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

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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 pressure tested and connected to the gas from the Frankhauser Trust E1 well. This well was recompleted in the Tecumseh sand which has produced low-BTU gas in wells outside the Elmdale field. However, upon testing the Tecumseh gas at this well it was found to be of pipeline quality with ~ 14% nitrogen and ~ 5% ethane. The plant ran successfully and was able to reduce the nitrogen content in the gas to ~ 7% without any adjustments. Gas from the Ireland sand was tested at Palmer 1 well and found to be of low-BTU with ~ 37%

nitrogen. Because of problems related to laying a pipeline to connect the Palmer 1 well to the plant, it was decided to relocate the plant to near the well.

Wireline logs from 26 wells located in and around the Elmdale field were analyzed to evaluate the potential of low-BTU gas in the area. Water samples were collected from 3 wells in the Elmdale field and tested for resistivity for use in the Archie equation for the above mentioned log analyses. The shallower sands in some of the wells show a potential for gas production. Additional wells need to be selectively recompleted and tested in order to validate the logs analyses and help determine the available low-BTU potential. Fifty-four gas sample analyses from the area around the Elmdale field were integrated to identify characteristics of low-BTU gas production. It was found that the shallower sands tend to produce low-BTU gas and that hydrocarbon wetness increased with depth and the age of the producing formation. However, the nitrogen-to-helium ratios remained unaffected by the age of the pay zone. Finally, gases from the deeper formations appear to display a greater compositional range.

Once relocated, the plant will be connected to the low-BTU gas from the Palmer 1 well, and thereafter optimized to maximize methane recovery.

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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 types of technologies.

It is the objective of this project to design, construct, operate, and optimize a micro-scale N_2 rejection plant to economically upgrading of low-BTU gas from stripper wells. Our goals were to build a low-cost, 2-tower micro-scale PSA (pressure swing adsorption) plant that would adsorb methane and heavier hydrocarbons under pressure while rejecting the N_2 followed by extraction of the hydrocarbons under vacuum.

EXECUTIVE SUMMARY

This project is a joint effort by the Kansas Geological Survey and American Energies Corporation (a company that primarily operates stripper wells in Kansas). Construction of the proposed micro-scale N_2 rejection plant to upgrade low-BTU gas was completed during the previous reporting quarter. In this reporting quarter, the plant was tested under pressure and vacuum and it was confirmed to be free of any leaks. Frankhauser Trust E1 well, located near the plant, was recompleted in Tecumseh sand which has produced low-BTU gas in a well outside the Elmdale field. However upon testing the Tecumseh gas, it was found to be of pipeline quality despite containing ~ 14% nitrogen due to the presence of ~ 5% ethane. The N_2 rejection plant was connected to a feed stream that predominantly drew upon the Tecumseh production from the Frankhauser Trust E1 well, and was found to operate without any problems. The plant was found to upgrade a feed stream containing ~ 14% nitrogen to a sales stream of ~ 7% nitrogen without any optimization adjustments.

Palmer 1 is a well located close to the Elmdale field and is completed in the Ireland sand. Gas from this well was tested and found to be of low-BTU (637 BTU/cu ft) with ~ 37% nitrogen. It was decided to relocate the plant to near this well because of unresolved problems related to laying a pipeline to connect the plant to this well.

Wireline logs from 26 wells in and around the Elmdale field was carried out to evaluate the gas producing potential of several shallow sands. Most of these wells currently produce pipeline quality gas from the Lansing Kansas City (LKC) zone. Produced water from 3 wells in the Elmdale field was analyzed for water resisitivity values for use in the Archie equation in above mentioned log analyses. Initial log analyses revealed that many of the shallower sands have potential to produce gas. Select candidate wells need to be recompleted in shallower sands to validate log analyses estimates and to determine the potential of low-BTU reserves in and around Elmdale field.

Regional analyses of low-BTU gas were initiated using available data from 54 samples. Analyses of limited data revealed that a) shallower zones tend to produce low-BTU gas, b) hydrocarbon-wetness increased with the depth and age of the formation, c) nitrogen-to-helium ratios were unaffected by the age of the producing zone, and d) deeper formations displayed a greater compositional range for hydrocarbon and non-hydrocarbon gases.

The project web-site, which can be publicly accessed at http://www.kgs.ku.edu/PRS/Microscale/index.html, was kept updated with all relevant results, reports, presentations, pictures, and data analyses.

Future plans include relocation of the N_2 rejection plant to near the Palmer 1 well that has been tested to produce the low-BTU gas from the Ireland sand. Upon relocation, the plant will be pressure tested and then connected to the low-BTU feed. The plant will then be optimized to maximize methane production at the lowest operating costs. Also select wells, whose logs have been analyzed, will be recompleted in prospective shallower sands and tested to validate the log analysis, increase low-BTU feed volumes, and to help map the low-BTU gas potential in and around the Elmdale field.

EXPERIMENTAL

PRESSURE TESTING PLANT

The plant was put through a pressure test to see if any vessels, pipe, fittings, and instrumentations leaked. We expect the operating pressure to be around 70 psia. Thus for reasons of safety, the plant was pressure tested at 105 psia and was found to hold the pressure without any leaks. Thereafter, the plant was tested by pulling a vacuum of 28 inches. The plant held the vacuum during the 2-day test period.

WELL RECOMPLETION

The Frankhauser Trust E1 well is located in the vicinity of the N_2-rejection plant. This well was originally completed and producing from the Lansing Kansas City (LKC) zone. Log analysis of the Tecumseh sand (detailed later) shows the gas effect on the neutron log, BVW (bulk volume water) cluster around 0.12 and water saturation varying between 0.5 and 0.6. The Tecumseh sand has produced low-BTU gas in the vicinity of the Elmdale field, and thus Frankhauser Trust E1 well was chosen to be recompleted. The Tecumseh was isolated from the LKC by a plug and tested. The open flow potential was tested at 230 mcf/d. During the test, the well flowed at rates of 33, 41, 52, and 66 mcf/d for wellhead pressures of 310, 299, 284, and 264 psi respectively.

GAS ANALYSES

The Kansas Geological Survey (KGS) procured a portable gas chromatograph (GC) for this project. This instrument was calibrated and the used to analyze a) feed gas to the plant, b) sales gas coming out of the plant, c) N_2-rich vent gas stream, and d) samples from various neighboring wells to identify low-BTU sources. Figure 1 compares KGS's analysis of the gas composition and BTU from Tecumseh sand with that carried out by a commercial laboratory in Wichita. Both analyses show similar results thus validating the GC setup and calibration carried out at the KGS. Future gas analyses for plant optimization and regional mapping of low-BTU resources will be carried out using KGS's GC. Figures 2A and 2B display the gas composition and BTU of feed gas entering the plant. This gas analyses clearly indicates that though the feed gas has around 14% N2, the presence of ethane (5% +) results in pipeline quality BTU (> 950 BTU/cu ft). Figures 3A and 3B display the gas composition of the sales gas stream exiting the plant, while Figure 4 is that of the vent stream. These results will be discussed further in the next section.

Figures 5A and 5B display the analyses of gas producing from the Ireland zone in Palmer 1 well and from the LKC and the Tecumseh sands in the Giger B1 well. Both these wells produce low-BTU gas. Figure 5C shows that Stauffer 1-35 also produces low-BTU gas from the unknown zone(s). The above mentioned 3 wells are located in the vicinity of the N_2-rejection plant.

PLANT OPERATION

The feed stream to the plant is a mix of the production from the Frankhauser Trust E1 well along with gas from other nearby wells. It is apparent from gas analyses of the feed stream (Figures 1, 2A and 2B) that the available gas is not low-BTU as its BTU exceeds the minimum requirements of the pipelines connecting Elmdale field despite containing +14% N_2. Thus, it was decided to run the plant on the available feed stock in order to gain an understanding of the plant's effectiveness in reducing the N_2-content without any optimization routines. The plant was operated at a feed rate of 80 mcf/d with an inflow pressure of 35 psia. The adsorption process was allowed to continue for 12 minutes which was then followed by 40 seconds of pressure equalization between the two towers. Following pressure equalization, the tower under adsorption was put under vacuum (25 inches) while that under desorption was connected to the feed stream for adsorption. The above timings were chosen arbitrarily and did not result from an optimization routine. Analysis of the sales gas downstream of the surge tank indicates that without any changes, this plant is able to reduce the +14% N_2 in the feed to around 7% N_2 (Figure 3A and 3B). Analyses of the N_2-rich vent stream (Figure 4) however revealed that it contained significant volume of methane (38%).

PLANT RELOCATION

Tecumseh gas at the Frankhauser Trust E1 well was found to have a BTU that was just above the minimum required for pipeline grade. Thus, this gas can be sold by

AEC without additional upgradation. Gas analyses from neighboring wells (Figures 5A to 5C) indicated that the best source of low-BTU gas was the Palmer 1 well. Thus, it was decided to relocate the plant to near the Palmer 1 well (shown in Figure 6) because difficulties in obtaining permission to lay a pipeline connecting the well to the plant. The Palmer well currently produces from the Ireland sand and upon testing it was found to flow 150 mcf/d at surface flowing pressure of 70 psia.

WATER ANALYSIS

Produced water was analyzed to determine resistivity for use in Archie equation in log analyses. Majority of the wells in and around Elmdale field produce pipeline quality gas from the LKC formation. Representative water samples are not available from other sands (such as the Tecumseh) because they are currently not being produced. Water was collected from 3 wells, namely Davis Giger 1, Kisser 1-29, and Pretzer 3. The Davis Giger 1 and Pretzer 3 produce from the LKC, while AEC suspects that the Kissel 1-29 well is open to some low-BTU gas zones. Water analyses revealed that the resistivity of produced water from the above mentioned wells was 0.079, 0.077, and 0.076 ohm-m respectively. Thus lacking sand specific resistivity data, a resistivity of 0.078 ohm-m was used in the Archie equation for log analyses discussed in the following section.

LOG-ANALYSES – LOW-BTU RESOURCE EVALUATION

One of the deliverables for this project is to complete a local resource evaluation of low-BTU reserves around the plant. Wireline logs from 26 wells in and around the Elmdale field were analyzed as a part of the resource evaluation study. Initially, the log analysis was carried out over the Tecumseh interval (Figure 7) in Frankhauser Trust E1 well that produced water-free. The Tecumseh interval extends from 704 to 714 ft, where the gas effect is visible on the neutron porosity log. The significant separation between the density porosity and the BVW (bulk volume water), which clusters around 0.12, implies water-free or minimal water production. The GR (gamma log) indicates relatively lower values. Thus, the wireline log signatures match the production observed at this well from Tecumseh zone. This exercise was used to define the Archie constants (m = 1.8, a = 1, Rw = 0.079) that were used universally for all the other zones at other wells lacking zone-specific data. The petrophysical cut-off parameters that defined the Tecumseh as a pay zone include the following: porosity > 0.19, Sw < 0.60, Vshale < 85%, and BVW < 0.15.

Wireline logs from 26 wells in and around the Elmdale field were available and analyzed. Most of these wells produce pipeline quality gas from the LKC zone. To evaluate the potential of low-BTU reserves in this area, shallower sands such as Ireland, Douglas, Tecumseh, Calhoun, Severy, and White Cloud sands were analyzed when present at the well of interest. For each well, the density porosity and neutron porosity logs (run on a limestone matrix of 2.71 g/cc) were corrected for the sandstone matrix density of 2.65 g/cc. Thus, a neutron cross over (where the neutron porosity becomes less than the density porosity log by taking an hour-glass shape) is considered indicative of gas effect. However, it is to be noted that low porosity zones often result in deeper invasion which masks the gas effect which is otherwise visible in high porosity zones with shallower invasion. Presence of gas effect on the neutron log is a strong indicator of presence of gas, but absence of gas effect may not mean that gas is absent because invasion may mask the effect on neutron log. The summary of this log analyses is presented in Figure 8. Based on the log signatures of each of these sands, we predicted the production potential of each of these zones.

Figure 9 displays strong gas production potential for Ireland sand (1014 to 1030 feet) in Palmer 1 well with high porosity, low GR values, clustering of the BVW around a low value of 0.14, and gas effect on the neutron log over the lower part of this interval. Figure 10 indicates that the Tecumseh interval (744 to 754 feet) has good indications of gas production with low BVW values (< 0.1), gas effect on the neutron log, and low GR values. The cut-off parameters defined for the Tecumseh pay zone in the Frankhauser Trust E1 well, when used in this analysis indicate that the Tecumseh interval in Palmer 1 well can be similarly defined as pay. Figure 11 shows that the Calhoun sand (654 to 657 feet) in this well may have some gas production potential with low BVW values (< 0.14), low GR values, and minor gas effects on the neutron log, and separation between the density porosity and BVW. However, no gas shows were recorded over this zone during the drilling stage. Figure 12 shows that the Severy sand (570 to 578 feet) has gas bearing potential with gas effect on the neutron log, moderate GR, and significant separation between density porosity and BVW. However, a transition zone is clearly visible in this zone. We would like to note that this well tested significant volumes of low-BTU gas in Tecumseh and Severy zones.

Log analyses of the other wells are detailed in Figures 13 to 61. In each case, the analyzed sand is marked by a red rectangle. It is be noted that this is the first pass in analyzing wireline log data and thus will need to be refined/revised in order to match production results with log signatures as wells get recompleted in sands analyzed.

REGIONAL GAS ANALYSIS

Fifty-four gas analyses were collected from published and private sources from the region of the Elmdale Gas Field in Kansas (Figure 62), so as to survey the likely range of compositions of natural gas in this region and to determine what strata may contain low-BTU gas resources. Several pay zones, ranging in age from Permian to Mississippian, produce gas in the region. In general, the shallower pay zones contain low-BTU gas (i.e. <950 BTU/scf) (Figure 63). Hydrocarbon wetness, the ratio of heavier molecular-weight hydrocarbons to that of methane plus the heavier molecular-weight hydrocarbons, increases with increasing age and depth of the producing formation (Figure 64). The presence of these heavier-molecular-weight hydrocarbons increase the heating value (BTU content) when natural gases contain them, and this partly account for the better BTU content of the deeper gases, in addition to the greater percentages on nitrogen in the shallower gases (Figure 65).

Nitrogen-to-helium ratios for all the gases essentially remains the same regardless of the age of the pay zone (Figure 66), suggesting a common source for these component gases. The greater percentages of nitrogen and helium in she shallower, low-BTU zones indicates that these zones will have better economics if helium is attempted to be recovered from the rejected noncombustible gases in the upgrading process. The compositional ranges of the ranges of hydrocarbon and nonhydrocarbon gases are expressed respectively in Figures 67A and 67B. The deeper formations have a greater range in composition, but this may be due to more samples being available.

TECHNOLOGY TRANSFER

A web site 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 & DISCUSSIONS

The construction of the N_2 rejection plant was completed. The plant was pressure tested and then connected to gas primarily produced from the Frankhasuer Trust E1 well recompleted in the Tecumseh zone. The Tecumseh has produced low-BTU gas nearby, such as at the Palmer 1 well. However, analyses of the Tecumseh gas at the Frankhauser Trust E1 well revealed that despite containing about 14% nitrogen it was pipeline quality (> 950 BTU/cu ft) because of presence of ethane (~ 5%). The plant was operated with gas from the Frankhauser Trust E1 well and it reduced the nitrogen content from ~ 14% to ~ 7% without adjustments of plant controls. Because production from the Frankhauser Trust E1 well was found to be pipeline grade, the plant is currently in the process of being relocated near the Palmer 1 well where gas production (from the Ireland) has been tested to be of 637 BTU/cu ft. Operation of the plant will be optimized for low-BTU upgradation once it is connected to the Palmer 1 well.

FUTURE TASKS

It is expected that during the next reporting period, the following tasks will be undertaken:

a) Complete relocation of the micro-scale N2 rejection plant from its current location to that near the Palmer 1 well.

b) Pressure test the plant to check for leaks.

c) Connect plant to production from Palmer 1 well and optimize plant to maximize methane recovery at minimum operating costs.

d) Recomplete and produce select sands at some wells to validate log analyses and help map local low-BTU resources.

CONCLUSIONS

The following items have been completed during this reporting period:

1) Pressure tested plant at 105 psi and found it to hold the pressure without any leaks. Pulled a vacuum of 28 inches and held it for a 2-day period. These tests confirmed that the plant was free of any leaks.

2) Frankhauser Trust E1 well was recompleted in Tecumseh sand which has produced low-BTU gas in neighboring wells. The well tested an open flow rate of 230 mcf/d and flowed at 52 mcf/d with a surface pressure of 284 psi.

3) The Tecumseh gas from Frankhauser Trust E1 well analyzed and found to have ~14% nitrogen, ~5% ethane and 954 BTU/cu ft. Thus, the Tecumseh gas was found to be of pipeline quality and did not require upgradation.

4) The plant was connected to a feed stream that was primarily drawing from the production of the Tecumseh zone in Frankhauser Trust E1 well. Without any adjustments, the plant was able to upgrade the feed gas with ~14% nitrogen to a sales stream with ~7% nitrogen.

5) The Ireland gas in Palmer 1 well was tested and found to be sub-pipeline quality with ~37% nitrogen and 637 BTU/cu ft. Due to difficulties in laying a pipeline to connect this well to the plant, it was decided to relocate the plant to near the Palmer 1.

6) The Ireland sand was tested at the Palmer 1 well and it flowed at 150 mcf/d with a well head pressure of 70 psi.

7) Produced water from 3 wells in the Elmdale field was analyzed to determine the water resistivity for use in Archie equations. The resistivity was found to be clustered around 0.078 ohm m for two wells producing out of Lansing Kansas City (LKC) and for one believed to be open to both LKC and other low-BTU sands.

8) Wireline logs from 26 wells in and around the Elmdale field were analyzed to determine the gas production potential of several sand bodies such as Ireland, Douglas, Tecumseh, Calhoun, Severy, and White Cloud. Gas production potential was identified in these sands at several wells. Additional production testing needs to be carried out at select wells to validate and refine the log analysis.

9) Regional analyses of low-BTU data was initiated using 54 gas samples and the following trends observed:

a) In general, the shallower zones tend to produce low-BTU gas.

b) Hydrocarbon-wetness increases with age and depth of the producing zone.

c) Nitrogen-to-helium ratios are unaffected by the age of the pay zone.

d) Given the limited data set available, the deeper formations appear to display a greater compositional range hydrocarbon and non-hydrocarbon gases.