could not have nitrogen content in excess of 28%. This constraint would disqualify the feed coming into this micro-NRU because the feed nitrogen content was 33% or higher. Additionally, AEC had to consider the cost of transporting the low-BTU gas from the production wells (in the Elmdale field, Chase County, Kansas) to the commercial plant, provided presence of a nearby pipeline whose operator agreed to transport the low-BTU gas. AEC estimated that the transportation costs would additionally be around 13% of the volume of low-BTU gas that it sold to the commercial upgradation plant.

Figure 12C compares the revenue that AEC would stand to collect if it sold the low-BTU gas to the commercial plant with what it would gain if it processed the same gas using the micro-NRU, assuming that the commercial plant would agree to set aside its constraint related to not accepting any gas with greater than 28% nitrogen. Thus, if AEC were to sell 100 mcf of low-BTU gas to the commercial plant, it would get paid for 38 mcf of pipeline quality gas after deduction of the upgradation and transportation costs (here estimated at 13% of the total gas volume sold). In comparison, if AEC were to use the micro-NRU to treat its low-BTU gas onsite, it could save on the transportation costs. Given the average sales/feed ratio achieved at the micro-NRU, if AEC were to sell 100 mcf of low-BTU gas with an average heat content of 615 BTU/cu ft and 715 BTU/cu ft, it would get paid for 39 and 57 mcf of pipeline quality gas respectively. Thus, the micro-NRU offers competitive value to low-BTU producers, particularly if available commercial upgradation plants are located far from the production sources and when such commercial plants restrict the amount of nitrogen in the feed gas.

PLANT ECONOMICS

Figure 13 summarizes the payout calculations for the micro-NRU whose construction costs totaled to $120,000. AEC built the plant using off-the-shelf vessels, pipelines, control valves, engine and compressor, in their workshop with its own maintenance/service crew. This achievement highlights the simplicity of the plant design, and should therefore provide confidence to other small operators to venture into building a micro-plant for their own needs without relying on expensive expertise from consultants. The payout calculations were carried out assuming the price of pipeline quality gas to be $4.00/mcf, feed volume of 150 mcf/d, and for two different qualities of feed gas at 615 and 715 BTU/cu ft. Based on average performance (sales/feed ratio) observed at the micro-NRU, the payout time calculates to be 17 and 12 months respectively, for the above two types of feed.

PLANT CONTROLS

The plant is easily optimized from a central (electronic) control panel that pneumatically opened and shut the different solenoid valves that control the flow of gas in and out of the two towers. The electronic panel allows the operator to input charge and vent times for each tower, which need to be synchronized for continuous operation. For unchanging feed line pressure and composition, the plant will work unattended with one daily check-up visit by the pumper/operator. However if the feed composition changes, the operator must re-set the operating conditions of the NRU using the control panel to produce pipeline quality gas at the downstream end. Only two parameters need to be changed in order to re-optimize the plant to upgrade the new low-BTU feed to pipeline quality, and these are the tower charge pressure and the vent pressure. The operator must try different combinations of these above two parameters by changing feed and vent pressures (or times) using the control panel to find the new settings for obtaining pipeline quality feed.

Based on experiences from this pilot NRU, the following are suggested general guidelines that an operator can follow to optimize the settings:

a) If the feed BTU and heavy hydrocarbon fraction increases, then the towers can be charged to lower pressures to obtain pipeline quality sales stream. Sales/feed ratios tend to improve with higher quality feed.

b) If the feed BTU and heavy hydrocarbon fraction decreases (i.e., feed quality deteriorates), the towers must be charged to higher pressures to upgrade to pipeline quality. Sales/feed ratios will decrease with poorer feed quality.

c) After having attained pipeline quality sales stream with a particular setting, the operator may test for optimum sales/feed ratio by adjusting the tower charge pressure downward to identify the lowest charge pressure, which results in the sales stream to be of pipeline quality.

TECHNOLOGY TRANSFER

A web site (http://www.kgs.ku.edu/PRS/Microscale/index.html) dedicated to this project has been updated with pictures, results, cross-sections, log analyses, etc. All reports and presentations have been posted on this web site. Results obtained at the end of this reporting period are being written up for submission to one of the widely read trade journals in the small producer community, i.e., either Oil & Gas Journal or World Oil. The expected date of publication is early fall 2009. Results from this study were presented at the fall meeting of the Stripper Well Consortium on September 8-9, 2008, Oklahoma Oil & Gas Trade Expo on October 16, 2008, and at the Kansas Geological Society on November 10, 2008.

PLANS

The micro-NRU continued to upgrade low-BTU feed gas at its current location until the beginning of 2009, when the wells supplying the gas had to be shut-in due to production of water and the attendant infrastructure limitations in trucking away produced water. Thus, AEC is currently under discussions with other operators of neighboring low-BTU gas producing wells to relocate the NRU and start gas upgradation.

Encouraged by the results of this demonstration micro-NRU, AEC has already built a bigger plant (Figure 14). At the time of writing of this report, this newly built plant (with tower height of 20 feet and diameter of 6 feet) has been moved to location and has been commissioned. The plant is awaiting legal clearance before start of operation. Based on the lessons learnt from the demonstration plant, the grate supporting the bed of activated carbon has been placed at the bottom of the tower (just above the feed entry flange) in order to minimize the dead space (volume) in comparison to the volume of the tower. This new plant will mobilize gas from a low-BTU field that is currently shut-in because of lack of rich-gas necessary for blending. This case thus demonstrates how micro-NRUs can be effective in activating shut-in fields and thereby providing new life to the marginal assets often in isolated locations and owned by small producers. Upgraded gas can either be consumed locally or be assimilated in the nation's gas grid to increase domestic energy supplies.

CONCLUSIONS

1. It is possible to upgrade low-BTU gas (as low as 630 BTU/cu ft) to pipeline quality (> 950 BTU/cu ft) using a simple, cost-effective micro-scale nitrogen rejection unit (NRU) with an adsorption bed consisting of readily available non-patented activated carbon made from coconut husks.

2. Approximating plant construction costs at $120,000 and assuming gas prices at $4/mcf and a feed of 150 mcf/d, the payout is estimated at 17 months for 615 BTU/cu ft feed and 12 months for 700 BTU/cu ft feed.

3. The dead space within each tower must be minimized relative to tower volume. Initial operation data indicate that greater bed mass (with minimum dead space) results in larger volumes of adsorbed hydrocarbons and therefore better sales/feed ratio.

4. The off-the-shelf bed of activated carbon is efficient in adsorbing heavy hydrocarbons (C_2H_6+) from the feed stream and desorbing it under vacuum. This efficient removal of heavy hydrocarbons leaves the vent gas poor in constituents with significant heat content, and therefore puts in doubt the viability of upgrading vent gas to pipeline quality.

5. The towers have to be evacuated (desorbed) from vent pressure (around 2psi) to maximum vacuum (≈25" Hg) quickly to maximize heavy hydrocarbon recovery and to

lower cycle time, which is inversely related to plant throughput. Efficient desorption results in better adsorption of hydrocarbons in the next cycle and may increase bed life. Thus it is recommended that operators employ the most effective compressor to evacuate the towers to maximum vacuum in the shortest time.

6. The compressor capacity is tied to the size of the towers, and plant efficiency will be compromised if a less-than-appropriate sized compressor is employed. Despite the cost of the compressor being one of the major expenses in building of the micro-plant, operators should not employ a less than capable compressor if plant efficiency and throughput are valued.

7. Plant settings will require re-optimization if feed composition (BTU and C_2H_6+/CH_4+ ratio) changes. Greater amounts of heavy hydrocarbons in feed results in higher sales/feed ratio and thus better plant operating economics. Two parameters, namely tower charge pressure and vent pressure, must be adjusted in order to optimize the plant to the new feed (composition).

8. A portable hydrocarbon meter is very effective during the process of plant optimization. Correlations developed between portable hydrocarbon meter and gas chromatographic (GC) analyses enable quick estimation of hydrocarbon concentration and BTU value from portable meter readings taken from different sampling points in the plant, particularly during the optimization process.

9. Both nitrogen content and the fraction of heavy hydrocarbons in the feed control the optimum plant settings and determine its efficiency.

STEP 1 - Tower 1 Adsorption, Tower 2 Desorption

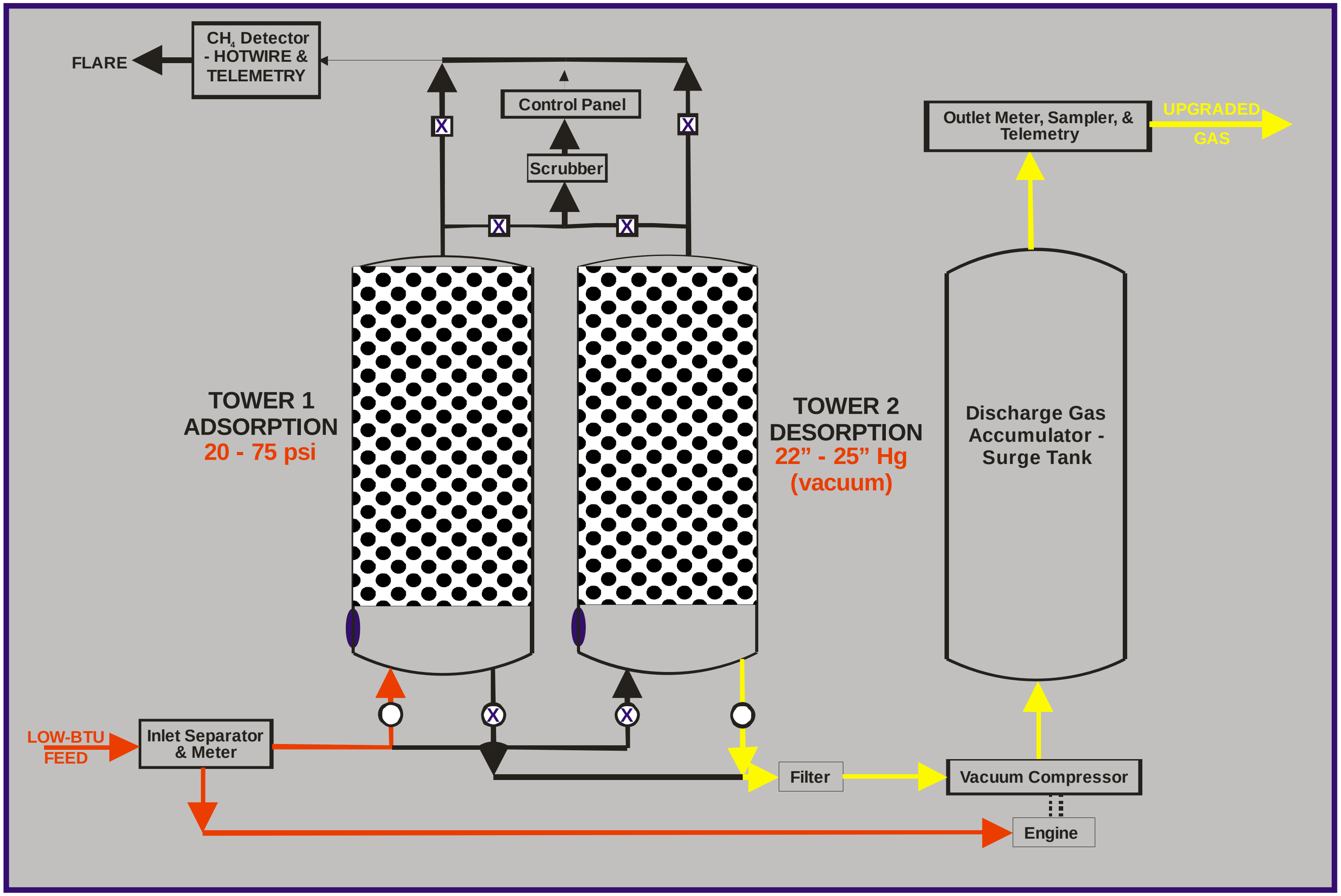


Figure 1: First step of operation - the feed gas charges up the evacuated Tower 1 to the set pressure (between 25 to 75 psi) depending on the plant settings determined by the feed gas quality, while Tower 2 is going through the evacuation process to vacuum ranging between 22 to 25 inches of Hg.

STEP 2 - Tower 1 Venting, Tower 2 in Vacuum

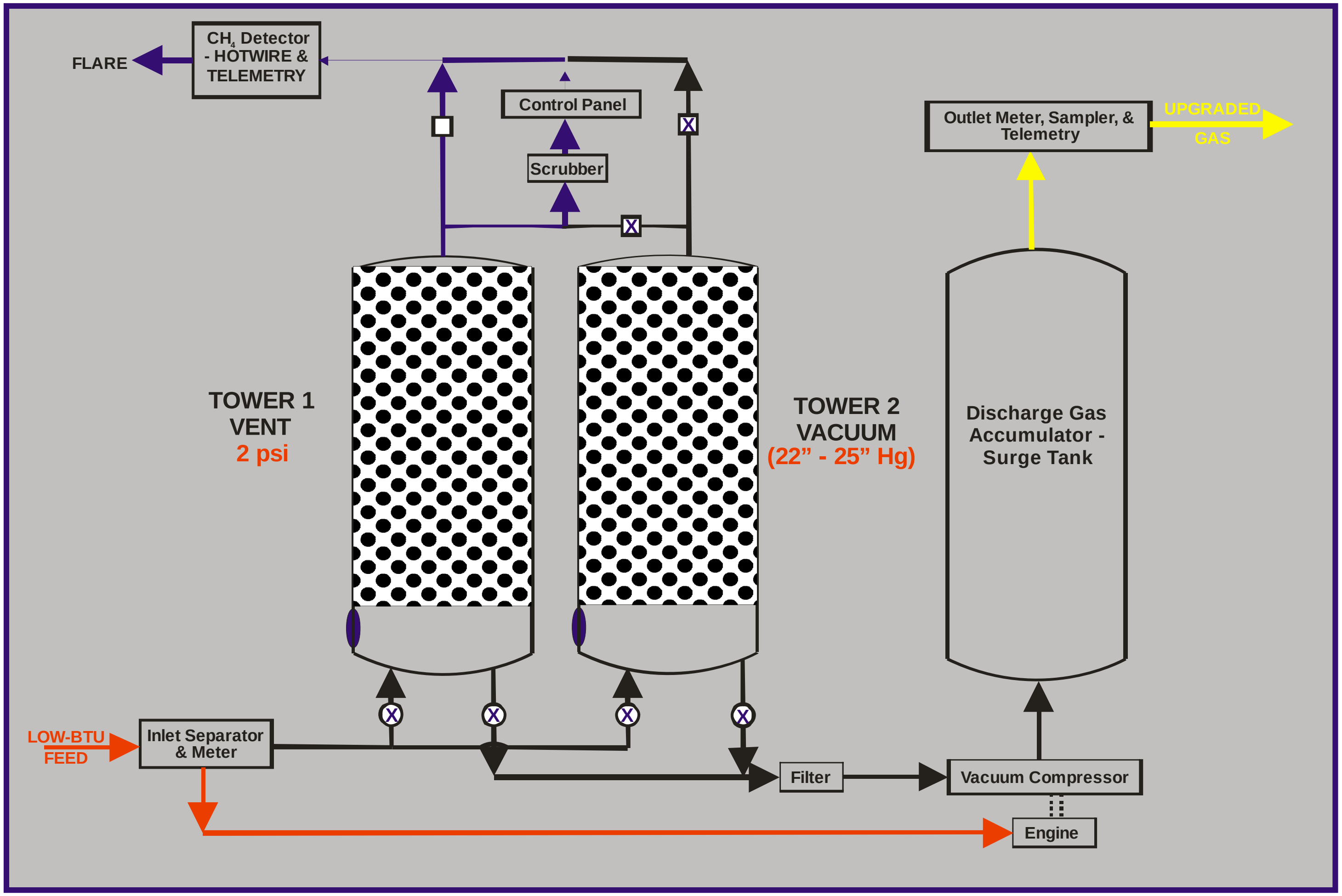


Figure 2: Second step of operation - Tower 1 is vented to 2 psi after having been charged to the set pressure thus allowing the removal of N_2-rich unadsorbed gas from the tower. This venting results in some loss of CH_4 but also prevents the unadsorbed N_2 from ending up in the surge tank during the 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

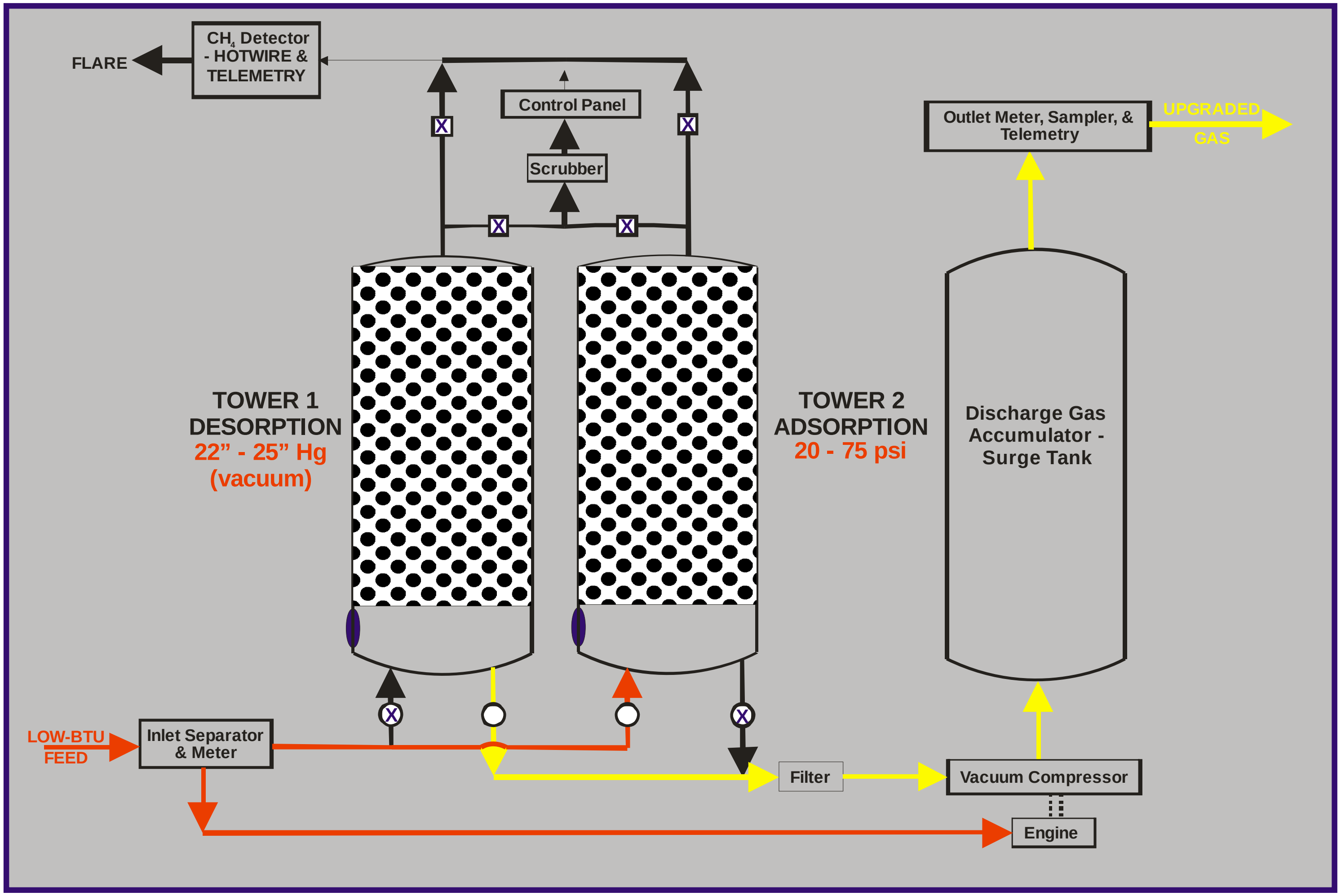
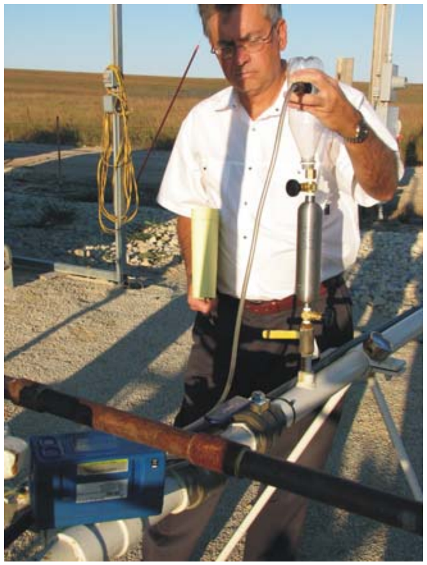


Figure 3: Third stage of operation - Tower 1 (after completion of the venting) is put under vacuum to evacuate the CH_4-rich gas adsorbed in the activated bed while Tower 2 is connected to the feed line and gets charged.

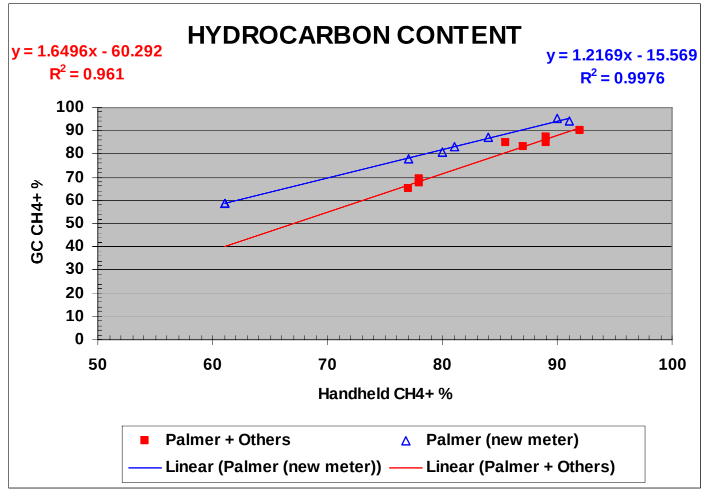
GAS ANALYSIS – PORTABLE GAS CHROMATOGRAPH

A.

B.



C.



D.

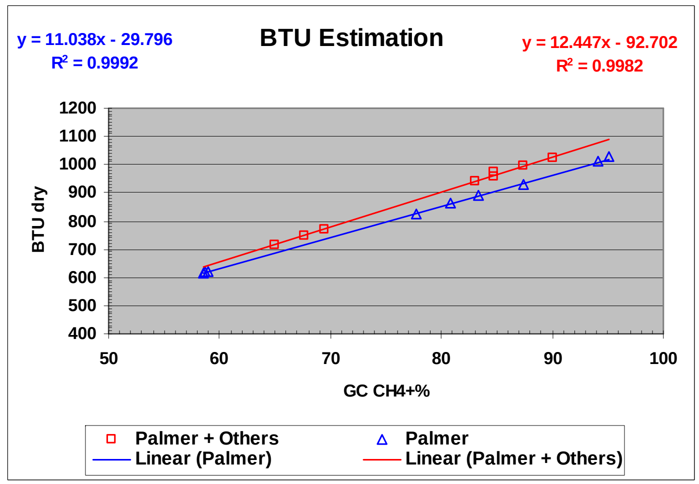


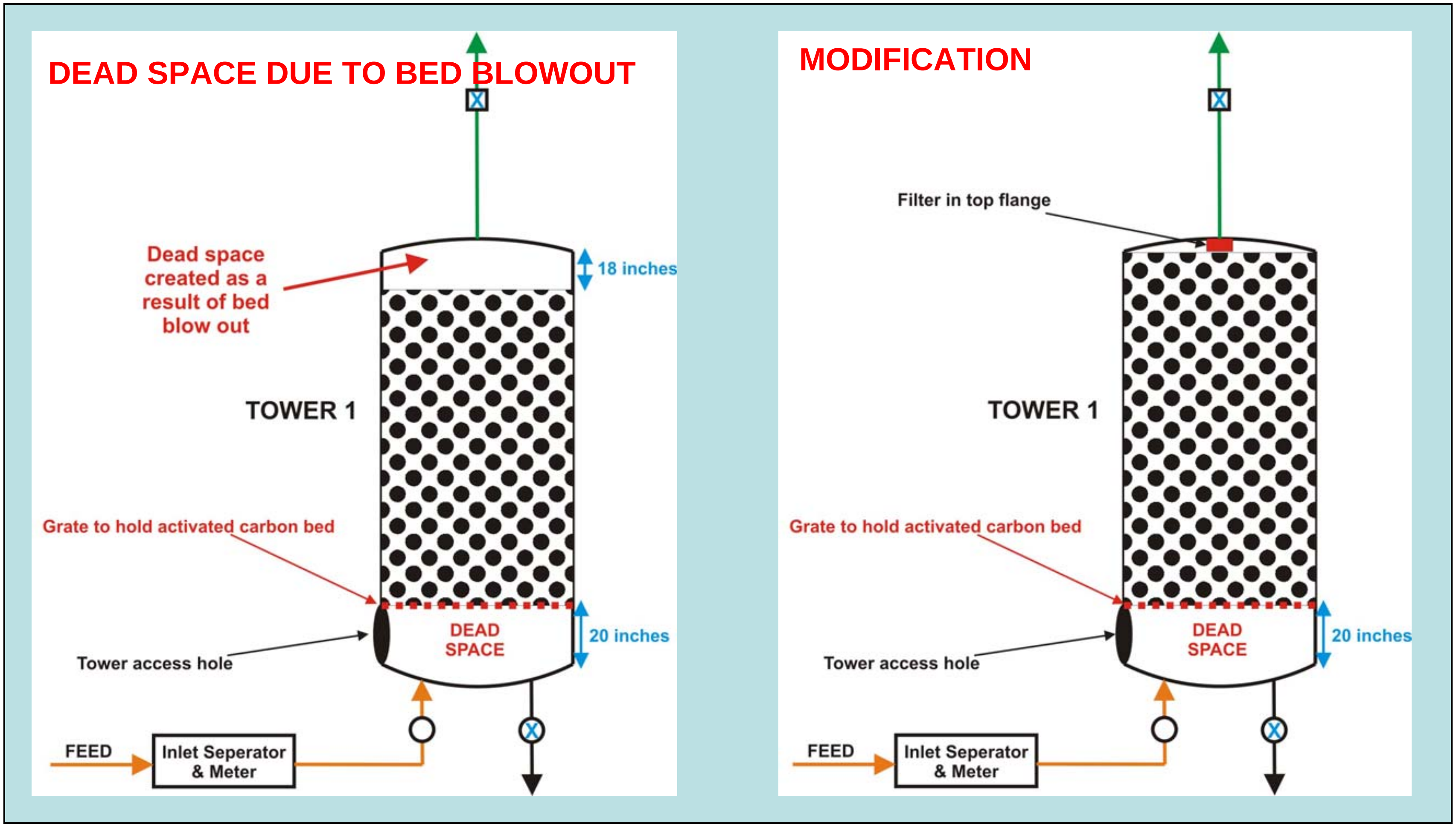
Figure 4: A) Portable gas meter that detects total hydrocarbons (handheld CH_4+ %). B) Field sampling of the feed stream using portable meter. C) Correlation between portable meter (handheld CH_4+ %) and gas chromatographic analyses (GC-CH_4+ %). D) Correlation between gas chromatographic analyses and heat content.

INITIAL TESTING

Test #	From	To	Charge Pr, psi	Vent from	Vent to, psi	Feed CH4+	Avg Sales CH4+	Sales/feed
1	31-May	3-Jun	34	Top	2	0.63	0.84	0.54
2	4-Jun	6-Jun	20	Top	2	0.66	0.85	0.58
3	7-Jun	10-Jun	20	Top & Bottom	2	0.68	0.83	0.51
4	11-Jun	14-Jun	30	Top & Bottom	2	0.67	0.85	0.44

Figure 5: Results from initial tests where the plant was operated under different settings until bed blow out.

BED BLOWOUT



A. B.

Figure 6: A) Dead space created at the top of the tower due to bed blowout. Permanent dead space (of about 20 inches) remains at the base of the 8 ft tall tower due an inadvertent design flaw. B) The tower topped with activated carbon and sealed in place by a filter set in the top flange.

Avg Feed @ 715 BTU/cu ft, C_2H_6+/CH_4+=7.9%

Vent from Top

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 %
34	2	63	84	0.54	76.7	73.2	63.1	687	953	75.7
20	2	67	85	0.60	72.6	75.4	59.2	743	964	77.4

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)

CH_4+ Recovery Efficiency - % of feed HC captured for sales

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

- Follows CH_4 recovery efficiency - HCs determine BTU content

Figure 7: Results of upgrading feed with average heat content of 715 BTU/cu ft to pipeline quality under two different plant settings.

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

Figure 8: Table showing that heavier hydrocarbons significantly contribute to the BTU content of natural gas. Thus, optimum plant settings will change when C_2H_6+/CH_4+ ratio changes.

HOW POOR A FEED CAN THE PLANT UPGRADE?

FEED 630 BTU/cu ft, avg C_2H_6+/CH_4+ = 3.9%

SIMULTANEOUS VENTING - TOP & BOTTOM OF THE TOWER

Pipeline quality

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

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

Figure 9: Results of upgrading feed with average heat content of 630 BTU/cu ft to pipeline quality under different plant settings.

ADSORPTION EFFECTIVENESS OF HEAVY HYDROCARBONS

Feed 746 BTU/cu ft, C_2H_6+/CH_4+ = 7.7%

Sample Bottle	KGS 1		
Sample date	Jun 06 2008		
Well	Feed Gas (Replicate)		
Component		Mole %	BTU
Neopentane		0.0000	0.00
CO2		0.1291	0.00
Helium		0.6408	0.00
Hydrogen		0.0000	0.00
Oxygen		0.0000	0.00
Nitrogen		31.4020	0.00
Argon		0.1925	0.00
Methane		62.4206	630.45
Ethane		2.9970	53.04
Propane		1.4761	37.14
i-Butane		0.2061	6.70
n-Butane		0.3663	11.95
i-Pentane		0.0758	3.03
n-Pentane		0.0757	3.03
n-Hexane		0.0143	0.68
n-Heptane		0.0036	0.20
Totals		99.9999	746.2200
Specific Gravity from Composition			0.7198
BTUs @	14.696	Saturated	733.21
BTUs @	14.696	Dry	746.22
Compressibility			0.99846
C2H4+		5.2149	
CH4+		67.6355	
C2H4+/CH4+		7.7	%

A.

Sample Bottle	KGS 5		
Sample date	Jun 06 2008		
Well	Sales Gas		
Component		Mole %	BTU
Neopentane		0.0000	0.00
CO2		0.1820	0.00
Helium		0.1225	0.00
Hydrogen		0.0000	0.00
Oxygen		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
Totals		99.9999	974.1200
Specific Gravity from Composition			0.6872
BTUs @	14.696	Saturated	957.11
BTUs @	14.696	Dry	974.12
Compressibility			0.99777
C2H4+		9.46	
CH4+		84.79	
C2H4+/CH4+		11.2	%

B.

	Sales/Feed	0.54		
100	moles of feed has	5.21	moles of C2H4+	
100	moles of feed result in	54	moles of sales	
54	moles of sales has	5.11	moles of C2H4+	
	C2H4+ recovery %	98.0		
100	moles of feed has	67.64	moles of CH4+	
100	moles of feed result in	54	moles of sales	
54	moles of sales has	45.78	moles of CH4+	
	CH4+ recovery %	67.7		

Figure 10: A) GC analysis of feed gas (at 746 BTU/cu ft) and B) GS analysis of sales gas when compared with that of feed shows that most of the heavy hydrocarbons (HCs) are adsorbed in the activated carbon.

ADSORPTION EFFECTIVENESS OF HEAVY HYDROCARBONS

Feed 601 BTU/cu ft, $C_2H_6+/CH_4+ = 3.7\%$

Sample Bottle	KGS 5		
Sample date	Aug 20 2008		
Well	Feed Gas - 2		
Component		Mole %	BTU
Neopentane		0.0008	0.00
CO2		0.0912	0.00
Helium		0.7318	0.00
Hydrogen		0.0000	0.00
Oxygen		0.0000	0.00
Nitrogen		41.8242	0.00
Argon		0.0006	0.00
Methane		55.2329	557.85
Ethane		1.4788	26.17
Propane		0.4625	11.64
i-Butane		0.0721	2.34
n-Butane		0.0758	2.47
i-Pentane		0.0157	0.63
n-Pentane		0.0114	0.46
n-Hexane		0.0021	0.10
n-Heptane		0.0000	0.00
Totals		99.9999	601.6600
Specific Gravity from Composition			0.7372
BTUs @	14.696	Saturated	591.17
BTUs @	14.696	Dry	601.66
Compressibility			0.99885
C2H4+		2.12	
CH4+		57.35	
C2H4+/CH4+		3.7	%

A.

Sample Bottle	KGS 1		
Sample date	Aug 20 2008		
Well	Sales Gas -1		
Component		Mole %	BTU
Neopentane		0.0025	0.00
CO2		0.1811	0.00
Helium		0.0816	0.00
Hydrogen		0.0000	0.00
Oxygen		0.0000	0.00
Nitrogen		11.3093	0.00
Argon		0.0454	0.00
Methane		82.9035	837.32
Ethane		3.7077	65.61
Propane		1.2601	31.71
i-Butane		0.1962	6.38
n-Butane		0.2189	7.14
i-Pentane		0.0473	1.89
n-Pentane		0.0367	1.47
n-Hexane		0.0076	0.36
n-Heptane		0.0022	0.12
Totals		100.0001	952.0000
Specific Gravity from Composition			0.6381
BTUs @	14.696	Saturated	935.41
BTUs @	14.696	Dry	952.00
Compressibility			0.99799
C2H4+, %		5.48	
CH4+, %		88.38	
C2H4+/CH4+		6.2	%

B.

	Sales/Feed	0.38		
100	moles of feed has	2.12	moles of C2H4+	
100	moles of feed result in	38	moles of sales	
38	moles of sales has	2.08	moles of C2H4+	
	C2H4+ recovery %	98.2		
100	moles of feed has	57.35	moles of CH4+	
100	moles of feed result in	38	moles of sales	
38	moles of sales has	33.58	moles of CH4+	
	CH4+ recovery %	58.6		

Figure 11: A) GC analysis of feed gas (at 623 BTU/cu ft) and B) GC analysis of sales gas when compared to that of feed 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.

PERFORMANCE COMPARISON WITH COMMERCIAL PLANT

This micro-plant is ideal for upgrading low-volume, low-pressure, low-BTU feed from isolated wells (fields) that are far from any commercial upgradation plants and electric grid.

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

A.

ADDITIONAL CONSTRAINTS

Feed limitations: Often can't have too high N_2 (< 28% N_2) concentration in the gas sold to the plant

Additional costs related to transportation from low-BTU source to commercial plant estimated at 13% of volume of gas transported

B.

	Max Feed N2 %	Feed BTU/cu ft	Sales Vol mcf/d	Sales/Feed Ratio	Price received mcf/d	Pipeline costs mcf/d	Revenue mcf/d
Commercial Plant	28		100		51	13	38
Micro-Plant	40	615	100	0.39	39	0	39
Micro-Plant	33	715	100	0.57	57	0	57

C.

Figure 12: A) Example of seller's (volume) percentage offered by a commercial low-BTU gas upgradation plant in Kansas. B) Associated constraints related to selling low-BTU gas to the commercial upgradation plant. C) Performance comparison of micro-NRU with commercial upgradation plant.

PLANT ECONOMICS

Plant Construction Costs = $120,000

Feed mcf/d	Feed BTU/cu ft	Sales/Feed Ratio	Sales mcf/d	Gas $/mcf	Payout, months
150	615	0.39	58.5	$4.00	17
150	715	0.57	85.5	$4.00	12

Figure 13: Payout calculation for micro-NRU using two different low-BTU feed gas.

CURRENT STATUS

Figure 14: Photograph of the new and larger plant that has been built by American Energies Corporation for installation in one of their low-BTU fields where the wells are currently shut for lack of availability of rich gas for blending.