IMPROVE GAS TURBINE/ENGINE PERFORMANCE AND REDUCE MAINTENANCE USING MEMBRANES FOR FUEL GAS CONDITIONING

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ABSTRACT

Unprocessed raw natural gas is the major source of fuel for turbines/engines in power generation and compression applications in many condensates rich shale gas plays such as Marcellus, Utica, Bakken, Eagle Ford and Niobrara. When raw natural gas containing heavy and sour gas is used as fuel for powering turbines and engines, serious damage is caused to their components, thereby reducing efficiencies and in some cases complete equipment shutdown. This has an immediate impact on oil and gas production leading to substantial losses in revenues.

This paper describes the use of unique heavy hydrocarbons and acid gas-permeable membranes to produce clean fuel gas from raw shale gas. Numerous fuel gas conditioning membrane units have been installed around the world by companies like Marathon Oil, Markwest Energy, Williams Energy, EQT Corp., Chevron for reducing the heavy & sour contents from raw gas. The key advantage of using membranes for clean fuel gas is its simplicity in operation. The membranes are passive units with no moving parts. No pre-treatment is required for their operation except for standard filtration. The units are designed for unattended operator attention and are virtually maintenance-free.

The membranes work on the principle of passing heavy hydrocarbons, acid gases and water through the membranes, leaving a clean gas to be used as fuel. Membrane Fuel Gas Conditioning Units also reduce the volume of VOC's and acid gas emissions caused due to combustion of acid gases and incomplete combustion of hydrocarbons in the firing chamber. These units have been used to improve turbine and engine performance and high maintenance problems due to poor fuel gas quality. Skids have been used to produce from 0.1 to 110 million scfd (MMscfd) of clean gas. Practical case studies of how these units have helped in resolving issues with problematic fuel gas are discussed in the paper.

INTRODUCTION

Raw unprocessed natural gas is widely used to power field or offshore turbines and engines that drive compressors or generate power. Oftentimes the raw unprocessed gas composition does not meet the minimum manufacturer specifications of engine or turbine due to the high concentrations of heavy hydrocarbons present in the raw gas. Excessive amounts of ethane, propane, butanes and C_{5+} hydrocarbons results in too low a methane number for gas engines, or too high a Wobbe Index for turbines leading to frequent pre-detonation or other issues. In order for the engines to run smoothly, the gas engines are required to be de-rated and hence cannot be run at or near full capacity. In turbines, coking on the nozzles and in the combustion chamber leads to reduced efficiencies due to fouling or damage to the blades.

Additionally, in both gas engines and turbines, increased emissions of unburned VOCs will result if the inlet gas is too rich. Compressor engine exhausts are a major source of a variety of strictly regulated emissions including NOx, CO, and non-methane hydrocarbons (VOC). Operators have to meet several stringent emissions requirements to remain within the thresholds of allowable emissions limits of the above mentioned components. In cases where the raw fuel gas is rich, high levels of heavy hydrocarbon content in the fuel gas are responsible for incomplete combustion and/or pre-detonation in the gas engines leading to increased CO and non-methane hydrocarbons emissions (NMHC) beyond the acceptable limits[1].

Membranes provide a simple solution to these rich fuel gas related issues discussed above. The raw unprocessed gas can be processed using a special type of membrane that is more permeable to heavy hydrocarbons and acid gases than to methane. Early work in this area was performed at Phillips Petroleum almost thirty years ago.[2] Over the last few years, Membrane Technology and Research, Inc. (MTR), of Newark, CA, has developed commercial systems and processes incorporating specialized membrane technology to treat heavy and/or sour fuel gas streams[3]. The process, known as FuelSep™, is in use at a number of sites and for a variety of upstream fuel gas streams. To date, these membranes have been installed at a large number of sites for heavy hydrocarbons separation from natural gas especially in the shale oil/gas production areas. Skid–mounted compact membrane units make the FuelSep™ process particularly suitable for remote wellheads and compression stations where high levels of heavy hydrocarbons present in the fuel gas are reduced significantly to remain within the emissions threshold limits. This paper describes and compares two case studies and process configurations.

MEMBRANE BACKGROUND

Membrane systems to remove carbon dioxide were introduced to the natural gas processing industry in the mid-1980s. These conventional-type membranes separate gases primarily based on differences in molecular size. The small carbon dioxide molecules permeate faster through the membranes compared to the relatively larger methane molecules, but retain the even larger heavy hydrocarbon molecules in the gas stream. In contrast, a new type of membrane that utilizes differences in gas solubility to permeate both heavy hydrocarbons and carbon dioxide has been developed, and these enhanced capabilities provide new opportunities for membrane use in natural gas separations.

HOW MEMBRANES WORK

Membranes used to filter liquids are often finely microporous, but membranes used to separate gases have only transient openings so small in size that they are within the range of the thermal motion of the polymer chains that make up the selective polymer layer. Permeation through gas separation membranes is therefore best described by a process called solution-diffusion. Gas molecules dissolve in the polymer membrane as a pseudo liquid phase and then diffuse across the membrane and then desorb from the polymer on the opposite interface which is typically maintained at a lower pressure as compared to the feed. The rate of gas permeation is a product of a solution term (how much mass dissolves per unit mass of membrane), and a diffusion term (how fast each individual sorbed molecule diffuses across the membrane). Fuel gas-conditioning membranes are chosen from materials that maximize the effect of the solubility term. Although each individual molecule of butane, for example, diffuses more slowly across the membrane than each individual molecule of methane, the very high solubility of butane more than compensates for the slower diffusion. Fuel gas conditioning membranes therefore preferentially permeate water, carbon dioxide, hydrogen sulfide, C_{2+} hydrocarbons and BTEX aromatics, while substantially retaining methane. Because most of us are familiar with conventional filtration, this result feels counter-intuitive with bigger molecules passing through the membrane and smaller molecules being rejected. Nevertheless, these unique properties are what make the membranes particularly useful in fuel gas conditioning applications.

MEMBRANE STRUCTURE

Membranes used to separate heavy hydrocarbons from natural gas typically have multilayer composite structures of the type shown in Figure 1. To obtain high permeation rates, the selective membrane must be very thin, typically between 0.5 and 5.0 µm thick, however, the membrane structure, must be able to support a pressure differential of 200 to 1,500 psi. In order to accomplish this, the thin selective layer is placed on a thicker support layer which is mechanically stronger in order to form the composite membrane structure.

Even though composite membranes have extremely thin selective layers, many square meters of membrane are required to separate a useful amount of gas. The units into which large areas of membrane are packaged are called membrane modules. In the FuelSep™ process, spiral-wound membrane modules of the type illustrated in Figure 1 are used. The membranes sheets are formed into a sealed membrane envelope, and then, with appropriate feed and permeate channel spacer netting, are wound around a perforated central collection pipe. The module is placed inside a tubular pressure vessel. One to six modules may be connected in series within each pipe. Pressurized feed gas passes axially down the module, across the membrane envelope on the feed side. A selective portion of the feed permeates into the membrane envelope, where it spirals towards the center and is collected through the perforated permeate collection pipe. The treated gas is withdrawn from the feed side at the residue end of the module.

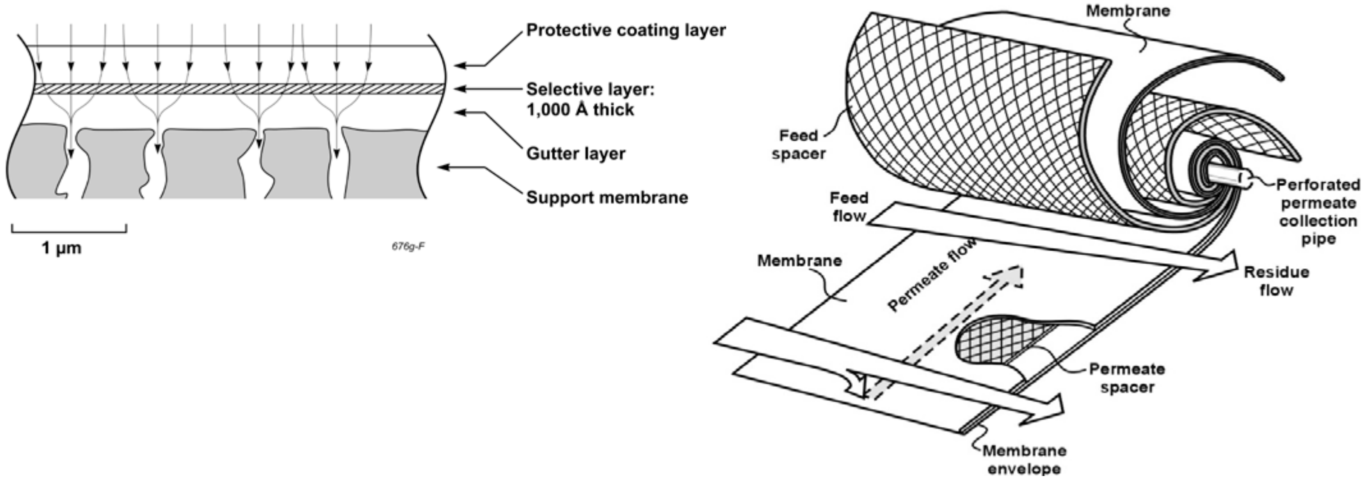


Figure 1. Schematic illustrations of a composite membrane and a spiral-wound module of the type used in fuel gas conditioning units.

ADVANTAGES

The key advantages of a membrane FGCU can be summarized thus:

- **Simple, passive system**
- **High on-stream factor (typically >99%)**
- **Ambient temperature operations**
- **Minimal or no operator attention**
- **Small footprint with low weight**
- **Large turndown ratio**
- **Rapid start up and shut down**
- **Low maintenance**
- **Low capital and operating costs**
- **Units are mobile and can be redeployed to other locations**
- **Handles fluctuating feed gas compositions**

Ease of Operation: A membrane FGCU is completely passive, has no moving parts, and requires no chemicals to operate. A single stage system can reach steady state performance within a few minutes of startup, and can be fully automated and remotely monitored, so that it can run unattended. Little or no maintenance is needed.

Easy & Low cost Installation: Units are skid-mounted and can be installed wherever a reasonably level patch of gravel or soil can be provided, without needing a permanent foundation. Normally, a skid will operate in one location for months or years, but skids are very robust, and can be trucked to a new site if circumstances change.
Flow-rate Range: Membranes are modular in nature; and subsequently, FuelSep™ can be used as a stand-alone operation to process gas streams from as low as 0.1 MMscfd to upwards of 100 MMscfd and more. In most upstream applications for fuel gas conditioning, typical membrane units are

designed for fuel gas flow-rates of 0.05 MMSCFD for a single genset up-to 5 MMSCFD for a large multi-unit compressor station.

No Pre-treatment: Typically, the feed gas requires no pretreatment, except for standard filtration.

Fuel Gas Dehydration: Membranes dehydrate the fuel gas; no separate hydrate control is required.

No Liquids: The separated heavy hydrocarbons are entirely in the gas phase – the inlet (feed) and the outlet streams (fuel and the reject streams) are all in gas phase. There is no accumulated liquid in the system, so there is no risk of pool fires or need to dispose of or store liquids.

Feed BTU Variations: It is not uncommon to experience variations in the BTU levels in the raw field gas. Such BTU variations in the raw feed gas can be easily handled by adding additional membrane modules to the existing membrane unit thereby maintaining a continuous and consistent delivery of clean conditioned fuel gas at an acceptable range of BTU values.

MEMBRANES VERSUS JT/REFRIGERATION

- Membranes, unlike JT and propane-based refrigeration process, separate the heavy hydrocarbons entirely in the gas phase and hence do not generate any liquids, thereby eliminating requirement for liquids storage, handling, and associated emissions permitting.
- Also, since the membrane process operates under ambient conditions, hydrates formation is avoided thereby eliminating similar cold temperature issues accompanied with JT and refrigeration processes.
- In addition to lowering the C3+ components of the fuel gas, membranes also significantly reduce the ethane content which further lowers the BTU content of the fuel gas.

Table 1 shows a brief comparison of all the three competing technologies.

Table 1. Comparative Evaluation Matrix for JT, Refrigeration and Membrane processes.

	JT Process	Refrigeration	Membranes
Separated Heavies Phase	**Liquid**	**Liquid**	**Gas**
Low Temps – Hydrate Issues	**Yes**	**Yes**	**No**
Reduce Ethane (C2)	**No**	**No**	**Yes**
Liquids Storage	**Yes**	**Yes**	**No**
Moving Parts	**No**	**Yes**	**No**
Raw Feed Gas – BTU Variability Handled?	**No**	**No**	**Yes**
Raw Feed Gas – Pressure Variability Handled?	**No**	**Likely**	**Yes**

CASE STUDIES

The paper will discuss the decision strategy employed, operational performance review of the membrane units currently installed at different locations around the world to provide clean fuel gas for power generation. Following three real case studies are presented in the paper:

1. Fuel Gas Conditioning for Dual Fuel Engines used at Marathon Oil drilling rig sites
2. Fuel Gas Conditioning Unit for 500 MW Power Plant Siemens Turbines in Brazil
3. Fuel Gas Conditioning for Wartsila Engines for GenSet on FPSO platform for Statoil

I. Fuel Gas Conditioning for Dual Fuel Engines used at Marathon Oil drilling rig site

A typical membrane FGCU installed for Marathon Oil in the Eagle Ford Shale, TX is illustrated in Figure 2. The block diagram for the membrane skid arrangement is presented in Figure 3. Client was burning diesel to generate power on four of their drilling rig sites. The sites had poor quality high-BTU natural gas available at the wellhead. Since diesel was 10 times more expensive than the cost of natural gas on an MMBtu basis, running the engines completely on diesel was way more expensive than natural gas. Therefore, Marathon decided to lease Caterpillar Dynamic Gas Blending technology for diesel engines to enable the use of natural gas to partially fuel the diesel-electric powered drilling rigs. The DGB technology used a computer controlled retrofit with engine sensors to meter in natural gas into the engine air intake which backed out the equivalent amount of diesel required. A maximum of 70% of the fuel could be provided by natural gas and the balance fuel requirement would have to be supplemented by diesel fuel injection.
Due to remote location of drilling-site, the wellhead gas available was the only source of fuel gas for the dual engines. However, the raw gas was poor in quality as it was extremely rich, containing more than 20% C_{2+} hydrocarbons. The impact was less than maximum substitution rate of 70% of natural gas and subsequent more diesel consumption. Due to substantially high levels of heavies in the fuel gas, the client decided to install membrane units for conditioning the fuel gas for the dual fuel engines.

Figure 2. Photograph of the Membrane system at Marathon Oil drilling rig facility in Texas.

A. Issues Faced By Client

The client faced several problems while using diesel and unconditioned natural gas as the engine fuel.

a. Increased Trucking and diesel cost –
The use of unconditioned raw wellhead natural gas brought only 50% or lesser of diesel substitution for CAT dual fuel engines, thereby increasing diesel fuel consumption. When conditioned fuel gas from membranes was used, full capacity of the dual fuel engines was realized with 70% of diesel being substituted with natural gas. Thus, the operational cost in terms of diesel trucking and cost of diesel was reduced significantly.

b. Pre-detonation
In some cases when the gas was rich enough to cause pre-detonation, the conversion kits installed on the engines would immediately revert to diesel on detection of pre-detonation resulting in no substitution and higher diesel costs.

B. Membrane Fuel Gas Conditioning Unit - Technical Details

Marathon Oil installed MTR's membrane fuel gas conditioning unit at each of their four drilling rig sites in Texas. Following are some relevant details for one site:

a. Type & No. of engines	- 1 X CAT 3512 with diesel and natural gas blending
b. Total sales gas	- 10 MMscfd
c. Max fuel demand with conditioned NG	- 0.3 MMscfd
d. Wellhead pressure	- 1100 psig
e. Lowest pressure	- 890 psig

Membrane System Details - Following is a list of some relevant details of the membrane system installed at Marathon's drilling site:

a. Fuel spec quality (CAT MN)	- > 50
b. No. of membrane Vessels	- ONE (1) at each drilling site
c. Feed pressure	- 635 psig
d. Permeate pressure	- 45 psig

Process – Process schematic for the membrane fuel gas conditioning scheme is shown in Figure 3. The inlet feed gas @ 1100 psig is taken as a slip-stream and first regulated down to 635 psig. The gas then enters the membrane skid starting with a filter coalescer, which removes any liquid condensates/aerosols from the feed gas. The overhead gas next enters the membrane tube. The membrane tube splits the inlet into two streams:

1. The membranes preferentially permeate heavy hydrocarbons, and the resulting LP permeate stream which is enriched in the heavy hydrocarbons is routed to flare/LP gathering line @ 45 psig.
2. The conditioned fuel gas with a lower LHV and a CAT methane number of higher than 50.

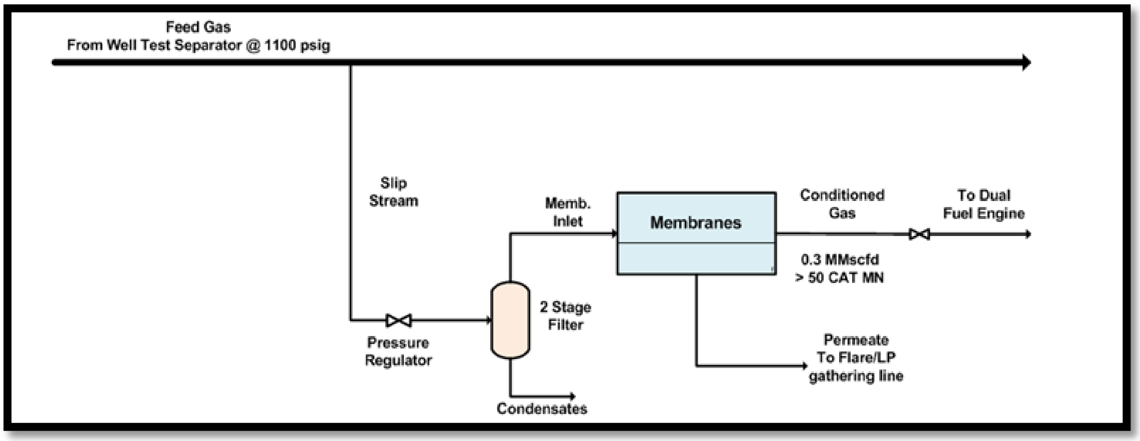


Figure 3. Block diagram of a membrane FGCU installed at Marathon Oil drilling rig facility in Texas.

C. Field Operation Data – BTU Reduction

Gas composition for the raw gas entering and exiting the membrane system is indicted in Table 2. As the membranes removes heavy hydrocarbons from the wellhead gas, the CAT methane number was improved from 33 for the raw gas to > 50 for the conditioned fuel gas which met the methane number requirement of 50 for CAT dynamic gas blending engines. Note that in addition to the C3+ components, the ethane content was also significantly reduced from 11.5% to 7.2% in the fuel gas, which was unattainable with typical JT and propane refrigeration based units.

Table 2. Performance Data for a membrane FGCU installed at Marathon for drilling rig site in Texas.

Composition	Raw Feed Gas	Conditioned Fuel Gas
Methane Number	33	> 50
Component (mol%)		
Carbon Dioxide (CO_2)	1.97	1.29
Nitrogen (N_2)	0.08	0.12
Methane (C1)	78.32	87.95
Ethane (C2)	11.48	7.21
Propane (C3)	4.35	2.129
Butanes (C4)	2.71	0.992
Pentanes (C5)	0.91	0.29
N -Hexanes (C6)	0.13	0.04
Water	0.060	0.001
Hydrogen Sulfide (H_2S)	0.003	0.002

D. Economic Analysis – Dual Fuel Savings

A rich fuel gas stream with a lower methane number hinders maximum usage of natural gas in terms of diesel substitution in dual fuel engines. When conditioned natural gas is used in the engines, 70% of the diesel can be substituted. As the rich gas has a higher propensity for detonation, operators were forced to substitute diesel with max of 50% unconditioned natural gas compared to 70% conditioned natural gas. The lean fuel used has thus allowed Marathon to maximize diesel substitution with natural gas and improve significantly upon diesel fuel savings.

Based on 20% of extra diesel substitution with conditioned natural gas, savings are calculated for 70% and 50% of diesel fuel substitution with conditioned and unconditioned natural gas respectively.

Assumptions:

1. Natural Gas price - $ 3.0/Mscf
2. Diesel Price - $ 2.6 /gal
3. Membrane, Installation and associated labor costs - $ 450,000
4. Diesel Heating Value (typical) - 128,488 BTU/gal
5. NG Heating Value (BTU/SCF) - 1050 BTU/scf

Table 3 present saving calculations in terms of diesel used based on 70% replacement with conditioned natural gas (membranes online) and 50% replacement with unconditioned natural gas (membranes offline).

Table 3. Data used to calculate diesel fuel savings with and without membranes.

Parameters	MEMBRANES	NO MEMBRANES
Total fuel used (NG + Diesel) , MMscfd	0.43	0.43
Natural Gas Consumption, MMscfd	0.30	0.21
Diesel Required (in Terms of NG Heat Equivalent MMscfd)	0.13	0.21
% Substitution of Diesel	70%	50%
NG Heating Value (BTU/SCF)	1,050	1,050
Diesel Required (Btu/d)	135,000,000	225,000,000
Diesel Heating Value (BTU/gal)	128,488	128,488
Diesel used (gpd)	1,051	1,751
ECONOMIC ANALYSIS		
Cost of NG ($/d)	$ 900	$ 643
Cost of DIESEL ($/d)	$ 2,732	$ 4,553
TOTAL FUEL COST (NG + DIESEL) ($/d)	$ 3,632	$ 5,196
TOTAL FUEL COST (NG + DIESEL) ($/month)	$ 108,953	$ 155,874
TOTAL MONTHLY SAVINGS ($/month)	**$ 46,921**	**NONE**

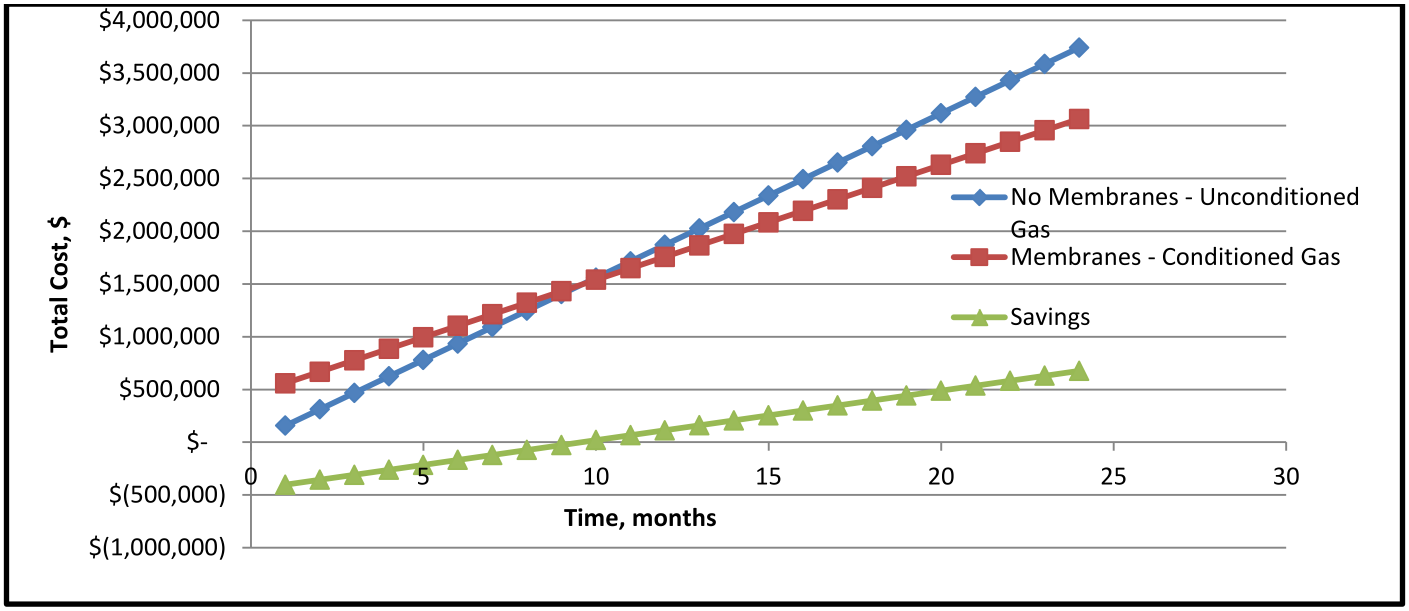


Figure 4. The graph presents savings on diesel when conditioned NG is used (with 70% diesel substitution). The figure also depicts pay-off time for membrane skid after which the profits are realized for the membrane skid arrangement.

Figure 4 clearly indicates that with the use of conditioned gas in dual fuel engines, more diesel fuel savings are realized thereby significantly reducing the operational cost of dual fuel engines. A baseline cost of $ 450,000 is assumed for membrane skid, installation, and any miscellaneous associated labor costs. Thus, initial savings in the graph start with negative $ 450,000. As mentioned earlier, the conditioned fuel from the membranes brings about 70% of diesel substitution for the dual fuel engines compared to 50% of diesel substitution with unconditioned natural gas. Thus, operating cost is considerably reduced after installation of the membranes skid. The total membrane investment pays off within a short period of time (approx 10 months) of installation and hence makes it a very valuable investment from the dual fuel engines perspective.

The above analysis has been done assuming a relatively low price for Diesel due to the current significantly depressed oil prices. The savings associated with using conditioned fuel gas in dual-fuel engines would be substantially higher as the prices of diesel increase to higher levels.

II. Fuel Gas Conditioning for 500 MW Power Plant Siemens Turbines in Brazil

The process schematic along with the picture of the Fuel Gas Conditioning Unit (FGCU) installed for natural-gas-powered combined cycle utility power plant for El Paso in Brazil is shown in Figure 5 and Figure 6. The motivation for installation of this very large system was unusual. During construction of the power plant, it was discovered that the gas to be used was slightly over specified for propane and butanes plus components. Burning non-spec propane and butane rich gas would have caused Siemens engine warranties to go void. El Paso had a long-term plan to install a refrigeration system as a solution to remove most of the C3+ hydrocarbons as NGLs. However, the unit had a long delivery date. To meet the schedule startup, clean gas was required for pre-conditioning tasks. A membrane gas treatment system was ordered with a 20-week delivery schedule. The system reduced the propane content of the gas from 2.0% to 1.5% and butane plus components to < 0.5%, bringing it into the design range. About 10% of the gas permeated the membrane with the excess propane and the stream was flared. Once the power plant commissioning tests were complete, the membrane unit was put on standby, to be turned on and used during annual maintenance of the refrigeration plant. The extra online operating time that was provided with this back-up alternative, was extremely valuable for such a large plant.

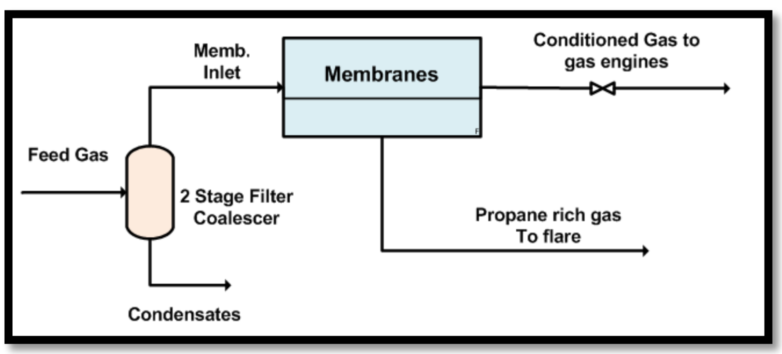


Figure 5. Block diagram of the Membrane system at power plant in Curitiba, Brazil.

Figure 6. Photograph of the Membrane system at El Paso combined cycle utility power plant.

A. Issues Faced By Client

The client faced several potential difficulties (listed below) in operating the Siemens engines at the site predominantly due to high level of propane in the raw fuel gas:

Engines Warranties Violation

The gas quality specifications for utility power plants are much tighter than gas engines or turbines used to produce field power. The Siemens engines warranties were tied to a max propane content of 1.5%, and C4+ content of 0.5 mol% in the conditioned fuel; and, if the client were to use the engines with high propane and butane+ content in the raw fuel gas, it would have immediately nullified their engine warranties on a very higher investment.

B. Membrane Fuel Gas Conditioning Unit - Technical Details & Field Performance Data

Utility Power Plant Details – El Paso installed MTR's membrane fuel gas conditioning unit to generate power for 500 MW Siemens Power Turbines. The membrane unit was designed to treat 90 MMscfd of feed. The membrane unit (shown in Figure 6) consisted of multiple membrane units containing several membrane modules.

Table 4 presents the design performance details of the FGCU system:

Table 4. Performance Data for the FGCU system installed to bring Utility Power Plant Turbine Feed Gas to Required Specifications.

Components	Gas Compositions	
	Feed Gas (mol %)	Conditioned Fuel Gas (mol %)
Propane	2.000	1.489
C4+	0.785	0.449

III. Fuel Gas Conditioning for Wartsila Engines for GenSet on FPSO platform

The process schematic along with the photograph of the Fuel Gas Conditioning Unit (FGCU) installed for Statoil offshore platform is shown in Figure 7 and Figure 8. The system was designed to produce 2 MMscfd of conditioned fuel gas. The system was installed in the North Sea where associated gas was being used to power a generator set and compressors. The gas was extremely rich, containing more than 15% C3+ heavy hydrocarbons. The platform was seeing power management issues where the engines were de-rated by 60% to run on raw gas. The membrane unit reduced the C3+ content of the fuel gas to about 5% C3+, allowing the engines to be run without any de-rate. A second pipeline was available to accept the heavy, low-pressure permeate gas.

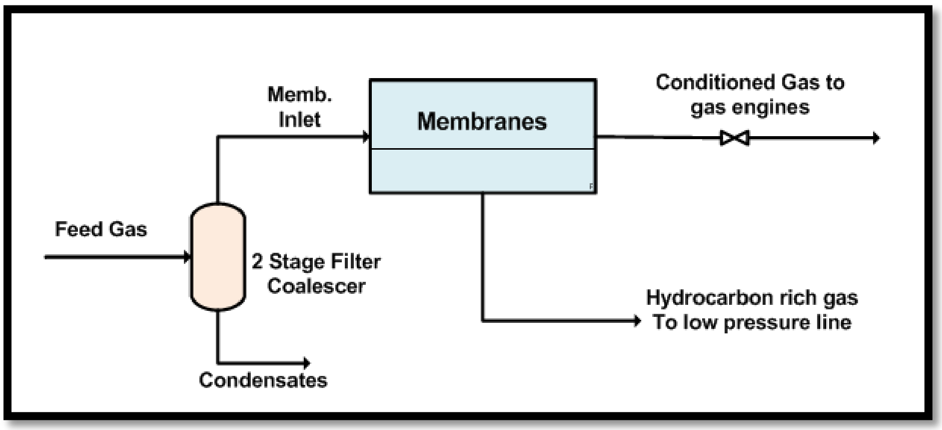
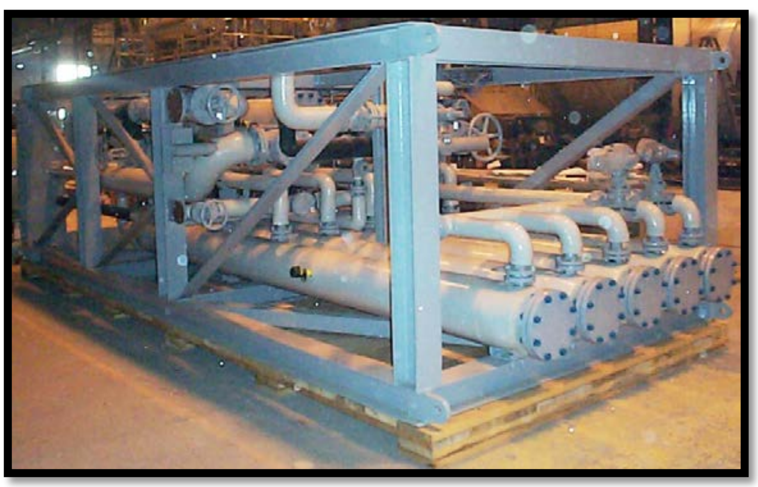


Figure 7. Block diagram of the Membrane system for fuel gas conditioning for Statoil.



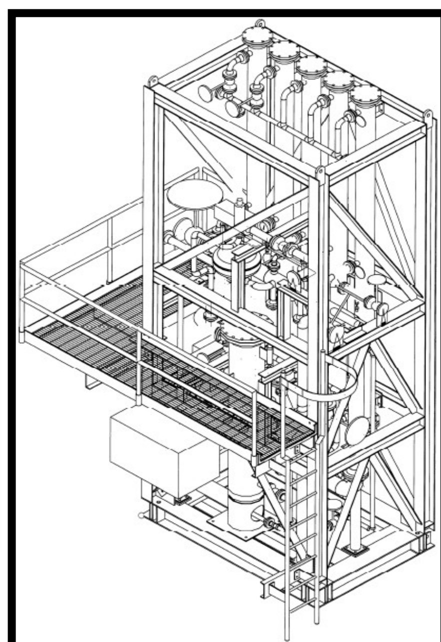


Figure 8. Photograph of a membrane fuel gas conditioning unit used for a field gas compressor engine. The membrane modules are contained in the horizontal pressure vessels. The unit could produce 2.0 MMscfd of clean gas.

A. Issues Faced By Client

The client faced following difficulties in operating the Wartsila engines at the site predominantly due to high level of heavy hydrocarbons in the raw fuel gas:

a. Engine Capacity De-rate –

With the raw fuel gas (higher BTU content), Statoil anticipated potentially increased operational issues related to knocking, detonation etc. leading to increased wear and tear of the engine components and increased maintenance costs. Hence, to avoid that, the engines had to be de-rated by approximately 60% of the maximum capacity.

b. Emissions Non-Compliance –

The significantly high content of heavy hydrocarbons meant high levels of emissions from the engines exhaust. This would have potentially resulted in non-compliance with the emissions regulations for the NOx, CO and unburned hydrocarbon.

c. Space Constraints

Space on the platform was very limited to accommodate large refrigeration unit that could bring down the heavy hydrocarbons content to permissible limits. Since, the feed gas had approximately 10% of ethane in the feed gas, a comparatively simpler and compact JT scheme could not be deployed on FPSO platform.

B. Membrane Fuel Gas Conditioning Unit - Technical Details & Field Performance Data

FPSO Details – Statoil installed MTR’s membrane fuel gas conditioning unit to generate 1.8 MMscfd of conditioned fuel for power generation.

System Size - The membrane unit (shown in Figure 8) consisted of multiple membrane vessels with membrane modules. The membranes were designed to generate a max fuel flow-rate of 2.0 MMscfd of conditioned fuel gas. In order to save space, the tubes containing the membrane modules were mounted vertically on the skid.

A design performance summary of the FGCU system is provided in **Table 5**. The table shows that methane number of raw gas was improved from **32** to **65** using MTR fuel gas conditioning membrane skid.

Table 5. Performance Data for Remote Site removing C_3+ Components from Associated Gas

Composition	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**

CONCLUSIONS

Poor quality fuel gas is a common issue for operators of engines and turbines in remote locations. Membrane systems offer a simple and economical solution to this problem, providing higher reliability and online operating time, while reducing maintenance and operating costs.

The following conclusions can be made from the case studies presented for different locations where membranes were successfully installed for power generation:

- **High engine efficiency –** Membranes significantly lowered heavy hydrocarbon content from high BTU rich raw feed gas to generate low BTU lean fuel gas which easily met the fuel quality spec of CAT methane number for dual fuel Caterpillar engines at four of the drilling sites for Marathon Oil. Thus, the engines could be run on their maximum efficiency for which they were designed for (70% diesel substitution with natural gas). The lean fuel gas minimized pre-detonation and knocking issues in the engines and also significantly reduced operating costs associated with high diesel consumption when raw unconditioned natural gas was used with only 50% of diesel substitution rate.

- **Emissions Reduction –** High Btu content of fuel gas is a ubiquitous problem faced during power generation especially in the rich shale gas areas. If the raw fuel gas (high BTU) is used as it is, the engines emissions do not meet the permit limit for the NOx, CO and unburned hydrocarbon levels. Therefore, heavy hydrocarbon reduction in the fuel gas is highly significant in order to remain within the permissible emissions limits of the station.

- **De-rate –** If raw gas is used as engine fuel, operators are forced to de-rate the engines in order to limit detonation issues related to the high Btu content of the raw gas. This lowers the maximum power generation on the engine. The lean fuel gas generated from the membranes had allowed Statoil to resolve the power management issues faced in a remote off-shore location by eliminating the de-rate issue.

- **Engine Warranties Violation or High Maintenance Costs –** The engine warranties are often violated if they are run on the raw gas without de-rate to minimize any revenue loss. This leads to increased maintenance costs of engines. As membranes provide clean fuel gas, the operational and maintenance costs associated due to warranties violation is significantly reduced.

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