CRYOGENIC PURIFICATION OF LOW PURITY HELIUM WITH TEMPERATURE SWING ADSORPTION AND MEMBRANE SEPARATION

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INTRODUCTION

Recovering high-purity helium from low-concentration sources is an increasingly critical challenge, particularly as global helium supplies tighten and industrial demand rises. To address this, Ability Engineering Technology (AET) has developed an integrated purification system capable of processing helium streams containing less than 10% by volume. By combining membrane separation with cryogenic temperature swing adsorption (TSA), the system achieves 5.0–6.0 grade helium at recovery rates exceeding 90%. This approach enables cost-effective reclamation from dilute sources, supporting both sustainability and supply chain resilience in helium-dependent applications.

Figure A: Membrane Test Bed

METHOD SUMMARY

Stage 1 – Membrane Separation:

- Helium feed gas with concentrations below 10% is enriched to over 50% using high-selectivity polymer membranes. The membrane stage exploits helium's high relative permeation rate compared to other components such as nitrogen and methane, as illustrated to the right.

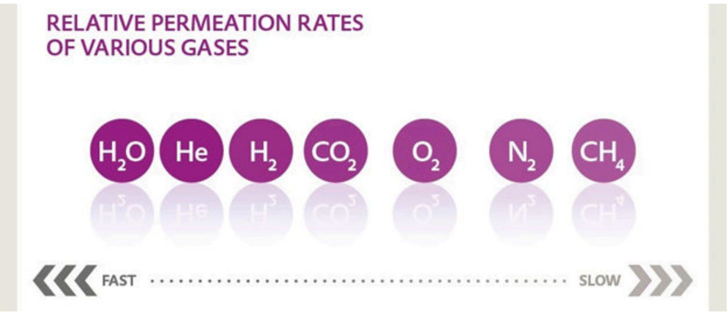

Figure B: Relative Permeation Through Evonik Sepuran Membranes (evonik.com)

Stage 2 – Cryogenic Temperature Swing Adsorption (TSA):

- The enriched helium stream undergoes further purification via a cryogenic TSA system with an integrated phase separator. Operating at liquid nitrogen temperatures, this stage effectively removes trace contaminants to achieve helium purity levels exceeding 5N.

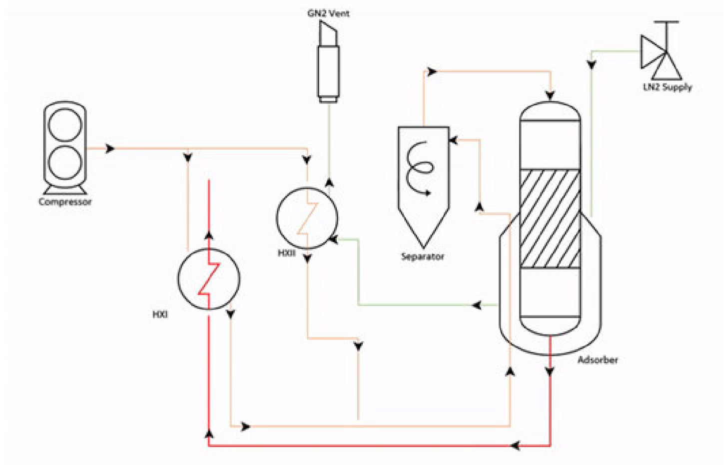

Figure C: AET's Cryogenic Adsorption Purifier General Process Map (abilityengineering.com)

ADDITIONAL EQUIPMENT

Key components used in testing included:

- Gas Analyzer Portable (Nuvair)
- Gas Analyzer Trace Nitrogen in Helium (GOW-MAC)
- Meeco Aquavolt 2 Trace Moisture Analyzer
- CryoNova Helium Compressor Skids

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MEMBRANE SEPARATION

Membrane-based gas purification has gained traction in recent years, with multiple manufacturers entering the field and promoting advanced separation capabilities. However, limited third-party validation has left performance data relatively scarce. In response, Evonik—a global leader in specialty chemical innovation—engaged AET to independently evaluate their Sepuran® Noble membrane technology for helium recovery from low-concentration gas streams.

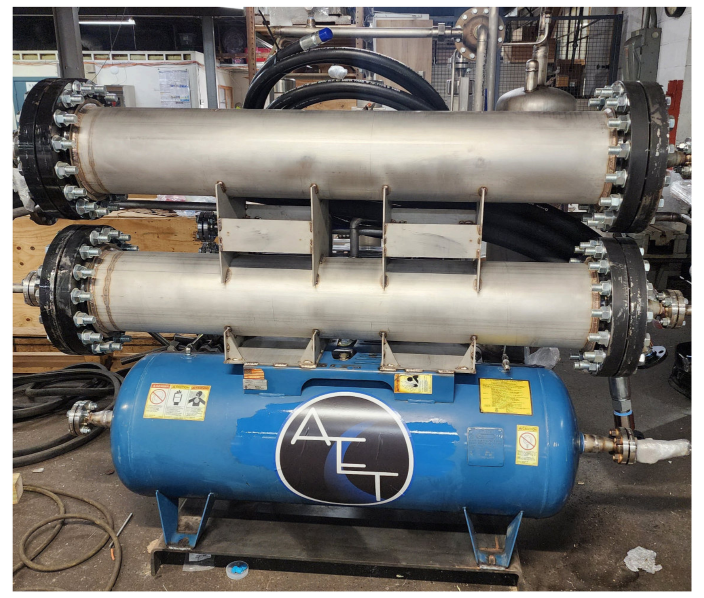

Figure D: 8" Test Bed Modular Membrane Housings

THEORETICAL CAPABILITY

Evonik's Sepuran® Noble membrane series is engineered specifically for the separation of inert gases such as helium, leveraging helium's low molecular weight and high diffusivity. The system utilizes these membranes to achieve progressive enrichment of helium concentrations at defined stages, as illustrated in the process schematic above. The separation performance at each stage was calculated based on system conditions and gas compositions.

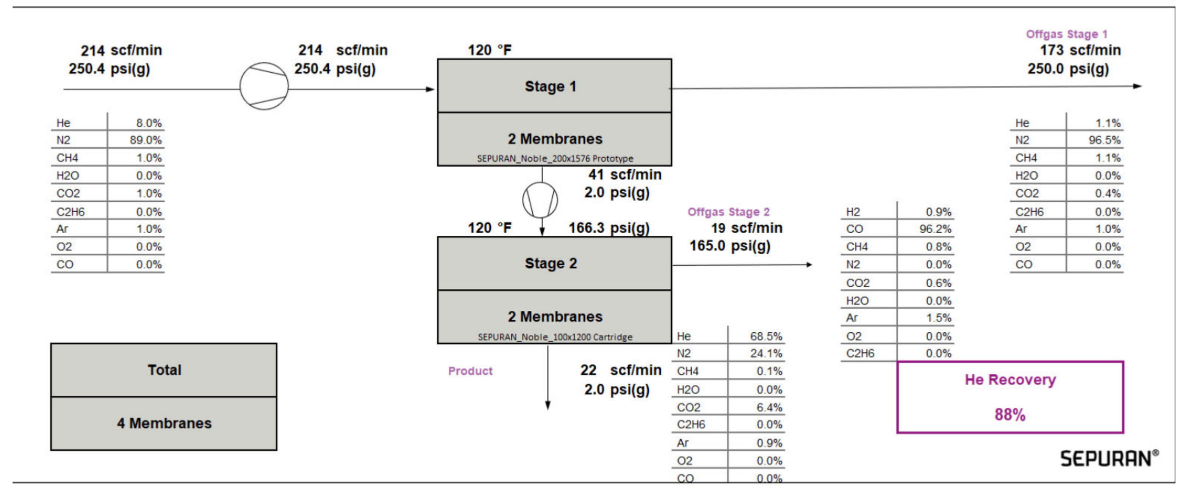

Figure E: Calculated Membrane Separation Courtesy of Evonik

TEST SKID RESULTS

The test skid was configured to process an 8% helium feed gas, which was first routed through a protective moisture removal dryer downstream of the initial compression stage operating at 250 psig. A handheld gas analyzer, connected to the 4-inch permeate outlet of the second-stage membrane module, recorded helium concentrations of up to 60%, with a representative reading of 57.8% at the time of sampling.

Figure F: Helium Concentration in Stream Analyzed by Nuvair Pro Trimix

TEMPERATURE SWING ADSORPTION

AET's purification system begins by directing the gas stream through an ambient-temperature, adsorption-based dryer to remove moisture. The pre-dried gas is then gradually cooled to liquid nitrogen temperatures using a series of strategically positioned heat exchangers (HX). Larger HXs facilitate counterflow heat exchange between incoming and outgoing process streams, while smaller HXs transfer heat between the gas and a liquid nitrogen circuit—the system's primary consumable. Upon reaching cryogenic conditions, the gas passes through an adsorption bed, where residual impurities are effectively captured. The purified helium stream is then reheated via the primary HX and discharged near ambient temperature.

Figure G: AET's Cryogenic Adsorption HP Purifier System

TEST SYSTEM

To rigorously evaluate the performance of AET's HP Series purifier, a full-scale experimental unit was designed and fabricated for deployment at CUBRC—an internationally recognized leader in hypersonic wind tunnel research. The facility's gas recovery system presents an ideal testbed, routinely handling variable gas mixtures with high nitrogen content. These conditions provide a robust environment for assessing system reliability, separation efficiency, and long-term operability under realistic field scenarios.

CONCLUSIONS AND FUTURE OUTLOOK

AET's integrated membrane skid and HP Series cryogenic purifier successfully demonstrated helium purification from an 8% helium-in-nitrogen feed to product purity exceeding 99.999% (5.0 grade). These results validate the use of high-selectivity membranes for initial enrichment, effectively separating fast-diffusing helium from slower, larger molecules such as nitrogen.

Ongoing testing will focus on optimizing membrane module configurations, refining adsorption cycle parameters, and evaluating system efficiency under varying feed conditions to further enhance performance and scalability.

Figure H: Nuvair Pro Trimix at Inlet of AET's Purifier and Gow-Mac Analyzer at Outlet