Membranes for fuel gas conditioning

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During the last 15 years, gas separation with polymer membranes has become an important separation technology. In the natural gas industry, the principal application of membranes has been the separation of carbon dioxide from natural gas. Over 200 systems have already been installed, with some units processing in excess of 100 MMSCFD. The membranes used in the CO_2 removal application are made from rigid, glassy polymers. Membrane Technology & Research, Inc. (MTR) has developed and commercialised a new membrane based process called VaporSep®. The enabling technology of VaporSep is a rubbery membrane, which has unique separation capabilities. The membrane permeates condensable vapours, such as C_3+ hydrocarbons, aromatics, and water vapour, while rejecting non-condensable gases, such as methane, ethane, nitrogen and hydrogen. Systems based on these membranes were first commercialised in 1990. Since then, MTR has supplied more than 50 systems to the chemical process industry worldwide. The majority of these units are found in the polymer industry in the production of polyvinyl chloride (PVC), polyethylene (PE), and polypropylene (PP).

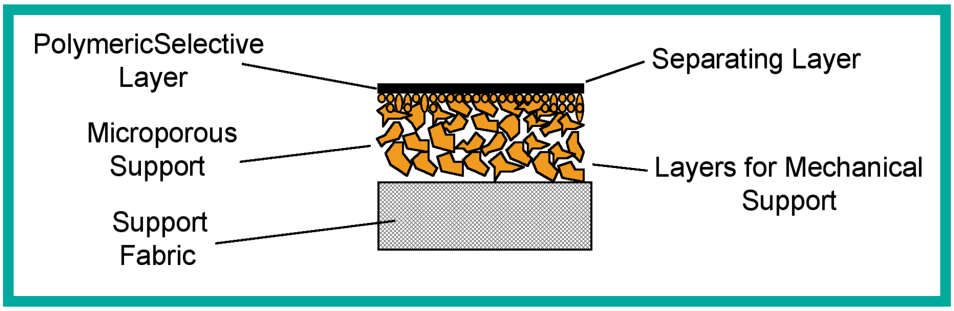

Figure 1. Membrane cross section.

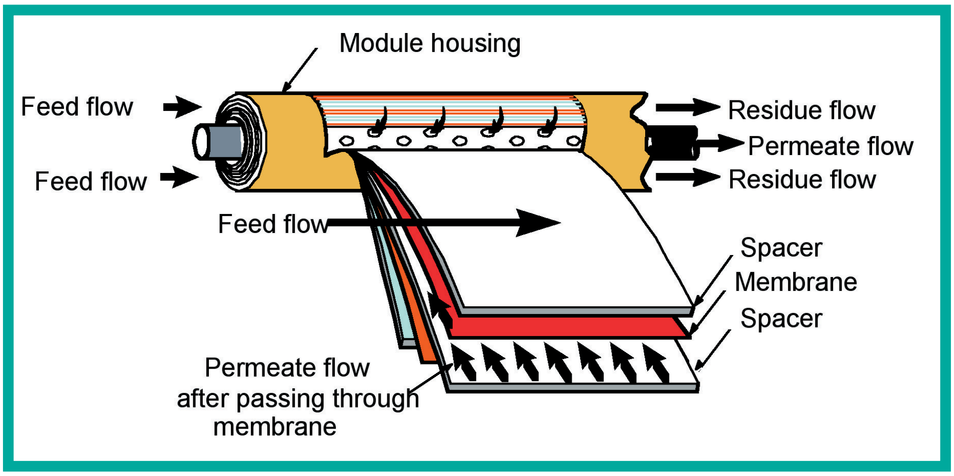

Figure 2. Spiral wound model.

These unique rubbery membranes have recently been applied to the separation of C_3+ hydrocarbons from methane and ethane in natural gas processing. One of the applications for the technology is to condition fuel gas used in gas engines and turbines in the natural gas industry. A detailed description of the application and the benefits of the membrane system are discussed below.

Membrane separation

Polymer membranes separate components of a gas mixture because the components permeate the membrane at different rates. In all membrane separations, the driving force is the difference in pressure between the feed and the permeate side of the membrane. In rigid, glassy polymers, the dominant factor determining membrane selectivity is the ratio of the gas diffusion coefficients, which is highly dependent on molecular size. Thus, glassy polymer membranes typically permeate the smaller molecules, methane and ethane, and reject the larger molecules, propane, butane, and higher hydrocarbons. In rubbery polymer membranes, the dominant factor determining membrane selectivity is the ratio of the gas solubilities, which reflects the ratio of the condensability of the components. Thus, rubbery polymer membranes preferentially permeate the larger, more condensable molecules such as propane, butane, and higher hydrocarbons and reject methane and ethane at pressure as the residue. This behaviour is counter-intuitive since any normal filter will allow the smaller molecules to pass through and retain the physically larger molecules. This reverse selective behaviour has been utilised by MTR to design commercially successful systems for various gas separations.

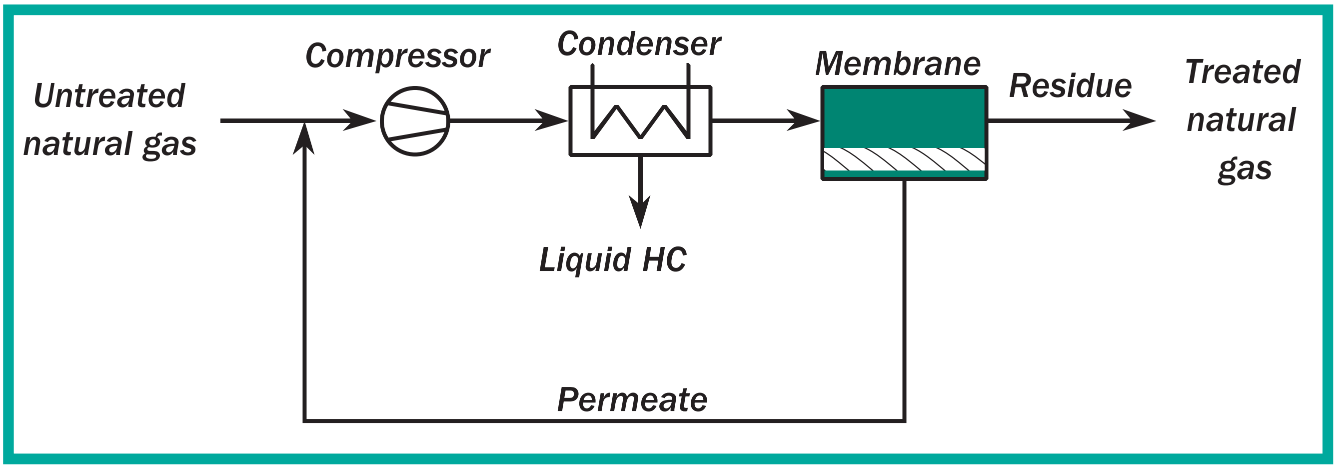

Figure 3. Flow scheme for natural as treatment.

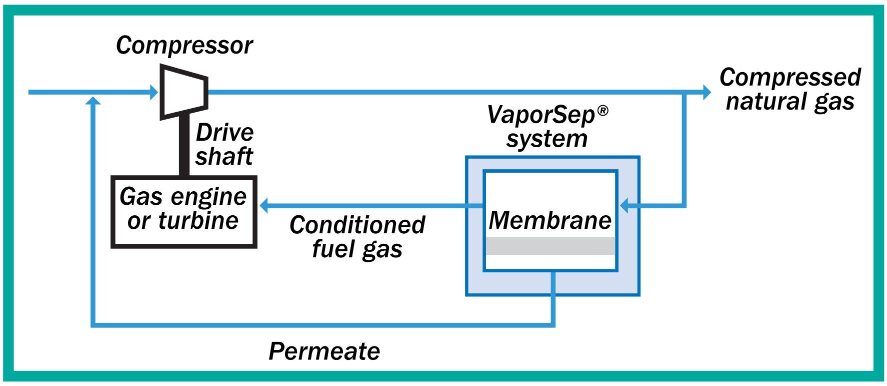

Figure 4. Fuel gas conditioning for gas engine.

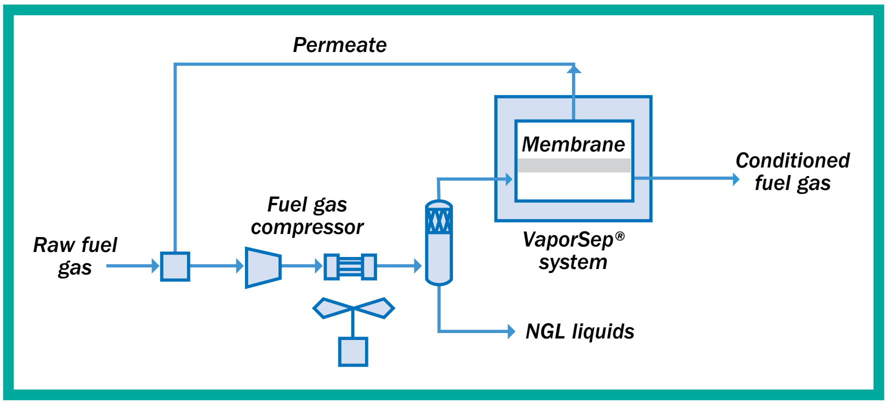

Figure 5. Fuel gas conditioning for gas turbine.

The membrane, shown in Figure 1, consists of three layers; a non-woven fabric which serves as the membrane substrate; a tough, durable, and solvent-resistant microporous support layer which provides mechanical support without mass transfer resistance, and a dense, defect free, rubbery layer which performs the separation.

After manufacture as flat sheets, the membrane is packaged into a spiral-wound module as shown in Figure 2. The feed gas enters the module and flows between the membrane sheets. Spacers are added on the feed and permeate side to create flow channels. As the hydrocarbon preferentially permeates through the membrane, the gas spirals inward to a central collection pipe. Methane and other light gases are rejected and exit as the residue stream. The membrane modules are placed into pressure vessels and configured in series and parallel flow combinations to meet the requirements of a particular application.

The membranes can be incorporated into systems in several different ways. Many systems have the basic design shown in Figure 3. The feed gas is first compressed and sent to a condenser where it is cooled. A portion of the heavy hydrocarbon fraction condenses and is recovered as a liquid. The non-condensed portion of the gas, which still contains a significant fraction of the heavy hydrocarbon components, passes across the surface of the membrane. The membrane separates the gas into two streams: a permeate stream enriched in heavy hydrocarbons and a residue stream which is depleted of heavy hydrocarbons. The permeate stream is recycled to the compressor inlet while the residue stream (which is maintained at pressure) is the treated natural gas stream.

Gas engine application

Natural gas is commonly used as a fuel in gas engines and turbines in the hydrocarbon processing industry. Frequently, raw natural gas is the only fuel available to operate compressor stations in remote locations and on offshore platforms. This gas has a high heating value, high hydrocarbon dew point, and low octane number, which can cause operating problems. In gas engines, the rich fuel may pre-detonate which can severely damage the internals of the firing chamber. In addition, condensation of hydrocarbons (due to day-night temperature variations) may damage the combustion chambers in gas engines and gas turbines, increasing maintenance costs and downtime. Since the engines and turbines drive other machinery, any disruption in their operation will reduce production resulting in significant revenue loss. Fuel gas conditioning is particularly important for gas turbines on offshore platforms, where this equipment is the only source of power. To increase the reliability and reduce unscheduled downtime of such key equipment, a simple technology that conditions fuel gas is required.

A flow diagram of the membrane to condition raw natural gas is shown in Figure 4. The gas, at a pressure of 100 psig, is compressed to 1000 psig and cooled in an air-

Figure 6. A photograph of a gas turbine conditioning unit. This compact unit has the dimensions 8 ft long X 6 ft wide x 6 ft high and can process up to 1.5 MMSCFD of fuel gas.

Table 1. Feed and conditioned gas for gas engine

Process conditions	Feed gas	Conditioned gas
Temperature (˚C)	35	33
Pressure (Psig)	1000	985
Total flow (MMSCFD)	0.95	0.5
Component (mole %)		
Carbon dioxide	1.3	0.6
Hydrogen sulfide	0.5	0.1
Methane	72.5	81.2
Ethane	9.5	9.0
Propane	9.9	7.1
i-Butane	2.4	0.9
n-Butane	2.5	0.9
n-Pentane	1.3	0.4
Water	0.1	0.0
Fuel heating value (Btu/scf)	1464	1316
Octane number	114	116
Hydrocarbon dew point (˚C)	35	4

Table 2. System performance summary gas turbine conditioning unit

Feed dew point (˚F)	100
Ambient temperature (˚F)	100
Conditioned gas dew point (˚F)	60
C_3+ removal (%)	60
NGL recovered (gallons/day)	21,300
Annual value of NGL (@ US$ 0.2/gal)	US$ 440 000
System dimensions (l x w x h, ft)	10 x 8 x 20
Payback time (months)	11

cooled aftercooler. The heavy hydrocarbons are condensed and recovered as a liquid. The high-pressure gas, saturated in heavy hydrocarbons, contains 6.2% of C_4+ hydrocarbons and over 5000 ppm hydrogen sulfide. This gas is not an ideal engine fuel. To improve the gas quality, the pressurised fuel stream is sent to the membrane system which reduces the total C_4+ hydrocarbon content to 2.1% and removes about 80% of the hydrogen sulfide. The treated gas is then routed to the gas engine as fuel. The heavy hydrocarbon rich permeate stream is sent to the feed side of the compressor. The fuel conditioning system is completely passive. The power to drive the separation is provided by the existing compressor, so that no new rotating equipment is required. In addition, the conditioning occurs at ambient temperature, avoiding the issues of hydrate formation. The composition and conditions for the feed and conditioned gas are given in Table 1.

The conditioned fuel gas is significantly depleted in the higher hydrocarbons. The hydrocarbon dew point of the gas is reduced from 35 to 4 ˚C. The membrane system selectively removes the hydrocarbons that cause knocking while retaining those that contribute to the heating value of the gas. At the same time, the system completely dehydrates the fuel gas. The system is skid-mounted and is approximately 5 ft long by 5 ft wide by 8 ft high. No operator attention is required and since the system has no moving part, maintenance expenses are minimal. The expected membrane life is from 3 to 5 years.

Gas turbine application

Gas turbines are used increasingly in the gas processing industry especially as compression drivers and for power generation on offshore platforms and remote locations. The turbines are frequently powered by raw, associated gas produced with the oil. This raw gas is typically rich in condensable hydrocarbons and at low pressure. Figure 5 shows a process flow diagram of a fuel conditioning system for gas turbine. The fuel is compressed in a screw compressor from 35 to 285 psig. The gas is then cooled, partially condensing the heavier hydrocarbons, which are removed from the gas in a separator. Since the gas from the separator is fully saturated, condensation may occur in the fuel line to the turbine. Moreover, this gas is very rich in hydrocarbons and may not meet the fuel specifications of the turbine manufacturer. Rich fuel tends to burn less efficiently in the combustors, leading to carbon formation, which fouls and damages the turbine blades. Injection of liquid hydrocarbons and incomplete combustion of the rich fuel can lead to unscheduled downtime and lost production.

As shown, the membrane is installed on the compressed fuel line. The membrane preferentially permeates the heavy hydrocarbons and the permeate stream is recycled to the compressor inlet. Removal of the heavy hydrocarbons lowers the hydrocarbon dew point of the treated stream, eliminating the possibility of hydrocarbon condensation in the fuel line. The extent of fuel gas conditioning is adjusted by the amount of gas permeating the membrane. Another benefit of the membrane system is the production of significant quantities of hydrocarbon liquids. The value of these liquids can easily justify the cost of the system. The performance of the system is shown in Table 2.

Typically 60 to 90% removal of C_3+ hydrocarbons is achieved and dew point depression from 20 to 80 ˚F is possible. In addition, based on a value of US$ 0.20/gallon of NGL, the recovered hydrocarbons provide a payback time of less than 12 months.

Conclusion

MTR has developed a unique membrane based process to condition fuel gas for gas engines and turbines. The membrane based fuel conditioner operates at ambient temperatures and requires no supervision. The system is compact, and in most cases it can be easily retrofitted into existing operations. The membrane system is a simple and economically compelling solution for improving gas engine and turbine reliability and increasing onstream time.