Emerging Membrane Technology for Natural Gas Dehydration

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Lonnie W. Smith
VP Business Development, Renewable Energy
PoroGen Corporation
6C Gill St., Woburn, MA 010801

Houston, TX Office: +1-281-570-4460
LSmith@PoroGen.com

www.porogen.com

Problem of Methane Emissions in Natural Gas

- Natural gas generates less CO2 emissions than coal but Methane is a more potent greenhouse gas.
- Curtailing methane loss is a priority as we move to expand natural gas economy
- Sources of Methane Emission Losses
  - In US, significant methane emissions are from Dehydrators & Acid Gas Removal
    - Locations include Well sites, Central Gathering Systems, Gas Plants, Transmission Pipelines, Compressor & Meter Stations, Underground Storage, and Offshore Platforms
  - Internationally - Significant Flaring
    - 2004: 150 billion cubic meters flared with 80% of global venting and flaring
    - < 15 countries (including Nigeria, Russia, Iran, Iraq, Angola, Qatar, Algeria, Venezuela, Equatorial Guinea, Indonesia, Brazil and Mexico).' World Bank, 2007

Current Available Natural Gas Dehydration Technology

Glycol Absorption

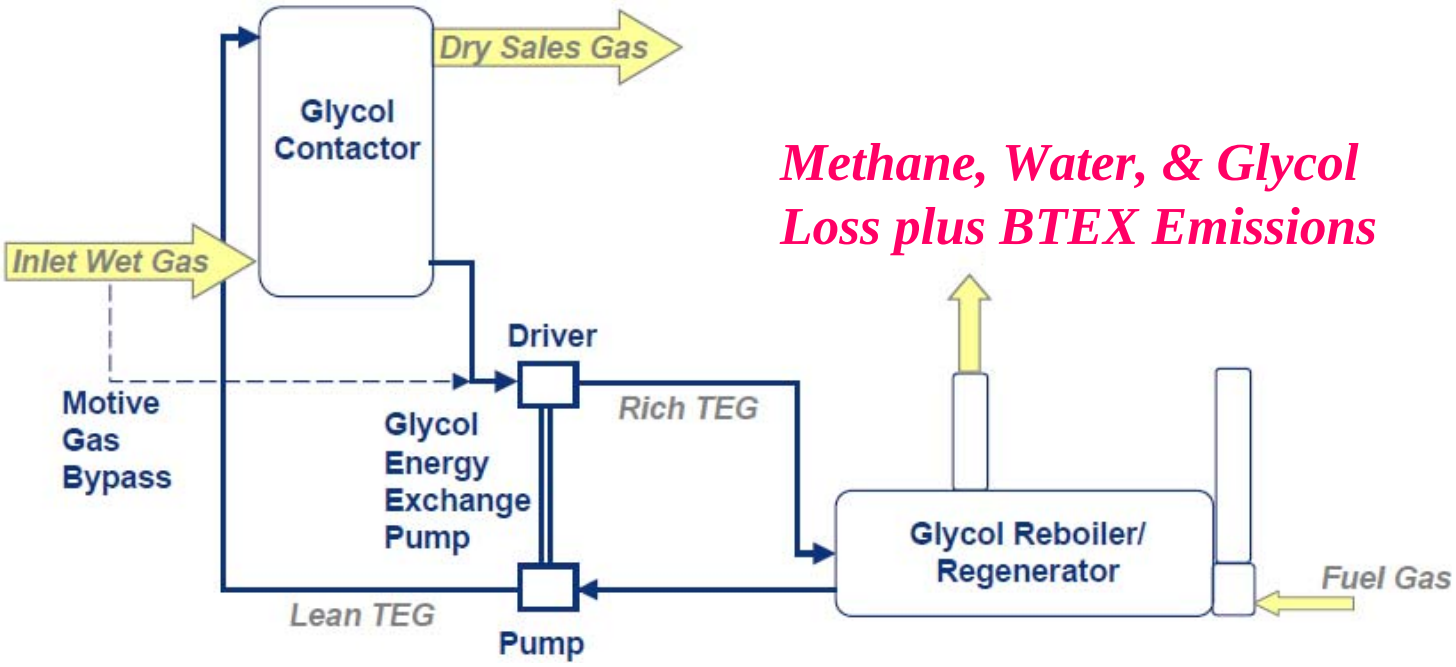
- Industry standard with ≈40,000 Units in the USA,
- ≈2,000 Units are subject to BTEX emission restrictions with more natural gas stranded due to permitting.

Membranes

- Limited installations mostly in Europe, Russia, China & 3rd world economies with minimal Natural Gas infrastructures.

Natural Gas Dehydration Standard Technology

Basic Glycol Dehydrator System Process Diagram



Methane, Water, & Glycol Loss plus BTEX Emissions

Natural Gas Dehydration, Lessons Learned from the, Natural Gas STAR Program, ConocoPhillips - The Colorado Oil and Gas Association, and The Independent Petroleum Association of Mountain States. Producers Technology Transfer Workshop, Durango, Colorado, September 13, 2007, epa.gov/gasstar

Glycol Absorption Dehydration Technology

- Positives
  - Established low cost industry standard
  - Well designed / operated system
  - Simple Mechanical Operation – single gas driven pump
- Negatives
  - Methane lost / emitted & BTEX emitted during regeneration
  - Added cost and design cannot attain zero emissions
  - Contamination of Natural Gas with TEG Solvent
  - Moving parts and liquid chemical inventory

Are Membranes Suited For Natural Gas Dehydration?

- Membranes have been widely adopted for over 25 years as a process unit in gas separations, including:
  - Nitrogen Production
  - Air Dehydration
  - Acid Gas CO_2 & H_2S Removal, CO_2 EOR Recovery
  - Other Separations: Hydrogen, Helium
- Why membrane use in natural gas dehydration has been limited?

This presentation will review limitations of prior art membrane technology and outline new and emerging membrane technology for natural gas dehydration

Membrane Technology in Natural Gas Processing - Status

- Attractive for Offshore & Unmanned applications
- Used in less developed Natural Gas Infrastructures vs. USA
- High Hydrocarbon losses, upwards of 10%: dehydration
- Employed for acid gas treatment (sweetening and EOR) when EXTENSIVE pretreatment is included

Membrane in Natural Gas Processing - Limitations

- Limited hydrocarbon dewpoint control
- Performs 1 purification task at a time
- Requires additional processing steps to protect membranes
  - Irreversibly Damaged by Heavy Hydrocarbons / Liquids & Chemicals (Solvents such as Methanol, Amines, Selexol)
  - Costly & Complex Pretreatment System (50%$^{+}$ of total Cost) required

Prior Membrane Process - Limitations

- Good News:

  Water vapor is the fastest permeating component in natural gas streams providing for high productivity and separation factor

- Bad News:

  Limited process efficiency because water vapor is a condensable gas and permeation stops once the permeate stream becomes saturated

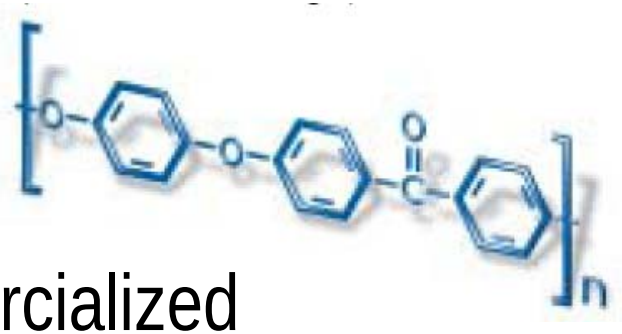
Pipeline water specification was met only with substantial methane loss

Membrane Technology Needs for Natural Gas Dehydration

What characteristics do Membranes require to meet market needs?

1. Robust, Durable, Chemically Resistant with no costly and complex pretreatment
2. Highly efficient thermodynamics (counter-current flow required – can be met only by hollow fiber devices)
    - Spiral wound membranes operate in less efficient cross-flow mode
3. Methane loss similar or better than Glycol Absorption

PoroGen's Membrane Technology Differentiation



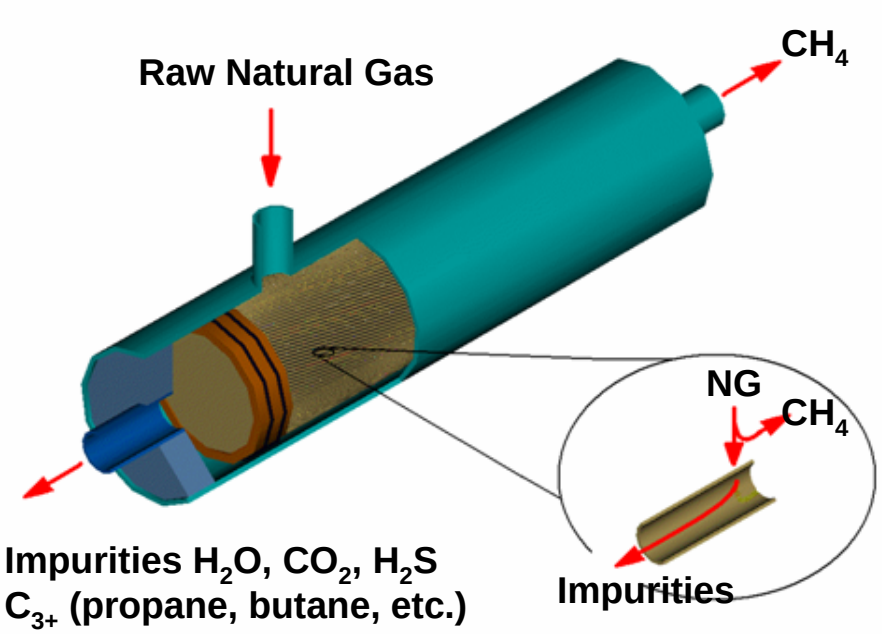
- PoroGen has developed and commercialized novel membrane technology based on best in class, chemically resistant engineering plastic PEEK

  PoroGen's patented technology enables PEEK membrane preparation by conventional melt extrusion

- PoroGen is the only worldwide manufacturer of PEEK membranes

PoroGen PEEK-SEP™ Membrane Module

PEEK- SEP Membrane Cartridge is installed into a vessel to form a Membrane Module



- One Step Natural Gas Process to remove multiple Contaminants (removes H2O, CO2, H2S and C3+)
- Chemically Robust membrane that requires no pretreatment

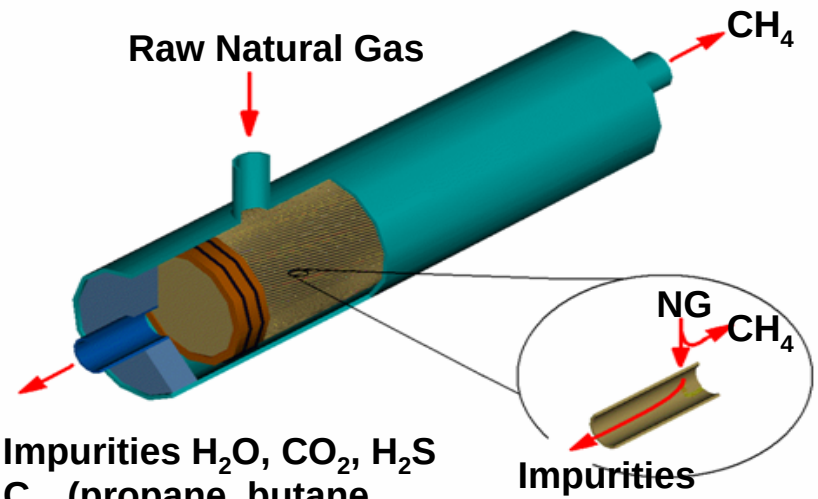
PEEK-SEP™ Operational Advantages in Natural Gas

- Total resistance to all gas and liquid components of Natural Gas:
  1. Water
  2. All aromatic hydrocarbons, amines, methanol, Selexol, glycol & other solvents
  3. Natural Gas Liquids (NGL)
- Operates in gas phase, can operate in Liquid and Gas phases simultaneously if designed for condensation mode

During field demonstrations in Kogalim (Siberia) PEEK-SEP modules were flooded with associated gas liquids, after liquids were drained performance was restored

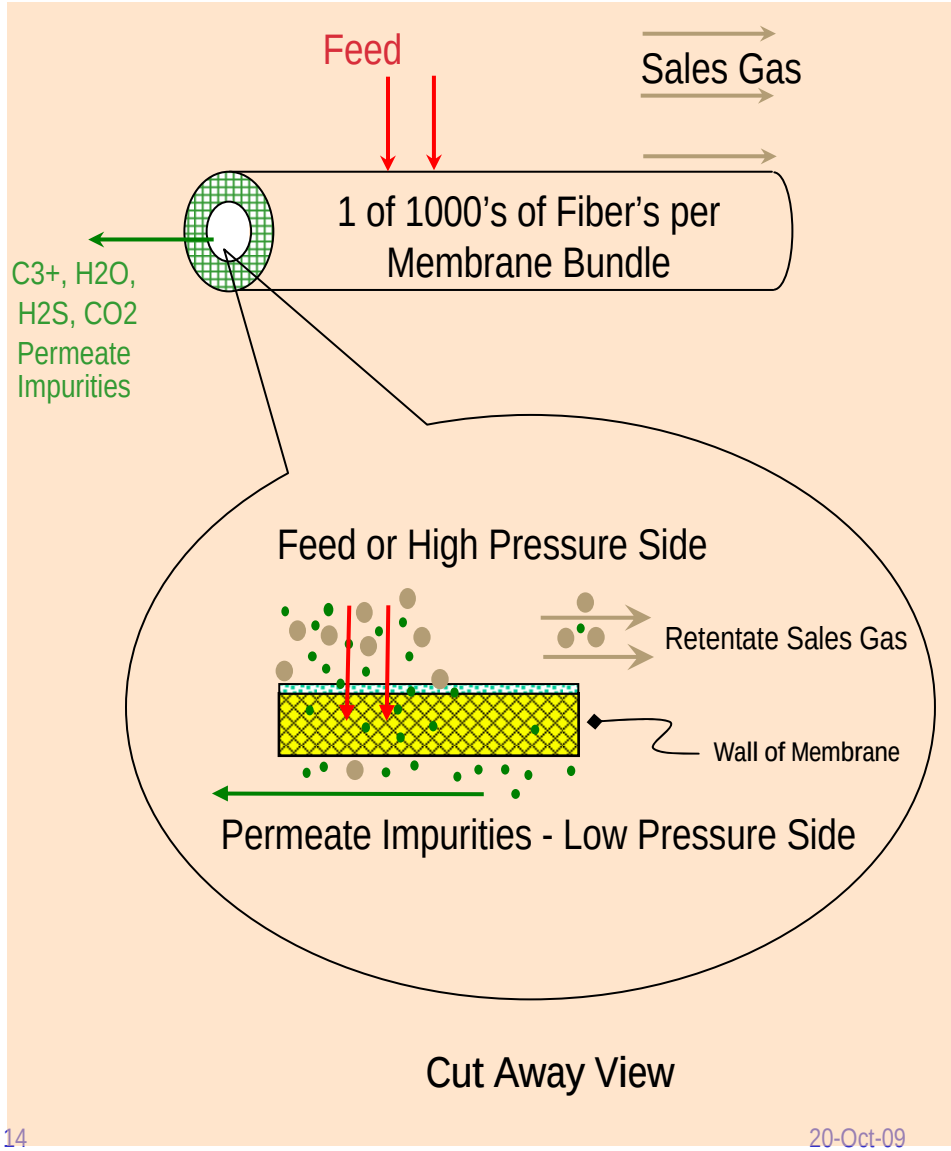
Principles of Membrane Gas Separation

PEEK-SEP™ Membrane Module

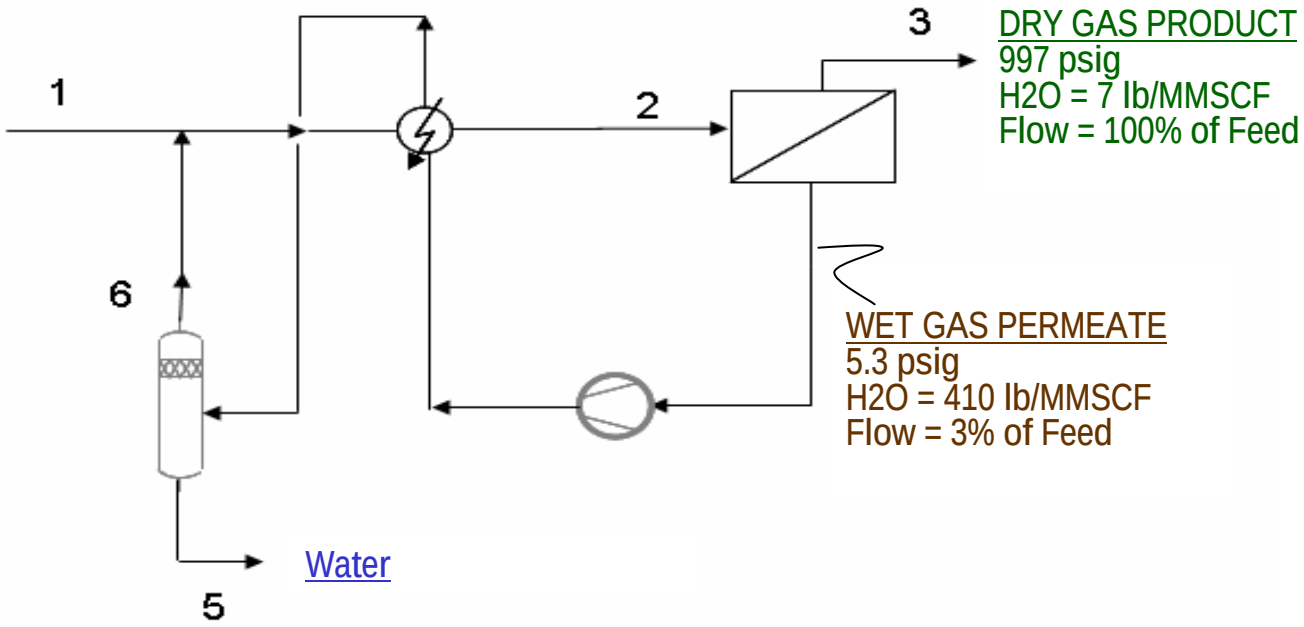


Impurities H_2O, CO_2, H_2S C_{3+} (propane, butane, etc.)

PEEK-SEP™ Membrane Cartridge



PEEK-SEP ™ Membrane Sample Application



- Removes water as a liquid with essentially zero air emissions in contrast to the Glycol Absorption which removes water as a vapor
- Fuel Consumption is 0.04% when recompressing to P/L pressure

PEEK-SEP™ P-Guard Natural Gas Membrane Dehydration

Advantages over Glycol Absorption

- Simple to operate, No moving parts
- No heat required, No chemical inventory required
- Ability to control degree of H_2O removal
- Effective for all segments of Natural Gas Production, Processing, Storage & Transportation
- Zero Methane or BTEX Air Emissions with specific design

PEEK-SEP™ Advantages over Prior Art Membranes

- More Compact footprint / Less weight
- No Contaminant Pretreatment or Superheating of Feed
- Ability to Control Degree of Water Removal
- Zero Methane or BTEX Air Emissions with specific design
- Why more cost effective?
  - Production & Processing: performs multiple purification tasks in 1 step without pretreatment (H_2O, NGL, H_2S, CO_2)
  - Storage & Transportation: Specific to local conditions, when Permeate used as a Fuel, Power or is used to maintain P/L Pressure

Summary

- Membranes are expected to play an increasing role in natural gas processing with the introduction of more efficient, chemically durable membranes
- Hybrid membrane/absorption technology currently under joint development by Gas Technology Institute and PoroGen is expected to provide further environmental and cost advantages