

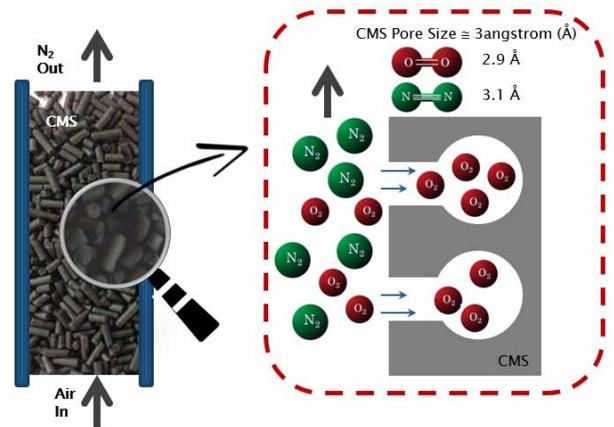
## N<sub>2</sub> Generation - Technology Primer

Holtec Gas Systems manufactures nitrogen generators based on both Pressure-Swing Adsorption and Membrane separation technologies. But which technology is right for you? While cost is a significant driver of this decision, there are many other factors which you should consider before choosing the best technology for your application.

### Pressure-Swing Adsorption (PSA) - Process Description

PSA technology works on the concept of adsorption - the process by which molecules temporarily adhere to the surface of materials they are in contact with. A PSA nitrogen generator consists of two or more adsorbers filled with separation material called carbon-molecular sieve (CMS). CMS is produced specifically to have pore sizes that correspond to the relatively small size of an oxygen molecule (compared to the relatively larger nitrogen molecule).

In a PSA nitrogen generator, compressed air is drawn from the atmosphere and directed into one adsorber. Under pressure, oxygen in the compressed air gets "stuck" in the pores of the CMS, allowing the remaining constituents (mostly nitrogen) to pass through the system unhindered.

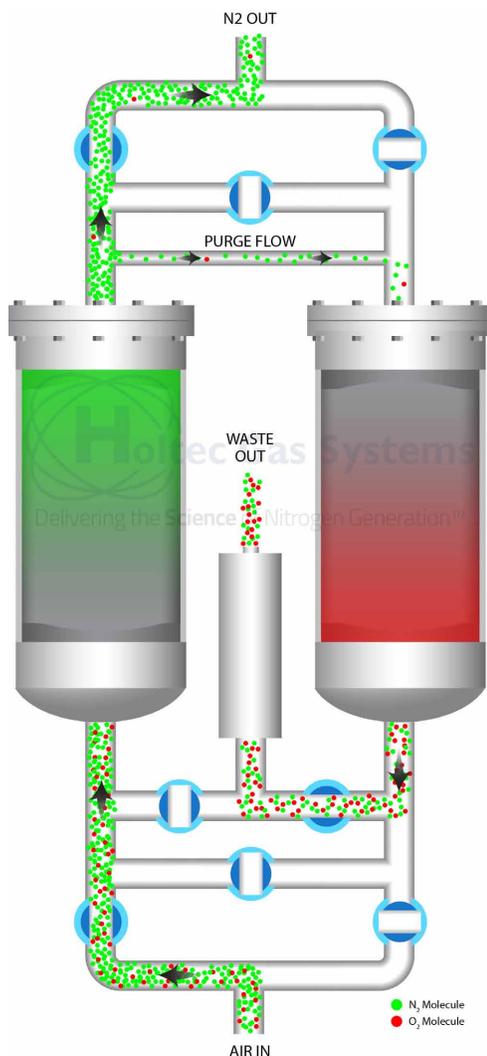


Sounds simple, doesn't it? There is only one problem. Eventually, oxygen molecules separation will no longer occur. This is called saturation, when oxygen molecules completely cover the surface of the CMS and there is no room for more to be adsorbed.

Fortunately, the adsorption process is reversed by depressurizing the adsorber. This is why PSA technology uses two or more adsorbers. At ambient pressure, oxygen is released from the surface of the CMS and is returned to the atmosphere as waste gas, thus regenerating the adsorber for use in the next cycle. While the first adsorber is regenerating, the second adsorber is actively producing nitrogen. At the end of the cycle, the first adsorber is once again ready to produce nitrogen and the second adsorber regenerates - and so on.

However, each time an adsorber cycles back on-line, there is a brief period during pressurization that no nitrogen is being produced. This is one reason why every PSA nitrogen generator requires a process nitrogen receiver tank.

Additionally, compressed air usage during the pressurization step is greater than the average flow. In order to ensure there is always enough clean, dry, oil-free compressed air to supply the system, a process air receiver is also usually needed.



### PSA Process Steps:

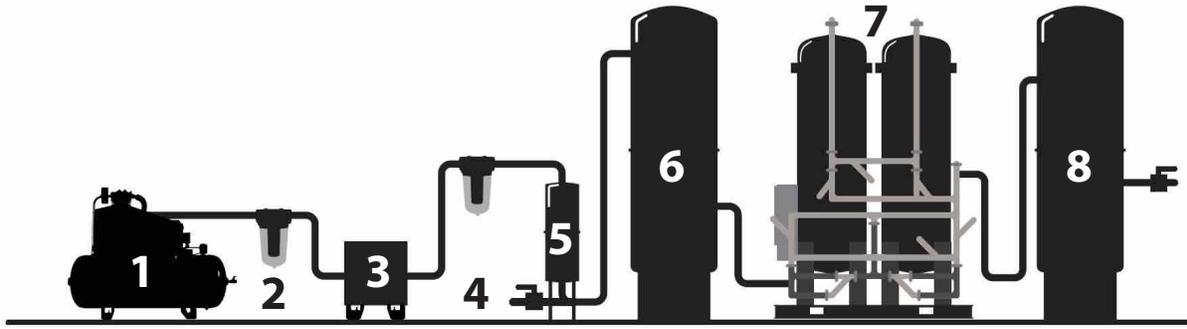
#### Purification

1. Pressurized air in
2. Adsorption of oxygen
3. High purity nitrogen out

#### Regeneration

4. Equalization of pressure (not depicted)
5. Regenerating bed depressurizes completely, allowing oxygen enriched gas to desorb
6. Waste gas exits through silencer

## Typical PSA Process Flow

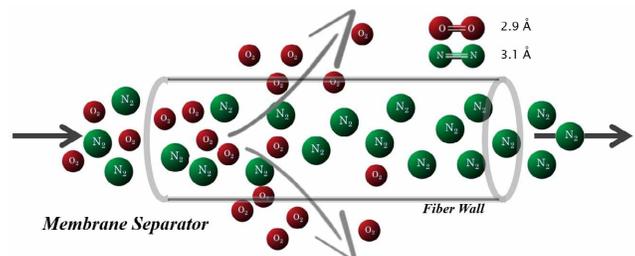


- 1. Compressor** - Compressed air is required with all PSA nitrogen generators. If your site has compressed air available, typically between 100-125 psig (6.9-8.6 barg), this air can be used to feed a new PSA. Depending on what type of compressor and air treatment already in place, the diagram above may change. If a new dedicated compressor is needed, a lubricated screw compressor is the most common choice for cost and maintenance reasons. The equipment recommendations above assume this type of compressor.
- 2. Liquid separator** - Used to remove bulk water and oil from the compressed air.
- 3. Dryer** - Used to condense and remove more water and oil from the feed air. If the system is installed indoors where temperatures will always be above freezing, a refrigerated dryer can be used to reduce the feed air dewpoint below 38 °F / 3 °C. If the system is outdoors in a climate where freezing temperatures are possible, a desiccant dryer will be needed.
- 4. 0.01 Micron coalescing filter** - Used to reduce oil aerosols to less than 0.0008 ppm.
- 5. Activated Carbon Bed**- Even after a high quality coalescing filter, there will still be oil vapor in the compressed air whenever a lubricated compressor is used. Holtec therefore always recommends the use of a large bed of activated carbon pellets in order to adsorb any remaining hydrocarbons, making the compressed air virtually oil-free. Cartridge style activated carbon filters are too small, meaning residence time will not be long enough to adsorb all oil and therefore this style of filter is not recommended.
- 6. Process Air Receiver** - Compressed air requirements calculated are always an average. But the PSA process requires regular pressurization and depressurization which means that the instantaneous air flow is always changing throughout the PSA cycle. It may be much lower than average or several times higher. An air receiver is therefore required to ensure optimum feed pressure is always available to the nitrogen generator and to make sure filters are not overflowed.
- 7. PSA Nitrogen Generator** - We hope you will choose a high quality, reliable, Holtec PSA nitrogen generator for this piece of equipment!
- 8. Process Nitrogen Receiver** - Just as compressed air flow changes throughout the cycle, so will the nitrogen production rate. Product purity will also vary, and there will also be several seconds each cycle where nitrogen is not being produced at all. A process nitrogen receiver is therefore required with every PSA system in order to provide your process with a constant, stable flow of nitrogen at the required pressure and purity.

**Through rigorous research and testing, Holtec has designed a proprietary simulation program in order to ensure that all filters, tanks, valves, and line sizes are properly sized for optimal operation, guaranteeing the least amount of customer problems. Maintenance is typically limited to standard compressor and dryer PM and regularly changing filters and activated carbon, which facilities utilizing compressed air are already familiar with.**

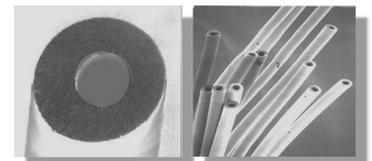
## Membrane Separation - Process Description

Membrane nitrogen generators separate nitrogen from atmosphere by passing compressed air through a permeable membrane. The process relies on the principle of selective gas permeation. Each gas has a different permeation rate, so as the compressed feed air stream passes across the membrane, gases with faster permeation rates like O<sub>2</sub> and CO<sub>2</sub> are released back into the atmosphere as waste gas (along with some N<sub>2</sub>).

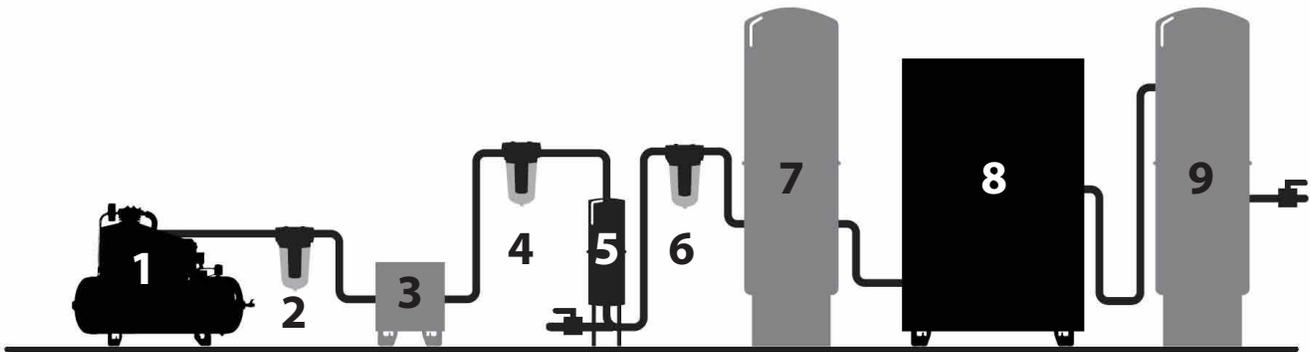


The product nitrogen, now stripped of most of the oxygen and carbon dioxide, passes out the other end of the separator at a slightly lower pressure for collection or directly into your application. Unlike a PSA system, a nitrogen receiver tank is not necessarily needed.

Membrane fibers magnified



## Typical Membrane Process Flow



- 1. Compressor** - Compressed air is required with all Membrane nitrogen generators. If your site has compressed air available, typically between this air can be used to feed a membrane system. Depending on what type of compressor and air treatment already in place, the diagram above may change. Membrane productivity and efficiency is significantly improved by higher pressures, and they are typically operated between 100-350 psig (6.9-24.1 barg).
- 2. Liquid separator** - Used to remove bulk water and oil from the compressed air.
- 3. Dryer** - Depending on the application, existing equipment, and the type of membrane selected, a dryer may or may not be required.
- 4. 0.01 Micron coalescing filter** - Used to reduce oil aerosols to less than 0.0008 ppm.
- 5. Activated Carbon Bed**- Even after a high quality coalescing filter, there will still be oil vapor in the compressed air whenever a lubricated compressor is used. Holtec therefore always recommends the use of a large bed of activated carbon pellets in order to adsorb any remaining hydrocarbons, making the compressed air virtually oil-free. Cartridge style activated carbon filters are too small, meaning residence time will not be long enough to adsorb all oil and therefore this style of filter is not recommended. They can, however, be utilized when oil-free compressors are used in order to eliminate other contaminants.
- 6. Dust Filter** - Dust from activated carbon would collect in the membrane separator and reduce performance, so we include a filter to remove.
- 7. Process Air Receiver** - Depending on the application and existing equipment, an air receiver may be necessary. The best location in process flow may change depending on the application.
- 8. Membrane Nitrogen Generator** - We hope you will choose a high quality, reliable, Holtec membrane nitrogen generator for this piece of equipment!
- 9. Process Nitrogen Receiver** - Unlike a PSA system, membrane nitrogen production is a steady state process where nitrogen is being produced all the time at a stable rate. A nitrogen receiver is therefore not a necessity, but one can be included when the customer wants to have stored nitrogen as well.

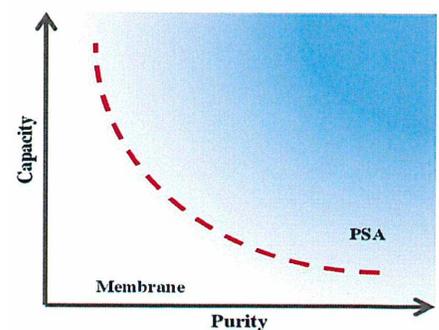
## PSA vs. Membrane Application Selection

Where cost and efficiency are the prime factors, PSA systems are almost universally the technology of choice. Even when these two decision drivers do not apply, at purities above 99.9%, PSA is the only choice for a gaseous nitrogen generator.

As illustrated in the graph to the right, where capacity or purity requirements are moderate, membrane systems may be an attractive technology when considering both initial investment and cost of operation. Small membrane systems involve fewer parts and assembly and therefore may be less costly to purchase.

However, membrane media is more costly than the CMS used in a PSA. Additionally, as purity increases, the compressed air requirement will rise faster for a membrane system than it will for a PSA. Therefore, as capacity and purity increase, PSA technology overtakes as the most cost effective option.

However, in applications where simplicity is more important than cost, membrane systems may be chosen even for larger nitrogen demands or higher purity. For example, in very remote locations where it is difficult for service personnel to reach (such as an oil platform), membrane systems are often chosen even though they are more costly to operate.



**PSA vs Membrane - As capacity and purity requirements increase, PSA is more attractive when considering initial and operating cost.**

## Example Systems



Above: Large standard two bed PSA



Above-right: High spec four bed PSA



Above: Containerized membrane system



Right: Small standard PSA with tanks mounted on skid.

Right: Small membrane system in stainless steel cabinet



## Point by Point Feature Comparison

Topic	Membrane	Pressure-Swing Adsorption (PSA)
<b>Purity Range</b>	Effective at purities up to 99.9% (Max 0.1% O <sub>2</sub> content).	Effective at purities up to 99.9995% (Max 5 ppm O <sub>2</sub> )
<b>Capacity vs. Purity</b>	Capacity reduced significantly as purity requirement increases.	Capacity reduced gradually as purity requirement increases.
<b>Feed Air/Operating Cost</b>	Nearly equal in efficiency to PSA technology at purities near 95%. However, efficiency reduced significantly at higher purities.	Significantly more efficient than membrane technology when nitrogen purity exceeds 95%. As purity increases, the difference in efficiency becomes more significant.
<b>Water Sensitivity</b>	Water liquid or vapor will not damage a membrane separator, but capacity will be temporarily reduced if liquid water enters. Once the membrane dries, capacity is restored.	PSA Systems require dry air, typically < 38°F (3°C) dew point. Carbon Molecular Sieve (CMS) is sensitive to higher moisture concentrations and capacity will decrease if exposed. Permanently damage may occur.
<b>Oil Sensitivity</b>	Contamination with oil will cause permanent and irreversible decline in performance.	Contamination with oil will cause permanent and irreversible decline in performance.
<b>Useable life</b>	The membrane film gets denser over time, a process called aging. Capacity is reduced most during the first 1-2 years of life. Reasonable performance should continue even after 10+ years if filtration is inspected, maintained, and replaced per manufacturer specification.	CMS performance does not decline with time, only with contamination. It is therefore possible to retain full performance even after 10+ years, if proper "clean air" recommendations are followed.
<b>Moving Parts</b>	Feed isolation valve opens and closes to start and stop the nitrogen generator. This can be done manually, as needed, or it can be automated to start and stop on demand.	Typically eight automated On/Off valves are used to direct compressed air flow into the online or regenerating adsorber, to release product nitrogen, to equalize pressure, and allow waste to exit through a silencer. The PSA will start and stop automatically on demand.

