Blending
Oxygen Enriched Air

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Table of Contents

INTRODUCTION

Blending Oxygen Enriched Air

Course Objectives:

1. To direct you in the safe methods of blending oxygen enriched air (Nitrox/EANx)
2. To inform you as to what types of blending systems are currently available.

This is accomplished by providing a comprehensive, one day long, course of instruction. We will utilize classroom training, hands on experience, and this manual for future reference.

Good luck and safe blending,

Bart Bjorkman
President

www.EnviroDive.com
The Nitrox People

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Gas Blending

The air that we breathe is a nitrox mixture. Its component gases are 21% oxygen and 79% nitrogen. If we choose to modify this gas ratio in nature's nitrox, we either have to augment or diminish one of the gases. Until recently all nitrox mixes were made by adding oxygen, resulting in an *enriched* gas mixture. Hence the term "Enriched Air Nitrox" or Oxygen Enriched Air.

In this program, we will focus on safely and accurately blending gases to achieve consistent results. This is accomplished by gaining a complete understanding of the equipment and protocols required to blend any enriched air nitrox mix.

To successfully blend nitrox we require four ingredients:

1. a source of breathing grade oxygen,
2. a source of breathing grade compressed air,
3. a reproducible system for blending gases in a controlled and safe fashion, and
4. the knowledge/skills and references for future safe blending.

Chapter One
Oxygen

Oxygen is a colorless, odorless, and tasteless gas that supports life and makes combustion possible.

Pure oxygen will not burn, but it will readily support/enhance combustion and is a factor in spontaneous combustion in an environment where hydrocarbons are present. Increased pressure will compound this situation.

Oxygen is generally available for our blending use in two forms: either as a gas or as a liquid.

♦ Liquid Oxygen

Liquid oxygen, or “LOX,” is delivered in *low* pressure, thermally insulated containers. The lower pressure of the oxygen in this form is not suitable for all blending systems. However, for some applications such as continuous blending systems, the low pressure is compatible with the operational design.

The main advantage of LOX is that a larger volume of usable oxygen is available than from a similarly sized “gas” container.

LOX evaporates at 1.5% per day.

♦ Gaseous Oxygen

Breathing grade oxygen gas is marked either “USP” (U.S. Pharmacopoeia), or “Aviator”.

The difference between these two types is not in the purity, but in the moisture content. Aviator grade oxygen is drier because it is designed for use at high altitudes where moisture freezing can be a problem.

We primarily use USP grade breathing oxygen for the blending of Nitrox, however, Aviator grade can be used.

♦ Purity Standards

There are purity standards for oxygen quality. The standards are set by industry groups such as the Compressed Gas Association (CGA). The purity standard for USP oxygen is that it be 99.5 percent pure.

Another way to get breathing grade oxygen is to manufacture it yourself. Currently, there are two types of oxygen generators available which provide the ability to manufacture oxygen for use in Nitrox. These systems will be discussed in the gas blending systems chapter.

The benefits of being able to manufacture oxygen, especially in situations such as a diving operation in a third world country where it may be difficult to obtain medical grade oxygen, is readily apparent.

Even in the U.S., in some states, oxygen is considered a controlled substance and can only be dispensed with a prescription. Usually this is not a problem, but it is nice to know that the situation can be circumvented, if need be, by producing oxygen on site.

What about welding oxygen? Can it be used for blending Nitrox?

According to sources in the gas supply business, welding oxygen is exactly the same gas as medical oxygen; the difference is in the method of handling. Before they are refilled, medical oxygen cylinders are emptied by the supplier, regardless of the volume of gas remaining inside. A vacuum is then placed on the cylinder. Contrast this with welding oxygen, where the cylinder is simply topped up. This may not seem like much of a difference, but consider that sitting beside the welding oxygen is a cylinder of acetylene. It is possible that conditions could arise where acetylene may migrate into the oxygen cylinder. We definitely do not want acetylene (or any other contaminant) in our breathing mix, so stay away from welding oxygen.

At what oxygen percentage do we have to treat enriched air as oxygen?

This is a controversial question and is often debated. There appears to be ample data to support each group’s claims.

Historically, the majority of the dive industry has safely followed the standards set by the National Oceanic and Atmospheric Administration (NOAA), and the Occupational Safety and Health Administration (OSHA). These federal organizations, in addition to technical/recreational diving agencies, have an enviable safety record using the 40% guideline.

Any enriched air mixture with an oxygen content of up to 40%, can be treated as air.

and

Any oxygen concentration above this amount must be treated as if it is pure oxygen.

How does this guideline affect us? What this means is that any part of any gas mixing, storage, or compressor system, that comes into contact with oxygen enriched air with a concentration of oxygen above 40%, requires much stricter protocols in the areas of design, cleaning, and material compatibility.

Keep in mind that some organizations are adamant that anything over 21% O2 or 23.5% O2 be treated as pure oxygen. Often, instead of basing their assumptions on engineering factors they base them on legal or PVHO rules, (Pressure Vessels for Human Occupancy), but that is not what we are talking about here.

Hazards

As Enriched Air Nitrox (EANx) gas blenders, we must be concerned about the physiological and operational hazards related to the use of oxygen.

♦ Physiological Hazards

The physiological, or "health hazards", are those based on the effects of oxygen on the human body. The body requires adequate perfusion of oxygen at the cell level to function properly. But what happens when we get too much or too little oxygen?

Is too much oxygen a concern for gas blenders? What happens if the best mix for a job is EAN32 and we supply a 40% mix? Is that diver at risk? Yes! Too much oxygen in our body could cause a potentially fatal toxic reaction, so this is a very real concern.

What about not enough oxygen? The condition of inadequate perfusion of oxygen to the cells for the maintenance of life is called "Hypoxia". This is the condition where there is not enough oxygen available for the body to function correctly.

This situation could arise from the oxygen in a steel cylinder being consumed in the oxidation process. In other words, if a tank is rusting inside, then the rusting process will use up the oxygen, leaving less, or none, for the diver. This would occur if moisture was allowed into a steel cylinder.

Or consider what could happen to a worker who planned the dive for the maximum time at depth for an EAN40 mix but was using an air mixture (21% O2) by mistake. Is this a likely recipe for decompression sickness? Yes. The result is *over staying* the time at depth.

Physiological hazards

***CAN BE PREVENTED*:**

- by using acceptable protocols while mixing gases,
- by correctly analyzing the end result,
- by having the diver *personally* analyze the gas and fill in the "Gas Blending Log" before removing the gas from the mixing facility.

Please Note: In some cases, the "Diving Supervisor" may be responsible for *personally* analyzing the gas and filling in the "Gas Blending Log". Check ***your*** company's written diving protocol.

How is the oxygen content of a gas mixture analyzed? A portable “oxygen analyzer” is used. These hand held units originated in the health care field to monitor the oxygen content of gases administered to patients. As Nitrox Gas Blenders, we use them to accurately monitor the oxygen content in our breathing gas. There are many kinds of oxygen analyzers, although the most common ones work on the same principal. (See manufacturers instructions for proper use and maintenance.)

♦ Operational Hazards

Operational hazards are unwanted incidents that occur during the preparation and handling of compressed breathing gases. Examples of operational hazards are *fires* and *explosions*.

To avoid the potential operational hazards associated with working in high concentrations of oxygen under pressure, we must understand what happens inside blending systems.

How does ignition actually take place? What events lead up to an oxygen fire?

There are four primary methods for ignition to take place in an oxygen enriched system;

1. Heat of compression
2. High speed particle impingement
3. Localized frictional heating
4. Material incompatibility (Spontaneous combustion)

1) Heat of Compression

According to Dr. Richard Boyd, of Global Manufacturing Corporation,

> *“Divers often do not understand or appreciate the enormous heat generated by sudden gas compression; for example, if a short section of tube is rapidly pressurized to 3000 psi, momentary temperatures of 1500 degrees Fahrenheit, or more, can be reached. Obviously many materials could be auto ignited at such temperatures. Under such conditions, in the presence of pure oxygen, even inert substances such as Teflon or Viton can be set afire!”*

How can we avoid this “heat of compression”? The simple answer is to open valves very slowly. Often the culprit is the wrong type of valve. All valves in a properly designed system for the use of oxygen should be slow opening. OSHA regulations state that ball valves should not be used for oxygen service at pressures greater than 125 psig and be replaced by slow opening type globe pattern valves.

Where possible, regulators should be used with oxygen, instead of valves.

Gauges are particularly difficult to oxygen clean and are susceptible to damage from sudden increases of pressure. Design your system so that gauges are protected by being downstream of flow restrictors, regulators or slow opening valves.

2) High Speed Particle Impingement

High speed particle impingement occurs when particles, that are caught in the gas stream, impact at high speed with an immovable object. (kinetic energy into heat). If sufficient heat is generated, the ignition of contaminants or component material is possible, often with disastrous results.

Any potential particle impact site must be at least 10 diameters downstream from a restrictive orifice where the gas velocity exceeds 150ft/sec. As an example, if an orifice restriction is one quarter inch in diameter, then there must not be any place for particles to impact within two and one half inches from the orifice.

It is important to design the system so that any potential impact site is of a material resistant to ignition such as Monel or brass and not aluminum or titanium.

The addition of a fine filter, such as a sintered bronze unit, ahead of high velocity components, will catch particles before entering the velocity stream.

Initially purge the system with a high pressure inert gas, to blow out any particles, before bringing the system online.

3) Friction

Friction causes concentrated localized heating, as a result of gases speeding up as they go past restrictions such as tight bends and restrictive apertures. An example of this would be a partially opened valve, or a worn out or damaged valve seat. Valve seats are often made from nylon. Under magnification, nylon has microscopic threads that ignite easily when escaping gas leaks past a worn out valve seat.

4) Material Compatibility

Material compatibility is complicated because both the pressure and the percentage of oxygen are involved. Oxygen's reaction increases with higher pressures, temperatures, and oxygen percentages. In other words, the higher the pressure, the temperature, or the oxygen content, the less it takes to have a problem, and/or the more violent the reaction can be.

A good example of this is a scuba regulator that is used in oxygen service. The first stage requires every seat, seal and diaphragm to be oxygen compatible, because it is in contact with high pressure oxygen. But, the low pressure second stage requires only the lubricant to be oxygen compatible, even though it is exposed to the same percentage of oxygen.

It is conceivable that conditions of material incompatibility could exist to cause spontaneous combustion. We know that this happens when sufficient hydrocarbons are present in a high pressure/oxygen situation.

A gas blending system that utilizes oxygen, must be:

- designed for oxygen use,
- oxygen clean, and
- oxygen compatible

♦ Designed for Oxygen Use

Designed for oxygen use means that due consideration is given for the special needs of oxygen under pressure, in the environment in which it is contained. Due to oxygen's dynamic qualities, which can enhance combustion (fire), sometimes very rapidly (explosion), the design of the system must minimize any tendency for heat generation, ignition of particles, or the accumulation of contamination.

This is accomplished by smooth piping bends, slow opening valves, one way check valves, minimal restrictions, regulators in place of valves, particle impact sites more than 10 diameters away from restrictive orifices, and well maintained compressors and filters.

Historically, gas blenders have been mixing EANx using oil lubricated compressors that pump to 3000 psig without incident. Prudence would dictate that this is a reasonable maximum pressure providing that all other oxygen service safe guards are in place.

In the Stephen Mastro and Glenn Butler report, they state that

> *"The general increase in scuba cylinder working pressures (e.g., the new genesis tanks) and compressor / storage banks in the 3300 to 4500 psi range creates a higher risk level when using oil pumped air (no matter how meticulously filtered)."*

♦ Oxygen Clean

Oxygen clean is the verifiable absence of particulate, fiber, oil, grease and other contaminants. *Verifiable absence* is determined through the use of qualitative and quantitative cleanliness measurement techniques. Oxygen cleaning will be covered in chapter two.

♦ Oxygen Compatible

Oxygen compatible is a bit of a misnomer, because almost any material will react with oxygen under the right set of circumstances.

For our purposes, *oxygen compatible means:*

a material that will not react with oxygen at the systems designed maximum pressure, oxygen content and operating temperature.

A good example of this is "O" rings. The standard “Buna-N” has an oxygen index (OI) of 21 percent meaning that it can ignite at normal atmospheric pressure with the oxygen content of air. EPDM has an oxygen index of 20 to 25percent, and Viton's OI is 56 to 100 percent.

In actual practice Buna N "O" rings are commonly used in oxygen service up to 250 psi, EPDM up to 3000 PSI and Viton, although it has the best OI, is avoided where possible, due to it's undesirable elasticity and durometer (hardness) properties and it's tendancy to give off a poisonous gas when ignited.

Some items that start out oxygen compatible, deteriorate over time to the point where they are no longer compatible. An example of this would be the carbon steel fittings that are found on the majority of hoses in scuba air fill stations. These often rust, makng them incompatible in the oxygen enriched environment.

For your information, it is questionable to use carbon steel fittings in the first place because they are rated (by ASTM) just slightly higher than aluminum and titanium, which are considered incompatible in an oxygen system.

Metals and alloys, such as Monel and brass, have the highest compatibility rating, followed by Inconel and stainless steel.

Keep in mind that each of these metals has a different maximum working pressure, so match the right ones to your system. While you are at it, you may consider replacing your synthetic pressure hoses with Teflon lined, stainless steel braided hose, with short sections of pipe on the ends. Teflon and Kel F, although ignitable by heat of compression, are considered compatible materials for oxygen service. The short section of pipe on the ends of the braided hose is not ignitable from heat of compression, and is therefore a good design feature.

If a system has been properly *designed for oxygen use, is oxygen clean, and has oxygen compatible components,* then the system is considered to be ***oxygen serviced.***

NOTES:

Chapter One Review Questions:

1) *What grade of oxygen do we use in gas blending*
2) *Because welding grade oxygen is the same quality as USP Grade, can we use it to gas blend with? Why or why not?*
3) *At what oxygen percentage do we have to treat enriched air as oxygen?*
4) *Give two examples of physiological hazards of blending EANx*
5) *Give two examples of operational hazards of blending EANx*
6) *What are the four primary methods for ignition to take place in an oxygen enriched system?*
7) *What is oxygen clean?*
8) *What is oxygen compatible?*
9) *What is designed for oxygen use?*
10) *What is oxygen service?*

Answers:

Chapter Two

Oxygen cleaning

While it is not the intent of this program to turn out life support technicians, it is important that EANx gas blenders have the working knowledge to be able to oxygen service items that are part of their blending system. This may include gas lines, cylinders, and valves.

There are six steps to oxygen cleaning and **<u>no short cuts</u>**.

1. Dismantling equipment completely
2. Inspection and gross cleaning
3. Pre cleaning and rinsing
4. Cleaning, rinsing and drying
5. Inspection and testing for clean
6. Reassembling, packaging and labeling

- There are no special conditions required for the initial dismantling and gross cleaning of equipment.
- Once into the pre-cleaning stage, the cleanliness of the work area is essential. Pick an area that can be meticulously cleaned and is free of dust and airborne contaminants.
- Proper ventilation is mandatory, as is running water and electricity.
- Ensure that all safety standards are met concerning proper safety wear such as safety glasses, rubber gloves, etc. (The time to think of an eye wash station is before dealing with caustic substances, and not after you get some in your eye!)

<u>Please Note</u>: When working on any equipment, you must always follow the manufacturers instructions.

For oxygen cleaning, the six steps, in detail, are as follows:

1. **Dismantling the equipment**:

- Start with dismantling the equipment ***completely***, (*down to its simplest components.)*
- Use the proper tools and techniques to insure no damage to the parts.
- Have a specific place to put small parts so they don't inadvertently go down the drain.

Inspection and gross cleaning:

- Inspect each part for contamination, corrosion, wear, and oxygen compatibility.

If in doubt throw it out.

- Use a non metallic, stiff bristle brush to remove any contamination. The part(s) may have to soak in a mild acidic solution such as white vinegar or a citrus based cleaning solution. *Make sure that whatever solution you use, it is compatible with the material being cleaned*.
- If you have access to an ultrasonic cleaner, that will speed up the gross cleaning process.
- The desired result is a component without any rust, scale, joint compound, burrs or any coarse particulate, whether organic or inorganic.
- Rinse the parts with fresh water and immediately move on to the pre cleaning process.

2. **Pre cleaning and rinsing:**

The object of the pre cleaning process is to remove all visible contamination. This is accomplished by using an approved cleaning solution, such as Simple Green, Blue Gold, Navy Oxygen Cleaner (NOC), or Delta Omega Technologies DOT 111-113. (Sources are listed in the appendix.)

These cleaners provide excellent cleaning properties, but most importantly, they rinse off well.

- Be sure to follow the mixing and safety instructions on the cleaning solution package.
- Again, using a non metallic, stiff bristle brush, scrub each part completely, with the pre cleaning solution, to remove all visible contamination. As every nook and cranny must be meticulously scrubbed, complete immersion in the desired pre cleaning solution, accompanied by judicious scrubbing, is standard operating procedure. (Gas blenders are known for their almost uncontrolled level of excitement when finding a new or unusual cleaning brush.)
- Cavitational cleaning by an ultrasonic bath is very effective at this stage, if you have one.
- Completely rinse each piece, in clean, fresh water.

For non removable piping or tubing,

- Circulate the pre cleaning solution via a pump. Everything from a hand bilge pump to an aquarium pump has been used for this application. Get creative. Ideally you want a minimum flow of 3 litres (a litre is about the size of a quart) per minute. Circulate for 15 minutes, or more if required. Rinse piping or tubing immediately with fresh water for 15 minutes.

Special notes about pre cleaning:

1. Some pre-cleaners like Simple Green, may leave a slight organic residue. Because everything organic is carbon based, these solutions are used in the pre cleaning stage only.

2. If an acidic solution was used in the gross cleaning, it is very important that the parts be rinsed *thoroughly* if an alkaline, like NOC, is used in the pre-cleaning, because acids and alkalines should not be mixed.

3. Environmental issues concern all of us. Please reuse pre-cleaners by filtering through coffee filters into a suitably marked container.

   Once the cleaning solution starts to lose its effectiveness, or it is contaminated with hydrocarbons, then use it for a less critical application, such as washing the compressor room floor, and dispose of it according to the manufacturers directions, if compatible with state or federal law.

4. Protective gloves not only protect your hands from the harsh solutions that you are using, but are also necessary to keep the oil from your hands off of the parts that you are cleaning.

4. Final Cleaning, Rinsing and Drying:

Final cleaning is done with either Naval Oxygen Cleaner (NOC) or Tribasic Sodium Phosphate (TSP). NOC is available from the suppliers listed in the appendix. TSP can be purchased in most hardware stores or building supply outlets. It is important to note that NOC should be used at 170 degrees F, whereas TSP is used at 160 degrees F.

- If possible, totally immerse the part in the cleaning solution and scrub thoroughly.
- If available, an ultrasonic bath is an excellent method of cleaning areas that are difficult or impossible to reach otherwise.
- Thoroughly rinse with clean water.
- Dry with oxygen compatible air or dry nitrogen. (Anhydrous nitrogen is relatively inexpensive and readily available from your gas supplier.)

For non-removable piping and tubing :

- Do not allow TSP to remain idle in the system *at any time*.
- TSP is not considered compatible with aluminum

- Circulate the NOC or TSP for up to 30 minutes, then

- Flush system for 30 minutes with fresh water heated to the same temperature as the cleaning solution.

- A preliminary test to see if the caustic cleaner is flushed, is to test the rinse water with a PH test strip. It should read eight or less. These PH strips are available at drug stores, pool chemical supply or wine making stores.

- Dry the system by purging with warm, dry nitrogen. Test for moisture by holding a kleenex or camera lens tissue up to the outlet, while purging with nitrogen. Any moisture should show on the tissue. **Note:** A poor system design may have cavities that trap moisture.

5. Testing:

It is one thing to physically oxygen clean a system, but how do you know it is clean enough? Testing! Keep in mind that **most testing techniques are limited to determining the presence of a contaminant, not the absence.**

There are five tests that help to determine if an object is oxygen clean:

1. PH test
2. Visual inspection using white light.
3. Visual inspection using ultra violet light
4. Water break test
5. Shake test

PH Test

The Ph test is used to verify that the caustic solutions used in the cleaning process were rinsed out sufficiently.

- Using a PH test strip, test an unused sample of the water being used for rinsing.
- Using a PH test strip, test a used sample of the final rinse water.
- If the used sample tests higher than the unused sample, then the system needs to be flushed some more, to remove the final traces of the caustic cleaning solution.
- A reading of eight (8) or less should indicate that the caustic cleaning solution has been completely rinsed out.

Visual Inspection Using White Light

If you have normal visual acuity, a visual inspection using a bright white light of at least 60 watts, (preferably 100 watts) and your eyes, will reveal contamination bigger than about 50 microns.

- Closely and thoroughly inspect the part, while keeping the light close enough to provide excellent illumination of the surface being inspected.
- Any evidence of contamination is cause for rejection. This means the parts rejected must be put through the complete oxygen cleaning process again.

Visual Inspection Using Ultra Violet Light

A visual inspection using an ultraviolet light having a wave length of 3600 to 3900 angstroms will indicate some contaminations which fluoresce under the ultraviolet light. (UV lights are available from laboratory equipment supply houses, electronic stores and stereo shops, and Global Manufacturing)

- Any evidence of fluorescence from oil, grease, ink, dye, particulate, or fibers is cause for rejection.
- Please note that most *synthetic* oils and greases do not fluoresce, while some non- metallic substrates may, leading to false results.
- If in doubt, re clean the item tested.

Water Break Test

The water break test is a good indictor

of any residual oils, greases and silicon.

- With an atomizer or spray bottle set on “mist”, using clean water, lightly mist the surface of the component that you are testing.
- If the part is oxygen clean, the water will form a continuous thin layer for a few seconds before succumbing to gravity and breaking away cleanly.
- If the layer of water forms into little adhering droplets, then that will indicate contamination.

Shake Test

The shake test is to confirm that all cleaning solutions have been thoroughly rinsed off of the parts.

- For the shake test you require a clean, capped, sample container of at least 500 ml capacity, (about two cups).
- Fill it half full with the final rinse water, and shake it vigorously for five seconds, then allow to stand undisturbed for 5 minutes.
- Any evidence of bubbles remaining on the surface means that the system was not rinsed well enough.

There are more conclusive tests for oxygen clean, but they require specialized equipment and/or training.

6. **Reassembling, Packaging and Labeling**

After the equipment parts and components pass for oxygen clean:

- replace any oxygen incompatible parts with oxygen compatible ones.
- Where lubrication is required, use hydrocarbon free lubricants, such as Christolube. (Supplier listed in the appendix).
- If Teflon tape is required, use good quality tape and ensure that the tape is not wrapped past the last two (outside) threads. That way there won't be any chance of Teflon threads extending into the system.
- Reassemble the components, being careful not to contaminate any of the parts by careless handling, or by using dirty tools.
- If the oxygen cleaned items are not going to be put into service immediately, then bag and tag the parts in a clean plastic bag, tightly sealed and clearly marked with the date of cleaning.
- Start an oxygen service log. Record the item and date serviced.
- Oxygen service as required but at least once a year.

A special note about scuba cylinders:

1. As scuba cylinders are normally too big to immerse, let them be their own container. Literally, just do all of the steps in the cylinder itself.
2. Pay special attention to the threads in the neck.
3. Make sure that the inspection light you use is oxygen clean or you may re contaminate your cylinder.
4. To dry the tank, turn it upside down and blow it dry with oxygen compatible air or dry nitrogen.
5. As flash rusting can some times occur in steel cylinders, use an inorganic corrosion inhibitor such as sodium nitrite, (available from sources listed in the appendix).
6. Remember that once the cylinder and the valve have been oxygen serviced, the tank must be labeled appropriately. This would include:
   - a four inch high green label encircling the tank with the words “Nitrox” or “EANX” clearly delineated in yellow,
   - a label that indicates oxygen service. This should not be part of the visual inspection label.
   - a contents label.

If there are any questions that come up about O2 cleaning, compatibility of parts, where to get supplies etc., please call the resources listed in the appendix. Companies like Global Manufacturing Corporation have a technical hot line.

Just a note of caution: There are a lot of self styled experts out there who love to dispense wisdom at every opportunity. Often, these people muddy the water by perpetuating myths and folklore that have little or no basis in fact. What’s worse is that they sometimes offer dangerous advice.

If you have a question pertaining to any of the subjects covered in this manual and you can’t find a resource listed in the appendix, please call EnviroDive Services, at 1-250-254-5076 (9 am to 5 pm Mountain Standard time). If we don’t have the answer to your question in our resource library, we will locate one of the leading experts to answer your questions.

NOTES:

Chapter Two Review Questions:

1) *What are the six steps to Oxygen cleaning?*
2) *What is the purpose of gross cleaning?*
3) *What solutions can we use in precleaning?*
4) *How come we can't use all of the precleaners as final cleaners?*
5) *Is NOC and TSP acid or alkaline?*
6) *What are the five tests for determining oxygen clean?*
7) *Do these tests determine the presence of contamination or the absence?*
8) *What type of lubrication can we use?*
9) *What happens if a part fails a test?*
10) *How must a scuba cylinder be marked for use with nitrox?*

Answers:

Notes:

Chapter Three

Oxygen Compatible Air

At the heart of every gas blending system is the air compressor. To mix nitrox, the compressor does not have to be an oil free compressor, but it does need to be in good mechanical condition, and have proper filtration. It is also recommended that a synthetic oil be used. Just make sure that any changes that you make to the compressor are acceptable to the manufacturer, or you may shorten the life of your compressor and maybe even void the warranty.

In Stephen J Mastro and Glen Butler's report, "Air Quality Requirements For The On-Site Production Of Oxygen Enriched Breathing Mixtures", they recommend an oil free compressor for the production of Nitrox. Some of the problems that they note in the use of standard oil lubricated compressors are: through mechanical wear, component failure, conditions of operation, and lack of maintenance, compressors in which the lubricating oil is in direct contact with the processed air ***can produce significant amounts of entrained lubrication oil in the discharge air***. Under certain operating conditions, dangerous amounts of carbon monoxide can also be produced. (This carbon monoxide would be produced by the incomplete combustion of the compressors lubricating oil)

Some common causes of significant oil discharge and the potential production of carbon monoxide are:

1) inadequate interstage drainage necessary to remove condensate and oil causing premature contamination of the final filter element beds.
2) lack of filter element inspection and replacement per manufacturers maintenance specifications.
3) overheating of compressor and lubricating oil due to loss of cooling water or air circulation.
4) the wrong type lubricating oil or low oil level resulting in the oil reaching auto ignition temperatures.
5) cylinder, piston, ring and valve wear or malfunction resulting in significant inter-stage oil carry over.
6) restriction of compressor first stage intake, or inter-stage leakage, resulting in abnormally high final stage compression ratios which can produce temperatures into the auto ignition range of factory recommended lubricating oils.

Breathing gas standards specify the amounts of contamination allowed in gasses to be breathed by an individual, and are set out by organizations such as the Compressed Gas Association.(CGA) source in the presence of high pressure oxygen.

Because of this, the diving industry, involved with the production of nitrox, got together in 1993 and agreed upon

The CGA Standard for "Grade E" Breathing Gases

- Oxygen by percentage 20-22
- Condensed Hydrocarbon (oil) 5.0 mg/m3
- Carbon Monoxide .... 10 parts per million
- Carbon Dioxide .... 500 parts per million
- Odor .... Not objectionable
- Gaseous Hydrocarbon .... 25 parts per million

<u>Please Note</u>: *In Canada* the condensed hydrocarbons allowed is a more restrictive 1. mg/m3

their own set of standards for **Oxygen Compatible Air.**

Keep in mind that the standards for breathing gases are the ***upper*** limits of contamination allowed for the continued health of the person breathing the air.

As gas blenders, however, we must also take into consideration, **fire safety**.

What this means is that although 5.0 mg/m3 condensed hydrocarbons are allowed in "Grade E" breathing air in the USA, this amount of contamination could lead to an accumulation of hydrocarbons in a blending system. With enough exposure, accumulated hydrocarbons would provide an ignition

Oxygen compatible air, or air to be used in blending gas mixtures other than air, must meet US CGA standards Grade E, or equivalent, with the following modifications:

1. ***the maximum allowable condensed hydrocarbons are .1 mg/m3***
2. ***the maximum allowable concentration of Carbon Monoxide is 2.0 parts per million***

Due to the increased importance, from a physical safety level, that these standards be met or exceeded,

verification of gas analysis and gas composition is required quarterly, by an appropriate testing facility,

unless otherwise legislated by a governing body, such as the Workers Compensation Board.

It is easy to confuse terms here. Keep in mind that *air analysis* is where a sample of compressed air from your facilities compressor is sent off to a laboratory for analysis. *Oxygen analysis,* on the other hand, is where we measure only the oxygen content of a gas mixture.

To check for condensed hydrocarbons in your system, periodically inspect the fitting immediately after the final filter with a cotton swab. If you can detect any accumulation or discoloration, there is a good chance that you are accumulating condensed hydrocarbons. This would require you to locate the reason for the accumulation, repair it, and oxygen clean the system if exposed to oxygen concentrations higher than 40%..

Please Note: In the presence of accumulated condensed hydrocarbons, it would be wise to use the forty percent rule as a guideline only. It would be foolish not to correct the cause and oxygen service the system.

Questions & Answers

***Q:** What do I do if my compressed breathing air is not up to oxygen compatible standards?*

A: If the condition is caused by a mechanical problem such as oil bypassing the rings, then the compressor is past due for some serious work by a certified compressor technician.

If the air analysis shows an elevated Carbon Monoxide (CO) reading, which is caused by incomplete combustion of hydrocarbons, it will likely be caused by over heated compressor oil, in which case, ***you will need to fix the cause***. Another source of elevated CO readings is poor quality ambient air, such as that found in some polluted areas. The solution here may be to install a Carbon Monoxide catalyzer which will convert the CO to CO_2. In some cases, just moving the air intake inside the building makes a significant difference.

Just watch out for elevated CO_2 (Carbon Dioxide) caused by the CO catalyzer, enclosed spaces, or lots of people exhaling in the immediate vicinity.

Any other toxic gases that are encountered should be removed or neutralized before compression. An example of this may be where someone is painting or cleaning parts with solvent in the vicinity of the air intake. The idea here is to supply your compressor with lots of clean, fresh air.

Q: *What do I do about excess particulate or unwanted hydrocarbons***?**

A: If you are maintaining your filters correctly, the compressor is in good shape, and your source of air is unpolluted, then you need contaminant specific removal. Enhanced mechanical filtration or chemical absorption will be required. Talk to your compressor filter people; just make sure that they understand your application. This is important because some filtration material, like low grade activated carbon, could be a ready ignition source if it is used incorrectly.

For additional sources of hyperfiltration, or just plain good advice, contact Global Manufacturing Corporation, Lawrence Factor, or Compressed Air Supplies. Their numbers are listed in the appendix.

No one would ever want to be responsible for the injury or death of another human being. That, alone, is not enough in our litigation happy society. We must not only know the required safety standards, and follow them to the letter, but we also need to be able to verify our correct actions.

Chapter Three Review Questions:

1) *My air analysis is within CGA Grade E standards, can I mix Nitrox with it?*
2) *How often should I get my air analyzed by an independent laboratory?*
3) *Is there a difference between analyzing oxygen and air analysis?*
4) *If my air is good enough to breathe, is it good enough to use to mix nitrox?*
5) *What is the maximum allowable condensed hydrocarbons?*
6) *What is the cause of elevated Carbon Dioxide in the compressed air?*
7) *With the exception of condensed hydrocarbons, what air quality standards do we use?*
8) *My compressor is bypassing oil into the airstream; can I use synthetic oil to be safe?*
9) *What would cause an elevated Carbon Monoxide reading?*
10) *Do I need an oil free compressor to pump oxygen compatible air?*

Answers:

Chapter Four

Gas Blending Methods

Is there a best way to blend EANx? Yes, there is, but it may be different for each application. Choosing what method is best for your diving operation begins with finding out what is available.

There are primarily five approaches to gas blending. They are:

1. Mixing by weight
2. Partial pressure blending
3. Continuous flow mixing
4. Oxygen generation
5. Supplied

Mixing By Weight

Mixing by weight is a reliable and accurate method of mixing EANx, but it is not suited for field operations, due to the accurate scales required.

Mixing by weight is done by:

- ♦ Calculating the correct weight, per cubic foot, of each constituent gas, then
- ♦ Adding the correct amount, by weight, of each gas, for the desired outcome.
- ♦ The combined gases are left for six hours to homogenize, by a naturally occurring process called molecular migration.
- ♦ The gas is then analyzed and any adjustments are made.

The potential outcome for an accurate mix is excellent.

As you can imagine, however, this method of blending is best suited for a static location, and where there is a need for a large volume of the same EANx mix.

Partial Pressure Blending

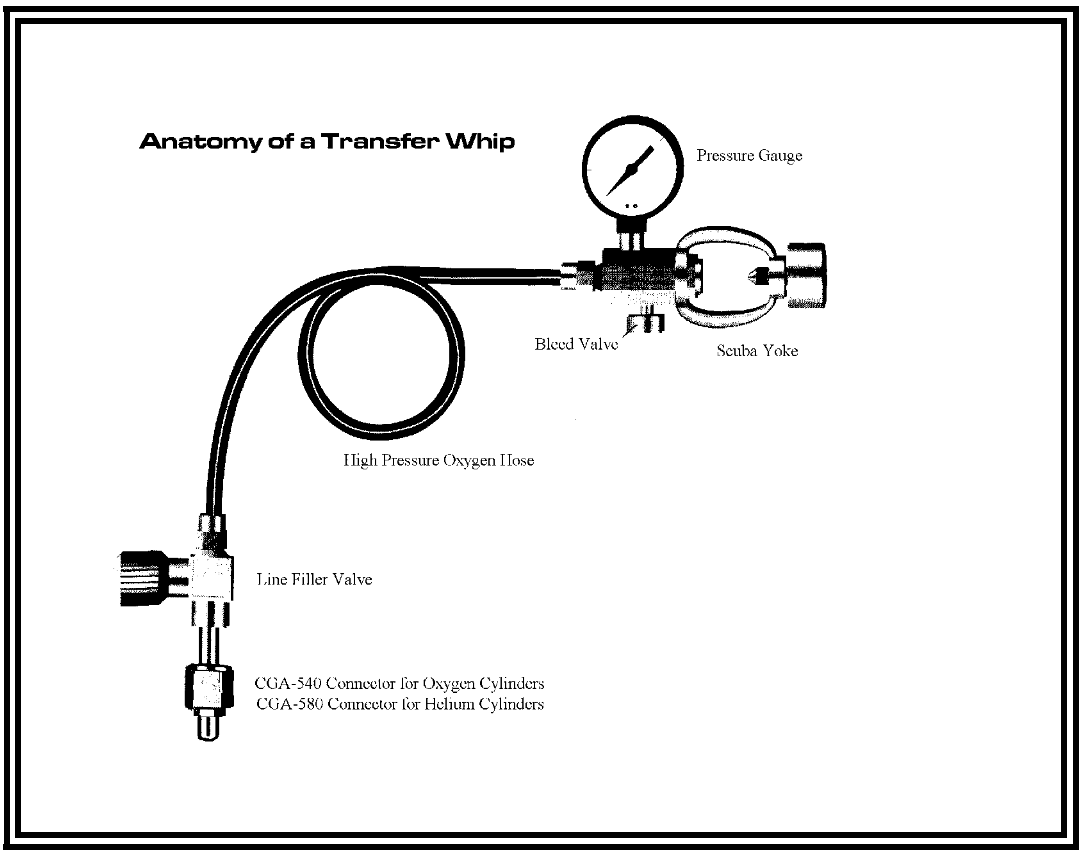
Partial pressure mixing equipment can range from the simplest and least expensive, to some very complicated and costly setups.

This gas blending method is based on the fact that the proportion, by *volume,* of each gas in a mixture, is directly related to its partial pressure (to the extent that the gases behave as "ideal" gases).

A note here about gas laws: the "Ideal" gas law assumes that pressure is directly proportional to the volume of a contained gas, whereas the "Real" gas law accounts for the fact that certain gases will compress more, or less, than other gases.

What this means is that, with the ideal gas law, we pretend that all gases react the same way, when compressed. (i.e.: the same amount of each gas takes up the same amount of space at the same pressure.)

In actual fact this doesn't happen, so, if we are dealing with really dissimilar gases, like helium and oxygen, then we would have to factor the differences in compressibility into the calculations, by using "Real" gas law equations.



Fortunately, for the purposes of mixing nitrox, oxygen and nitrogen are similar enough in the compressibility department that we can use ideal gas laws, and treat them the same.

Partial pressure blending of nitrox, in its simplest form, consists of transfilling oxygen from an oxygen cylinder into a scuba cylinder, and then topping the scuba cylinder up with compressed air.

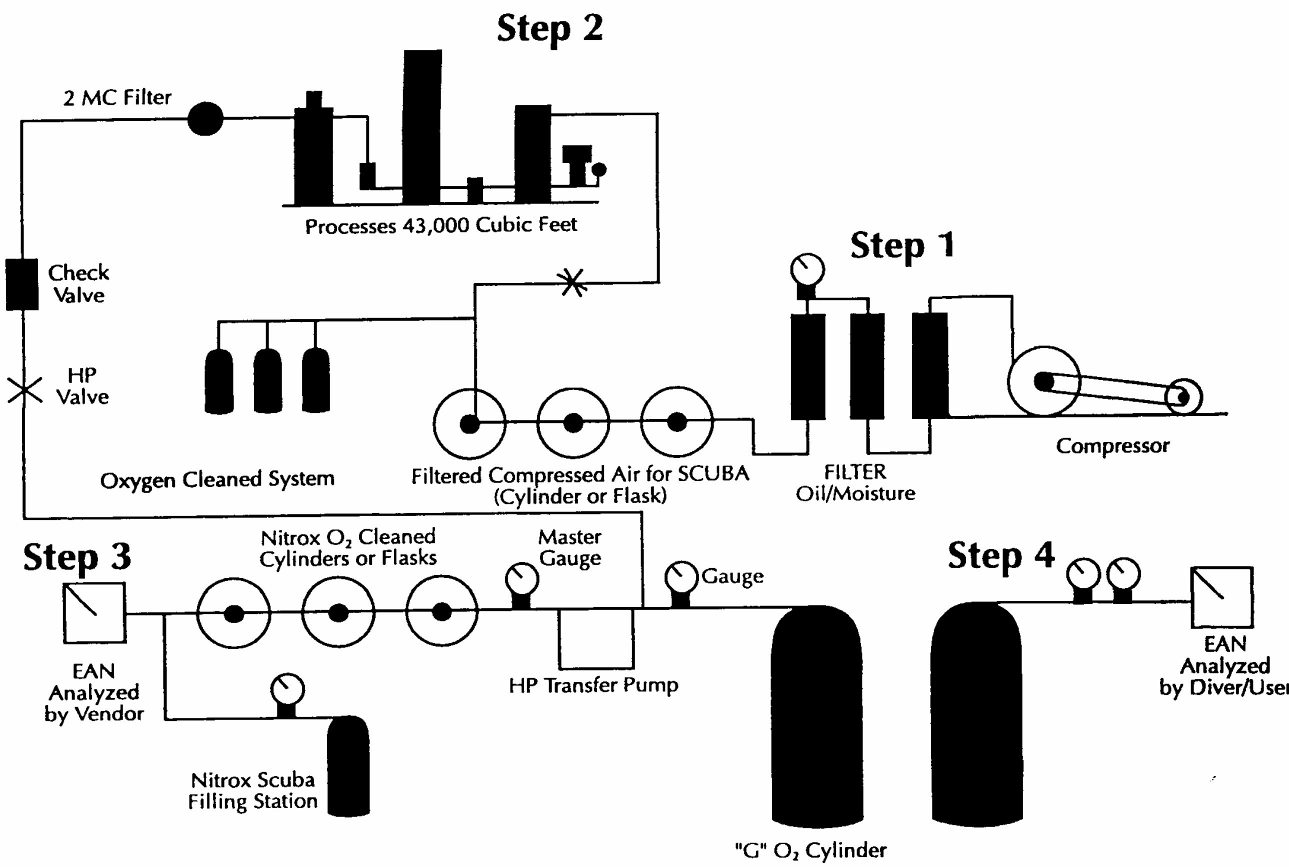
This method is simple, and is low cost, but is it safe?

Because it is impossible to know when an oxygen serviced cylinder, that is in use, has passed the threshold of acceptable contamination, partial pressure blending directly into a SCUBA cylinder, for mixes below 40 percent, is not acceptable.

For technical mixes above a forty percent oxygen content there is no alternative. For this application you must ensure that the cylinder is, in fact, in current oxygen
service. If in doubt, use the tests from chapter two.

Therefore, with the partial pressure blending method, everything must be oxygen serviced *and remain that way*. Some facilities partial pressure blend on a larger scale, and then bank the nitrox in a cascade system. That way they can store

Oxygen Enriched Air (EAN)
Nitrox Double Filtration Partial Pressure Mixing System



Remember that *everything* that comes into contact with high pressure oxygen, above 40%, must be oxygen serviced.

up to a 40% mix and decant as required.

These partial pressure EANx blending systems can be quite complicated and deluxe. They are custom built, often using oil free compressors and booster pumps to achieve their mixes.

The oxygen service standards must be absolute in the high pressure, oxygen rich areas, and safeguards, such as one way valves to prevent oxygen enriched air from backing into non oxygen serviced areas, are standard.

A drawback to partial pressure blending systems, is that when the pressure in the oxygen cylinder gets below what is required to trans-fill into the empty mixing cylinder, it becomes wasted, unless it is cascaded, or a booster pump is used. It gets costly to send back partially full oxygen tanks.

Partial pressure blending is a workable gas blending method, ***but***:

- you have to maintain your equipment at an oxygen serviced level,
- you have to have a verifiable oxygen compatible air source ,
- you will have oxygen remaining that can't be used unless you have a booster pump
- it is slow

On the plus side, it is the only system that can mix above 40 percent oxygen mixes.

Partial pressure blending: Steps:

Providing that you have met the requirements for oxygen service, the steps to partial pressure blending nitrox are as follows:

- Always analyze the gas in any partially full cylinder
- Compute the desired outcome (equations/formulas in the next chapter)
- Transfill USP grade oxygen, to the desired amount, into a properly labeled and O2 serviced cylinder at a rate **not to exceed 70 psig per minute**
- Pump oxygen compatible air into the scuba cylinder at a rate **not to exceed 100 psig** until the O2 percent is less than 40%
- Accelerate the mixing by introducing O2 compatible air at an increased flow, causing turbulence. The turbulence mixes the oxygen and the air more thoroughly. Do not let the cylinder get hot
- Let the cylinder cool to ambient temperature
- Analyze the gas
- Top up to the desired pressure, if required/indicated
- Let the cylinder stand for six hours to allow for molecular migration, unless it was well mixed by induced turbulence. This can be speeded up by rolling the tanks, but usually is not necessary.

As you can see, mixing by the partial pressure blending method is initially appealing because of the low cost for entry level equipment. However, this has to be balanced with the additional time and energy expended on oxygen service, slow fills and potential hazards.

Advantages:

1. low initial startup costs
2. equipment capable of higher than 40% EANx mixes
3. portability

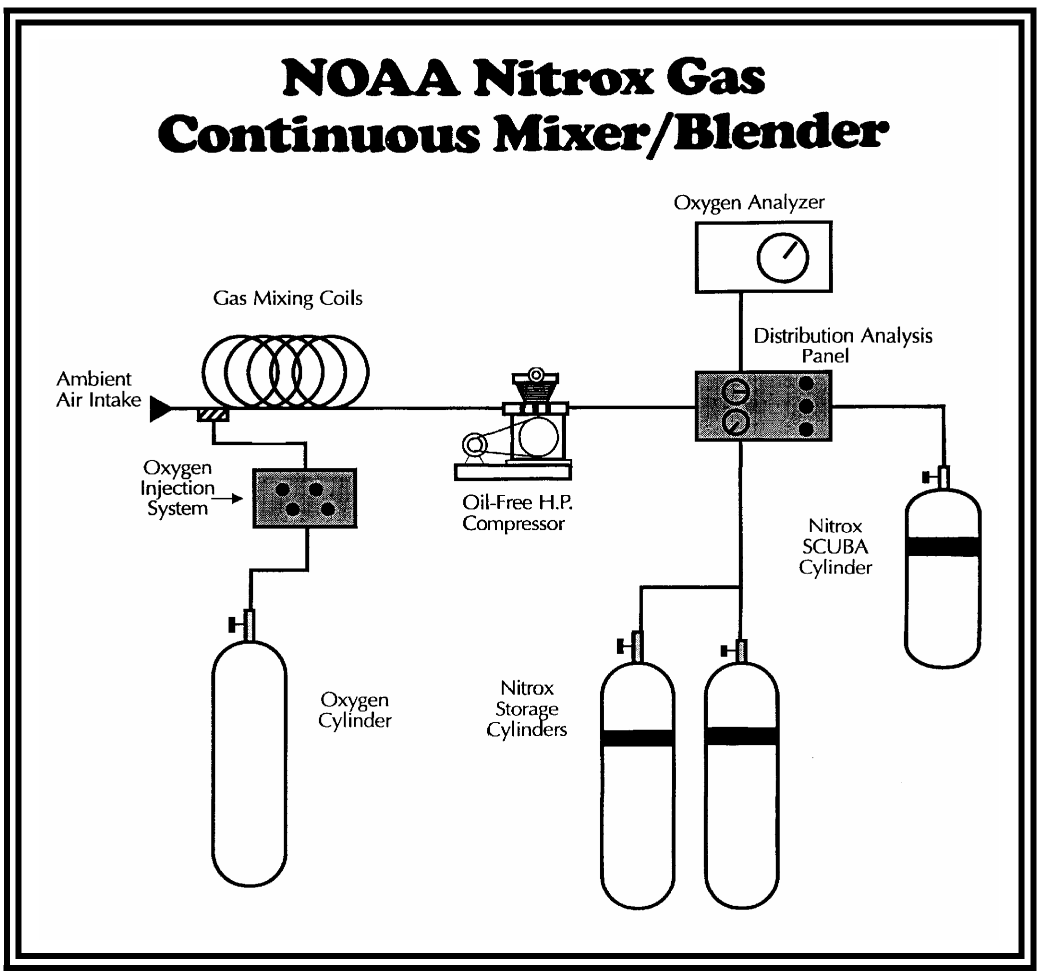
Disadvantages:

1. Everything must be oxygen serviced
2. Unable to utilize all of the oxygen supply due to higher working pressure requirements
3. Gas Analysis is after the mixing.

Continuous Flow Mixing

Continuous flow mixing is where ambient air is mixed with low pressure oxygen before being compressed, analyzed and then dispensed or stored.

Dr. Morgan Wells, while the director of the National Oceanic and Atmospheric Administration (NOAA), patented the system that was to become the world standard.



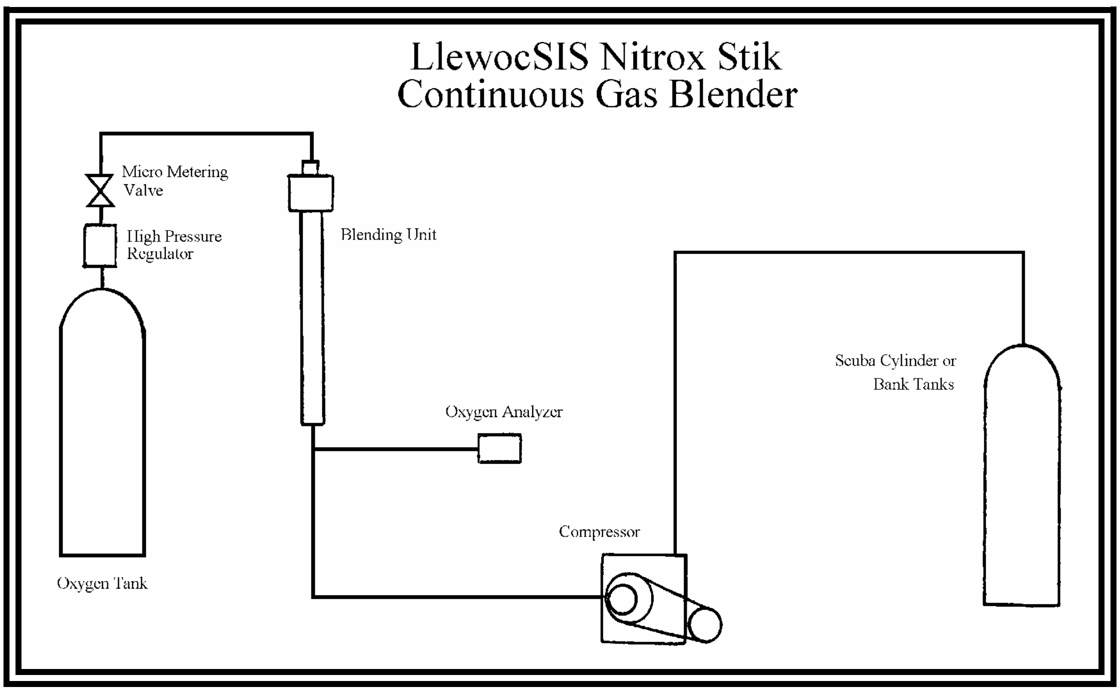
The one drawback to his design is that everything downstream of the mixer still has to be oxygen serviced, because the mixing coils do not fully mix the oxygen and air, resulting in streams of unmixed oxygen going through the compressor.

The benefits of continuous mixing is that the air and the oxygen can be introduced at the same temperature and at low pressure. As well, the mix can be continuously monitored resulting in a high degree of accuracy in the final mix.

Ross Cowell, a Canadian inventor, recognized that if the oxygen air mix could be made totally homogenous (thoroughly mixed) before the compressor, and the oxygen content was kept below 40%, then it would not be necessary to oxygen service any components downstream of the oxygen regulator.

The primary benefit is that as long as a compressor was capable of producing breathing grade air, then a Cowell unit could be attached to the compressor inlet.

The result is that almost anyone with a compressor can mix EANx up to 40%, safely and accurately. His unit is called the *LlewocSIS* or *Nitrox Stik.*



Note: again, we must caution the blender to always be watchful of accumulating condensed hydrocarbons (even in systems where the oxygen content is under 40%.)

If condensed hydrocarbons are detected, eliminate the cause and oxygen service the system.

Advantages:

1. Safety: the air and oxygen are premixed under low pressure
2. Space requirements: some portable units are about the size of a divers forearm
3. Complete mixes: there is no waiting for molecular migration.
4. Accurate mixes: the gas mix is analyzed continuously while blending
5. Complete utilization of oxygen supply without the need of a booster pump.
6. Portable: some units fit into a pelican case, and have no power requirements

Disadvantages:

1. The NOAA continuous blending systems requires an oxygen serviced oil-free compressors. (oil lubricated compressors, because of their design, cannot be oxygen serviced.)
2. The LlewocSIS continuous blending system limits the final mix to 40% oxygen content.
3. More expensive than some partial pressure blending systems.

Oxygen Generation Systems

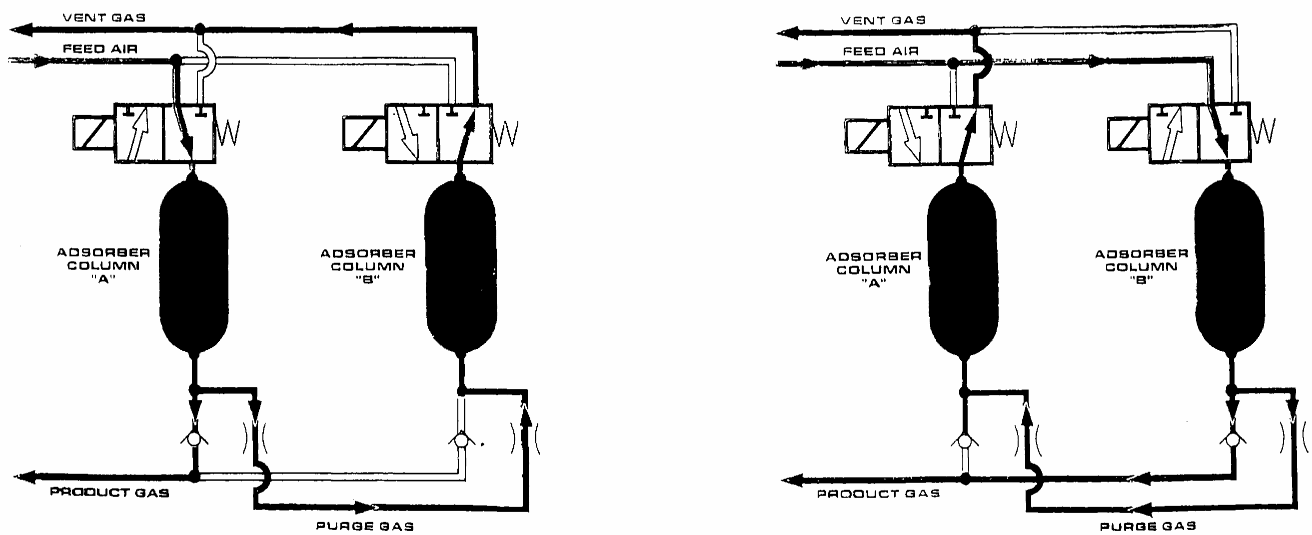
There are basically two types of oxygen generation systems on the market today. They are:

1. Pressure Swing Absorption (PSA)
2. Differential Permeability (DP)

Pressure Swing Absorption

Although technically not a *nitrox* gas blending system, these units can produce up to 95% oxygen at delivery pressures in excess of 3000 psi, thus replacing high pressure bottled oxygen.

Litton PSA System



This system depends on the selective absorption / desorption of gases on molecular sieve materials during pressurization and depressurization with air. One of two sieve beds is pressurized with air from a compressor. The molecular sieve attracts, and absorbs, nitrogen when the pressurized air is passed through it, producing oxygen.

Meanwhile the depressurized bed is purging the nitrogen. This process is alternated, resulting in the continuous production of oxygen.

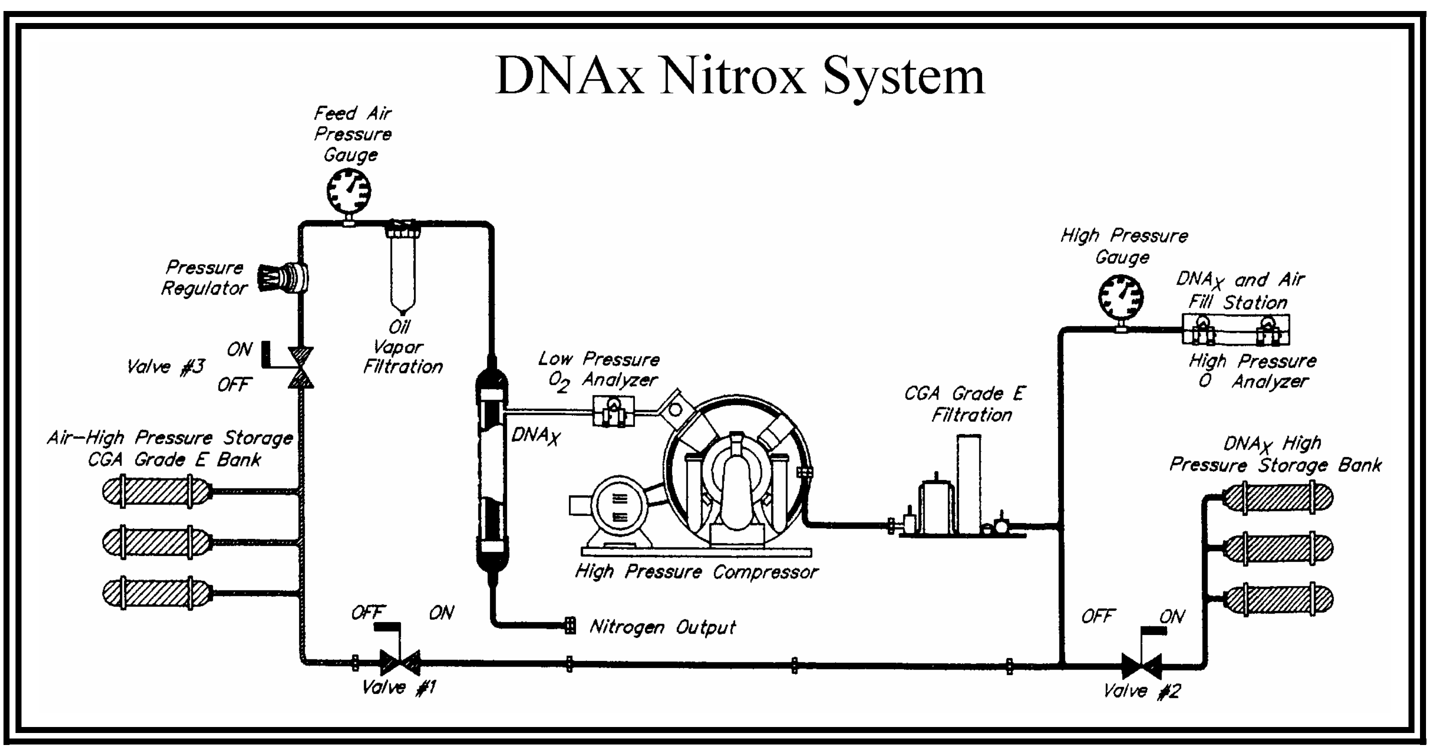
The PSA system is considered to be an oxygen concentrator and, as such, can be used in conjunction with a continuous blending system. It may also be used with a partial pressure blending system if the oxygen is stored.

Differential Permeability

A nitrox production system which produces its own oxygen. This system selectively separates slow gases, like nitrogen, from fast gases, such as oxygen. It actually removes nitrogen from the air.

The concept is based on the principal of osmosis, which is the principal of diffusion through a semi-permeable membrane.

Think of the last time that you dumped spaghetti into a strainer: the water went through and the spaghetti stayed in the strainer. Well, in scientific terms, the strainer was the semi-permeable membrane, and the water diffused through it, effectively trapping the spaghetti.

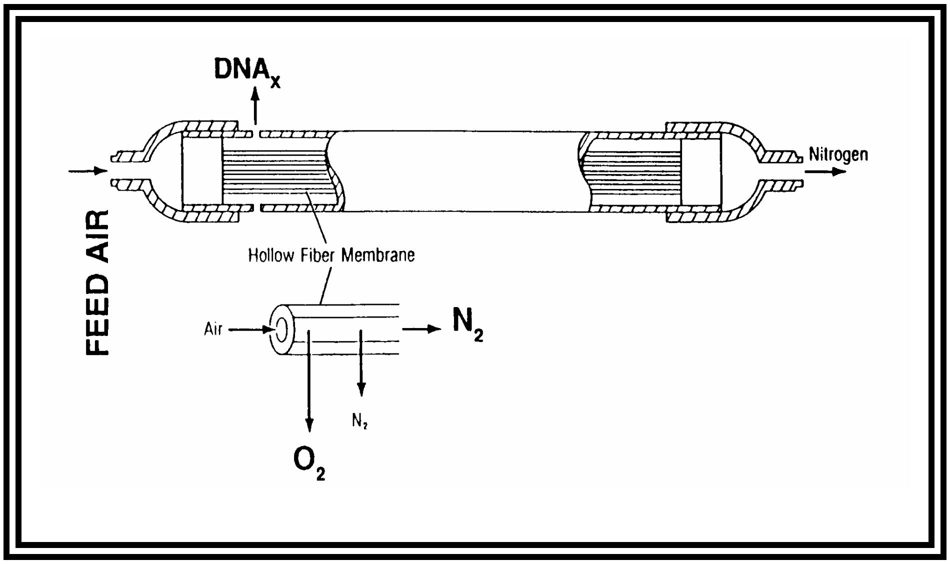


In the differential permeability process of separating gases, the oxygen flows through, and the nitrogen is trapped. The blending technician can control the oxygen/nitrogen ratio.

Disadvantages:

1. Higher initial cost than some systems
2. Strict O2 service requirements with the PSA system.

PSA system is a source for O2 only.



EANx From Commercial Suppliers

Depending on your location, you may have access to a commercial supply of premixed EANx. It can often be ordered from industrial gas supply houses such as Praxair or Air Liquide.

It is interesting to note that the DNAx system, from Undersea Breathing Systems Inc., does not require the operators of their system to be blending technicians. In addition, they do not require any oxygen servicing.

Advantages:

1. Produces own oxygen, eliminating outside sources
2. No gas blender training (with the DNAx system)
3. No need for oxygen servicing (with the DNAx system)
4. Relatively compact
5. Accurate mix
6. Molecular migration not an issue

Advantages:

1. low start up costs
2. no oxygen service requirements if supply is below 40%
3. no equipment maintenance worries
4. No high pressure oxygen stored on site

Disadvantages

1. dependent on suppliers
2. higher cost of doing business

Chapter Four Review Questions

1) *Why wait six hours before analyzing when mixing by weight?*
2) *What is meant by "real gas law"?*
3) *What is meant by "ideal gas law"?*
4) *Why is oxygen service important when partial pressure mixing*
5) *Explain how to partial pressure blend?*
6) *How is continuous flow mixing different from partial pressure blending?*
7) *Is pressure swing absorption a gas mixing system?*
8) *Do you have to wait six hours to analyze when mixing with differential permeability*
9) *Are their any advantages in obtaining EANx from commercial suppliers?*
10) *What is the blending system best suited to you?*

Answers:

Notes:

Chapter Five

Gas Mixing Formulas

There are four basic formulas that we need to know to be able to fill our nitrox tanks. If a diver requests a specific mix, it is imperative that we provide that mix.

It sounds simple enough, but it is surprisingly rare that the diver gets the exact mix that they ask for.

The four formulas are for:

1. a partial pressure fill, starting with an empty cylinder
2. a continuous blending fill, starting with a partially full tank
3. a partial pressure fill, starting with a partially full tank
4. starting with a partially full tank, adding a banked mix, and topping with air

How to calculate a partial pressure fill, starting with an empty tank:

- ♦ Start with the amount of oxygen in the desired mix, which we express as the fraction of oxygen or "FO2"
- ♦ From this we subtract the fraction of oxygen in ambient air which is 21% (note that we express percentages as decimals).
- ♦ Divide the sum by the fraction of nitrogen in ambient air which is .79
- ♦ Then multiply by the desired ending pressure in the cylinder.

$$\frac{\text{Desired FO2} - .21 \text{ (the amount of O2 in air)}}{.79 \text{ (the amount of N2 in air)}} \times \text{Desired ending psig in the cylinder}$$

Example: A diver asks for an EANx 32 in his steel 72 cubic foot cylinder, rated at 2400 psi working pressure.

$$\frac{.32 - .21}{.79} \times 2400 = 334$$

.32 is the desired O2 percentage in the final mix
.21 is the O2 percentage in air
.79 is the nitrogen percentage in air
2400 is the final PSIG in the tank
334 is the amount of pure O2 required

To mix this, you would transfill 334 psi of oxygen into the scuba cylinder and add 2066 psi of oxygen compatible air, to bring it up to the 2400 psi working pressure. The result will be an EANx 32%, at 2400 psi. The steps to follow are:

- Slowly drain off any gas in the scuba cylinder, until it is empty
- Transfill with oxygen at 70 psi per minute until 334 psi is reached
- Add oxygen compatible air at a rate of 100 psi per minute until the mix is under 40% O2 content
- Speed up the fill rate to induce turbulence, but not heat
- Fill to the desired working pressure
- Let cool to ambient temperature
- Analyze mixture
- Record in fill log

This formula will also work if your top up gas is an EANX mixture. In this case simply change the fractions of oxygen and nitrogen to reflect the EANx gas percentages instead of those found in air.

Example: A diver wants an EANx 40 in his 3000 psig cylinder, and you have a bank of EANx 32

$$\frac{.40 - .32}{.68} \times 3000 = 353$$

.40 is the desired O2 percentage in the final mix
.32 is the O2 percentage in your bank bottles
.68 is the nitrogen percentage in your bank bottles (100% - 32% O2)
3000 is the final PSIG in the tank
353 is the amount of additional O2 required

To mix this, you will transfill 353 psi of oxygen into the empty cylinder, and top up with 2647 psi of EANx 32 to the 3000 psi working pressure. The analyzed result will be a EANx 40 mix.

How to calculate a continuous blending fill, starting with a partially full tank:

When continuous mixing, the oxygen content of the final mix is controlled by the fraction of oxygen introduced into the gas stream.

- multiply the desired pressure in the tank by the desired fraction of oxygen to get the psig of O2 in the final mix
- multiply the present pressure in the tank by the existing fraction of oxygen to get the psig of O2 in the present mix
- subtract the present pressure from the desired pressure.
- subtract the psig of O2 in the present mix from the psig present in the final mix
- Divide the difference in O2 psig by the difference in total psig

Example: A diver has 1200 psig of an EANx 32 mix and wants an EANx 36 mix, in a cylinder that has a working pressure of 3000 psig

1)

$$\begin{array}{rcl} \mathbf{3000} \times \mathbf{.36} = \mathbf{1080} & & \text{(psig of oxygen in the final mix)} \\ \underline{\mathbf{1200}} \times \mathbf{.32} = \underline{\mathbf{384}} & & \text{(psig of oxygen in the present mix)} \\ \mathbf{1800} \qquad\qquad \mathbf{696} & & \end{array}$$

2)

$$\frac{\mathbf{696}}{\mathbf{1800}} = \mathbf{.386}$$

3000 is the final psig in the tank
.36 is the desired O2 percentage in the final mix
1200 is the starting psig in the tank
.32 is the starting O2 percentage in the tank
696 is the difference in O2 required (in psi)
1800 is the difference in total tank pressure required
.386 is the O2 required in the additional mix (38.6%)

In other words, 38.6% of the 1800 psi added to the tank must be O2, so this divers cylinder would be topped up with 1800 psig of EANx .386

How to calculate a partial pressure fill, starting with a partially full tank:

How would we do the above scenario with partial pressure blending?

- Use the continuous blending formula to find the percentage of oxygen required (FO2).
- Simply plug the FO2 required (in this case 38.6%) into the partial pressure formula.

In this case:

$$\frac{.386 - .21}{.79} \times 1800 = 401$$

.386 is the O2 percentage in the additional mix
.21 is the O2 percentage in air
.79 is the nitrogen percentage in air
1800 is the difference in psi required
401 is the amount of additional O2 required

Transfill 401 psig of oxygen into the cylinder that already contains 1200 psig of EANx 32, then top up the remainder with oxygen compatible air.

This example is also a good demonstration of why a booster pump would be required if partial pressure filling methods were used for filling partially full cylinders. Without the booster pump, the pressure in the O2 cylinder would need to be high enough to add 401 psi to the 1200 psi already in the scuba tank.

How to fill a partially full tank, using a banked mix, and topping with air

Example: A diver has 1200 psig of a EANx 32 mix and wants an EANx 36 mix, in a cylinder that has a working pressure of 3000 psig. You have a banked mix of 40%.

3000 x .36 = 1080		(psig of oxygen in the final mix)
1200 x .32 = 384		(psig of oxygen in the present mix)
1800	**696**	(psig of oxygen to be added)

3000 is the final psig in the tank
.36 is the desired O2 percentage in the final mix
1200 is the starting psig in the tank
.32 is the starting O2 percentage in the tank
696 is the difference in O2 required (in psig)
1800 is the difference in total tank pressure required

Then, to calculate the amount of banked mix to be added:

$$\frac{696 - (.21 \times 1800)}{.19} = 1673$$

.19 is the difference between the bank mix (in this case, a 40% mix), and air (at .21)
696 is the psig of O2 needed
1800 is the total psig to be added to the tank
1673 is the psig of bank mix to be added (in this case, a 40% bank mix)

So….. To properly fill this tank, you would add 1673 psig of your 40% bank mix, and top with 127 psig air (1200 + 1673 + 127 = 3000).

Please Note:

1) If calculations show that the amount of bank mix to be added is greater than the total psig to be added, then some gas must be drained from the tank before starting.
2) The .19 will change, based on the bank mix being used. For example, if the bank mix being used is a 32% mix, then the .19 will change to .11 (.32 - .21)

To check/confirm your calculations:

Calculate and compare the O2 in the final 36% mix:

3000 psig x .36 = 1080 (psig O2 in 36% mix)

To the total of the components:

1673 psig	**x**	**.40 =**	**669.20**	(O2 in 40% added)
1200 psig	**x**	**.32 =**	**384.00**	(O2 in starting mix)
127 psig	**x**	**.21 =**	**26.67**	(O2 in top up air)
3000 psig			**1079.87**	(Total psig O2 in mix)

Please Note: It is a good idea to always double check all of the calculations. Put your answers back into the formulas, and see if they work out correctly.

Comparing the final answer(s) to a total of all the components is another way to check the calculations.

Chapter Five Review Questions:

1) *You require 3000 psi of a 36% mix. Using a partial pressure blending method, how much pure oxygen do you add to the tank?*
2) *What is the flow rate, per minute, when adding oxygen to a tank?*
3) *What is the flow rate, per minute, of air into an oxygen enriched environment?*
4) *You require 2400 psi of a 36% mix. You have 1200 psi of a 32% mix remaining in the tank. What is the percentage of oxygen in you continuous blend?*
5) *a) Under what conditions could you continuous blend higher than 40%?*
   b) Is it recommended?
   c) Can you partial pressure blend oxygen concentrations higher than 40%?
6) *A 3000 psi tank has 1800 psi of a 32% mix in it. The customer wants a 36% mix. How would you fill it, using your 40% banked mix, and topping with air.*
7) *You require 3000 psi of 40%. There is 1000 psi of 32% in a cylinder. How much oxygen do you add by the partial pressure method?*
8) *Would you require a booster pump for question #7?*
9) *Would the booster pump be required to be o2 serviced? Why?*
10) *In the field, will you use charts or the equations to do your calculations?*

Answers:

Notes:

Appendix I

Answers to Review Questions

Chapter 1 Answers:

1) USP United States Pharmacopoeia

2) No... A welding oxygen tank is not completely emptied prior to refilling, which could result in contamination.

3) 40%

4) Oxygen toxicity, hypoxia, decompression sickness.

5) Fire, explosion.

6)
   1) Heat of Compression
   2) High speed particle impingement
   3) Localized frictional heating
   4) Material compatibility

7) Oxygen clean is the *"verifiable"* absence of particles, fibers, oil, grease, and other contaminants

8) Oxygen compatible means a material that will not react with oxygen at the systems designed maximum pressure and oxygen content.

9) Designed for oxygen use means that due consideration is given for special needs of oxygen under pressure, in the environment in which it is contained.

10) If a system has been properly designed for oxygen use, is oxygen clean, and has oxygen compatible components, then the system is considered to be oxygen serviced.

Chapter 2 Answers:

1)
   1) Dismantling equipment completely
   2) inspection and gross cleaning
   3) Pre cleaning and rinsing
   4) Final cleaning, rinsing and drying
   5) Inspection and testing for clean
   6) Re assembling, packaging and labeling

2) To remove rust, scale, joint compound, burrs, or any coarse particulate, whether organic or inorganic.

3) An approved cleaning solution, such as simple green, blue gold, NOC, or Delta Omega Technologies DOT 111-113.

4) Some pre-cleaners, like simple green, may leave a slight organic residue. Because everything organic is carbon based, these solutions are used in the pre-cleaning stage only.

5) NOC and TSP are alkaline.

6)
   1) PH test
   2) Visual inspection using white light
   3) Visual inspection using ultra violet light
   4) Water break test
   5) Shake test

7) The presence of a contaminant.

8) Oxygen compatible, such as Christolube.

9) Return that part for another oxygen cleaning series.

10)
   1) With a 4 inch high band wrapped around the tank, that is clearly marked with Nitrox or EANx,
   2) with a contents sticker, and
   3) with a Visual Inspection label, that is marked with the level of O2 servicing done on the tank.

Chapter 3 Answers:

1) Yes or no, depending on the blending method used. If the system used provides a homogenous mix, below 40%, such as the LlewocSIS Nitrox Stik, or the membrane system, then yes because any nitrox gas mixture below 40%, can be treated as air, as per NOAA standards.

If partial pressure blending is the method used, then the answer is no. For oxygen compatible air, we must have modified CGA Grade “E” standard, which has no more than .1 mg/m3 condensed hydrocarbons, and 2 ppm carbon monoxide. The CGA grade “E” Standards allow 5 mg/m3 condensed hydrocarbons, and 10 ppm carbon monoxide.

2) 4 times per year, unless otherwise legislated.

3) Yes. Air analysis is a sample of compressed air, that is analyzed for specific contents and contaminations. Oxygen analysis only measures the oxygen content.

4) See answer to question #1.

5) Maximum allowable condensed hydrocarbons is .1 mg/m3.

6) Carbon dioxide is the result of forcing carbon monoxide over a catalyst with CO_2 being a product. Or... CO_2 occurs naturally, as the exhaled by product of respiration. If enough exhaled CO_2 was drawn into a compressor intake, elevated CO_2 levels could result.

7) CGA “E” Standard, with a modified carbon monoxide allowance.

8) No. Fix the problem.

9) Carbon monoxide is the result of incomplete combustion. Therefore, its source would be from intake air near automobile exhaust, or the incomplete combustion of compressor oil.

10) No. providing that the compressed air meets the modified CGA “E” standards.

Chapter 4 Answers:

1) To allow for thorough mixing through molecular migration.

2) Real gas laws account for the difference of compressibility of gases. i.e. some gasses that are compressed to the same pressure, will have different volumes.

3) Using the ideal gas law, we act as if gases compressed to the same pressure, result in the same volumes.

4) When partial pressure mixing, parts of the system come into contact with more than 40% oxygen, at pressures higher than 250 psi, resulting in a potential operation hazard if O2 servicing is not complete/thorough.

5) Decant pure oxygen into an oxygen serviced cylinder, and top up with oxygen compatible air.

6) Continuous flow has the oxygen and air, under low pressure, pre mixed and analyzed, before the compressor intake. This results in a homogenous, accurate mix. Partial pressure blending requires mixing high pressure oxygen and air separately, then analyzing the result.

7) No. It is an oxygen generator or concentrator.

8) No. The mix is derived from removing nitrogen. As such, it is a naturally homogenous mix.

9) Yes.
   1) Low initial start up costs, due to no requirement for mixing equipment.
   2) No oxygen service requirements if premix is below 40%.
   3) No additional equipment maintenance other than normal.
   4) No High pressure O2 stored on site.

10) Consider:
   1) Availability of O2
   2) O2 service requirements
   3) Cost
   4) Usage

Chapter 5 Answers:

1) $$\frac{.36 - .21}{.79} \times 3000 = 569.6 \text{ psi of } O_2$$

2) 70 psi per minute.

3) 100 psi per minute.

4)
$$\begin{array}{lcl} 2400 \times .36 & = & 864 \\ \underline{1200} \times .32 & = & \underline{384} \\ 1200 & & 480 \end{array} \qquad \frac{480}{1200} = .40 \text{ or } 40\%$$

5) a) With an oil free or oil-less compressor, full oxygen servicing of all parts of the system, and a maximum working pressure of 3000 psi.
b) No
c) Yes, but complete O2 servicing is required, of all components.

6)
$$\begin{array}{lcl} 3000 \times .36 & = & 1080 \\ \underline{1800} \times .32 & = & \underline{576} \\ 1200 & & 504 \end{array} \qquad \frac{504 - (.21 \times 1200)}{.19} = 1326$$

1326 psig is higher than the 1200 psig required to fill the tank to 3000 psig, so some of the 32% mix needs to be drained out first. How much to drain out is based on trial and error. If the tank is drained to 1500 psig, the new calculations are:

$$\begin{array}{lcl} 3000 \times .36 & = & 1080 \\ \underline{1500} \times .32 & = & \underline{480} \\ 1500 & & 600 \end{array} \qquad \frac{600 - (.21 \times 1500)}{.19} = 1500 \text{ psig 40\% mix to be added}$$

(No need to top with air, as tank is full)

7)
$$\begin{array}{lcl} 3000 \times .40 & = & 1200 \\ \underline{1000} \times .32 & = & \underline{320} \\ 2000 & & 880 \end{array} \qquad \frac{880}{2000} = .44 \text{ or } 44\%$$

$$\frac{.44 - .21}{.79} \times 2000 = 582.3 \text{ psi}$$

8) As you are adding 582 psi of O2 on top of 1000 psi air, you would most likely require a booster pump, unless an adequate supply of high pressure O2 was available.

9) Yes, as it’s being used for high pressure oxygen, at over 40%.

10) Whatever you are most comfortable with.

Appendix II

Nitrox Partial Pressure Fill Chart

ENDING OXYGEN PERCENTAGE

ENDING CYLINDER PSI	22 %	23 %	24 %	25 %	26 %	27 %	28 %	29 %	30 %	31 %	32 %	33 %	34 %	35 %	36 %
500	6	13	19	25	32	38	44	51	57	63	70	76	82	89	95
600	8	15	23	30	38	46	53	61	68	76	84	91	99	106	114
700	9	18	27	35	44	53	62	71	80	89	97	106	115	124	133
800	10	20	30	41	51	61	71	81	91	101	111	122	132	142	152
900	11	23	34	46	57	68	80	91	103	114	125	137	148	159	171
1000	13	25	38	51	63	76	89	101	114	127	139	152	165	177	190
1100	14	28	42	56	70	84	97	111	125	139	153	167	181	195	209
1200	15	30	46	61	76	91	106	122	137	152	167	182	197	213	228
1300	16	33	49	66	82	99	115	132	148	165	181	197	214	230	247
1400	18	35	53	71	89	106	124	142	159	177	195	213	230	248	266
1500	19	38	57	76	95	114	133	152	171	190	209	228	247	266	285
1600	20	41	61	81	101	122	142	162	202	203	223	243	263	284	304
1700	22	43	65	86	108	129	151	172	194	215	237	258	280	301	323
1800	23	46	68	91	114	137	159	182	205	228	251	273	296	319	342
1900	24	48	72	96	120	144	168	192	216	241	265	289	313	337	361
2000	25	51	76	101	127	152	177	203	228	253	278	304	329	354	380
2100	27	53	80	106	133	160	186	213	239	266	292	319	346	372	399
2200	28	56	83	111	139	167	194	222	250	278	306	334	362	389	417
2300	29	58	87	116	145	174	203	232	260	291	320	349	378	407	436
2400	30	61	91	121	151	182	212	243	273	303	334	364	394	425	455
2500	32	63	94	126	158	189	221	253	284	316	348	379	411	443	474
2600	33	66	98	131	164	197	230	263	296	329	362	394	427	460	493
2700	34	68	102	136	170	205	239	273	307	341	375	410	444	478	512
2800	35	71	106	141	177	212	248	283	318	354	389	425	460	496	531
2900	37	73	110	146	183	220	256	293	330	367	403	440	477	513	550
3000	38	76	113	151	189	227	265	303	341	379	417	455	493	531	569
3100	39	78	117	156	196	235	274	313	353	392	431	470	510	549	588
3200	41	81	121	162	202	243	283	324	364	405	445	486	526	567	607
3300	42	84	125	167	208	250	292	334	375	417	459	501	543	584	626

ENDING OXYGEN PERCENTAGE

ENDING CYLINDER PSI	37 %	38 %	39 %	40 %	45 %	50 %	55 %	60 %	65 %	70 %	75 %	80 %	85 %	90 %	95 %
500	101	108	114	120	152	184	215	247	278	310	342	373	405	437	468
600	122	129	137	144	182	220	258	296	334	372	410	448	486	524	562
700	142	151	159	168	213	257	301	346	390	434	478	523	567	611	656
800	162	172	182	192	243	294	344	395	446	496	547	597	648	699	749
900	182	194	205	216	273	330	387	444	501	558	615	672	729	786	843
1000	203	215	228	241	304	367	430	494	557	620	684	747	810	873	937
1100	223	237	251	265	334	404	473	543	613	682	752	822	891	961	1030
1200	243	258	273	289	365	441	516	592	668	744	820	896	972	1048	1124
1300	263	280	296	313	395	477	559	642	724	806	889	971	1053	1135	1218
1400	284	301	319	337	425	514	603	691	780	868	957	1046	1134	1223	1311
1500	304	323	342	361	456	551	646	741	835	930	1025	1120	1215	1310	1405
1600	324	344	365	385	486	587	687	790	891	992	1094	1195	1296	1397	1499
1700	344	366	387	409	516	624	732	839	947	1054	1162	1270	1377	1485	1592
1800	365	387	410	433	547	661	775	889	1003	1116	1230	1344	1458	1572	1686
1900	385	409	433	457	577	697	818	938	1058	1178	1299	1419	1539	1659	1780
2000	405	430	456	481	608	734	861	987	1114	1240	1367	1494	1620	1747	1873
2100	425	452	478	505	638	771	904	1037	1170	1303	1435	1568	1701	1834	1967
2200	445	473	501	529	668	807	947	1086	1225	1364	1504	1643	1782	1922	2061
2300	465	494	524	553	699	844	990	1135	1281	1426	1572	1717	1863	2008	2154
2400	486	516	546	577	729	881	1033	1184	1337	1488	1641	1792	1944	2096	2248
2500	506	537	569	601	759	917	1076	1234	1392	1550	1709	1867	2025	2183	2342
2600	526	559	592	625	790	954	1119	1283	1448	1612	1777	1941	2106	2270	2435
2700	546	581	615	649	820	991	1162	1332	1504	1674	1846	2016	2187	2358	2529
2800	567	602	637	673	851	1027	1205	1382	1559	1736	1914	2091	2268	2445	2623
2900	587	624	660	697	881	1064	1248	1431	1615	1798	1982	2165	2349	2532	2716
3000	607	645	683	721	911	1101	1291	1481	1671	1860	2051	2240	2430	2620	2810
3100	627	667	706	745	942	1137	1334	1530	1727	1922	2119	2315	2511	2707	2904
3200	648	688	729	769	972	1174	1377	1579	1782	1984	2187	2389	2592	2794	2997
3300	668	710	751	793	1002	1211	1420	1629	1838	2046	2256	2464	2673	2882	3091

Appendix III
Resources

Cleaning Solutions:

Blue Gold

- **Modern Chemical Inc**
  PO Box 368
  Jacksonville, Arkansas
  USA 72078
  (501) 988-1311

Simple Green

- Available in various hardware/supermarket stores.

TSP

- Available in various hardware/supermarket stores

Synthetic Lubricants

CF 2000 (synthetic compressor oil)

- **Undersea Breathing Systems, Inc (DNAx System)**
  3599 - 23rd Avenue South, #9
  Lake Worth, Florida
  USA 33461
  (561) 588-7698

Christolube (synthetic grease)

- **Lubrication Technology, Inc**
  310 Morton Street
  Jackson, Ohio
  USA 45640
  (614) 286-2644

Air Analysis

- Lawrence Factor, Inc
  4740 North West 157th Street
  Miami Lakes, Florida
  USA 33014
  (305) 430-0864

- **TRI Environmental**
  9063 Bee Caves Road
  Austin, Texas
  USA 78733-6201
  (800) 880-8378

Compressors & Compressor Parts/Supplies

- *Compressed Air Supplies (parts & supplies)*
  800 Old Griffin Road, #3
  Dania, Florida
  USA 33004
  (954) 929-4462

- Lawrence Factor, Inc (filter towers)
  4740 North West 157th Street
  Miami Lakes, Florida
  USA 33014
  (305) 430-0864

- **Rix Industries (oil free compressors)**
  4900 Industrial Way
  Benicia, California
  USA 94510
  (707) 747-5900

Booster Pumps

- *Haskel International, Inc*
  100 E Graham Place
  Burbank, California
  USA 91502
  (818) 843-4000

Oxygen Enriched Air Systems

- **EnviroDive Services (TheNitrox Stik Continuous Gas Blender)**
  www.envirodive.com
  c/o PO Box 238 or PO Box 735
  Porthill, Idaho / Creston, BC
  USA 83853 / Canada V0B 1G0
  (250) 254-5076 / (250) 254-5076

- **Hyperbarics International, Inc (NOAA Continuous Blender)**
  490 Carribean Drive
  Key Largo, Florida
  USA 33037
  (305) 451-2551

- **ANDI (Litton InstaGas (PSA) System)**
  74 Woodcleft Avenue
  Freeport, New York
  USA 11520
  (516) 546-2026

- **Nitrox Technologies, Inc (Membrane/Air Separation Systems)**
  551 Middle Rincon Road
  Santa Rosa, California
  USA 95409
  (707) 538-7598

- **Undersea Breathing Systems, Inc (DNAx System)**
  3599 - 23rd Avenue South, #9
  Lake Worth, Florida
  USA 33461
  (561) 588-7698

Partial Pressure Blending Fill Whips, etc.

- **Global Mfg. Corp.**
  1829 South 68th Street
  West Allis, Wisconsin
  USA 53214
  (414) 774-1616

Oxygen Analyzers

- **Maxtec Inc**
  PO Box 511106
  Salt Lake City, Utah
  USA 84151-1106
  (800) 748-5355

Technical Support/Information

- **Wendell Hull & Associates**
  Las Cruces, New Mexico
  (918) 746-1918

- **Global Mfg. Corp.**
  1829 South 68th Street
  West Allis, Wisconsin
  USA 53214
  (414) 774-1616

- **EnviroDive Services**
  www.envirodive.com

c/o PO Box 238	or	PO Box 735
Porthill, Idaho		Creston, BC
USA 83853		Canada V0B 1G0
(250) 254-5076		(250) 254-5076

- **Diving Services Consultants**
  www.tecrecdiving.com
  1894 Daimler Road
  Rockford, Illinois
  USA 61112
  (815) 387-2184