GENERON* AIR SEPARATION SYSTEM

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A. Introduction

The use of membrane technology for air separation is now commercially available in GENERON* air separation systems from The Dow Chemical Company. The GENERON air separation system separates compressed air into an enriched nitrogen product stream containing up to 99% nitrogen and an enriched oxygen vent stream containing up to 40% oxygen. This separation is accomplished utilizing hollow fiber membranes housed in the modules shown here with no moving parts and no complex pretreatment.

Although the current GENERON air separation system has been designed and optimized for production of the enriched nitrogen product stream, both streams are recovered simultaneously. The nitrogen stream produced by this GENERON air separation system is clean and dry.

Under the design conditions of 95% N_2/25°C and 90 psig feed pressure, GENERON air separation systems will deliver up to 15,000 ft^3/hour of enriched nitrogen product. The ten module system shown here will deliver 3,000 ft^3/hour.

B. Description of Module

As mentioned earlier, the GENERON air separation system module is a hollow fiber membrane device designed similarly to a tube and shell heat exchanger. The feed air is introduced into the module through the centrally located feedcore. The feedcore traverses the full length of the module and it is embedded and plugged in the non-feed tubesheet. Between the two tubesheets are the hollow fibers, lying parallel to the feedcore.

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The fibers are embedded in the tubesheets and are opened on the endplate sides of the tubesheet (referred to as the permeate or low pressure side of the module). The low and high pressure sides of the module are separated by double sets of O-rings on the tubesheets.

The feed air leaves the feedcore through holes placed in the feedcore between the two tubesheets into the area of hollow fibers. The feed air passes radially to the pressure case. As the air passes the hollow fibers, the oxygen is being depleted through the hollow fiber wall at a faster rate than nitrogen leaving an oxygen depleted nitrogen stream. The nitrogen stream is tapped off from the middle of the pressure case. The oxygen rich permeate stream passes down the bore of the fiber and is removed from both ends of the module.

The pressure drop across the module is 5 psig under design conditions. Hence the nitrogen product stream exits the GENERON air separation system at approximately 85 psig. The oxygen rich stream exits at less than 0.5 psig.

C. Practical Application of Membrane Separation

There is nothing mystical about the practical application of membrane gas separations. Although the mechanism is generally accepted to be solubility/diffusion, the principle of membrane separation is that gases pass through the membrane wall at different rates. How fast they pass through a membrane dictates the amount of surface area required to maintain a level of product flow. This dictates the number of modules, which is the major component in the capital cost.

The difference in permeation rates of gases, in this case oxygen and nitrogen in air, dictates the amount of compressed air feed flow to the amount of product flow. This sets the size of the feed air compressor motor and the power to operate this motor is the major component in the operating cost.

Membrane separations are steady-state and are cycled only during start-up and shut-down. However, as a normal quality assurance test the GENERON air separation system modules are cycled and little performance change is observed for 20,000 on/off cycles (Graph I, Table I).

In contrast, adsorption technology is typically a kinetic phenomenon necessitating pressurization and depressurization to effect a separation. Again in practical terms, this translates to the need for multiple adsorption beds and cycling among them to achieve an even product flow.

D. Trace Feed Air Components

The two major contaminants in air are carbon dioxide and water vapor (Table II). Neither gas is a poison to the membrane. Both gases are faster permeating materials than oxygen and are concentrated in the permeate stream. Therefore, free of cost, the product gas pressure dew point is controlable between -30°C and -43°C and the carbon dioxide is <25 ppm at design conditions. The level of removal is subject to the operating mode of the skid. Increasing feed pressure, decreasing feed air temperature, and decreasing feed flow will further decrease the level of water vapor and carbon dioxide in the product nitrogen stream.

E. System Components and Operation

The GENERON air separation system shown earlier is a total system. Installation is fast and simple requiring only piping for feed air and product gas. GENERON air separation systems are also available with integral compressors and/or chillers. Electrical service for the compressor is 230V 3-phase while the chiller requires ony 110V service.

What are the GENERON system components and their function? (Table III)

E.1. Feed Air Filtration

The feed air needs to be free of liquids such as water and compressor oils. A coalescing filter with automatic drain is part of the system package. Long exposure to feed air liquids will impair module performance by reducing the available fiber surface area due to the fibers sticking together. As a result channelling of the feed air increases, thus reducing product flow.

E.2. Pressure Control Valve

The feed air to the system is preset to 90 psig with a system pressure control valve. "Pop valves" are set for 135 psig and pressure cases are rated for 150 psig. The feed valve is set to automatically close at feed pressures greater than 111 psig. Other feed pressures can be used and their effect on performance is shown in the following graph (Graph II).

Increasing feed pressure does increase the output per module and efficiency of input to output flows. However, higher feed pressures may shorten the life of the module due to channelling.

E.3. Feed Air Valve

Next is the feed air valve to the system. It is designed to minimize the flow surges to the modules maximizing the module life. This is particularly important during the start-up of the system. High pressure, high feed air temperature and high oxygen levels in product gas are all shutdown modes on the feed air valve with audible and visual alarms available.

The feed valve is two solenoid valves 1.6 cm and 3.2 cm. The 1.6 cm solenoid opens first to bring the system slowly up to 50 psig pressure and 60 seconds later the 3.2 cm solenoid valve automatically opens. This prevents start-up flow surges, which could affect the module performance.

At this point the feed air is introduced into the module. The system is designed with the modules operated in parallel. Different system designs are available, where modules are operated in series. At higher nitrogen purities operation in series would improve system performance.

E.4. Product Flow Control Valves

The purity of the nitrogen product gas from the permeators is controlled by needle valves on the product lines. These needle valves are preset to design conditions before shipping. Once the product purity is set, it is not necessary to continuously reset the needle valves. Only a change in feed air pressure, feed air temperature, desired product purity or installation of a new module would necessitate a recalibration of the needle valves. These needle valves are easily adjusted to the desired purity by the use of "quick connects" to the oxygen analyzer.

Note: These same Flow Control Valves are used to vary the purity of the oxygen enriched air stream. The flow rate of the permeate stream is controlled by the feed pressure and temperature.

E.5. Product Distribution/Divertor Valve

During normal start up when product gas purity is changing from 79% nitrogen (air) to product (>95% nitrogen) the product gas is vented. This valve can be switched to divert product gas to the distribution system once the product gas purity drops below the set point (7.5% oxygen set before delivery). This set point can be readjusted in the oxygen analyzer.

F. System Economics

The operating cost of a GENERON air separation system for the generation of nitrogen is mainly maintenance and power cost for the feed air compressor motor. The GENERON air separation system has been designed to minimize the operator attention and maintenance downtime. Pressure checks and filter element replacement are the only routine operator or maintenance items.

All testing on the GENERON air separation system has been done using an oil-flooded screw air compressor. These types of compressors are known for low capital, maintenance and installation cost.

The feed air temperture to the skid also affects the economics as can be seen from the following graph (Graph III). Operating the skid with a feed air temperature of 15°C vs. 35°C would lower the feed air requirement by 40%. Since it takes much less horsepower to cool the feed air than to compress it, the operating cost is substantially reduced. Also, the cost of a smaller compressor with a chiller is less than the larger compressor, operated at higher ambient feed air temperatures.

The power requirement is 0.91 KWH/ccf of 95% nitrogen using a screw compressor/chiller and 0.71 KWH/ccf using a reciprocating compressor/chiller (Table IV). The GENERON air separation system has been designed to operate on existing incremental plant air which would be essentially free feed air. The total operating cost under all operation and capital depreciation options is \$0.07/ccf to \$0.15/ccf of 95% nitrogen (no value placed on the oxygen enriched air vent stream). Selling prices for the GENERON air separation system are available from your local Dow Sales Office. The system is available in sizes up to 15,000 ft^3/hour.

So as you can see, the GENERON air separation system is a simple cost effective means to a high quality nitrogen product. In addition, I hope I have unshrouded the mystery sometimes associated with membrane separations via my in-depth explanation of the GENERON air separation system.

TABLE I

FACTORS AFFECTING NITROGEN PURITY

- Feed Flow Rate
- Feed Air Pressure
- Feed Air Temperature
- Product Control Valve Setting
- Channelling

TABLE II

TRACE FEED AIR COMPONENTS

	Product Gas
Water vapor	-30 to -43°C
Carbon dioxide	<25 ppm

TABLE III

GENERON SYSTEM - COMPONENTS

- Compressor/Chiller (optional equipment)
- Prefilter
- Feed Air Valve
- Pressure Control Valve
- Membranes
- Flow Control Valve
- Product Distribution/Diverter Valves
- Vent (oxygen enriched air) System
- Instrumentation/Control Panel

TABLE IV

ECONOMICS

Power Demand	0.71 - 0.91 KWH/ccf
Total Operating Cost	$0.07 to $0.15/ccf

*95% Nitrogen/90 psig/25°C
assume $0.05/KWH

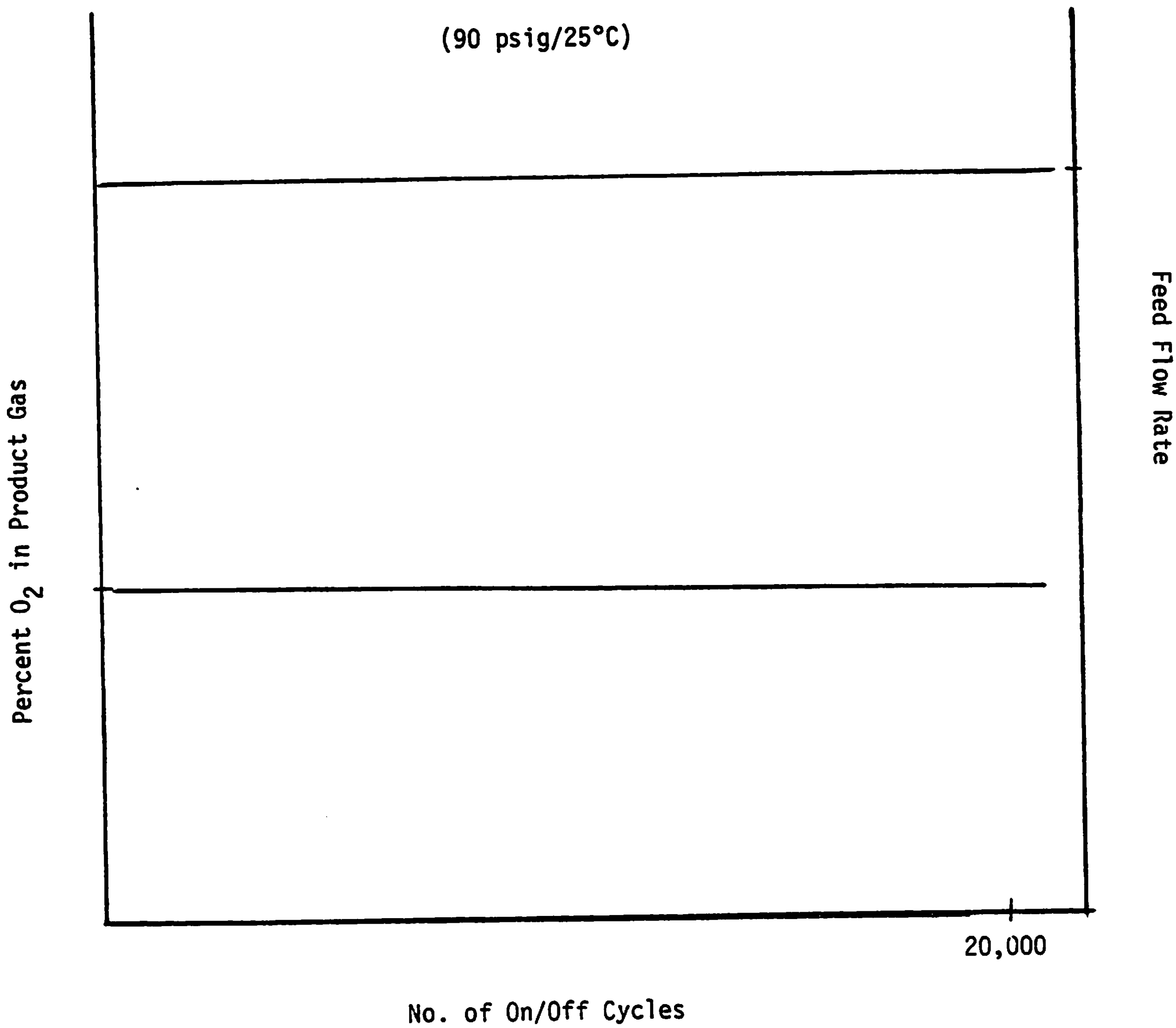
GRAPH I

FEED FLOW/PRODUCT PURITY

vs.

NO. OF ON/OFF CYCLES

(90 psig/25°C)



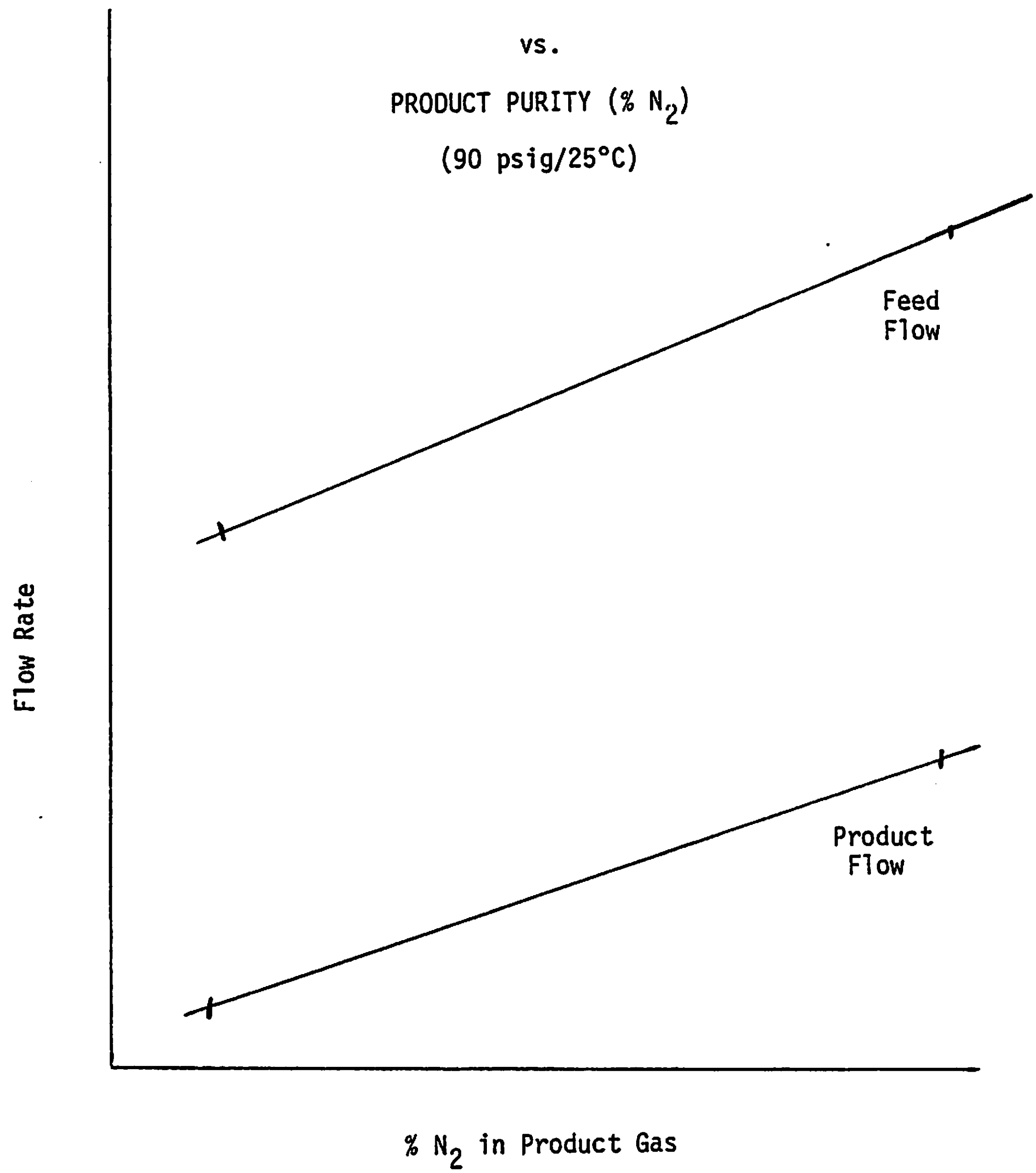
GRAPH II

FLOW RATE

vs.

PRODUCT PURITY (% N_2)

(90 psig/25°C)



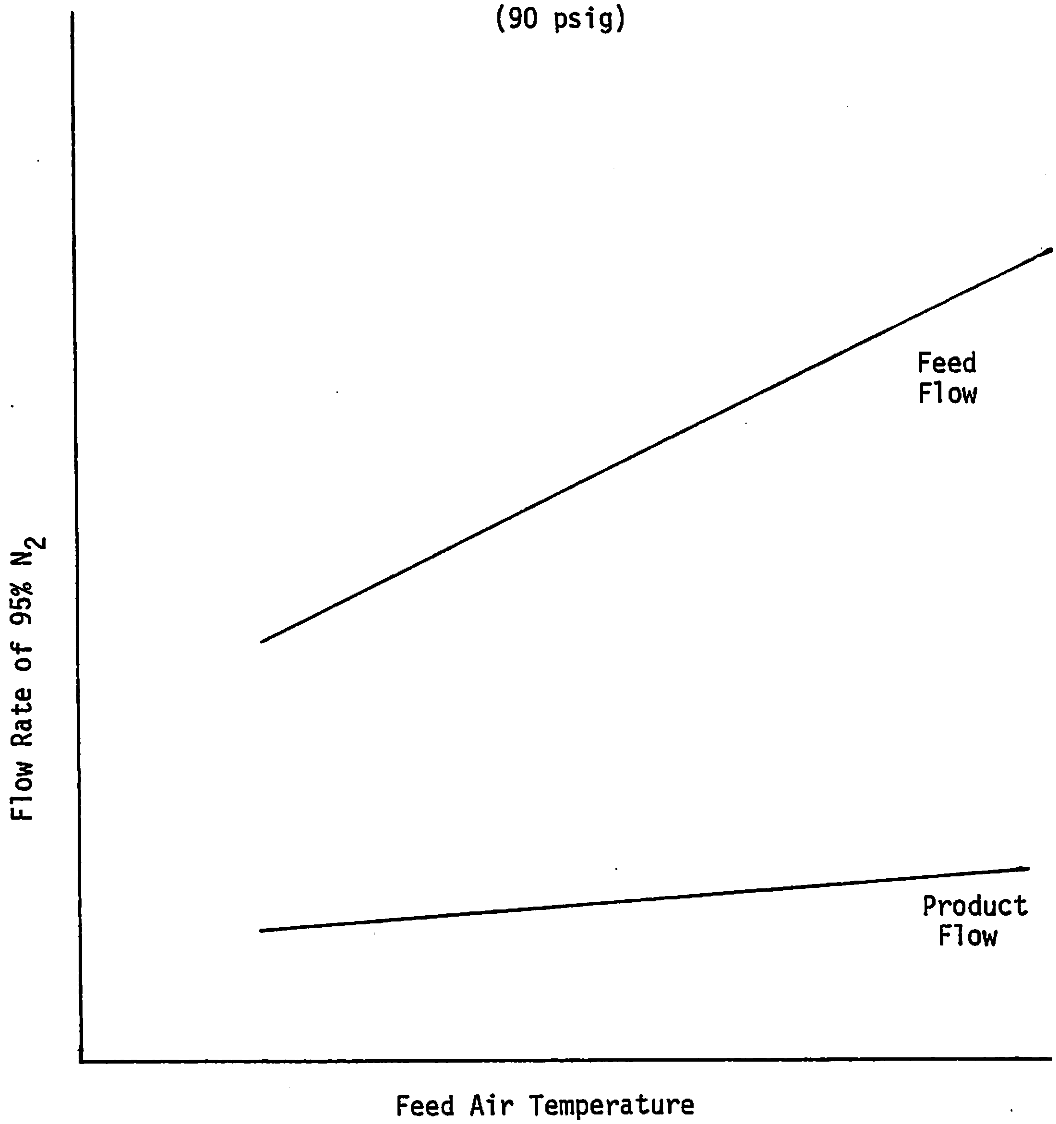
GRAPH III

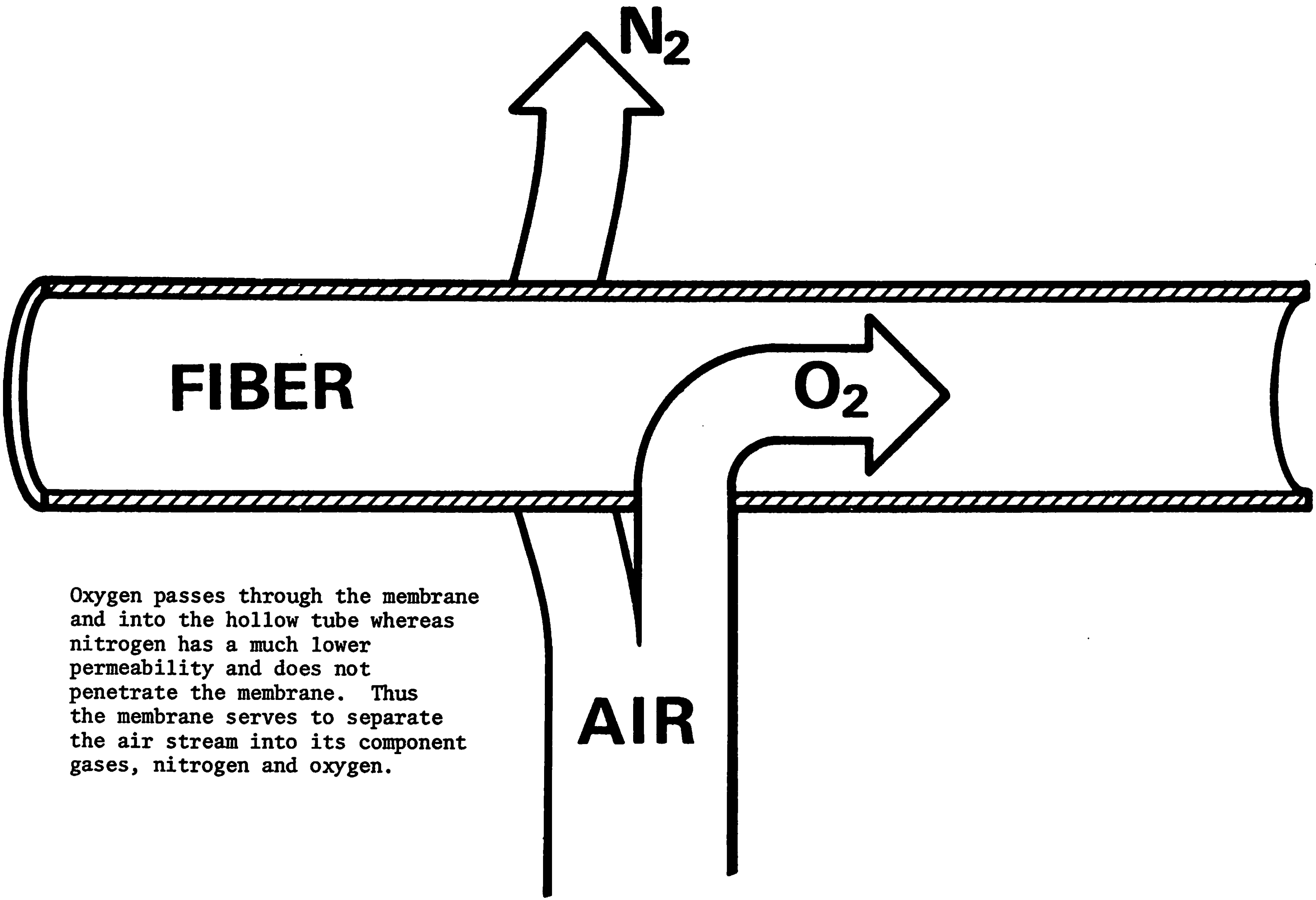
FLOW RATE

vs.

FEED AIR TEMPERATURE (°C)

(90 psig)





Oxygen passes through the membrane and into the hollow tube whereas nitrogen has a much lower permeability and does not penetrate the membrane. Thus the membrane serves to separate the air stream into its component gases, nitrogen and oxygen.

Millions of membrane tubes make up the fiber bundle in each module of the GENERON* air separation system. The fiber bundle is strategically constructed to facilitate the flow of gases around and through the individual hollow fibers. Oxygen (and water vapor) flow through the membrane walls into the hollow fibers and exits at the ends of the module. Dry enriched nitrogen exits via an outlet on the side of the module.