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Field Demonstration of a Membrane Process to Recover Heavy Hydrocarbons and to Remove Water from Natural Gas

2006 Annual Report

Contract Number DE-FC26-99FT40723
Report Period: September 30, 2005 through September 29, 2006

by

Membrane Technology and Research, Inc.
1360 Willow Road
Menlo Park, CA 94025

March 9, 2007

prepared for

the U.S. Department of Energy
National Energy Technology Laboratory (NETL)
Morgantown Energy Technology Center
Morgantown, WV

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ANNUAL PROGRESS REPORT

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Other Partners:	Gas Research Institute/Chevron Texaco/BP Amoco
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Abstract

The objective of this project is to design, construct and field demonstrate a membrane system to recover natural gas liquids (NGL) and remove water from raw natural gas. An extended field test to demonstrate system performance under real-world high-pressure conditions is being conducted to convince industry users of the efficiency and reliability of the process. The system was designed and fabricated by Membrane Technology and Research, Inc. (MTR) and installed and operated at BP Amoco's Pascagoula, MS plant. The Gas Research Institute is partially supporting the field demonstration and BP-Amoco helped install the unit and provides onsite operators and utilities. The gas processed by the membrane system meets pipeline specifications for dew point and BTU value and can be delivered without further treatment to the pipeline. Based on data from prior membrane module tests, the process is likely to be significantly less expensive than glycol dehydration followed by propane refrigeration, the principal competitive technology. During the course of this project, MTR has sold 13 commercial units related to the field test technology, and by the end of this demonstration project the process will be ready for broader commercialization. A route to commercialization has been developed during this project and involves collaboration with other companies already servicing the natural gas processing industry.

Table of Contents

1. INTRODUCTION

The objective of this project is to design, construct and field demonstrate a membrane system to recover natural gas liquids (NGL) and remove water from raw natural gas. An extended field test to demonstrate system performance under real-world high-pressure conditions is being conducted to convince industry users of the efficiency and reliability of the process. The system was designed and fabricated by Membrane Technology and Research, Inc. (MTR) and installed and operated at BP Amoco's Pascagoula, MS plant. The Gas Research Institute is partially supporting the field demonstration and BP-Amoco helped install the unit and provides onsite operators and utilities. The gas processed by the membrane system meets pipeline specifications for dew point and BTU value and can be delivered without further treatment to the pipeline. Based on data from prior membrane module tests, the process is likely to be significantly less expensive than glycol dehydration followed by propane refrigeration, the principal competitive technology.

During the course of this project, MTR has sold 13 commercial units related to the field test technology, and by the end of this demonstration project the process will be ready for broader commercialization. A route to commercialization has been developed during this project that involves collaboration with other companies already servicing the natural gas processing industry.

2. PROGRESS FROM SEPTEMBER 30, 2005 - SEPTEMBER 29, 2006

The MTR membrane system was installed at the BP Amoco Pascagoula gas processing plant during 2004. The plant was undergoing a very significant expansion in capacity and the installation of the membrane unit did not begin until late in the third quarter of 2004. The system startup and initial testing began in February 2005. Plant upgrades by BP Amoco at Pascagoula, membrane replacement by MTR, and some minor delays due to the Gulf Coast hurricane season delayed continuous operation of the unit until December 2005. The unit operated continuously and smoothly, with essentially no change in performance levels from December 2005-September 2006. We expect to run the unit for a few additional months into 2007. A photo of the MTR membrane unit at Pascagoula is provided in Figure 1.

Summarizing our commercialization efforts during this report period, significant progress was made toward introducing MTR's NGL membrane and systems into the natural gas market. We sold two additional fuel gas conditioning units (FGCUs) in 2006, both to North American customers. Figure 2 provides a photo of the unit purchased by a major U.S. pipeline company. Sales of hydrocarbon-selective membrane systems in natural gas FGCUs now number thirteen, and orders are open for several additional units worldwide.

Figure 1. MTR's field demonstration membrane-based gas treating unit at BP Amoco's gas processing plant in Pascagoula, MS. The unit operated virtually continuously from December 2005-September 2006 with essentially constant conditioning performance.

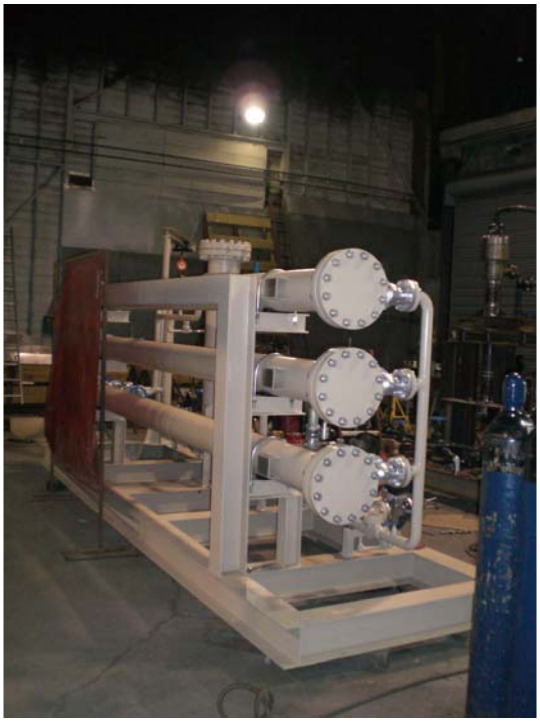

Figure 2. The FGCU unit ordered by a major U.S. pipeline company in the third quarter 2006. Another order from this company is expected in the first quarter of 2007.

The work accomplished during the period September 30, 2005-September 29, 2006 is summarized by task below.

Task 4.0 Develop Field Test Plan

The field test plan and execution status is summarized in Table 1.

Table 1. Test Plan for NGL Field Demonstration

Month	Testing Protocol	MTR Personnel Involvement	Status
1	Startup/solving teething issues in the unit. Initial testing at available plant conditions	Yes (1 week). Daily data collection and analysis of all key streams	Complete
2	Parametric testing of variation in pressure and flow rate	Yes (1 week). Pressure variation: 500 – 1000 psia Flowrate variation: 1-3 MMSCFD	Complete
3	Continuous operation at available plant conditions	No	Complete
4	Continuous operation at available plant conditions	Yes (1 week). Daily data collection and analysis of all key streams	Complete
5	Continuous operation at available plant conditions	No	Complete
6	Parametric testing of variation in pressure and flow rate	Yes (1 week). Pressure variation: 500 – 1000 psia Flow rate variation: 1-3 MMSCFD	Complete

We began continuous field tests in fourth quarter 2005, and ran continuously through September 2006 with excellent unit performance and operating results. The field test may be extended well into 2007 if the BP Amoco plant continues to provide support of day-to-day operating expenses; we expect BP's decision on the extension in early 2007.

Task 5.1 Prepare Membranes and Modules

This task was completed in 2003.

Task 5.2 Design and Construct Field Demonstration System

This task was completed in 2003, with some field modifications in 2004.

Task 5.3 Install Systems at Site/Initial Evaluation

This task was completed in 2004.

Task 5.4 Operate System Continuously

The system was commissioned in February 2005, but was performing below expectations within a few days. A decision was made to replace the membrane modules, so new modules were prepared while plant upgrades were being performed at Pascagoula. A restart in September 2005 was successful in its first week, and after some small changes in filters and level controllers were made, the system was restarted again for longer-term, continuous high-pressure testing, and the unit operated essentially continuously from December 2005-September 2006 with constant conditioning performance. The field test may be extended well into 2007 if the BP Amoco plant continues to provide support of day-to-day operating expenses; we expect BP's decision on the extension in early 2007.

Task 5.5 Survey Industry Users/Analyze Economics

As mentioned in our previous reports, we have identified the following three applications relevant to this project as focus areas in terms of commercialization of the technology:

- Fuel gas conditioning (gas engines and turbines)
- NGL recovery from rich associated gas streams (up to 15 MMSCFD)
- Gas processing for dewpoint control (up to 20 MMSCFD).

We have continued to pursue the development of these applications and have acquired significant insights in both the technical and marketing areas. Based on this knowledge, MTR and ABB Lummus Global (our commercialization partner in the gas processing product area) have developed various strategies and tactics to address what we have learned are key requirements of the customers.

In particular, we have

- Developed a standardized layout and membrane skid to lower repetitive engineering costs and to develop essentially reusable systems.
- Developed a detailed package of system specifications to allow rapid transfer of information to potential clients.

- Built a network of fabrication shops and contacts to minimize building costs and accelerate delivery schedules.

Completing all of these tasks has allowed the MTR-ABB alliance to respond quickly and efficiently to inquiries from potential customers, as well as to offer units that are well-priced in therms of payback time for the user.

Task 5.6 Develop Commercialization Plan

Most of our seven-point commercialization plan was developed during the previous reporting periods. We have already built and installed several commercial FGCU units for use in remote gas processing locations, and continue to receive inquiries and orders from companies worldwide in this product area. We presented summaries of our FGCU progress at the Spring 2006 Laurance Reid Gas Processors' Conference and the Gas Processors' Association (GPA); slides from the Laurance Reid presentation are attached as Appendix A. We also participated for the first time in the biannual International Expo in Calgary, Alberta, in June 2006. Our booth and handout materials included several FGCU case studies.

Continuous operation of the demonstration unit provided us with some excellent opportunities to showcase the unit with project participants and prospective clients. We took several guests from GTI and from other operating companies for a site visit following the Spring 2006 GPA meeting. During the visit, an operator from the site offered the unsolicited comment that the unit had been operating very smoothly since the December 2005 start-up, confirming our impressions from our operating interactions with BP Amoco.

In pursuing commercialization of the technology, we determined that several key issues had to be tackled. A separate Confidential Appendix (a Confidential Business Information document) summarizes the major challenges we are addressing in our commercialization plan, including pertinent examples from this year's commercialization efforts.

MTR's marketing efforts have focused on utilization of our website, www.mtrinc.com. The website approach has produced consistent results in generating high quality leads and inquiries for sales of fuel gas conditioning units. All systems sales related to this project have been developed starting from our website marketing efforts. We continue to generate inquiries every week from our website, in addition to leads from other established marketing channels.

Task 6.0 Final Report/Conference Presentation

In 2004 and 2006, ABB/MTR made two conference presentations, at the prestigious Laurance Reid Gas Conditioning Conference the Annual GPA Conference.We will present at these same conferences in 2007. Slides from the 2006 Laurance Reid Conference are attached as Appendix A.

During the past year, DOE agreed to an extension of this project through the first quarter of 2007. The final report for this project will be prepared within three months of project completion, as required by DOE.

3. CONCLUSIONS

There have been two distinct parts to this demonstration project. The first part involved building, installing, and testing a demonstration plant for NGL separation and recovery and the second part involved commercialization activities. The first part of the project experienced many unavoidable delays due to the various requirements and delays at the host site. The first tests started in 2005. The unit operated from December 2005-September 2006 with essentially constant conditioning/ separation performance. The field test may be extended well into 2007 if the BP Amoco plant continues to provide support of day-to-day operating expenses; we expect BP's decision on the extension in early 2007.

The second portion of the project, the commercialization of the technology, has progressed very well. We have sold and installed several commercial units using the membrane technology developed in this project and these installations have been operating satisfactorily for their clients. We attribute part of this success to our efforts at firming up our processes and procedures for commercialization of the technology and implementing them. In particular, our website marketing strategy is yielding very good results in leads generation.

4. REFERENCES

1. Pat Hale, Randall Gas Technologies-ABB Lummus Global Inc, and Kaaeid Lokhandwala, Membrane Technology and Research, Inc., "Advances in Membrane Materials Provide New Solutions in the Gas Business," presentation at Laurance Reid Gas Conditioning Conference (LRGCC), University of Oklahoma, Norman, OK, February 27-March 3, 2004.

2. Pat Hale, Randall Gas Technologies-ABB Lummus Global Inc, & Kaaeid Lokhandwala, Membrane Technology and Research, Inc., "Advances in Membrane Materials Provide New Solutions in the Gas Business," presentation at 83rd GPA Annual Meeting, New Orleans, LA, March 13-16, 2004.

3. Kaaeid Lokhandwala, Ankur Jariwala, and Richard W. Baker, R.W., "Only raw sour gas available for engine fuel? Proven membrane process cleans gas for engines," presentation at *The 56th Laurance Reid Gas Conditioning Conference*, Norman, OK, February 27 - March 1, 2006.

4. Kaaeid Lokhandwala, Ankur Jariwala, and Richard W. Baker, R.W., "Only raw sour gas available for engine fuel? Proven membrane process cleans gas for engines," presentation at *Gas Processors' Association (GPA) Annual Meeting*, Grapevine (near Dallas), TX, March 5-8, 2006.

Appendix A.
2006 LAURENCE REID PRESENTATION

Only Raw Sour Gas Available for Engine Fuel? Proven Membrane Process Cleans Gas for Engines

By

Kaaeid A. Lokhandwala, Ankur Jariwala and Richard Baker

Membrane Technology and Research, Inc.

1360 Willow Road, Menlo Park, CA 94025

Website: www.mtrinc.com

Presented at

The 56th Laurance Reid Gas Conditioning Conference

February 27 – March 1, 2006

Norman, OK

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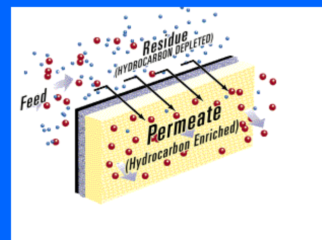
Membrane Separation Mechanism



Permeability = Diffusivity * Solubility
(P) (D) (S)

Membrane Selectivity

$$\frac{P_1}{P_2} = \frac{D_1 \cdot S_1}{D_2 \cdot S_2}$$

Rubbery Membranes Reject Lighter Gases such as N_2, CH_4 and H_2 and Permeate Heavier Hydrocarbon Components

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Glassy v/s Rubbery Membranes

Glassy Membranes

Fast Gas — Slow Gas

H_2O, Hydrogen, CO_2, Nitrogen, Methane, Ethane, Propane, Hexane

Rubbery Membranes

Fast Gas — Slow Gas

H_2O, Hexane, Propane, Ethane, CO_2, Methane, Hydrogen, Nitrogen

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Membrane System Installations Increasing References and Application Envelopes

Gas/Gas Separation Systems

H_2/N_2, CH_4	~ 250 Units	Glassy Membranes
O_2/N_2	~ 5,000 Units	
CO_2/CH_4	~ 250 Units	

Vapor/Gas Separation Systems

Hydrocarbon/N_2. CH_4	~ 125 Units	Rubbery Membranes

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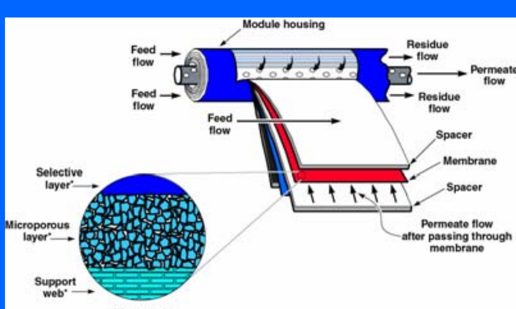
Membrane Structure and Packaging



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Fuel Gas Conditioning Remote Site Considerations

- Increasingly Natural Gas ***Production is Coming for Remote Locations***
- ***Raw Gas*** in Gathering Systems ***Requires Compression***
- ***Fuel Choices are Limited*** – Diesel or Raw Gas
- Diesel represents ***cost, transportation logistics, storage*** and other issues
- Poor Quality ***Raw Gas Results in Deration*** of Available Power to Compressors and Gensets
- ***Derated Compressors or Gensets*** = ***Loss in Production Volumes and Equipment Shutdowns***
- ***A Simple Process Technology*** Which Operates ***Without Attention and Consumables*** Is Required

Reverse-Selective Membranes Have Been Now Proven to Meet These Requirements

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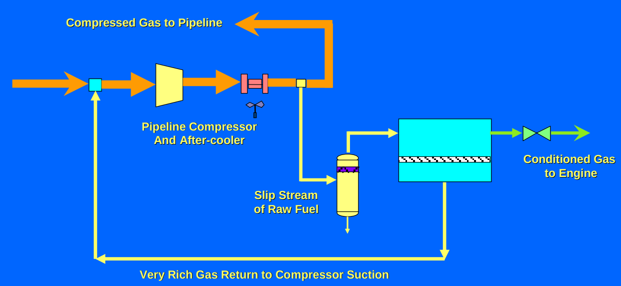
How Does The Process Work ?



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Selected Field Experience Data
Membrane FGCU's

- Kakap-H Remote Platform
  Star Energy, Indonesia
- Sour Gas Processing - H2S Reduction in Fuel Gas
  Dominion Exploration, British Columbia, Canada
- 3 Engine Gen-set on Petrojarl - I (FPSO)
  Statoil (PGS) – North Sea
- Gas Conditioning for 500 MW Power Plant Turbines
  El Paso Gas/UEG, Curitiba, Brazil
- Superior and Waukesha Engines Fuel Gas Conditioning
  Sid Richardson, New Mexico (2 Units)

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Kakap-H Remote Platform
Star Energy, Indonesia

Components	Gas Compositions	
	Feed Gas (mol%)	Conditioned Fuel Gas (mol %)
Propane	4.60	1.48
i-Butane	1.97	0.52
n-Butane	1.53	0.30
Pentanes	1.74	0.28
Hexane	1.05	0.126
C_{6+}	0.91	0.078
Balance Methane and Ethane		
Total C_{3+} Hydrocarbons	**11.76**	**2.78**
METHANE NUMBER	**16**	**71**

Acknowledgement: Data Provided by Mr. Zikri Syah, Star Energy

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Kakap-H Remote Platform
Star Energy, Indonesia

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Sour Gas Processing - H_2S Reduction in Fuel Gas
British Columbia, Canada

Gas Stream Component	Feed Gas (mol %)	Conditioned Gas (mol %)
Hydrogen Sulfide	0.34	0.004
Propane	2.72	0.624
i-Butane	0.37	0.049
n-Butane	0.67	0.088
i-Pentane	0.18	0.018
n-Pentane	0.19	0.019
Hexane	0.16	0.010
C_{6+}	0.14	0.008
Total C_{3+} Hydrocarbons	**4.43**	**0.82**
H_2S Content	**3400 ppm**	**40 ppm**

Acknowledgement: Data Provided by Mr. Brett Kimpton, Dominion Exploration

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Sour Gas Processing - H_2S Reduction in Fuel Gas
British Columbia, Canada

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3 Engine GenSet on Petrojarl - I (FPSO)
Statoil (PGS/Wartsila) – North Sea

Stream Name	Inlet Feed (Mol-%)	Conditioned Fuel Gas (Mol-%)
Methane	72.94	86.95
Ethane	9.73	5.68
Propane	8.51	3.18
Butanes	5.05	1.10
Pentanes	1.63	0.30
Carbon Dioxide	0.40	0.25
Nitrogen	1.22	2.49
N-Hexane	0.52	0.06
Methane Number	**32**	**65**
Pressure (bar)	13.8	10.3
Volume (MMSCFD)	5.5	1.8

3 Engine Gen-set on Petrojarl - I (FPSO)
Statoil (PGS/Wartsila) – North Sea

Gas Conditioning for 500 MW Power Plant Turbines
El Paso Gas/UEG, Curitiba, Brazil

Component	**Gas Compositions**	
	Feed Gas (mol %)	**Conditioned Fuel Gas (mol %)**
Propane	2.000	1.489
C_{4+}	0.785	0.449
Pressure (psig)	700-900	
Flow Rate (MMSCFD)	**120 MMSCFD**	

Gas Conditioning for 500 MW Power Plant Turbines
El Paso Gas/UEG, Curitiba, Brazil

Superior and Waukesha Engines Fuel Gas Conditioning
Sid Richardson, New Mexico (2 Units)

Stream Name	Inlet Feed (mol-%)	Guaranteed Conditioned Fuel Gas (mol-%)	Actual Inlet Feed (mol-%)	Actual Conditioned Fuel Gas (mol-%)
Methane	73.3	81.99	69.58	81.19
Ethane	10.89	6.93	11.23	6.89
Propane	6.00	2.63	6.53	2.35
Butanes	2.55	0.56	2.53	0.66
Pentanes	1.07	0.2	0.77	0.16
Carbon Dioxide	1.63	0.85	4.67	3.07
Nitrogen	3.71	6.69	4.05	5.41
N-Hexane	0.83	0.126	0.37	0.07
Methane Number	39	67	44.4	68

Acknowledgement: Data Provided by Gary McCoy, Sid Richardson, Dallas, TX

Superior and Waukesha Engines Fuel Gas Conditioning
Sid Richardson, New Mexico (2 Units)

Where Can These Membrane Skids be Used Right Now?

- Remote Compressor Stations Currently Derated Due to Raw Fuel – Elimination of Engine Derate will Immediately Increase Gas Production/Transportation Volumes
- Sour Gas Production Sites without access to clean gas - Elimination of Diesel or Expensive solvent systems. Especially Suitable to Colder Climates
- Derated GenSet Due to Fuel Quality – Elimination of Derate will allow additional power generation for production activities
- Offshore Platforms – Reduced Power Generation or Compressor Utilization due to poor fuel gas would be eliminated resulting in higher volume gas and oil production

Other Opportunities for Reverse Selective Membranes

- Fuel Gas Conditioning to Increase BTU Value by Reducing N_2 and CO_2
- Direct Wellhead Nitrogen Removal from Natural Gas
- Direct Wellhead CO_2 Removal From Natural Gas

Summary

- Reverse Selective Membranes Have Been Successfully Proven in Well head Natural Gas Conditioning Applications
- More than 100 combined Installations of these membranes Worldwide in Petrochemicals and Oil/Gas Industries.
- Standardized Fuel Gas Conditioning Units Designed for Unattended Operation Reduce Deployment Time and Cost
- Immediate Production Boost and Additional Revenue Generation in Gas Gathering is Possible in Many Locations Currently Operating Under Derated Conditions.