Technical and Operating Support for Pilot Demonstration of Morphysorb Acid Gas Removal Process

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GTI Project 61166

Contract Number: DE-FC26-01NT41028

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ABSTRACT

GTI and Krupp Uhde have been jointly developing advanced technology for removing high concentrations of acid gas from high-pressure natural gas for over a decade. This technology, the Morphysorb® process, based on N-formyl and N-acetyl morpholine mixtures, has now been tested in a large-scale facility and this paper presents preliminary results from acceptance testing at that facility. Earlier publications have discussed the bench-scale and pilot plant work that led up to this important milestone.

The site was Duke Energy's new Kwoen sour gas upgrader near Chetwynd B.C., Canada. This facility has a nameplate capacity of 300 MMscfd of sour natural gas. The objective of the Morphysorb process at this site was to remove 33 MMscfd of acid gas (H_2S and CO_2) for reinjection downhole. This represents about half the acid gas present in the feed to the plant. In so doing, proportionately more of the plant "sales" gas, which is sent for final processing at the nearby Pine River plant, can be sent down the line without coming up against the sulfur removal capacity limits of Pine River plant, than could with other solvents that were evaluated. Other benefits include less loss of methane downhole with the rejected acid gas and lower circulation and recycle compression horsepower than with competitive solvents. On the downside, the process is expected to have higher solvent vaporization losses than competitive solvents, but this is a comparatively minor drawback when weighed against the value of the benefits. These benefits (and drawbacks) were developed into quantitative "acceptance" criteria, which will determine if the solvent will continue to be used at the site and for award of monetary bonuses to the process developer (GTI).

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INTRODUCTION

Morphysorb® technology is the use of mixtures of N- Formyl Morpholine (NFM) and N-Acetyl Morpholine (NAM) as a solvent for the bulk removal of CO_2 and/or H_2S from natural gas and other streams. The technology is jointly owned by GTI and Uhde GmbH (formerly Krupp Uhde GmbH). The solvent has a high relative absorption of these compounds as compared to competing solvents, which results in lower circulation rates, and it has lower relative absorption of higher hydrocarbons, which results in more heating value in the sales gas and less losses. The high performance of Morphysorb® technology reduces producer's operating costs significantly: up to 60% over the existing state-of-the-art physical solvent technologies depending upon sour gas composition and conditions. Also, this process may, in lieu of operating cost savings, increases the plant capacity up to 30%.

Over the past 6 years, GTI in coordination with Uhde GmbH (GTI's commercialization partner) has conducted over 100+ field experiments processing more than 50 MMscf at the Shell-owned (now Kinder Morgan-owned) Fandango plant site in south Texas using the GTI (IGT) pilot plant unit.

GTI has negotiated an agreement Duke Energy Gas Transmission, Canada (DEGTC is a wholly owned subsidiary of Duke Energy) to test the Morphysorb process in a field experiment in their Kwoen plant, near Chetwynd BC, Canada which, if successful, can be the first commercial application of Morphysorb This plant processes 300 MMscfd of sour gas (over 23% acid gas concentration). In that plant the target is to remove 30 MMscfd of sour gas for reinjection. The balance of the sweetened gas, which is still quite sour, is sent to another plant for final acid gas removal and sulfur recovery using conventional technology.

This field experimental test of Morphysorb was carried out at Duke Energy's Kwoen Plant in November 2002. The test objectives were to demonstrate Morphysorb operability in a commercial unit and to confirm that the advantages observed in the pilot plant could be achieved on a commercial scale and could meet the specific performance targets as agreed in GTI's demonstration agreement with Duke Energy. The process is commercially licensed to DEGTC under a separate agreement with Uhde.

GTI's role was to develop test criteria for validation test (such as length of the test, criteria for steady state), parameters measured, determine the sampling location and sampling frequency analysis of data, set up a lab trailer, design sampling loops, observe and conduct performance test and sample collection, analysis of test data and report preparation.

EXECUTIVE SUMMARY

GTI and Duke Energy Gas Transmission Company, Inc. Canada (DEGTC) have entered into an agreement to test the performance of the Morphysorb® solvent (jointly owned by Uhde and GTI) in DEGTC's Kwoen Sour Gas Upgrader plant near Chetwynd, B.C., Canada. As part of that agreement, GTI is required to conduct a performance test at the Kwoen plant of 72 hours duration. Gas sampling and analytical equipment in a laboratory trailer was set up in anticipation of this requirement. The parties as per the agreement have established certain performance metrics. The metrics are acid gas pickup per unit volume of liquid, recycle rate as volume rate of gas, methane losses in the reinjection gas as mole percent, solvent losses as mass of solvent per volume rate of gas, and absence of any problems related to foaming. A further provision of the agreement stipulates that GTI may adjust the specific values of the metrics if the feed gas conditions (composition, flow, temperature or pressure) are not substantially as specified in the agreement.

The test was conducted over the period November 12 – November 15, 2002. The testing resulted in two useful "steady-state" periods (which differ in conditions significantly from each other) for the purpose of computation of the adjusted performance specification metric values and analysis of results. Material balances were computed for these two periods that were sufficiently close to balance, and the resultant values for the performance specification metrics were computed. In all cases the performance metrics satisfied the established criteria by being either less than adjusted maximum values or greater than minimum adjusted values.

GTI has continued monitoring the Kwoen plant performance and collect crucial design data for future commercial applications of the Morphysorb process during this reporting period. These data was quite helpful in ensuring the smooth running of the plant and in avoiding potential operational problems associated with corrosion, foaming, off spec gas and reduced performance. GTI agreed to accept plant samples on a monthly basis from the DEGTC Kwoen plant and to subject the samples to analyses that GTI feels are appropriate and necessary for monitoring the performance. This report is an evaluation of such analytical efforts from samples received through mid-May of 2003.

As of end of June, approximately 39 Bcf of sour gas processed and injected ~3.4 Bcf of acid gas to well since plant startup in August' 02.

EXPERIMENTAL

Task 1: Morphysorb Demonstration Plant

The overall objective Morphysorb demonstration project to prove earlier laboratory and simulation predictions for overall cost savings at Duke facility by removing acid gas from subquality natural gas by utilizing a new physical solvent system.

The role of GTI is limited to assist in basic design engineering services based on the GTI's knowledge acquired through lab, bench-scale and pilot plant experiments, in procuring plant facilities, plant start-up, establishing analytical set up for evaluating plant/technology performance, data collection, analysis and report preparation.

The Kwoen Gas Plant is located near Chetwynd, British Columbia in Canada. The plant was designed to reduce the acid gas load of the existing Pine River Gas Plant (PRGP), which is located about 18 miles upstream from Kwoen. The Kwoen processing plant, referred to by DEGTC as a sour gas upgrader, consists of bulk acid gas removal unit and an acid gas injection facility. The Kwoen plant will take a slipstream of the gas flowing to the PRGP and remove about 30 MMscfd of acid gas for downhole injection. A schematic of Kwoen plant is given in Figure 1.

The acid gas is absorbed in Morphysorb solution in two parallel 150 MMscfd capacity absorbers. The rich Morphysorb solvent is consecutively flashed at 425 psia and 185 psia in Flash 1 and 2 Flash vessels. To minimize methane losses, the flash gas from these vessels is compressed and recycled to absorber feed. The Flash 3 and Flash 4 vessels, which operate at 65 psia and 25 psia respectively, will generate the acid gas stream that will be compressed and liquefied for downhole injection. The semi-lean Morphysorb solution flows from the Flash 4 vessel back to the absorbers.

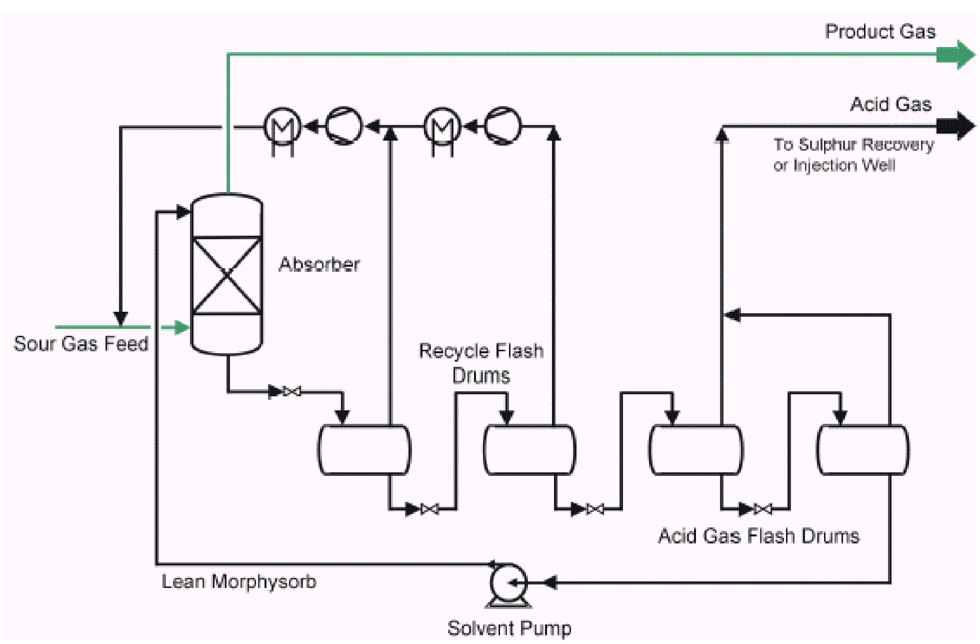

Figure 1: Process Flow Diagram for Kwoen Plant

GTI has collected and received the following Morphysorb solvent samples since the Kwoen plant startup. A total of four samples were collected and analyzed to date. The details are given in Table 1.

Table 1. Morphysorb Solvent Samples

Sample	Date Collected	Remarks
Virgin	July 2002	This sample was collected soon after the solvent was loaded into the plant and recirculated 48 hours for proper mixing.
1	November 15, 2002	This sample was collected on November 15, 2002 during plant performance testing.
2	November 28, 2002	This sample was collected on November 28, 2002 during GTI staff visit to the plant.
3	March 14, 2003	This sample was collected by Duke Energy and shipped to GTI in April 2003.

The following analysis were completed on all the collected solvent samples:

- N-Formyl morpholine, N- Acetyl morpholine, Morpholine and Water
- Hydrocarbons
- Traces of organic N-compounds
- Formate, Acetate, Oxalate, Chloride and Sulfate
- Silica
- ICP/OES Analysis for metals (Na, K, Mg, Ca, Sr, Ba, Ti, V, Cr, Mo, Mn, Fe, Co, Ni, Cu, Zn, Cd, Al, Sn, Pb, As, Sb, Se)
- Sulfur and Phosphorous
- Measuring of the content and analysis of solids filtering with 0.2 micron PTFE membrane filter. Analysis of solids: TOC, total sulfur, total nitrogen by combustion method.

RESULTS AND DISCUSSION

Solvent Integrity:

The solvent samples as detailed above were collected and analyzed to determine the concentration of NFM, NAM and water. The weight percent of NFM and NAM was calculated assuming that the liquid was composed of only NFM, NAM and H_2O. The H_2O concentration was measured with a Karl Fischer titration apparatus as well as GC-TCD method. Measurements during the performance test show that the solvent was about 50% NFM and 50% NAM, or a 1:1 ratio. In the original charge this ratio was in the range of .96 to 1.00. Averaging all the liquid samples collected to date, the average ratio of NFM to NAM is 1.00.

Solvent Degradation Analysis:

NFM and NAM are the products of reaction of morpholine with formic and acetic acid respectively. The solvent samples were analyzed using a Dionex Ion Chromatograph for thermal and chemical degradation products such as formate, acetate, sulfate, oxalate and chloride (Table 1). As seen in figure 1, concentrations of anions are quite constant over the period of the last several months and there has not been a significant change since plant start-up.

Table 1. Weight percentages of anions in the sample

	Acetate	Formate	Chloride	Sulfate	Oxalate
Virgin (July 02)	0.05377	0.00815	0.00223	0.00144	0.01909
Sample 1 (11/15/02)	0.05420	0.00843	0.00309	0.00232	0.01941
Sample 2 (11/28/02)	0.05448	0.00870	0.00285	0.00219	0.01911
Sample 3 (3/14/03)	0.05424	0.00863	0.00331	0.00291	0.01902

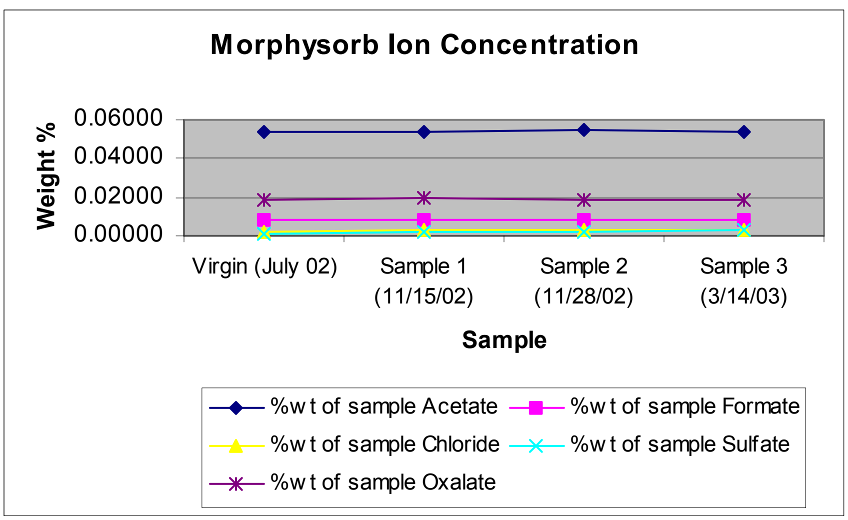

Figure 1. Morphysorb Anion Concentration

We recommend continuing measuring the concentration of dissolved iron in the solvent, e.g. once per month, to find out if a steady state concentration is being approached. To our knowledge corrosion of carbon steel by carbonic acids of this range of concentration is not significant at temperatures below 80°C, even in aqueous solution. The slow increase in iron concentration in the solvent from start-up until the present is typical for a passivation process at the carbon steel surface.

In February, a paper on Morphysorb process application at Duke Energy was presented at Laurance Reid Gas Conditioning Conference in Oklahoma City, OK. The copy of the paper is attached in Appendix A of this report.

Work for Next Quarter:

GTI will continue to monitor plant performance and provide any technical assistance as required by Duke Energy from time to time. GTI will also receive and analyze the solvent samples collected during next quarter.

CONCLUSION

GTI is interested in obtaining continuing data on the plant to support future plants and DEGTC is interested in reviewing data that may help in operating the plant and in avoiding various difficulties including corrosion, foaming, off spec gas and reduced performance. GTI has received six samples to date since the Kwoen plant startup in August 2002. GTI is continuing to receive such samples until end of this year. The analysis of solvent samples indicates that solvent is very stable after nine months of operation and did not undergo any appreciable formation of solvent degradation products that would affect the solvent performance.

As of end of June, approximately 39 Bcf of sour gas processed and injected ~3.4 Bcf of acid gas to well since plant startup in August' 02.

REFERENCES

1. Hugman, V. and Springer, "Chemical Composition of Discovered and Undiscovered Natural Gas in the U.S. Lower-48, March 1993, Energy and Environmental Analysis, Inc.

2. Tannehill, C. C. and Gibbs, J. E., "Gas Processing Industry Lower 48 States," July 1991, Purvin & Gertz, Inc., GRI-911/0232.

3. Macriss, R. A., and Duncan, D., "Acid-Gas and Trace Impurity Removal," Annual Report for 1975, A.G.A Project No. IU-4-10, 1976.

4. N. Palla, A. L. Lee, Dr. M. Gross, H. M. Hooper, J. Menzel and D. Leppin "Advancements in Treating Subquality Natural Gas Using N-Formyl Morpholine", Proceedings of the 77th GPA Annual Convention, 1998

1. M. Gross et al. , "A New Solvent Process for Acid Gas Removal and its Impact on BTEX Emissions", Proceedings of the 49th Laurance Reid Gas Conditioning Conference, February 1999
2. M.Gross, J. Menzel," Acid Gas Removal for Upgrading natural and Synthesis Gas-Part I", paper published in Hydrocarbon Engineering, November 1997.
3. M.Gross, J.Menzel," Acid Gas Removal for Upgrading natural and Synthesis Gas-Part II", paper published in Hydrocarbon Engineering, June 1998.

LIST OF ACRONYMS AND ABBREVIATIONS

NFM—N-Formyl Morpholine

NAM—N-Acetyl Morpholine

Scf—Standard Cubic Feet

Gal—Gallons

MM—Million

DEGTC—Duke Energy Gas Transmission Company

GTI—Gas Technology Institute

KU—Krupp Uhde

Appendix A

Paper Presented at Laurance Reid Gas Conditioning Conference

Performance of Morphysorb® Solvent in a Commercial Acid Gas Treating Plant

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ABSTRACT

Uhde GmbH and GTI's Morphysorb process has been demonstrated for the first time at commercial scale in Duke Energy Gas Transmission, Canada's (DEGTC) Kwoen Gas plant. This plant is a cost effective and environmentally beneficial method of de-bottlenecking Duke Energy Gas Transmission's Pine River Processing facilities.

Instead of recovering the sulfur from the extracted acid gas, the plant is designed to reinject over 30 MMscfd H_2S and CO_2 into depleted sour gas production reservoirs, thereby minimizing sulfur and carbon dioxide emissions from the facility and saving the gas producers significant costs of marketing the elemental sulfur.

This paper describes the background and need for this plant and the rationale for selecting the new process over other alternatives and provides plant design details. Results from operations at full capacity (150 MMscfd) in one of two absorber trains, which were used to determine process acceptance, are presented. The process has met and in some cases exceeded, all the performance targets set by DEGTC, which were substantially above expectations for alternative solvents, and is now in commercial service.

BACKGROUND

The Kwoen Gas plant is a new addition to the Pine River gathering and processing system located in Northeastern British Columbia, Canada. Pine River is the one of three large midstreaming areas that Westcoast Energy had developed and operated until March 2002 (Figure 1), at which time Duke Energy Gas Transmission (DEGT) acquired Westcoast Energy. DEGT is a gas gathering and processing service provider to the oil & gas producers in Northeastern British Columbia and does not own the gas that is being processed in its British Columbia gas plants.

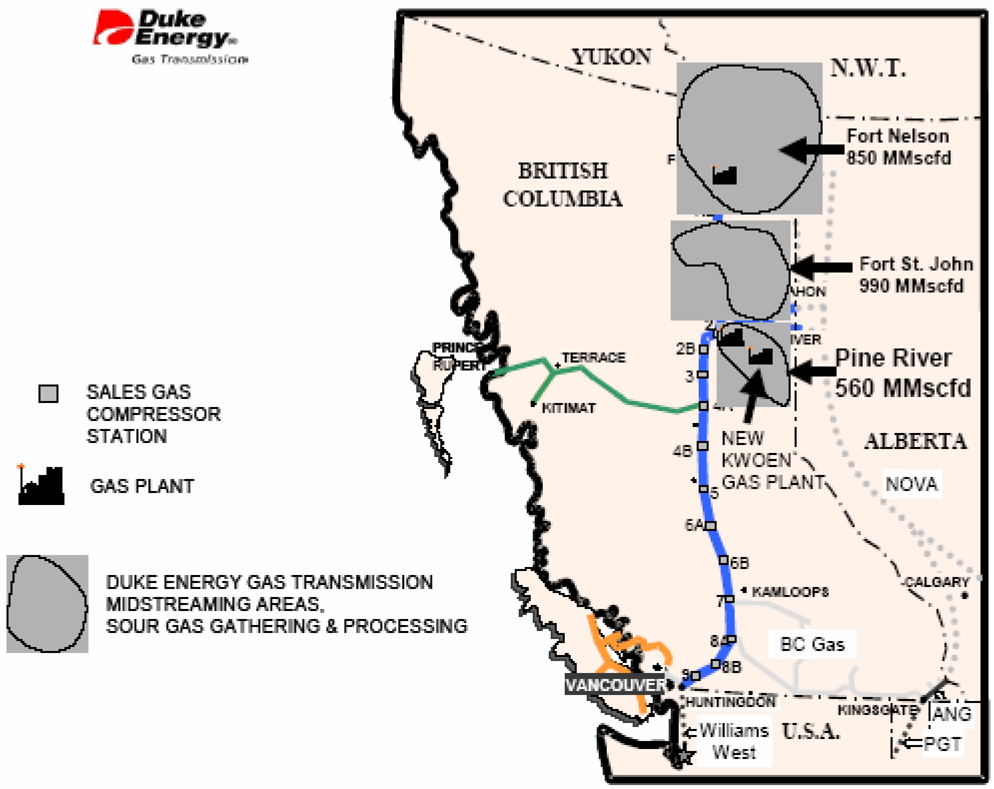

Figure 1. DEGT Canada Midstreaming Areas

The Pine River System was originally developed in 1979. The original system was comprised of a 260 MMscfd gas plant and an 83 mile Gas Gathering trunk line and laterals (Figure 2). The plant consisted of two identical trains of Shell Sulfinol gas treating units, solid desiccant dehydration and MCRC Sulfur recovery units. The plant was capable of removing 50 MMscfd of acid gas (H_2S and CO_2) and could produce 1050 long tons (LT)/day of elemental sulfur at a recovery rate of 99%. The plant capacity was nearly doubled after an expansion in 1994. The plant was outfitted with a third Sulfinol gas treating train, a triethylene glycol dehydration unit and a 1000 LT/day MCRC sulfur recovery train. The gas dehydration system in the original two trains was replaced by a new triethylene glycol system. The capacity of the expanded Pine River Plant is rated at 560 MMscfd sour gas, 94 MMscfd acid gas and 2000 LT/day sulfur Production. The design plant feed contains 16.8 % total acid gas, 9.3% H_2S and 7.5 % CO_2.

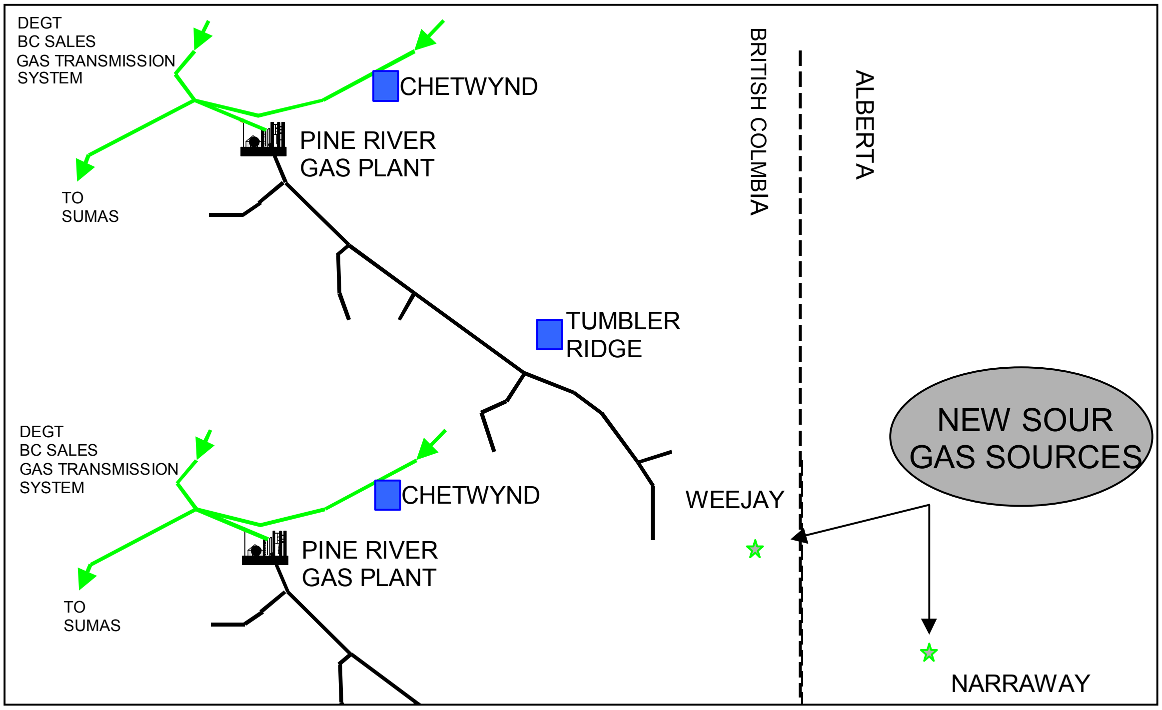

Figure 2. Pine River Gathering & Processing System

The sour gas feed sources to the Pine River system range from 5% to 40 % acid gas. Producers must dehydrate the sour gas production prior to entering the DEGT gas gathering receipt points. The use of molecular sieve adsorption is the most common method of dehydrating the sour gas in the Pine River area. The natural gas liquids (NGL) content of the gas is extremely low, 1.4 bbl/MMscf , and the acid-free gas composition meets the sales gas dewpoint specification; therefore hydrocarbon liquid recovery facilities are not required at Pine River. The plant feed does contain a significant amount of trace sulfur components. The carbonyl sulphide (COS) and mercaptan content is in excess of 300 ppm.

The gas treating Solvent employed at Pine River is Sulfinol-D. The gas plant has a total circulation rate of 11,600 USgpm, split between three trains. The solvent is ideally suited for removing COS and is one of the most energy efficient gas treating systems that is operated by DEGT Canada. The Sulfinol-D system is designed to achieve a sales gas specification of less than 16 ppm total sulfur.

EXPANSION OPPORTUNITY

Since the start up of the 1994 Pine River Expansion, the acid gas quantity was higher than the original design, 21.0% versus 16.8%, the expansion design basis composition. The plant capacity was fully utilized due to the maximum amount of total acid gas and H_2S that flowed into the plant, however from a raw gas flow perspective, the raw feed was 120 MMscfd less than the plant design. In order to process an additional 120 MMscfd of sour gas, DEGT could either add more gas treating and sulfur conversion capacity at Pine River or install processing capacity in the Pine River Gathering system that would off-load acid gas prior to reaching the Pine River Plant--DEGT would pursue the latter option.

By the year 2000, new sources of sour gas in excess of 130 MMscfd flow capacity were in need of transportation and processing service. The location of new sour gas wells was as much as 69 miles beyond the current Pine River gathering area. In order to gain access to the gas production areas, new processing capacity, sour gas compression and a sour gas pipeline were required to be installed. Thus a new Pine River Expansion project was commissioned. The extent of the pipeline project and the location of the Kwoen Gas Plant, which consisted of new sour gas compression and processing facilities, is shown in Figure 3.

THE PINE RIVER EXPANSION CONCEPT

The Kwoen Gas Plant is designed to exploit the remaining hydraulic capacity that exists at the Pine River Plant. The processing plant consists of a bulk acid gas removal unit and acid gas re-injection facility. The plant does not produce a sales gas specification product; it simply upgrades the feed gas to the extent of allowing the maximum sour gas flow through the Pine River Plant. The plant is located 18 miles upstream from the Pine River Plant in a location adjacent to depleted gas production reservoirs. The plant will take a slipstream of gas flowing to the Pine River Gas Plant and remove sufficient acid gas in order to allow an incremental 130 MMscfd of new gas to flow onto the gathering system. The plant is sized to remove the same quantity of acid gas that is contained in the expansion sour gas flow, 28 MMscfd acid gas. A schematic of the

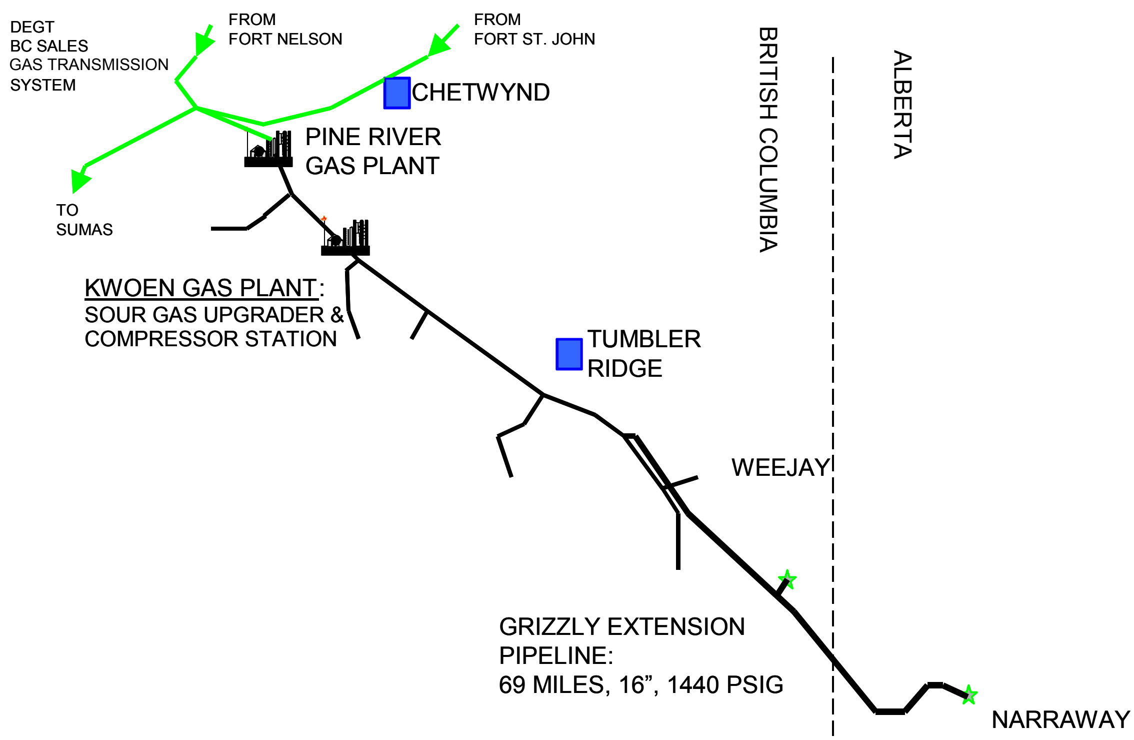

Figure 3. Pine River Expansion 2002

gas that is contained in the expansion sour gas flow, 28 MMscfd acid gas. A schematic of the expansion concept is shown in Figure 4. A summary of sour gas flowrates and compositions, both pre-expansion and post-expansion is shown in Table 1.

Talisman Energy, a major sour gas producer and shipper on the DEGT Pine River system, proposed the concept of sour gas upgrading to Westcoast Energy in 1997. Talisman has injection well candidates that could be employed in the scheme, as well. Talisman and other producers have an on-going requirement to expand the capacity of the Pine River System in order to quickly capture the value of newly found gas reserves.

In July 2000, Kværner Process Systems, Calgary was retained to design and construct the new processing facility. In addition to the plant, a new 9,500 hp centrifugal sour compressor was also installed at the Kwoen Plant Site, upstream of the processing unit. The purpose of this compressor is to hydraulically de-bottleneck the sour gas gathering system

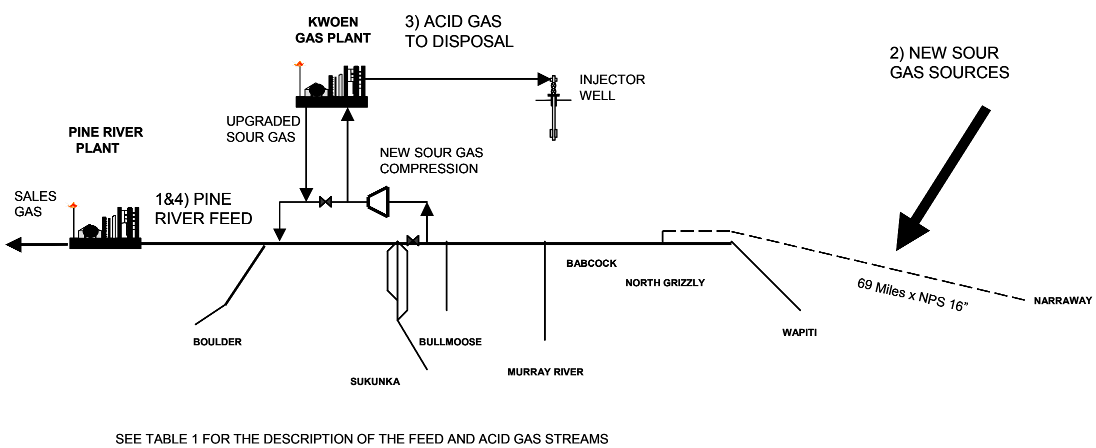

Figure 4. Kwoen Sour Gas Upgrader Concept

Table 1. Sour Gas Upgrading Capacity Addition

Impact on Pine River Feed Rate and Composition

GAS STREAM	**1) PINE RIVER FEED PRE-EXPANSION**	**2) NEW SOUR GAS**	**3) KWOEN ACID GAS**	**4) PINE RIVER FEED POST -EXPANSION**
GAS FLOW	435.3	130	(28.5)	536.8

(MMscfd)				
HYDROCARBON (MMscfd)	342.9	102	(0.5)	444.4
CO_2 (MMscfd)	40.1	8.5	(5.6)	43.0
H_2S (MMscfd)	52.3	19.5	(22.4)	49.4
TOTAL ACID GAS (MMscfd)	92.4	28.0	(28.0)	92.4
ACID GAS, mol%	21.2	21.5	98.2	17.2
INLET SULPHUR LT/DAY	2008	748	(860)	1897

GAS TREATING PROCESS DESCRIPTION

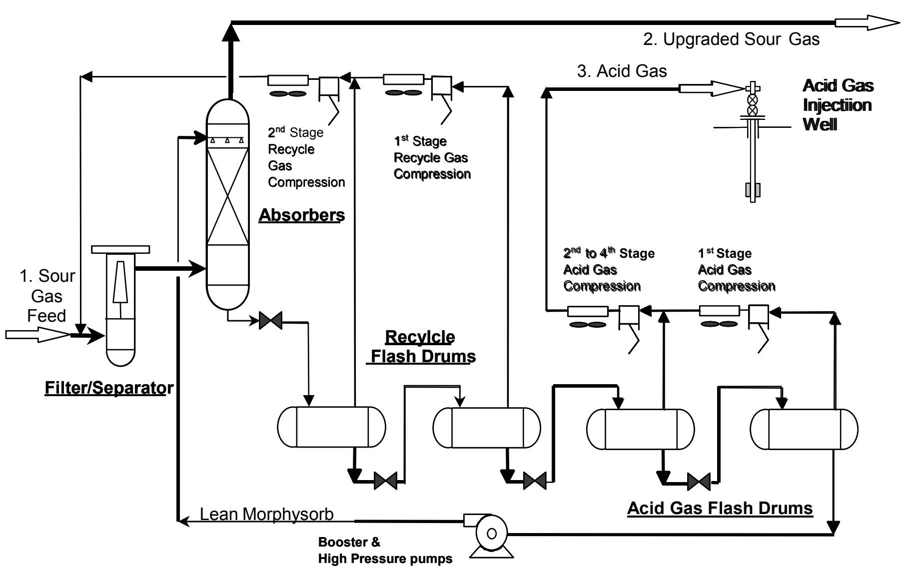

Figure 5. Kwoen Sour Gas Upgrader Simplified Flow Diagram

The Kwoen Gas Plant process is a simple flash regeneration design. A block flow diagram is shown in Figure 5. A total of 300 MMscfd of sour gas flowing to the Pine River Gas Plant is directed to the Kwoen Plant, which operates at 1100 psia.

The gas is absorbed by a Morphysorb solution in two parallel 150 MMscfd packed column absorbers. The lean Morphysorb flow to each absorber is as high as 1500 USgpm. The rich Morphysorb leaves the bottom of the absorbers loaded with extracted H_2S and CO_2. The rich Morphysorb is consecutively flashed at 425 psia and 185 psia. The off gas from these drums is recycled to the absorber feed via a 1750 hp 2 stage reciprocating compressor. The recycle operation is necessary in order to minimize methane losses. The final two flash drums yields the gas feed to the acid gas compressors as well as producing a regenerated (lean) Morphysorb stream. The acid gas flash drums operate at 65 psia and 25 psia respectively. The lean Morphysorb flows from the final flash drum back to the absorbers via the booster and high-pressure pumps. The plant also contains a mechanical and carbon filtration system. The filtration flow rate is 9% of the total Morphysorb circulation. A summary of the design operating stream conditions and compositions is shown in Table 2.

Table 2. Predicted Performance of the Morphysorb Solution Used at the Kwoen Sour Gas Upgrader

Stream	**1. Sour Feed Gas**	**2. Upgraded Acid Gas**	**3. Acid Gas**
Flow, MMscfd	300	266	34
Pressure, psia	1085	1074	1015
Temperature, ^oF	63	55	120
mol%			
CO_2	8.60	7.21	19.60
H_2S	13.54	5.33	78.71
CH_4	77.26	86.81	1.47
C_2H_6	0.21	0.23	0.09
C_3H_8	0.02	0.02	0.02

COS	0.02	0.02	0.05
CH_4S	0.01	0.00	0.04
N_2	0.34	0.38	0.00
H_20	0.01	0.00	0.04

The Morphysorb solvent was predicted to remove 33 MMscfd of acid gas from the sour gas feed (actual conditions in the plant indicate over 40 MMscfd is possible). The sour gas was to be upgraded from 22.1% acid gas to 12.5%. Fifty percent of the feed acid gas is removed by the Kwoen sour gas upgrader. The design acid gas quality is 78.7% H_2S, 19.6% CO_2 and 1.7% hydrocarbon and trace sulfur. Thirty percent of the inlet trace sulfur is expected to be removed by the Morphysorb solution.

Since the plant is only required to achieve a bulk removal of acid gas, instead of specification sales gas, the plant has a relatively simple design. Flash regeneration and auto refrigeration of the Morphysorb eliminates the need for a number of traditional gas treating unit operations. This includes all of the equipment attached to an amine plant regenerator system such as the still, reboiler, process heat medium system, overhead condenser, reflux drum and reflux pumps, nor does the plant have rich/lean exchangers or lean solution coolers. Finally, the plant has no requirement for a residue gas dehydration system. The feed gas is dehydrated prior to entry into the Pine River Gathering pipeline system and the Morphysorb solution only contains water absorbed from the gas, obviating the need for a dehydration system in the plant design. A photograph of the Kwoen Gas Plant is shown in Figure 6.

The lack of process heating requirements and the third party power supply for the large process and compression load keeps the fuel consumption extremely low. The flash regeneration design of the Kwoen plant requires no process heat input. Plant heating is only required to keep the plant process piping, vessels and tanks warm during cold weather, especially in the winter when the ambient temperature can easily reach –40 ^oF. The total design running power load of the inlet sour compression and plant is 22,000 hp. This load is entirely supplied by local power generator and distributor, BC Hydro.

Figure 6. Photo of Kwoen Plant ca. April 2002

In order to maintain a high level of reliability, the plant has been designed with a significant amount of sparing for rotating equipment. The plant has 3 50% acid gas compression units, 2 100% recycle compressors and 100% sparing for Morphysorb booster and high-pressure pumps.

PHYSICAL SOLVENT SELECTION

The Kwoen Gas Plant uses the new, patented gas treating solvent Morphysorb®. This is the first full-scale application of the technology. Uhde Gmbh (KU) licenses the Morphysorb technology. It was co-developed by and is jointly owned with the Gas Technology Institute (GTI) and Uhde [1], [2]. Morphysorb is a physical solvent, which consists of a mixture of N- Formylmorpholine (NFM) and N- Acetylmorpholine. The process was extensively tested in bench-scale and pilot plant facilities through the early and mid-1990s and is now ready for field application.

Other suitable physical solvents were also being seriously considered for the Kwoen Plant. Morphysorb was selected to be tested at the Kwoen plant due to KU's prediction of lower hydrocarbon losses to acid gas, larger capacity for acid gas removal, and lower pumping and recycle horsepower requirements.

Physical solvents have the sometimes undesirable characteristic of absorbing a substantial amount of hydrocarbons, especially NGL fractions [3]. Fortunately for DEGT's Kwoen application, the NGL content is sufficiently low enough, to make NGL co-absorption a minor issue. Uhde predicted that the absorbed hydrocarbon content for the Kwoen acid gas would be 1.5 mol% or less, which is equivalent to the Sulfur Plant feed at the Pine River Gas Plant. Lower affinities for hydrocarbons will also translate into less recycle volumes thus saving recycle compression horsepower.

The benefits of Morphysorb were expected to be partially offset by higher solvent losses. The Morphysorb loss to the upgraded sour gas (volatilization loss) is expected to be greater than other physical solvents that were originally considered for the Kwoen Gas Plant. Design modifications can reduce these losses. but the present project scope does not have plant modifications of this type included. As detailed below, Morphysorb losses as measured by a variety of techniques are in-line with losses expected with alternate solvents. This will be monitored and a more accurate value for the losses will be determined after a year or so of operation.

Like other physical solvents used for gas treating, Morphysorb has a strong selectivity for removing H_2S over CO_2. Despite the addition of 740 LT/day of additional feed sulfur in the expansion sour gas volumes, the selective nature of Morphysorb will actually reduce the Sulfur Plant feed to the Pine River plant, from a pre-expansion rate of 2000 ton/day to 1900 ton/day. At design flow rates, the Kwoen Gas Plant will be reducing the H_2S/CO_2 ratio of the Pine River Sulfur Plant feed from 1.3 to 1.1.

ACID GAS HANDLING & DISPOSAL

The Kwoen acid gas compressors consist of 3 50% capacity 4000 hp reciprocating four-stage units. The acid gas flow from the final flash drum, which is designed for 17 MMscfd acid gas, is compressed in the first stage of the acid gas compressors. This compressed stream is combined with 16.6 MMscfd of 65 psia flash gas to be compressed an additional three stages. The final discharge pressure is 1100 psia. The compressor aftercooler liquefies the acid gas prior to entering the acid gas pipeline.

The acid gas will be transported through a nine mile 6 in. diameter pipeline. The design pressure of the pipeline is 2125 psig. The liquefied acid gas arrives at the injection well as a liquid and flows down the well tubing to a depth greater than 8200 feet. The reservoir will be re-filled with acid gas to a pressure of less than 80% of the hydrostatic head of the tubing, thus leaving the reservoir in a non-overpressured condition. The flowing sandface pressure shall remain less than fracture pressure. New injectors will be tied into the existing acid gas pipeline in the future.

The acid gas storage capacity of the injection reservoirs that are easily accessible and available during the project life is over 200 Bcf, a thirty-year capacity.

PROCESSING TECHNOLOGY COMPARISON

Two methods of incremental gas processing capacity were originally considered in order to treat the incremental gas:

1) Expand Pine River

The Pine River Expansion would consist of adding a new 130 MMscfd gas processing system that is complete with a new gas treating train, TEG dehydration and an MCRC sulfur recovery unit.

2) Install a Sour Gas Upgrader, The Kwoen Gas Plant

The 300 MMscfd Sour Gas Upgrader as described in the process design section.

A summary of the scope of work and capital costs relating to each processing scheme is shown in Table 3.

The Kwoen Sour gas upgrading project has some significant cost and producer economic advantages over the addition of a fourth processing train at Pine River. The Kwoen Sour Gas Upgrader has the advantages of lower capital costs, greater sales gas yields and the reinjection of sulfur as H_2S.

The capital cost for the Kwoen sour gas upgrading facilities is $94 MM CND versus $258 MM CND for a new processing train at the Pine River Plant. The Kwoen Sour Gas Upgrader estimate does have a provision for the addition of acid gas pumps and pipeline extensions. Presented as a ratio of capital cost over treated sour gas volume, the Kwoen Plant was installed at $0.8 MM/MMscfd versus $2.0 MM/MMscfd for a new processing train.

The Kwoen plant design is expected to yield 3.0 MMscfd more sales gas than a traditional gas treating/sulfur recovery design. No fuel is required to run compressor engines, significant plant power generators or large heat medium systems.

The Kwoen Gas Plant is designed to inject over 860 LT of sulfur as H_2S every day. Sulfur disposal by reinjection will result in a cost savings for the Pine River producers since the netback price for sulfur in the Pine River region is currently negative and the price is forecast to stay quite low for the foreseeable future. At an elemental sulfur netback price of minus $10/LT, the Pine River producers are expecting to save over $3 MM CND/yr.

Partially offsetting the advantages of capital costs and higher gas yields, the operating costs are slightly higher for the Kwoen plant due to the power requirements of the facility. Given the price of power at Kwoen site and the current netback price for gas, it was concluded that the production of the incremental gas was sufficient justification for paying the cost of using third party supplied power.

Table 3. Sour Gas Upgrading Versus New Processing Train at Pine River: Capital Costs & Sales Gas Yields

PROJECT	**SOUR GAS UPGRADER**	**PINE RIVER- NEW TRAIN**
PROCESSING OBJECTIVE	130 MMscfd raw gas 15.0% H_2S, 6.5% CO_2	
SCOPE OF WORK	1.) 300 MMscfd Morphysorb Sour Gas Upgrader Plant 2.) 28 MMscfd Acid Gas Compresson 3.) Acid gas injection Pipeline and Facilities	1.) 130 MMscfd, 3000 USgpm Gas Plant 2.) 102 MMscfd TEG Dehydration Unit 3.) 740 LT/day MCRC Sulfur Recovery Unit, 99% Recovery
Captial Cost (MM CND $)	94	258
Capital Cost Impact $MM/MMscfd-feed [3]	0.8	2.0
Incremental Sales Gas (MMscfd)	101	98

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ENVIRONMENTAL BENEFITS

The Kwoen Gas Plant Design will have significantly less air emissions than a new gas processing/ sulfur recovery train at Pine River. A comparison of the emissions predicted from the two designs is shown in Table 4. The upgrader design is predicted to have 5,250 LT/yr less SO_2 Emissions and 105 LT/day less NOx emissions. The re-injection of CO_2 by the Kwoen Plant is 176,000 LT/day less than the emissions from a new train at Pine River. This is quite timely with Canada's recent ratification of the Kyoto accord.

Table 4. Sour Gas Upgrading Versus New Processing Train at Pine River: Sulfur Dioxide, Oxides Of Nitrogen And Carbon Dioxide Emissions

PROJECT	***SOUR GAS UPGRADER***	***PINE RIVER- NEW TRAIN***
Sulfur Emissions (LT/YR)	*150*	*5,400*
NOx Emissions (LT/YR)	*5*	*110*
CO_2 Emissions (LT/yr)	*12,000 at Kwoen Plant* *56,000 at Pine River*	*244,000*

CURRENT PROJECT STATUS

The Kwoen plant was mechanically completed in early August 2002. Morphysorb solvent was delivered to the site and loaded to the process train and brought up to operating pressure with sweet gas in the system. Initial testing with sour gas began in early September. Initial planned flowrates of 90 MMscfd, utilizing gas that was available at that time, were achieved and initial process data and observations made. This was carried out in a single column that was running far below capacity. Operations at this level were continued while various mechanical issues involving compression equipment and sulfur deposition ahead of the injection well were resolved. At the end of October reliable operation was deemed achievable and plans for an acceptance test were made. Originally, this was anticipated to be full flow in both contactors but availability of gas and bottlenecks downstream required that one contactor only be run at full flow. The test was to demonstrate that the Morphysorb process is capable of achieving performance on several metrics established between the process owners and DEGTC. These involved the recycle gas flowrate, methane losses to injection well stream, solvent loss, specific circulation rate, total acid gas removal, and operability. GTI had responsibility to collect and analyze gas and liquid samples and develop a performance report, funded in part by the U.S. Dept. of Energy, NETL Branch. DEGTC observed the testing and sample analysis and reviewed the results.

Description of Kwoen Plant Operations during Performance Test

As agreed in a kick-off meeting prior to the performance test, the plant was operated with one contactor in operation with feed gas flow of ~150 MMscfd with fixed solvent circulation rate.

Any deviations from the contractually agreed design basis (e.g. feedstock composition/characteristics) were noted for recalculation purpose. A total actual test run of 53 hours was achieved as against 72 planned hours.

Frequency of Measurement

Electronic and manual methods were used to collect the process parameter data. The electronically–collected parameters were recorded using a computerized data acquisition system in place at the Kwoen plant. The process operating data, which can be read out on the data acquisition system, is recorded in a Microsoft Excel spreadsheet using macros and recorded every five minutes.

Some process operating data related to the Performance Guarantee Test not available with the automatic data acquisition system was recorded manually every four hours.

Sample Collection

A total number of seven gas sampling points and two liquid sampling points were used for sample collection during the performance test. The locations of sampling points are shown in the following Figure 7.

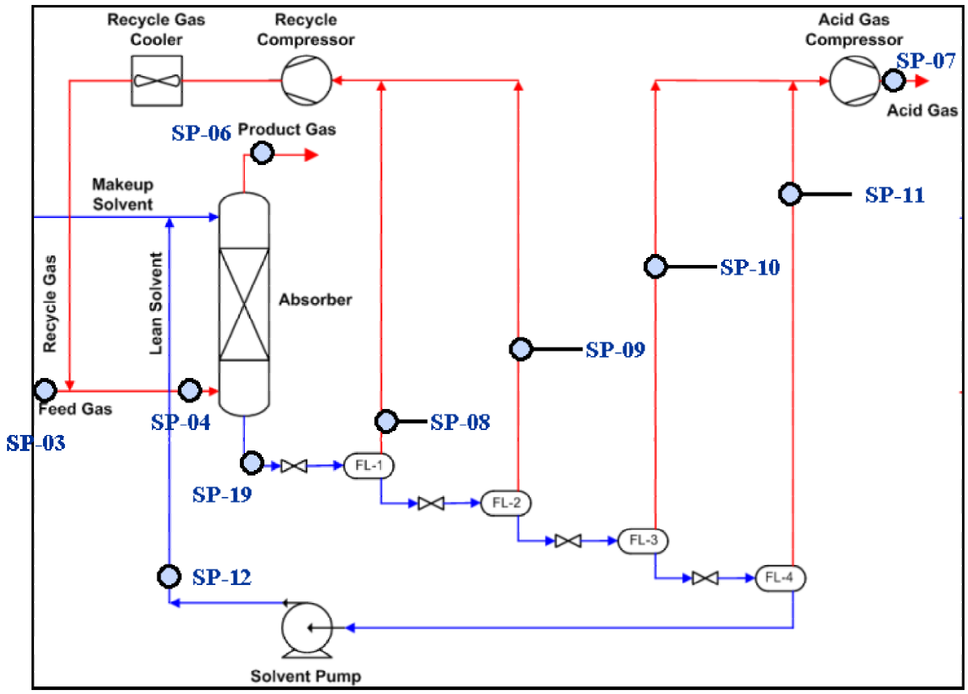

Figure 7: Kwoen Plant Sampling Points

A full set of gas samples consist of Feed, Product, Flash Gas 1 to 4 and Acid gas. Samples were obtained from each of the sample locations during collection of a full set of samples (three times for entire duration of the test) and partial samples (Feed, Product and Acid Gas collected in four other instances). Thus, we have collected a total of seven sample sets during the 72-hour performance test period. The samples are collected based on GTI standard operating procedure for sample collection. GTI established a temporary laboratory at the site to analyze the gas and liquid samples collected during the performance test. In addition to the GTI onsite analysis, Duke had its own independent online analyzers for measuring CO_2, H_2S in feed, product and CO_2, H_2S and CH_4 in acid gas streams. A typical sampling location is shown in Figure 8.

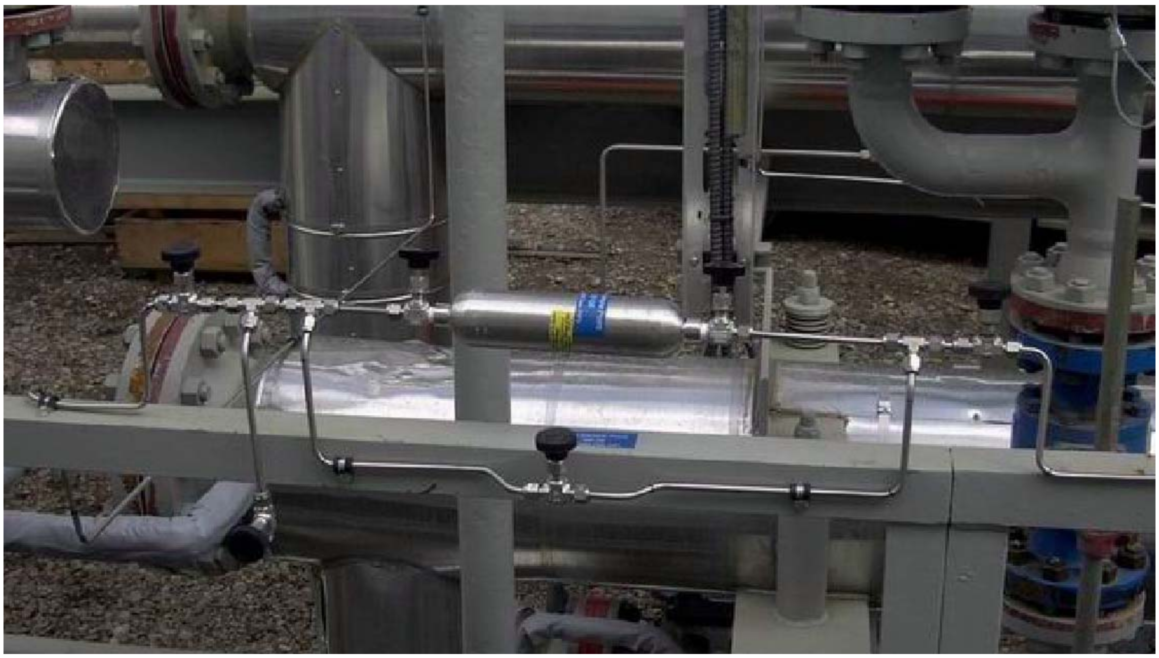

Figure 8. Typical Sampling arrangement at sample location

All the gas and liquid samples that were collected were analyzed immediately after sample collection.

Data Analysis

The test data discussed is this paper was collected during performance test period November 12 – November 15, 2002. The liquid circulation rate was set at a fixed value for these tests. It was not at the maximum value possible in this plant with current hardware. The testing resulted in two useful "steady state" periods (which differ in conditions significantly from each other) for the purpose of computation of the adjusted performance specification metric values and analysis of results. These are summarized in the table below. In all cases the metrics satisfied the established criteria by Duke Energy.

Testing Period 1
(Sampling Sets 1 to 4)

Test Start Time	Test End Time	Total # of Hours
11/12/02, 17:30 hrs	11/13/02, 07:20 hrs	13 hrs 50 minutes
11/13/02, 11:00 hrs	11/13/02, 19:15 hrs	8hrs 15 minutes
11/14/02, 02:00 hrs	11/14/02, 10:00hrs	8 hrs
	Total	***30 hrs 5 minutes***

Feed Gas Conditions: Flow 138.10 MMscfd, Pressure 1076.8 psig, Temperature 60.9 F
Acid Gas Composition in Feed Gas: 15.3 mole% H_2S, 11.8% CO_2

Feed Gas Flow, MMScfd	Acid Gas Flow, MMScfd	Recycle Gas Flow, MMscfd	CH_4 Losses in Acid Gas Stream, mole%	Overall Mass Balance (Based on GTI Analysis)	Overall Mass Balance (Based on Duke's Analyzers
138.1	**21.18**	**9.9**	**1.2**	**107.37**	**108.76**

Testing Period 2
(Sampling Sets 5 to 7)

Test Start Time	Test End Time	Total # of Hours
11/14/02, 17:30 hrs	11/15/02, 17:30 hrs	24 hours
	Total	***24 hrs***

Feed Gas Conditions: Flow 146.8 MMscfd, Pressure 1084.9 psig, Temperature 51.4 F
Acid Gas Composition in Feed Gas: 14.8 mole% H_2S, 12.6% CO_2

Feed Gas Flow, MMScfd	Acid Gas Pick up, MMScfd	Recycle Gas Flow, MMscfd	CH_4 Losses in Acid Gas Stream, mole%	Overall Mass Balance (Based on GTI	Overall Mass Balance (Based on Duke's Analyzers

				Analysis)	
146.8	**22.35**	**11.0**	**1.0**	**105.99**	**106.35**

GTI measured solvent losses on product gas sample collected during performance test and solvent losses are well within expected levels. Two different techniques were used to accurately measure solvent losses: UV absorption spectroscopy and GC FID analysis respectively.

NAM and NFM in the gas phase sample were collected by sparging gas through 20 ml of deionized water at a rate of about 200 ml/minute. Two spargers were set up in series to check for breakthrough. The total of 37 liters of gas volume passed through the spargers. The analysis of the resultant concentrated sample indicates the solvent concentration of 4 ppmv in product gas, which is well within expected limits (< 8 ppmv in product gas per simulation).

The above sample was also analyzed using GC-FID method. The NFM/NAM concentration is once again well within the expected levels (3.1 ppmv).

No foaming incidents or upsets have occurred during the performance test nor during operations before or after, which have as of the time of this writing been conducted for in excess of four months with approximately 5 Bcf of raw gas having been processed. We deem this to be a positive indication of the solvent's low propensity for foaming, which is often exacerbated in the early stages of operations by the presence of foreign contaminants in the system.

Typical gas composition of gas streams measured during the performance test is given in figure 9.

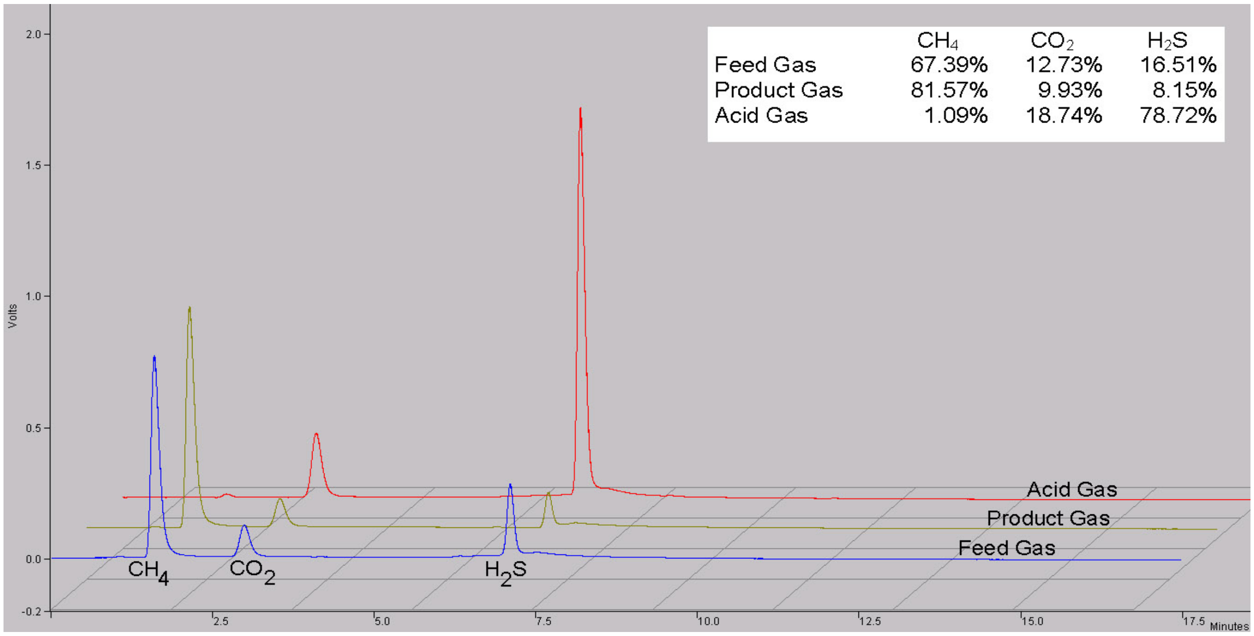

Figure 10. Feed, Product and Acid Gas Chromatograms for a representative set during performance test

Overall Summary of Test

- The overall mass balance based on both GTI and Duke's analysis is fairly good (better than 10%).
- All the testing objectives for Morphysorb were achieved for the performance test.
- Very low methane losses (~1 mole%) were observed in acid gas stream
- The operability of the solvent was very good. No foaming problems were encountered. As of the writing of this paper, more than 5 Bcf of sour gas has been processed with the Morphysorb process.
- Operations personnel reported that the Morphysorb unit was stable and required no special attention once it reached a steady state condition.
- Morphysorb solvent performed as expected and in line with previous experiences and computer simulations.

APPLICATIONS

Sour Gas Upgrading with Morphysorb is a process worth considering for de-bottlenecking existing gas plants as the feed acid gas content climbs above the optimum host plant design. Preferentially, the feed gas should be hydrocarbon dry in order to reduce the impact of losing heavier hydrocarbons to the gas treating solvent.

Acid gas reinjection can have the benefits of keeping capital costs and emissions lower than sulfur recovery technology provided that acid gas reinjection reservoirs are accessible, suitable to receive acid gas and are volumetrically large.

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REFERENCES CITED

1. N. Palla, A. L. Lee, Dr. M. Gross, H. M. Hooper, J. Menzel and D. Leppin "Advancements in Treating Subquality Natural Gas Using N-Formyl Morpholine", Proceedings of the 77th GPA Annual Convention, 1998

2 M. Gross et al. , "A New Solvent Process for Acid Gas Removal and its Impact on BTEX Emissions", Proceedings of the 49th Laurance Reid Gas Conditioning Conference, February 1999

3. GPSA Engineering Data Book 11th ed., Vol. II, Sec.21, p.14, Gas Processors Association, 1998

4. Capital Costs, Internal Duke Energy Gas Transmission Company, Canada studies