OEM Manual
Membrane Based Air Separation Systems

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Table of Contents

1. Introduction 1

2. System Design Considerations 2

3. Safety 3

3.1 Enriched Nitrogen Stream 3
3.2 Enriched Oxygen Stream 4
3.3 Pressurized Equipment 4
3.4 Electrical Equipment 4

4. Feed Air Supply & Pre-Treatment 5

4.1 Air Compressor 5
4.2 Air Receiver Tank 5
4.3 Moisture Separator 5
4.4 Refrigerated Dryer (Optional) 6
4.5 Coalescing Filters 6
4.6 Process Heater (Optional) 6
4.7 Carbon Bed 7
4.8 Particulate Filter 7
4.9 Module Inlet Valve 7

5. Membrane Modules 8

5.1 Module Description 8
5.2 Module Installation Guidelines 8

6. Non-Permeate Stream 9

6.1 Purity Control Valve 9
6.2 Back Pressure Regulator 9
6.3 Back Flow / Over-Pressurization Protection 9

7. Permeate Stream 10

8. Instrumentation 11

9. Operation & Maintenance 12

9.1 Start-Up 12
9.2 Operating Characteristics 12
9.3 System Maintenance 13

Appendix A: Module Specifications & Feed Air Impurity Limits

Appendix B: Module Storage Protocol

Appendix C: Module Change-Out Procedure

Appendix D: Membrane Array Trouble Shooting

Section 1: Introduction

The Generon air separation device is a simple, hollow fiber membrane module capable of separating compressed air into streams of enriched nitrogen and enriched oxygen. The enriched nitrogen stream can be recovered at a pressure 5-30 psig below the feed air pressure, depending on operating conditions, while the oxygen-enriched stream can be recovered at atmospheric pressure.

The principle allowing this separation is the difference in permeation rate of the oxygen and nitrogen through the polymer membrane. In the case of the Generon air separation module the membrane employed permeates oxygen and water vapor faster than nitrogen. This phenomenon allows oxygen and water vapor to permeate through the membrane to atmosphere, while the nitrogen is left behind as the non-permeated gas inside the hollow fibers; exiting the module as a dry, pressurized stream.

Figure 1 shows the flow pattern of a Generon air separation module.

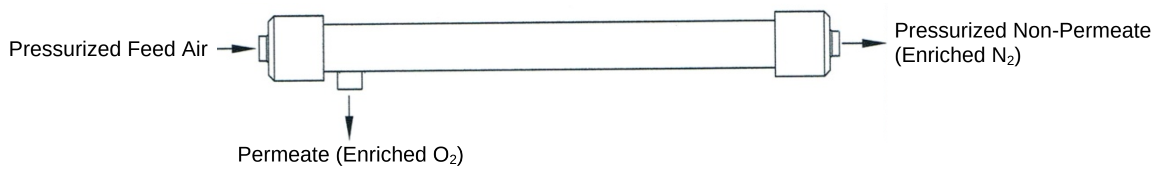

Figure 1: Flow Pattern, Generon Air Separation Module

Section 2: System Design Considerations

The Generon air separation module is the key component in a nitrogen generation system, but additional equipment is required to ensure that the overall system operates at maximum performance and reliability. Figure 2 shows a typical process flow diagram for a membrane based nitrogen generator; a detailed description of the equipment is given later in this manual.

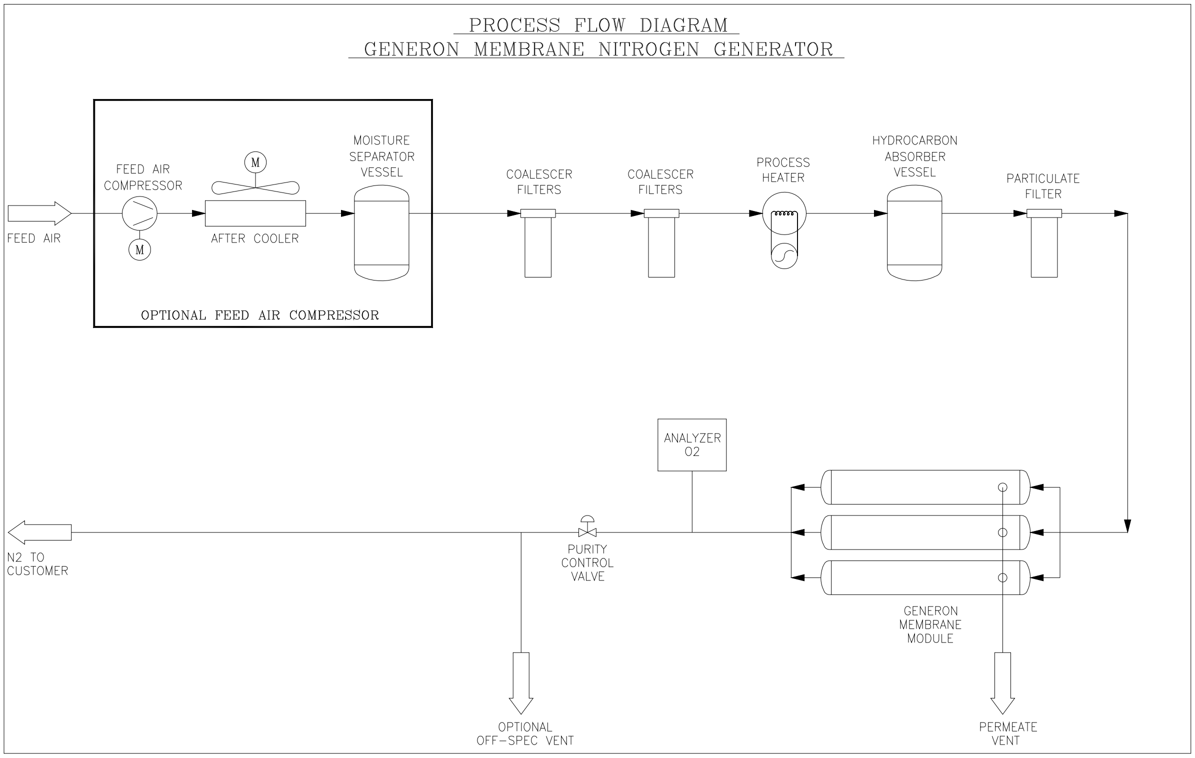

Figure 2: Sample Process Flow Diagram

Membrane air separation modules are high surface area devices, and must be protected from contamination by particulate matter and organic materials (e.g. lubricating oils, solvent vapors, etc…) which may be entrained in the feed air stream. The feed air requirements for Generon air separation modules can be found in Appendix A.

System piping material should be chosen to prevent the introduction of particulate matter into the streams, especially after the final particulate filter. Generon recommends using the stainless steel pipe and fittings. **Cadmium-plated carbon steel pipe and fittings, and galvanized pipe and fittings should not be used.**

All connections must be sealed with Teflon tape or Formula 8 thread sealant. Other types of thread sealant can reduce module performance and/or cause permanent damage to the membrane module.

Section 3: Safety

Generon air separation modules are capable of generating enriched oxygen and enriched nitrogen streams. Typical system set-ups include pressurized equipment and electrical equipment. The following sub-sections give a brief overview of the safety considerations that must be accounted for when operating an air separation module.

3.1 Enriched Nitrogen Stream

The enriched nitrogen stream is the pressurized, non-permeate outlet of the air separation module. The concentration of oxygen in this stream **will not support human life**. If released in an unventilated area the nitrogen will displace oxygen, which can cause injury and/or death by asphyxiation to anyone in the area.

A general indication of the symptoms and effects experienced when exposed to various levels of oxygen deficient atmospheres are given in Table I.

Table I: Symptoms of Oxygen Deficient Atmospheres

O_2 Content [vol%]	Symptoms and Effects [at atmospheric pressure]
15-19%	Decreased ability to work strenuously. May impair coordination and may induce early symptoms in persons with coronary, pulmonary, or circulatory problems.
12-14%	Respiration increases with exertion, increase of pulse rate, impaired coordination, perception and judgment affected.
10-12%	Respirations increase in rate and depth, poor judgment, blueness of lips.
8-10%	Mental failure, fainting, unconsciousness, ashen face, blueness of lips, nausea, vomiting.
6-8%	8 minutes exposure, fatal; 6 minutes exposure, 50% fatal; 4-5 minutes exposure, recovery possible with treatment.
Less than 6%	Coma in 40 seconds, convulsions, respiration ceases; death.

Avoid confined spaces until oxygen adequacy (i.e. oxygen concentration of 20.9 vol%) has been proven by analysis or other positive means, or until breathing air has been provided by air pack, air hose, or other trusted sources. Confined areas/spaces include, but are not limited to, the following:

1. Pits, deep depressions, and wells.
2. Above ground confined spaces: refrigerators, furnace boxes, combustion chambers, silos, food storage barns, etc...
3. Tanks: portable, storage, and/or mixing.
4. Gas generators, gas tanks, gas holders, and/or receivers.

Do not allow the enriched nitrogen stream to be vented other than through proper piping. Warning signs should be posted in any area and/or confined space which may be a potentially oxygen deficient area. Appropriate warning signs are available from the Generon IGS Service Department.

3.2 Enriched Oxygen Stream

The enriched oxygen stream is the unpressurized, permeate outlet of the air separation module. The concentration of oxygen in this stream is 21–50 vol%; for reference atmospheric air has an oxygen content of 20.9 vol%. The enriched oxygen stream will not burn, but oxygen concentrations above 28 vol% can support combustion of other materials much more readily than air. The enriched oxygen vent gas must be discharged in well-ventilated, safe areas.

3.3 Pressurized Equipment

Air separation systems are operated under pressure. A hazardous work program must be followed when working around and/or servicing any equipment associated with the air separation system.

The system should not be subjected to excessive external forces or impact. Excessive force or impact applied to a pressurized line may result in the sudden release of pressurized gas, and possibly inflict injury to nearby personnel.

Always isolate areas that are set to be serviced. Depressurize all lines and vessels before disconnecting lines and/or disassembling any part of the system. Associated air and nitrogen supply lines should be shut off and locked out.

Leak checks should be performed on all piping components to ensure no compressed air or product nitrogen is allowed to escape. Leak checks must be performed with an accepted leak detector (e.g. *Snoop® Liquid Leak Detector*).

3.4 Electrical Equipment

Air separation systems typically contain equipment that requires electrical power (e.g. heater, instrumentation, etc…). Normal commercial safety practices must be followed when performing maintenance and/or troubleshooting.

Personnel unfamiliar with the electrical equipment associated with the air separation system should not attempt to service this equipment. The electrical currents supplied to the various electrical components can be at levels high enough to cause severe injury and/or death.

When installing an air separation system **ensure that all applicable earth grounds are installed as required by the National Electric Code and/or local requirements**. Refer to the appropriate manufacturer's manuals for correct grounding procedures for each piece of electrical equipment.

Section 4: Feed Air Supply & Pre-Treatment

The following section details equipment that is typically used to generate the clean, dry feed air supply for a membrane based nitrogen generator. Every application is different, so the amount of pre-treatment required can vary. The minimum feed air requirements for Generon air separation modules can be found in Appendix A. **Failure to meet these requirements can reduce module performance and/or cause permanent damage to the membrane module.**

The filtration equipment discussed in the following section must be maintained throughout the life of the system. Excessive pressure drop through any component of the system will cause a loss in overall system performance. It is critical that these components, especially the filter elements, be regularly maintained to achieve peak system performance.

All connections must be sealed with Teflon tape or Formula 8 thread sealant. Other types of thread sealant can reduce module performance and/or cause permanent damage to the membrane module.

4.1 Air Compressor

Any type of air compressor can be used in an air separation system. However, proper compressor sizing is required for the system to run efficiently. The feed air requirement of the system and ambient site conditions (e.g. temperature, humidity, and elevation) must be known to size the compressor.

If an oil-lubricated compressor is selected Generon recommends PAO (poly-alpha-olefin) or mineral type oils be used as the compressor lubricant. Synthetic or glycol based oils can cause accelerated deterioration of the hollow fiber membrane if the pre-treatment system (e.g. filter elements and carbon bed) are not properly maintained; using synthetic or glycol based oils will increase the frequency of carbon bed change-outs (i.e. 4-6 times more frequent).

4.2 Air Receiver Tank

Installing an air receiver tank after the compressor will aid in water removal, and minimize pressure fluctuations due to compressor loading/unloading. The typical rule of thumb for air receiver tank sizing is 1 gallon per ACFM, or 4 gallons per compressor HP. All air receiver tanks should be equipped with an automatic drain valve for water removal and a pressure relief valve for safety.

4.3 Moisture Separator

After the air receiver tank a moisture separator (centrifugal or baffle plate) should be installed to remove any bulk liquids that may have condensed out of the compressed air. Most compressors include their own moisture separator. However, Generon recommends installing an additional one after the compressor because as the compressed air cools in the downstream piping more liquid may condense out.

The moisture separators should be equipped with an automatic drain to prevent liquid build up, and a high level alarm to eliminate water carry over. The size of the moisture separator is based on the system specific process conditions (i.e. feed flow and pressure).

4.4 Refrigeration Dryer (Optional)

In addition to a moisture separator a refrigerated dryer can also be installed to remove liquids from the compressed air stream.

The refrigeration dryer should be sized such that the pressure dewpoint of the compressed air exiting the dryer is 36–55°F (2.2–12.8°C); sizing is based on the system specific process conditions and ambient site conditions. As with the moisture separator the refrigeration dryer needs to be equipped with automatic drain valves to prevent liquid buildup and carryover.

4.5 Coalescing Filter

A coalescing filter is used to remove oil that may be entrained in the compressed air. Generon recommends placing two (2) coalescing filters in series. The first filter equipped with a coarse coalescing filter element (i.e. 1.0 micron); the second filter equipped with a fine coalescing filter element (i.e. 0.01 micron).

The size of the coalescing filters is based on the system specific process conditions (flow, pressure, and temperature). Each filter should have an automatic drain to prevent oil build-up and carryover; Generon recommends timer activated solenoid drain valves.

The filter elements will need to be replaced periodically (e.g. every six (6) months). The change-out interval will depend on the quality of the compressed air. A differential pressure gauge measuring pressure drop across the filter can be used to gauge element loading (i.e. high differential pressure indicates a 'dirty' filter element).

4.6 Process Heater

A process heater installed after the coalescing filters will provide additional protection against liquids reaching the membrane modules. The main purpose of the heater is to 'super-heat' the compressed air, reducing the chance of liquids condensing in the feed stream.

A heater installed prior to the modules will also provide more control of system performance (i.e. operator can adjust the temperature of the compressed air being fed to the modules). For example, operating the modules at a higher temperature (e.g. 113–122°F, or 45–50°C) will increase module productivity (i.e. increase non-permeate flow), but decrease recovery (i.e. non-permeate/feed flow ratio). For detailed information on module performance at different operating temperatures please contact a Generon technical representative.

Air separation modules are typically operated from 77°F (25°C) to 131°F (55°C); **prolonged operation at temperatures exceeding 131°F (55°C) can reduce module performance and/or cause permanent damage to the membrane module**. Note: the 6800HT membrane module is designed for operation up to 158°F (70°C)

If a heater is installed the following control and safety features must be included to prevent the system from overheating:

1. Temperature controller to control the heater
2. Temperature Switch(s) to shutdown the heater if:
   - Internal Heater Temperature (i.e. element temperature) exceeds 392°F (200°C)
   - Heater Outlet Temperature or Module Inlet Temperature exceeds 131°F (55°C)
3. Feed Air Flow Switch to shutdown the heater if no air is flowing through the heater

4.7 Carbon Bed

A carbon bed (packed-bed type) is required for any system that utilizes an oil-lubricated compressor for the feed air supply. The carbon bed should be sized based on the process conditions (i.e. flow, pressure, temperature, residual oil content, type of compressor oil used, etc…) and the loading capacity of the activated carbon. For information on carbon bed sizing please contact Generon technical representative or your activated carbon supplier.

Note: A pressure relief valve should be installed on the carbon bed vessel; the vessel should also be designed such that the activated carbon can be removed and replaced relatively easily.

4.8 Particulate Filter

The particulate filter is used to remove any fine particles (e.g. carbon dust) that may carry-over from the carbon bed. Generon recommends a particulate filter equipped with a 0.01 micron filter element. The coalescing filters must be sized based on the system specific process conditions (flow, pressure, and temperature).

The filter element will need to be replaced periodically (e.g. every six (6) months). The change-out interval will depend on the amount of fine particles in the compressed air. A differential pressure gauge measuring pressure drop across the filter can be used to gauge element loading (i.e. high differential pressure indicates a 'dirty' filter element).

4.9 Module Inlet Valve

A membrane module will permeate (i.e. consume) air even if the non-permeate flow is shut-off (i.e. no nitrogen in being produced by the system). To prevent air from being 'wasted' an inlet valve is typically installed just before the membrane module(s).

Generon has performed pressurization cycle tests on the membrane modules, and has determined that the modules will withstand fast pressurization. However, rapid pressure cycling should be avoided to maintain the efficiencies of the air filtration components (e.g. moisture separator, coalescing filters, carbon bed, and particulate filter). The pressurization rate can be manually controlled system using a multi-turn valve (e.g. needle valve or gate valve); an ON/OFF valve (e.g. ball valve) should be avoided. If the system being designed is automated (i.e. the used of an actuated ON/OFF valve if required) please contact a Generon technical representative for information on how to prevent a rapid rate of pressurization. **The maximum rate of pressurization during start-up is 100 psi/min (6.9 bar/min).**

Section 5: Membrane Modules

Generon membrane modules are available in various sizes depending on the specific application. All modules contain a membrane bundle which is comprised of hollow membrane fibers, epoxy tubesheets, and in some cases a center core tube. An integral case or protective sheath may also be included (i.e. depends on the module type being used).

Care must be taken when handling the module. Touching tube sheet face can cause fibers to be closed off, decreasing the productivity and efficiency of the module. Fiber damage can also occur if contact is made with fibers through the permeate port. Excessive shock or vibration must be avoided during module operation, and when the module is stored or handled. Fiber breakage will reduce productivity and efficiency.

5.1 Module Description

7200 series modules are housed in a 10" NPS ASME Code Approved pressure vessel case. The case is subject to the record keeping, inspection, and operating requirements associated with ASME code. The ASME U-1A Forms for each module case are available from Generon.

4100, 6150, 6500, and 6800 series modules are not housed in an ASME Code pressure vessel. However, they should be handled in a similar manner since the heads (i.e. feed air inlet and non-permeate outlet sections) of these modules are pressure containing parts. This applies whether the cases are constructed of aluminum or stainless steel. **The permeate flow cannot be restricted because this would result in pressurization of the module casing which is not intended for pressure service.**

210 series modules are approximately 2" NPS sized unit: **these modules are not housed in an ASME Code pressure vessel.** However, they should be handled in a similar manner since the heads (i.e. feed air inlet and non-permeate outlet sections) of these modules are pressure containing parts. **On standard 210 modules the permeate flow cannot be restricted because this would result in pressurization of the module casing which is not intended for pressure service. Generon does offer a 210H series module, which is fitted with an outer case. The outer case allows for the permeate stream to be pressurized.**

Please contact a Generon technical representative if special module case requirements are required.

5.2 Module Installation

Generon recommends using flexible hose or tubing for the inlet and outlet connections of the modules. Rigid pipe or tube connections can put undue stress on case components, which may lead to leaks or module damage. **When installed the membrane module must be adequately supported. The inlet and outlet piping connections cannot be used to support the module.**

Generon also recommends installing the module such that the permeate port is facing down to prevent liquid water, or other debris, from collecting in it.

All connections must be sealed with Teflon tape or Formula 8 thread sealant. Other types of thread sealant can reduce module performance and/or cause permanent damage to the membrane module.

For installation of cartridge-style membrane modules, refer to Generon instruction W0929. Please contact a Generon technical representative if access to W0929 has not already been provided.

Section 6: Non-Permeate Stream

In most membrane based air separation systems the 'product' stream is the enriched nitrogen non-permeate stream. This section discusses the equipment associated with the non-permeate stream.

6.1 Purity Control Valve

The non-permeate flow control valve is used to control the non-permeate flow of the module. By regulating this flow the operator is able to control the purity of the non-permeate gas. Higher flows correspond to higher oxygen levels in the non-permeate.

The purity control valve is typically a needle valve because it allows for fine adjustments in flow, and therefore purity. Appropriate valve sizing methods should be used when selecting the purity control valve.

6.2 Back-Pressure Regulator (Optional)

A back-pressure regulator can be installed after the purity control valve if variable downstream pressures are expected; variable downstream pressures can be caused by fluctuations in non-permeate demand. Variable downstream pressures can cause undesirable changes in non-permeate flow and purity. A back-pressure regulator acts as a pressure-relieving device; anytime the upstream pressure reaches the set-pressure the valve will open, allowing the non-permeate gas to flow through the regulator.

If installed the back-pressure regulator will maintain a constant pressure drop across the purity control valve. This keeps the non-permeate flow and purity constant, even as the downstream pressure fluctuates.

6.3 Back-flow / Over-Pressurization Protection

A check valve installed on the non-permeate line will prevent gas from flowing back through the modules if there is a loss in feed flow. Gas that flows back through the modules will permeate through the membrane and be lost via the permeate vent.

A pressure relief valve will prevent the modules from exceeding their maximum operating pressure; this is only required if the non-permeate piping could be subjected to pressures greater than the maximum operating pressure due to a downstream process.

Section 7: Permeate Stream

In most membrane based air separation systems the oxygen enriched permeate stream is simply vented to atmosphere (i.e. it is not collected). The concentration of oxygen in this stream is 21–50 vol% depending on the specific application; increasing the non-permeate flow will increase the oxygen content in the permeate stream. The permeate stream will not burn, however oxygen concentrations above 28 vol% can support combustion of other materials much more readily than air. Therefore the permeate stream must be discharged in well-ventilated, safe areas.

If permeate piping is required it must be sized to minimize back-pressure on the module (**i.e. permeate pressure should never exceed 0.5 psig, or 0.035 barg**). Excessive permeate back-pressure will dramatically reduce the modules productivity and efficiency. **It is important to never block, or restrict the permeate stream. If an application calls for the collection of the permeate stream please contact a Generon technical representative.**

All connections must be sealed with Teflon tape or Formula 8 thread sealant. Other types of thread sealant can reduce module performance and/or cause permanent damage to the membrane module.

Section 8: Instrumentation

The following section describes the types of instrumentation that are typically found on an air separation system. The amount of instrumentation depends on the intended use of the system. Typically instrumentation includes:

1. Pressure Gauges / Transmitters

- Used to monitor pressure at various points in the system (e.g. inlet pressure, outlet pressure, etc…).
- **Generon recommends installing a feed pressure gauge at the system, or module array, inlet.**

2. Differential Pressure Gauges / Transmitters

- Used to monitor differential pressure across pieces of equipment (e.g. filters, modules, etc…)
- When installed across a filter these gauges / transmitters can show how 'clean' or 'dirty' the filter element is.

3. Temperatures Gauges / Transmitters

- Used to monitor temperature at various points in the system.
- **Required if a heater is installed on the system.**

4. Flowmeters

- Used to monitor flow at various points in the system (e.g. inlet flow, outlet flow, etc…).
- Typically installed on the non-permeate stream.
- **Accuracy of the flowmeter depends on the system application. For most applications ±5% is sufficient.**

5. Oxygen Analyzer

- Used to monitor oxygen content, typically on the enriched nitrogen non-permeate stream.
- **The type of oxygen analyzer selected (e.g. ZrO_2, fuel-cell, paramagnetic, etc…) depends on the system application.**

6. Automated Control Valve

- Used to automatically control flow, and therefore purity, of the enriched nitrogen non-permeate stream.
- Control is typically based on feedback from an oxygen analyzer installed on the non-permeate stream.

For more information on instrumentation typically installed on membrane based air separation systems, or if you have questions on potential system control schemes, please contact a Generon technical representative.

Section 9: System Operation & Maintenance

The following section describes the operation and maintenance associated with membrane based air separation systems.

9.1 System Start-Up

Prior to initial start-up the entire system must be inspected to ensure that all piping/tubing connections are tight, that all drains are functional, and that all critical instrumentation are calibrated and operating properly. Some equipment (e.g. refrigeration dryer, oxygen analyzer, etc…) may have a 'warm-up' time associated with their operation; consult the vendor's O&M manual for equipment specific information.

During system start-up the oxygen content of the permeate and non-permeate stream may vary as the system reaches a steady-state operating condition (i.e. pressures & temperatures stabilize); if the operating temperature differs greatly from the ambient temperature it may take 45 – 60 minutes to reach steady-state. During start-up it may be necessary to vent both the permeate and non-permeate stream if the composition of the product gas is critical to the downstream process. **The maximum rate of pressurization during start-up is 100 psi/min (6.9 bar/min).**

9.2 Operating Characteristics

Membrane based air separation systems have three (3) main process variables: feed pressure, operating temperature (i.e. temperature of the air entering the module), and non-permeate O_2 content. Table II summarizes the effect of changing these variables.

Table II: Generon Operating Characteristics – Generon IGS Membrane Module

Variable Changed	Type of Change	Held Constant	Productivity [1]	Recovery [2]
Feed Pressure	Increase	• Operating Temp • Non-Permeate O_2	Increase	Increase
Feed Pressure	Decrease	• Operating Temp • Non-Permeate O_2	Decrease	Decrease
Operating Temp	Increase	• Feed Pressure • Non-Permeate O_2	Increase	Decrease
Operating Temp	Decrease	• Feed Pressure • Non-Permeate O_2	Decrease	Increase
Non-Permeate O_2 [3]	Increase	• Feed Pressure • Operating Temp	Increase	Increase
Non-Permeate O_2 [3]	Decrease	• Feed Pressure • Operating Temp	Decrease	Decrease

[1]: Productivity = Non-Permeate Flow (i.e. enriched nitrogen stream)
[2]: Recovery = (Non-Permeate Flow) / (Feed Flow); measure of membrane module efficiency
[3]: The purity control valve is used to make changes to the non-permeate O_2 content (ref. Section 6.1)

Changes to the feed pressure and/or non-permeate flow will be seen relatively quickly (i.e. non-permeate O_2 content will change, and stabilize, in 3 – 5 minutes). However, changes in operating temperature will take longer to see since the entire system (e.g. piping, modules, etc…) must heat up or cool down. Process variables, especially feed pressure and non-permeate flow, should be changed incrementally to avoid over-shooting the desired operating condition.

For more information on system operating characteristics please contact a Generon technical representative.

9.2 System Maintenance

Membrane based air separation systems are designed to be operated with minimal maintenance. Table III gives a typical maintenance schedule.

Table III: Typical Maintenance Schedule

Operation	Daily	Quarterly	Semi-Annually
Log Process Parameters [1]	X		
Manually Check Filter Drains	X		
Verify O_2 Analyzer Calibration [2]		X	
Test Alarms / Shutdowns		X	
Replace Filter Elements			X
Replace Activated Carbon in Carbon Bed			X
Inspect Instrumentation / Equipment			X
Inspect Electrical Connections			X
Leak Test Process Connections [3]			X

[1]: Pressure, Temperature, Flow, Purity, System Run Hours, etc…
[2]: Consult Oxygen Analyzer O&M Manual. Frequency can vary by analyzer type.
[3]: Leak checks must be performed with an accepted leak detector (e.g. *Snoop® Liquid Leak Detector*).

It is critical that the system be properly maintained, especially the feed stream pre-treatment equipment (e.g. filters, heater, etc…). Failure to maintain the feed air requirements outlined in Appendix A can reduce module performance and cause permanent damage to the membrane module.

Appendix A
Module Specifications & Feed Air Impurity Limits

Table 1: Module Specifications

Module Series	***Standard***	***High Pressure***	***Combined Polymer***	***High Temperature***
Max Feed Pressure	203 psig (14.0 barg)	*See Note 1*	175 psig (12.1 barg)	203 psig (14.0 barg)
Min Temperature [2]	40°F (4.4°C)			
Max Temperature	131°F (55°C)			158°F (70°C)
C_{7+} Content	≤ 10 ppb$_v$			
Moisture Content	≤ 90% relative humidity at operating pressure; no liquid water			
Max. Particle Size	0.01 micron			

[1]: 7200HP – 350 psig (24.1 barg); 6150HHP, 6500HHP, and 6800HHP – 500 psig (34.5 barg)
[2]: For operation at low temperatures (i.e. below 40°F, or 4.4°C) please contact a Generon technical representative.

Table 2: Feed Air Impurity Limits

Component	**Max. Feed Concentration (ppm$_v$)**
Total Organics (i.e. C_7+)	0.01
Sulfur Dioxide (SO_2)	5
Nitrogen Dioxide (NO_2)	10
Ammonia (NH_3	35
Ozone (O_3)	0.1
Chlorine (Cl_2)	1
Other Acid Gases (e.g. HCl)	5

The quality of air supplied to the air compressor will affect the performance and lifetime of the modules. If ambient air feeding the compressor contains impurities above the limits defined in Table 2 please contact a Generon technical representative.

All connections must be sealed with Teflon tape or Formula 8 thread sealant. Other types of thread sealant can reduce module performance and/or cause permanent damage to the membrane module.

Appendix B
Module Storage Protocol

The following procedures must be followed when storing Generon membrane modules.

1. Plug or cap all inlet and outlet ports (i.e. feed, non-permeate, and permeate).

   All connections must be sealed with Teflon tape or Formula 8 thread sealant. Other types of thread sealant can reduce module performance and/or cause permanent damage to the membrane module.

   Block exposed permeate holes drilled into the outer sleeve by wrapping tape over the holes.

2. Once the ports are plugged, store modules in an area, preferably indoors, that is free of chemical vapors (e.g. paints, solvents, etc…). Do not store modules in direct sunlight; exposure to direct sunlight will raise the effective storage temperature.

3. The temperature of the storage area should be stable (i.e. no big swings in temperatures). The optimum ambient temperature during storage is 77°F ± 9°F (25°C ± 5°C). Storage temperatures outside of this range should be avoided at all costs.

4. If freezing temperatures are expected in the storage area, modules should be purged with dry air or nitrogen, with a dew point of at least -76°F (-60°C). This is to prevent water vapor from condensing and/or freezing in the modules during storage; condensed and/or frozen water in modules can damage the membranes.

5. If modules are stored below 32°F (0°C), they must be thawed for a minimum of 24 hours prior to use.

If above measures have been implemented membrane modules can be stored for 10+ years.

Failure to meet these requirements can result in reduced module performance and/or cause permanent damage to the membrane module.

Appendix C
Module Change-Out Procedure

When changing out Generon membrane modules on an existing air separation system the following procedures must be followed:

1. The ambient temperature during change-out should be above -20°C and below +50°C. If it is raining or snowing postpone the change-out, or conduct the work in a sheltered area.

2. Each membrane module is connected to the system with piping/hose/tubing. If present, close the inlet and outlet isolation valves on the membrane module that you want to change out. **Always close the inlet valve first, followed by the outlet valve.** Allow five minutes for the membrane module to depressurize.

   If there are no inlet and outlet isolation valves for the modules the entire air separation system will need to be shutdown and depressurized.

3. Disconnect the inlet and outlet piping/hose/tubing from the membrane module. Inspect the piping/hose/tubing for excessive wear, replace if necessary.

4. Remove the existing membrane module. Make sure you do not exceed the appropriate weight limits for lifting and handling. Use lift assists, cranes, or machinery where required.

5. Install the new membrane module in the same way the old one was installed.

   The inlet and outlet ports of the new membrane module are plugged to avoid exposure to particles, dust, and chemical vapors (e.g. paints, solvents, etc...). Remove all the plugs before installing the module.

6. Reconnect the inlet and outlet piping/hose/tubing to the new membrane module.

   All connections must be sealed with Teflon tape or Formula 8 thread sealant. Other types of thread sealant can reduce module performance and/or cause permanent damage to the membrane module.

7. Open the inlet and outlet isolation valves. **Always open the outlet valve first, followed by the inlet valve.**

8. Pressurize the air separation system and check for leaks using an accepted leak detector (e.g. *Snoop® Liquid Leak Detector*).

Appendix D
Membrane Array Trouble Shooting

When one has a membrane nitrogen generator using several membrane modules in a parallel array it is possible to determine if an individual module is in disrepair by sampling the gasses exiting the membrane module.

All of the membrane modules in the array will be operating with the same pressure drop since they are manifolded together for both the inlet gas and nitrogen rich product gas. This is true whether the modules are working well or not. At the start of service life the modules have similar performance and pressure drop characteristics so the product (and permeate) gas coming from the individual modules are fairly close to any other membrane module in the parallel array. Over time however if the system is losing performance one can evaluate if individual modules are performing poorly by monitoring their discharge flow rates and purities. The two discharge streams are namely the Retentate (nitrogen product) or the Permeate (low-pressure stream).

Possible module problems are…

…Decreased Performance due to Fouling

If a membrane module is fouled in service one will see a loss in Permeate flow but a noticeable rise in Permeate O2 concentration. The Retentate flow will again be fairly unchanged but the O2 level will rise since less of the O2 can permeate But, the rise is less noticeable compared to the change in the Permeate.

…Leaks

If a membrane module develops a leak one will see this most quickly by measuring its individual Permeate flow and/or Permeate O2 concentration (the permeate flow will be high and the permeate O2 concentration will be lower). The Retentate flow rate and %O2 may not be greatly impacted (especially if the leak is on the inlet part of the module).

Monitoring the permeate O2 level is typically used to find problem membrane modules since it can detect both a fouled or leaky module (product O2 levels in a leaky module may not show a big change in the product O2 level). **Generon therefore recommends monitoring the O2 level in the Permeate stream as the preferred location and method to determine membrane module performance decline.**

If the membrane module has higher O2 levels in the permeate over time (while in a system operating to give the same product O2 concentration) then it is fouling relative to others. If the permeate O2 concentration for an individual module is trending downward then one would assume the module is leaking. It is useful to document the individual modules permeate and product stream O2 levels at start-up to compare with future readings (since there will be some variation between module even at the start-up).

Some systems with inadequate pretreatment may show first the decrease performance due to fouling and then these fouled modules will start to generate leaks.

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