A Sustainable Approach to the Supply of Nitrogen

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Nitrogen (N2) is commonly employed in both industrial and analytical applications where it is desired or necessary to exclude oxygen and moisture. Typical industrial applications include laser cutting, modified atmosphere packaging, aluminum degassing, ink, edible oil and chemical blanketing, and boiler layup. Applications that use nitrogen in the laboratory include gas chromatography (GC), liquid chromatography with mass spectroscopy detection (LCMS), fourier transform infrared spectroscopy (FTIR), Inductively coupled plasma spectroscopy (ICP), glove boxes, and blanketing of reactions that require an inert atmosphere.

Nitrogen is usually generated via the fractional distillation of air. While N2 is not considered a greenhouse gas, it is important to recognize that isolation of the gas from air by fractional distillation is an energy intensive process. The energy employed to generate N2 produces a significant quantity of CO2 (Carbon Dioxide). CO2 is believed to be a greenhouse gas that has a significant unfavorable impact on worldwide climate change. Therefore it is important to consider alternative approaches of nitrogen generation and their relative contribution to greenhouse gases.

The generation of N2 is an excellent example of how a significant reduction in the generation of greenhouse gases can be achieved by selecting an alternative process that performs the desired operation while consuming less energy. In addition to the CO2 created by the generation of N2, transportation of the gas from the location where it is manufactured to the location where it is used generates additional CO2, thus providing a further negative impact on the environment.

Alternative approaches to the generation of N2 have a considerably lower energy input than fractional distillation of air. These approaches can be employed on an in-house basis thus obviating the transportation impact. An additional benefit of in-house generation of N2 is the lower cost and increase in safety relative to the use of cylinders, dewars and bulk nitrogen supplied by fractional distillation plants. In this paper the generation of N2 via the use of hollow fiber membranes and Pressure Swing Adsorbtion (PSA) will be considered. Additionally, this paper will demonstrate that localized generation of nitrogen using these techniques requires considerably lower energy to generate nitrogen than fractional distillation of air.

Nitrogen generation by fractional distillation of air

The fractional distillation of air involves withdrawing the air from the atmosphere using a compressor. The compressed air is then chilled to approximately 10°C and passed through a moisture separator; an oil absorber; and molecular sieves to remove water vapor, oil, particulate matter, and other contaminants. The dried, purified air enters a multi-pass heat exchanger, then a Joule-Thompson type expansion engine (to chill it to below the condensation point -195.8°C at 1 atm) and liquefy it. The purified nitrogen is pressurized and stored in bottles as a gas or directly stored in dewars or delivery tankers as a liquid. The gas or liquid is then transported to the end user's facility. Once the nitrogen has been consumed, the empty bottle or dewar must eventually be transported back to the distillation site to be refilled. The energy used for transportation will be discussed later.

Nitrogen generation using an in-house hollow fiber membrane system

Pure nitrogen can be generated from air using an in-house hollow fiber membrane system. The membrane module, which is the heart of the system, is designed to preferentially allow oxygen and water vapor in the air to permeate the membrane wall (Figure 1) while nitrogen remains within the hollow fiber and exits to supply the application. The process of in-house generation of nitrogen using a hollow fiber membrane system involves withdrawing air from the atmosphere using a compressor. Next, the compressed air passes through a high-efficiency coalescing filter to remove water vapor and particulate matter. The clean, dried air then passes through an activated carbon scrubber, removing hydrocarbons before entering the separation module. The air passes through hollow fiber membranes to separate the oxygen and any remaining water vapor from the nitrogen-enriched gas stream. The nitrogen passes through a final filter, containing coalescing media or activated carbon, if required, based on the application to ensure a clean, commercially sterile supply of high-purity nitrogen. Lastly, the purified nitrogen passes to the outlet port of the system that is directly connected to the desired application.

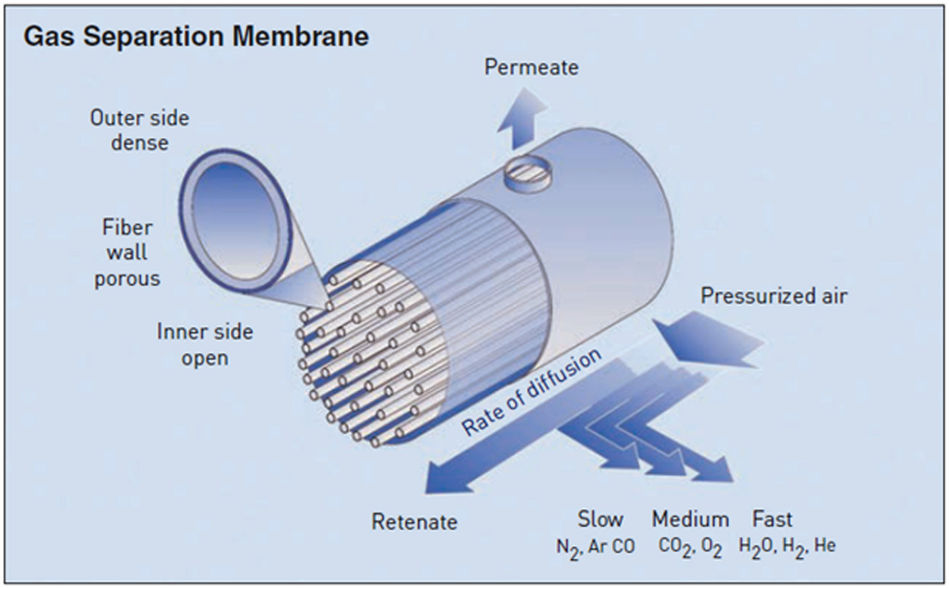

Figure 1

Figure 2

The hollow fiber used to separate nitrogen from air has a small internal diameter. Thousands of fibers are bundled together to provide a large surface area to provide the desired flow of nitrogen (Figure 2). In a typical system, a high-purity gas greater than 99.5% N_2 at a flow rate of hundreds of cubic feet per minute at an outlet pressure of 100 psig can be obtained.

Nitrogen generation using an in-house pressure swing adsorption system.

Pressure Swing Adsorption (PSA) technology is used to separate nitrogen from oxygen based on the preferential adsorbtion and desorption of oxygen and other contaminants on carbon molecular sieve. Pressurized air is passed through a vessel packed with a carbon molecular sieve that adsorbs oxygen while the nitrogen passes through the vessel. Once the molecular sieve is saturated with oxygen, the pressure is lowered, and the contaminants (including oxygen, CO_2 and water vapor) which have been trapped are released to atmosphere. Carbon molecular sieve has a high degree of microporosity making it ideal for oxygen adsorption.

To obtain a continuous flow of N_2 and maximize system utility, two vessels are connected in parallel, so that one vessel is providing nitrogen to the system while the other vessel is being regenerated. In addition to producing a continuous supply of nitrogen, the use of two adsorbent vessels allows for pressure equalization, in which the gas from one vessel is used to pressurize the other vessel, reducing the overall cost of operation while maintaining steady pressure.

Energy considerations for obtaining nitrogen via the fractional distillation of air

Obtaining nitrogen using the fractional distillation of air is an energy intensive process because it is necessary to condense the ambient air into liquid air by cooling and compressing it. While the amount of energy that required clearly depends on the dynamics and efficiency of the system used, it is apparent that a considerable amount of energy must be expended. Once N_2 has been separated from the air, it is necessary to employ additional energy to purify it to the desired level and fill the desired container.

The overall energy that is required to operate the fractional distillation facility and to transport the tank to and from the end user's site is a significant contributor of the greenhouse gas CO_2 in the atmosphere. Moreover, fractional distillation of air to produce N_2 is normally performed on a continuous basis on a large scale. Typically, commercial facilities are designed to generate hundreds or thousands of tons of the gases per day. The amount of energy required to transport the nitrogen is dependent on the distance from the plant to the end facility. However the impact of over the road trucking from the delivery of nitrogen is not trivial. For example, a tractor trailer delivering nitrogen and traveling 400 miles per day (104,400 miles/year) will create 360,000 pounds or 163 metric tons of CO_2 per year. (reference: http://www.roadnet.com/pages/products/carbon-emissions/)

Energy considerations for obtaining nitrogen using an in-house generator

When a hollow fiber membrane or pressure swing adsorption system is used for the generation of nitrogen, the only energy required is that which is used to power the compressor that supplies air to the system.

The European Industrial Gas Association (EIGA) (EIGA Position Paper PP-33 – December 2010) notes that an Air Separation plant uses 1976 kJ of electricity per kilogram of nitrogen produced. The stated purity of supplied liquid nitrogen is 99.9%. So, by way of comparison, the energy needed to create 99.9% nitrogen using PSA can be calculated to be only 1420 kJ of electricity per kilogram of nitrogen. Therefore, PSA uses about 28% less energy than liquid nitrogen created by traditional air separation. This translates to 28% less greenhouse gases from the emissions of the electrical generation. For applications requiring nitrogen or 98% purity (LCMS as an example) the energy needed drops to 759 kJ of electricity per kilogram of nitrogen, or 62% less energy than liquid nitrogen.

Comparing the greenhouse gas contribution for the generation of nitrogen by fractional distillation and in-house methods

Clearly, the amount of greenhouse gas that is generated by providing nitrogen gas to the laboratory or factory is dependent on the mode of generation as well as the manner of delivering the gas to the end user. In addition, the manner in which the expended energy is created is a critical issue. The energy employed for fractional distillation and operation of the compressor is very dependent on local considerations (fossil fuels, nuclear, wind, biomass, etc.), while the energy required for transport of the gas to the end user is derived from fossil fuels. The use of a hollow fiber membrane or PSA for the generation of nitrogen utilizes significantly less energy and hence generates less greenhouse gas than fractional distillation. Additionally, less energy is required for the isolation of the gas, and no transportation of heavy bottles is required.

Comparing the cost of bottled nitrogen and nitrogen obtained via an in-house system

An in-house system can provide a significant economic benefit compared to the use of bottled nitrogen, in addition to the environmental benefits. As a conservative example, the cost of the two approaches is compared for a facility that uses a flow of 20 L/min (slpm) of N2 for 4 hr per day. Over the period of one year (250 days), 1,200,000 L of N2 will be consumed, equivalent to 186 standard 9 × 56 in. cylinders. It can be seen that considerable savings can be obtained using a nitrogen generator and the payback period is typically just slightly more than one year. The payback period will vary depending on the local situation. In addition, the price of electrical power, labor, and gas tanks will vary for each facility.

Conclusion

Generating nitrogen gas through an in house system is a sustainable, environmentally friendly and energy-efficient approach to providing pure, clean, dry nitrogen gas. As a result of the lower energy consumption (up to 62% less) and elimination of the need to transport the gas, less greenhouse gases are emitted, thereby helping to protect the environment. Additionally, in-house systems generate nitrogen at a pressure and flow rate required for the application ensuring that no gas is wasted. By using an in-house system, dependence on outside vendors is eliminated and administrative costs are reduced, and the dangers of handling high pressure cylinders are eliminated.

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