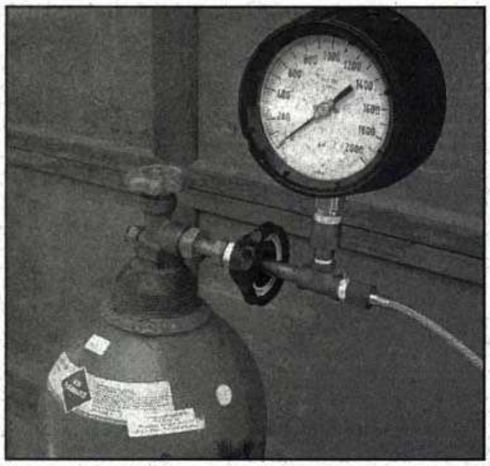
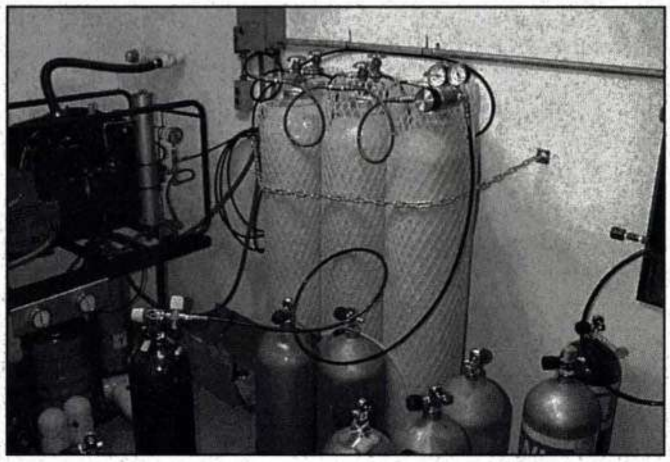
New 4th Edition

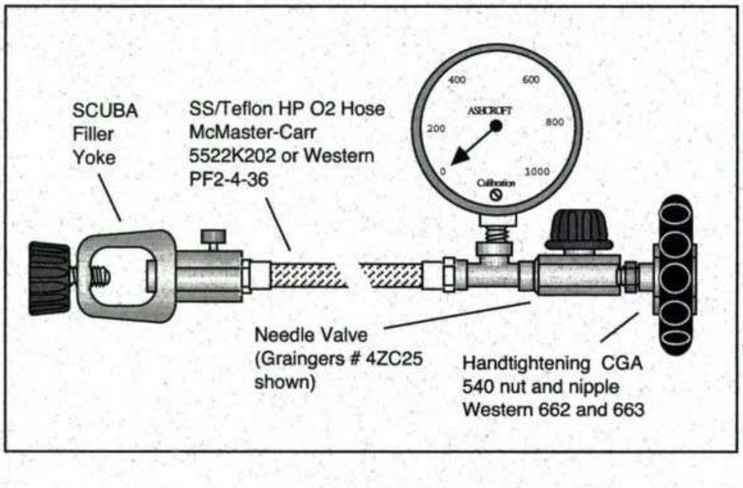
Vance Harlow's

Oxygen Hacker's Companion

The Compleat & Unauthorized Sourcebook on the Handling and Use of Oxygen, Nitrox and Trimix, for Dive, Aviation and Emergency Use.







AIRSPEED PRESS

Vance Harlow's
OXYGEN HACKER'S COMPANION

CONTENTS Page

Vance Harlow's
The Oxygen Hacker's Companion

WARNING and DISCLAIMER

Both the use and the handling of high pressure oxygen can be extremely dangerous if done without adequate knowledge, equipment, or caution.
This book does not pretend to be specific, comprehensive, or complete instructions for the use or handling of HP gases, but rather is a compendium of information on the subject that the author has collected from a variety of sources, and has found useful in his own projects.

Since the author and publisher have no control on how anyone might make use of the information in this book the author and publisher take no responsibility for the results, nor for the accuracy or completeness of the information. The author and publisher take no responsibility for any damage or injury resulting from the use or misuse of the information contained in this publication.
If you are not comfortable with the terms of this disclaimer, or satisfied with the contents of this booklet, you are encouraged to return it (within a reasonable length of time) for a full refund of your money.

We welcome any feedback. Please address any comments, complaints, inquiries, and especially corrections, to:

AIRSPEED PRESS
79 Old Denny Hill
Warner, NH 03278

To email us, please use the contact form at our webpage.

For additional copies of this book, of information on our othr publications, visit our website at **www.airspeedpress.com**

This is version 4.9

Introduction

Oxygen is a very useful and potent gas with many applications, especially for the diver and the aviator. Unfortunately for the individual who wants to learn more about O2 handling, high pressure gases, especially oxygen, exist in a gray area deep inside a bewildering maze of Compressed Gas Association (CGA) guidelines, Dept. of Transportation (DOT) regulations, Food and Drug Administration (FDA) laws, state laws, and industry codes. To which a diver using O2 can add NOAA and Navy guidelines, and the dictates of a half dozen "tech diving" certifying organizations. Aviators can add the Federal Aviation Administration (FAA).

The sheer pressures involved - 200 atmospheres or more - are so much higher than most of us are used to dealing with, or can obtain in our basement or garages, and this too adds an aura of black art to the subject. Dive shops and gas suppliers are both well aware of this mystique, and often as not seem to enjoy their role as initiates of a discipline which is shrouded in mystery, and are often reluctant to share information.

There is also always a certain overcaution and "political correctness" at work with large institutions that leads them to be overly cautious in how they deal with such subjects. DAN is probably not about to advise you about using welding O2 in emergency treatment. PADI may reluctantly and half-heartedly allow itself to be dragged into the nitrox certification game, but isn't about to tell where to buy your own oxygen mixing whip - let alone how to save a few bucks by making one. And your local industrial/medical gas dealer probably won't offer you much help with how to clean and fill your own O2 tanks.

As a result, straightforward information about using and handling O2 is hard to come by, and much of what you hear will be third hand and of dubious validity.

The purpose of this booklet is not to teach how to administer O2 in a medical emergency, use custom dive gases, or breathe O2 at high altitudes. Those subjects are all covered better elsewhere and in more detail. Anyone intending to do any of these things should take the appropriate courses and/or read the appropriate books. The purpose of this booklet is simply to fill in some of the gaps in the other literature, and make available a lot of real -world information regarding the nuts and bolts of actually handling O2, and sources for the necessary parts, that has not been readily available in the past.

There's a right way and a wrong way to do almost anything as the anal compulsives and authority freaks among us are fond of pointing out. There are also usually several intermediate paths which prowl the gray area in between. Usually they are a lot cheaper and less hassle, but the trick is to be sure you stay on the right side of the line.

In this book, I make occasional reference to the doings of a certain Cale. Cale is the fearless kamikaze of the amateur HP gas field. He is well informed, technically able, but with a few surprisingly large blind spots and a gift for operating in that gray area just short of disaster. Whether this is because of skill and knowledge or pure luck so far is hard to say. I use him here not as an example that anyone in their right mind should follow, but as an example of the "other" way to do it. Those who would follow his extremely questionable example do so at their own risk!

INTRO TO THE 4th EDITION

This 4th Edition marks the third major revision of this book, and its entry into respectability. Not because we have changed so much, but because the dive industry has caught up with the oxy hacker underground, and much of what we have been preaching, that sounded so iconoclastic and radical four years ago, is respectable and mainstream now. Such as that O2 cleaning is kitchen science not rocket science, that regs used with recreational nitrox mixes don't need to be O2 cleaned or fitted with green and yellow trim and that it doesn't take $5000 worth of overpriced gear and a college degree to mix nitrox or trimix.

PADI and SKIN DIVER magazine, who not too long ago were united in denouncing nitrox as the "voodoo gas" now endorse it wholeheartedly.

A recent DAN summit on nitrox use (to which we were, ironically, not invited) concluded that the stuff was - surprise! - OK. That there was no increased risk of DCS from nitrox use, that there was no need to track OPU O2 exposure for recreational nitrox divers, endorsed the 1.6 ata maximum PO2 limit, and concluded that standard, uncleaned SCUBA gear was fine with mixes of 40% and below.

And SCUBA DIVING magazine, after many test dives, recently came out and acknowledged the "less fatigue" benefits of nitrox. They also, interestingly enough, found evidence that divers do get better "gas mileage" off a tank of nitrox than they do off a comparable tank of air!

To old friends and readers none of this will come as a surprise.

Those old friends may, however, note with some regret one change resulting from our new respectability; Cale's old bogus tank bill-of-sale is gone. It was always intended to be mostly tongue-in-cheek, but over the years several industry types looking for reasons to discredit the book have claimed that "The Oxy Hacker endorses stealing tanks and breaking the law", so we figured the joke was getting old and it was time for it to go. On the other hand, besides a complete cosmetic redo to bring the OXY HACKER in line with our newer books, we've added a lot of good stuff, including much improved analyzer and sampler plans (and a $5 BC QR sampler). argon, and, for those of you with access to a compressor, a $25 continuous mixer that works just like the $2000 commercial units and makes nitrox blending as easy as filling a tank.

No Cause For Complacency, Though

When this book first came out, one of the main points it made was that O2, while dangerous, was not nearly as dangerous as we were being told, and that there was no reason why a diver could not handle it just as safely as a dive shop.

In the years since then there there has been a small but steady stream of incidents involving O2 to remind us that, if O2 isn't as dangerous as we were once told, it still is far from being safe. At a recent dive industry workshop on O2 safety put on by scientists from the White Sands NASA labs the message was that handling HP O2 always involved a certain element of risk. That one takes all the precautions one can, in the light of the best information one can obtain, but that there is always still an element of a crapshoot to the process due to the inherent unpredictability of the gas.

The good news, though, is that considering the huge increase in nitrox use and hence mixing, both in garages and in dive shops, the number of incidents has been tiny. There have been a couple of tank fires during the O2 priming stage of PP mixing. A titanium regulator combusted while being used with 100% O2. A couple boosters not designed specifically for O2 use combusted while being used with 100% or high FO2s. A filler whip hose lit when someone was topping off a primed tank and opened the tank valve too quickly, sending a surge of O2 up the empty and dirty hose. And oddest of all, a tank is rumored to have combusted while on the back of a diver leaving a dive store. Most if not all of these incidents could have been prevented by better technique or following some of the more basic rules of O2 safety.

Another point worth mentioning raised at the White Sands presentation is that O2 cleaning must be an ongoing process not a one-time ritual. Many older mixing systems have not been cleaned since they were installed, and may be reaching the danger point due to the gradual build-up of contaminants. This is a good warning. I think a lot of us who carefully overcleaned our tanks and whips a few years ago during the " rocket science" years are now growing so complacent that we too often neglect even the the kitchen science precautions. Don't! The thing about O2 is that everything works fine until it doesn't. There's always an invisible margin between you and disaster, but until you cross it you have no way of knowing how wide it is. If you begin each day's mixing by starting where you left off the day before, and cutting one more corner, then the inevitable outcome, soon or later, is kabooomm! Pick reasonable limits, and stick to them.

Advice To The Beginning Mixer

I can still remember vividly the first time I opened with trembling hand the O2 tank valve to begin mixing my first tank of nitrox. I'd read everything I could (not much in those days - mainly the NOAA manual and a couple of agency mix manuals which were cribs of it), built my whip and analyzer and O2 cleaned my tanks - but still I was waiting for the sky to come crashing down! There just had to be a catch, I couldn't help but feel - it just couldn't be so easy. Well, it was, and is.

I still get emails regularly from divers who've bought this book, and are having a much worse case of the same jitters. They ask all sorts of convoluted questions, quote to me bizarre and contradictory info picked up at the local dive shop as if it is supposed to mean something, and go on and on about the necessity of a digital gauge so they can get their mix within 0.1%.

I tell them to just get mixing, with as little expense as possible, and see how it works out, and get some experience before deciding about bells and whistles. That if they do the day will quickly come when they will be laughing about how badly they'd managed to convolute themselves by thinking about it too much. Most do, and I hear back from some of them, telling me how was true it was. A few don't, and go on and take one mix course after another and buy every manual on the market without ever actually getting their nerve up to open that valve.

I used to find these contacts a little disturbing, because I'd put a lot of work in the book, trying to tell people everything they needed to know, and felt I must have somehow let them down. Eventually it dawned on me - these folks didn't really need more information, what they are fishing for - subconsciously or not - is permission! They are so brainwashed by the "everything that isn't specifically permitted is forbidden" and "you need a C- card for everything you do" mentality that the dive industry too often seems to promote, that they just can't get it into their heads that it's just a matter of going and doing it. That there's no nitrox police or Federal Bureau of Compressed Gases waiting to bust them, nor an evil, capricious O2 genie waiting to blow them sky high (actually, there is, but he's got a long waiting list!) and that all they have to do to do it is do it.

On the other hand most of my readers seem to get the point, jump right in and never look back. I heard from two dive buddies who bought this book just before going to Florida to dive some caves. One built the analyzer and the other built the whip. They drove their rented minivan straight to the welding supply from the airport, loaded up 3 K tanks of O2, and started mixing soon as they unloaded. They hit the water the next day with two sets of doubles filled with their first homebrew nitrox. They mixed 2000+ cf of nitrox in the next week, and saved over $400. That's what this book is all about!

A Note To Metric Readers

I'm not a very metric person, and the demand overseas for this book took me quite by surprise, but I finally bit the bullet and went through and put in metric equivalents (sometimes the wrong ones, but that's another story) wherever possible.

Actually our measurements aren't that hard to deal with. For the purposes of this book, all one needs to know is that:

- to turn psi (pounds per square inch) into bar, divide by 15.

- To turn cf (cubic feet) into liters, multiply by 28.

- To turn feet into meters divide by 3.328 if you really care, otherwise by 3.

Oh, and a kg is a little over two pounds, 2.2 to be exact.

I haven't bothered to give metric equivalents for the sample calculations and worksheets - they were already cluttered enough. Actually, for demonstration purposes the sample calculations and worksheets in the book work fine either way. Just plug in any pressure or depth units you like, and pretend the Doria lies at 240m, but that you can dive it because you've got the new 3000 bar tanks.

If you are photocopying the blank worksheets to use, simply cross out my primitive units and write in yours on the master.

On some of the calculations - those dealing with tank volume or pressures at depths - you metric folk have it easy. Your tanks come labeled for their water capacity volume and your pressures are already in atmospheres.

Percentages, thankfully, remain the same (though I'm told English diehards still cling to a percentage system based on 120 parts, that being the number of pieces King Etherod could chop a "wilde boare" into, using his favorite broadsword).

Tank capacities are a little more complicated. In the US we usually describe a tank by it's cubic foot capacity when it's filled to its rated pressure, as in a "steel 72" or an "alu 80" with no mention of what that pressure is (though we will sometimes qualify it as HP or LP). The former (once the standard dive tank in the US, but no longer made in any quantity) works out to a 14 liter/150 bar tank, and the latter, now the standard recreational dive tank here, is an 11 liter/200 bar tank.

The standard big industrial/medical gas tank, of the sort one would get from a gas supplier to do mixing with, is somewhere around 250 cf, which is to say about 7m3.

The easiest way to make sense of it is to just remember this: a tank between 10 and 30 cf would be a pony or portable med tank. Full size dive tanks run between 60 and 120 cf, with 80 the standard, and large tanks used by tech types run 95 to 140 cf. Anything bigger would be a full size industrial or medical tank.

Our LP steel 95/98 seems to be your 15 liter/200 bar, but the feds will only let us fill them to 180 bar. The caver's favorite tank, the LP 104, holds 16 liters WC and is also rated for 180 bar, though everyone who can get away with it fills them to 220 or so.

I haven't been able to get a definitive answer on how tanks should be described metrically (probably because there isn't one), so in this text I've described smaller tanks by their water capacity, eg. a "3 liter emergency O2 tank", and bigger supply tanks by their contents capacity, eg. a "7m3 O2 supply tank".

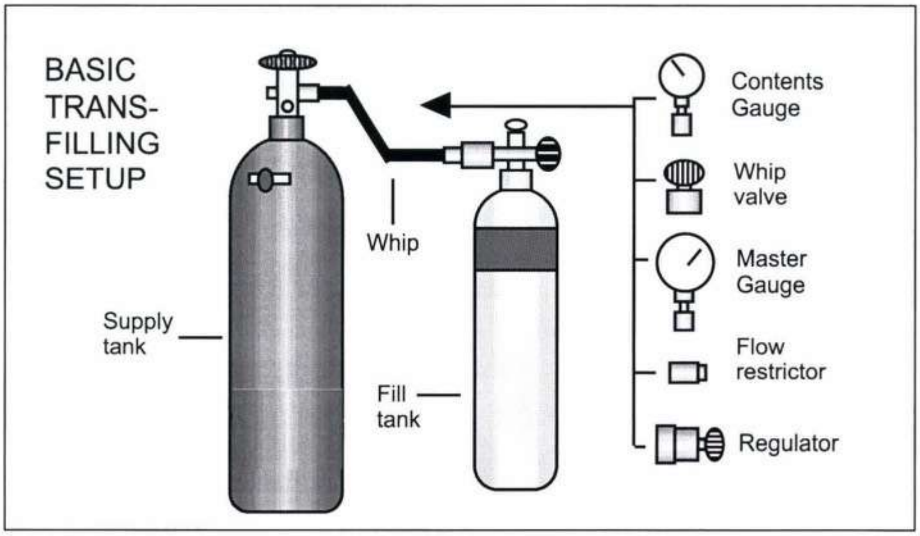
On the components and fittings, there's no way I can include the fittings sizes and specifications for every country where this book may find its way. But it's easy to offset - as long as you know you need a HP hose, a gauge, and a tank adaptor, for example, to make a whip, and that welding/HP gas dealers carry them, it's easy enough to buy what you need, regardless of what the names, sizes and thread profiles might be.

Chapter 1
THE BASICS

Transfilling

The basic operation in HP gas handling, for the purposes covered in this book, is transfilling - taking gas from one HP cylinder and transferring it into another.

This is done using a "whip" - a length of a suitable hose with the appropriate fittings on each end to mate to the valves on the two tanks. The whip may also have a master gauge, which reads the whip pressure to allow measuring the amount of gas being transferred, a precision needle valve to allow better control over the operation, extra gauges to read tank pressures, and check valves or restrictors for special applications, but the basic operation still remains the same.



Transfilling seems simple enough on paper, but it is a potentially dangerous activity, especially with O2, and should not be attempted without an understanding of the risks involved and how to reduce them.

O2 is not in itself flammable, but it is a potent oxidizer. It can drastically lower the ignitability of any flammable substance (and this includes many materials we don't even think of as flammable, such as stainless steel, aluminum, plastics and wallboard) and vastly accelerate and intensify the combustion once it has been initiated. All these effects increase dramatically as the pressure of the O2 increases.

An O2 fire can be an awesome and terrifying event. Once the intial ignition takes place, the flow of HP O2 can create jets of intense combustion that can melt or burn harder to ignite materials such as hard plastics and metals, and a vicious cycle is created, that will continue until all the available oxygen or fuel is consumed. Hoses will often burst at this point, and the escaping gas cause them to flail about, spewing fire or oxygen. The combustion can also send high pressure surges of superheated gas in each direction, which can ignite additional fires down the the line, or overpressure components to the failure point.

A fire extinguisher at this point is unlikely to to have much effect because of the intensity of the fire and the continuing flow of O2, so shutting off the O2 (or getting the hell out) becomes the priority.

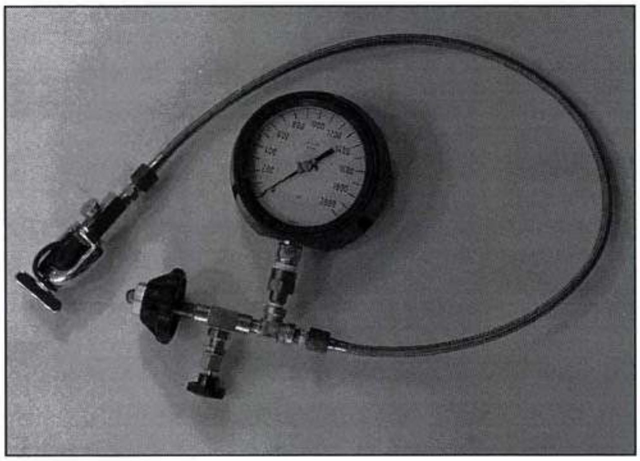
For combustion to occur, three things are necessary - fuel, an oxidizer and a source of heat to ignite them. This is known as the combustion triangle.

Since the transfilling takes place within a closed system, it would seem easy to avoid heat, but this is where the greatest danger lies - the process of transfilling itself can create enough heat within the system to ignite any combustible that has found its way inside. This is due to a a phenomenon called adiabatic heating.

Whenever a gas is compressed, it gets hot. The more it is compressed, or the faster it is, the more it heats up. When a valve is opened on an HP tank, the gas blasts forth from the tank and through the whip at near-sonic velocities. When it comes to a restriction, sharp turn or dead end it abruptly recompresses, creating a localized "hot spot" of intense heat that can ignite many materials normally not thought of as flammable.

Most of the procedures for transfilling are intended specifically to avoid adiabatic heating.

Actually, we try to avoid combustion in two ways - by eliminating the fuel available and by avoiding sudden surges of pressure and high flow rates which might cause adiabatic heating.



An O2 Transfilling Whip For Partial Pressure Nitrox Blending

Limiting the fuel is done by avoiding materials in the system which might combust in the presence of high O2 levels, and by cleaning the components to keep them free of any contaminants , hydrocarbons especially, that might combust. This is what is meant by "O2-cleaning".

Avoiding adiabatic heating is done by designing the transfilling system to avoid bottlenecks and restrictions which might promote adiabatic heating, and, since it is impossible to avoid them altogether, by keeping flow rates very low, and by opening and closing valves in such a way and order as to avoid sudden surges of pressure.

The specific procedure for this will vary with the transfilling rig being used, but there are a few basic safety rules that are pretty much universal.

The valve on the tank being filled should always be wide open before the transfill is begun, and the valve on the supply tank, or a special valve on the whip itself, used to control the fill. This way there are no dead ends, and the tank being filled acts as a buffer to cushion the shock when the gas begins to flow.

The valve controlling the mix is always opened as slowly as possible, and the rate of transfer, as measured by the rate at which the pressure in the tank being filled increases, carefully watched.

For transfilling O2, the rate of transfer should be no more than 60psi (4bar)/min. The fill speed can be double-checked by monitoring the temperature of the tank being filled, by feeling the shoulder of the tank. Since compression creates heat, a tank will always heat up somewhat while being filled, but if the flow rate is kept as low as it should be when transfilling O2 the tank will be able to dissipate most of the heat as it is created and never get more than slightly warm to the touch. If the tank feels hot, the fill rate is much too high.

Adiabatic heating is not the only possible source of ignition. Tiny particles of grit and metal shavings - including some formed when the fittings making up the system are tightened - can be blasted through the passages by the gas, where they strike metal surfaces and spark. The materials used in an HP O2 system must be carefully chosen the minimize the chance of sparking.

These issues are discussed in much greater length later in the book, but it is important to be aware of these considerations right from the start.

Technique

The methods and procedures of good gas handling go under the general category of technique. Good technique means knowing one's gas handling setup, and being able to use it safely and effectively.

One of the reasons it is so hard to reach any conclusions about the where to draw the line with O2-cleaning, air standards and FO2's is that safety in gas mixing is so dependent upon the mixer's technique. With good technique, it is possible to blow a charge of 100% O2 into almost any old random, non-O2-cleaned tank with an (almost) perfect assurance of getting away with it. With lousy enough technique it is possible to cause combustion in (almost) even the most perfectly cleaned tank and valve. This poses a enigma for anyone trying to formulate standards - should they assume a reasonable level of competence, and come up with reasonable rules, or assume the worse and make a bunch of onerous rules that attempt to address every single way in which it is possible to screw up?

When it comes to safety side of technique, about 90% of it involves simply understanding the dangers of adiabatic heating and knowing how handle the transfill process to minimize it -and having the patience and discipline to keep doing it right, tank after tank.

Proper gear - precise, slow-acting needle valves, flow restrictors and the like - can make it easier and safer, but can't make it foolproof . There's no substitute for good technique. The less safety features are available, the more important good technique becomes.

The other aspect of good technique has to do with being able get the results one wants the first time, with a minimum of fiddling around. This involves things like knowing the idiosyncrasies of one's equipment and the mixing process - knowing how to accurately read one's gauges, and how to compensate for heating and compressibility. Some of this can be learned out of a book, but much of it comes only with experience.

A large part of good technique is attitude. Mixing requires full concentration. It shouldn't be done late at night when one is tired, or in haste. Nor is mixing is a social event - don't mix when friends are around, unless they are involved in the mixing process, and are aware of the rules.

Small tanks, it should be mentioned here, require especially good technique, since the smaller the tank is, the less ability it has to absorb surges, and the harder it is to keep the fill rates down. Small aviation, med and dive pony tanks are the hardest tanks of all to fill safely.

The Gas Laws

The Gas Laws are the scientific basis for all the calculations and concepts involved in transfilling and gas mixing. They are adequately covered in just about any basic diving text, so there's no need to go into them here in any depth, but it is probably worth reviewing briefly the two key Gas Laws that concern the gas mixer, Boyle's Law and Dalton's Law of Partial Pressure.

Boyle's Law states that:

"For any gas at a constant temperature the volume will vary inversely with the absolute pressure while the density will vary directly with the absolute pressure".

In short, if one puts the same amount of gas in a space half as big as it was in before, and the pressure will double. Or, double the pressure in a gas container, and there will be twice as much gas in it.

And Dalton's law states:

"The total pressure exerted by a mixture of gases is equal to the sum of the pressures that would be exerted by each of the gases if it alone were present and occupied the total volume."

The pressure Dalton's law refers to , that is contributed by an individual gas, is what we call the partial pressure. For example, if a tank was filled with 1000 psi of air, the PO2 - partial pressure of the oxygen - would be, since oxygen makes up 20.9% of air,

PO2 = 1000psi x 20.9% = 209psi

on the other hand, the air we breath at sea level has a PO2 of,

PO2 = 14.7 psi x 20.9% = 3.07psi

Or if we wanted to take it the other way, suppose we had some nitrogen and oxygen and wanted to make our own air from scratch in a 2200 psi tank.

We would add:

2200psi x 21% = 462 psi 02,
and
2200psi x 79% =1378 psi N2

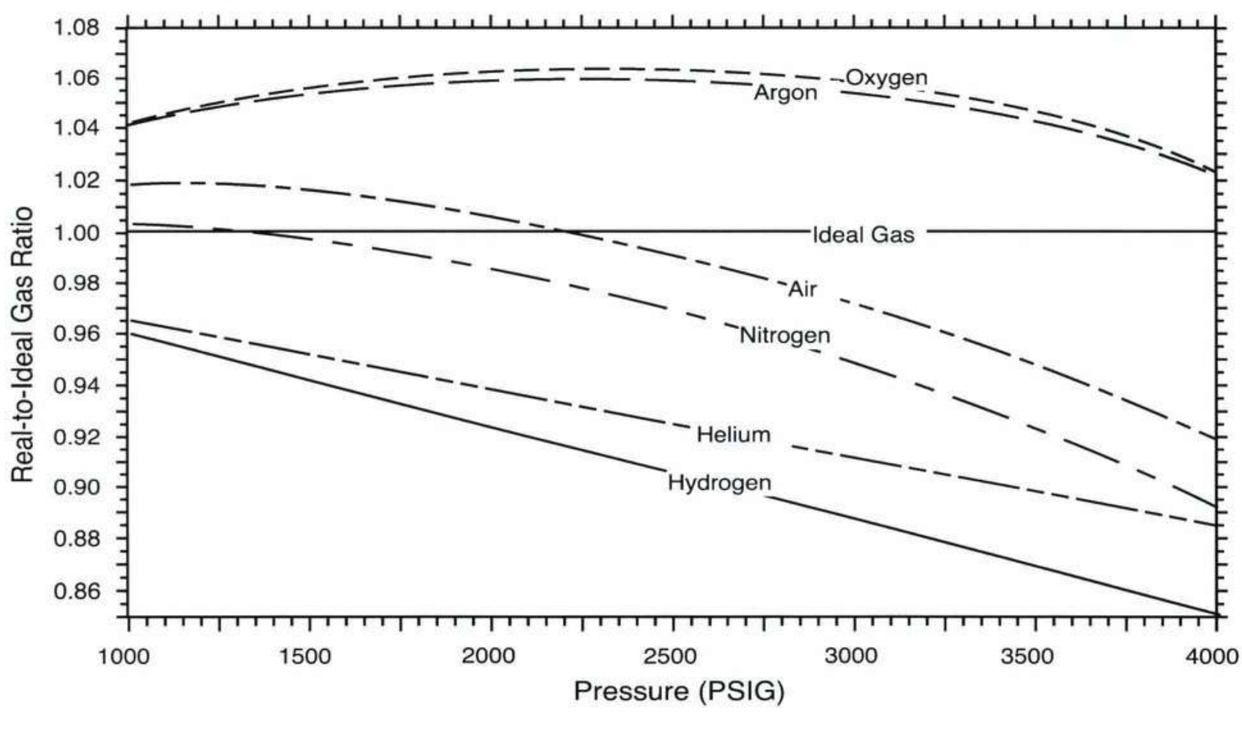
This is exactly how one mixes nitrox or trimix, though in mixing them one usually uses air rather than N2, so slightly more complicated calculations are necessary to take into account the O2 already in the air.

Note that the partial pressure of any gas in a mix is the function of both percent and pressure. If we want to talk about the fraction of any particular gas in the mix we would refer to the F(raction) (name of gas), as in FO2 or FHe. The fraction of a gas doesn't change with pressure, but the partial pressure does.

Real and Ideal Gas Laws

The gas laws were derived at a time when the technology to compress gases to extremely high pressures did not exist. They were arrived at empirically - through experiments and observations. Later on, as the ability to achieve very high pressures and measure them accurately, as well as the understanding of what was going on at the molecular level improved, it was found that gases didn't really behave as consistently as the Gas Laws would have it. A new set of laws were

Compressibility of Common Dive Gases



derived to cover the ways gases really behaved, called the Real Gas Laws, and the old laws were called the Ideal Gas Laws. However, since the Ideal Gas laws are much easier to use, and accurate enough for most purposes, they remain in use.

The main difference is something called compressibility - how well a gas tolerates being compressed. Some gases turn out to be easier to compress than others, and all gases become harder to compress as the pressure increases. That is to say, the higher the pressure they are compressed to, the less additional volume one gets for the effort. This isn't much of a problem with most gases below 3000 psi or so, so it really isn't a concern for anyone bottling O2 or mixing nitrox. But the worst dive gas of all, as far as compressibility goes, is helium, and compressibility must be taken into account anytime He is present in a mix.

Analyzing

After the O2 has been added, and the tank topped up with air, the mix must be analyzed, to confirm that it came out as it was supposed to. This is usually done using two pieces of gear, a sampler that trickles a little gas from the tank so it can be analyzed, and an analyzer that reads the percentage of O2 in the gas.

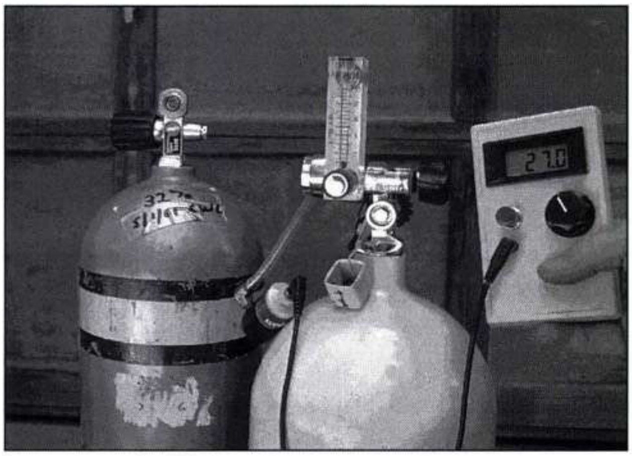
An analyzer is as essential a piece of gear to the mixer as the whip, since there are any number of minor errors possible that could lead to an unsafe mix, and without an analyzer there is no way to catch them.

Once the mix is analyzed, it is tagged with the analysis and date so there can be no confusion later on about what the tank contains.

Is It Legal?

Many of the so-called laws and regulations you will hear quoted concerning O2 and compressed gases in general are not laws at all, but rules invented by gas dealers or dive shops for their own convenience, and sometimes, profit.

You'll frequently hear people say things like "it's illegal for you to fill your own tank" or "I could get in big trouble for filling a tank without an inspection sticker", or "I can't sell you O2 without a prescription". The head of one of the tech agencies even posted recently on one of the newsgroups that oxygen cleaning for use above 40% was a matter of federal LAW!



Analyzing a mix using a flowmeter and a Maxtec concentrator..

Usually, look a little deeper and you'll find they are wrong. There is no law that stops an individual from transferring compressed gases from one tank to another. Nor is there anything to prevent you from doing your own O2-cleaning of tanks and gear, or mixing and bottling your own custom dive gases without doing any cleaning, or breathing welding O2. For that matter, there's nothing in the law to stop you from diving nitrox or trimix dive gases without the blessings of any of the dive certifying organizations.

Mind you, that's not to say you should, only to say that there are no laws against it!

The VIP program for SCUBA tanks, for example, is a program that the dive industry initiated, mostly for safety, though not a little for profit. It has no basis in law.

The CGA (Compressed Gas Association), the trade organization for the compressed gas industry, also sets standards for the handling of compressed gases. Most of these, though, are only guidelines, without force of law, and many tend to be extremely conservative. For example, where NOAA, the US Navy and most dive agencies set the percentage above which equipment must be specially cleaned for O2 use at 40%, the CGA insists that anything used with above 23.5% must be specially cleaned!

The only regulations concerning compressed gases that have the force of law are those of the FDA, which has authority over medical O2 (as well as state laws regarding medical use of O2), and the DOT, which has authority over compressed gas transport. However, the DOT's authority is actually (though you may have a hard time convincing a dive shop of it next time you want to get an out-of-hydro tank filled) limited to cylinders "offered for transportation in interstate commerce" so cylinders owned by private individuals for personal use are exempt! See the appendix for more information.

Fittings Compatibility

One of the first problems anyone messing with compressed gases will run into is incompatible or hard-to-find fittings. Compressed gas equipment, in the USA, generally uses tapered NGT (National Gas Thread) threads on most fittings. These are interchangeable with the NPT (National Pipe Thread) fittings used for plumbing fittings.

Valves on high pressure tanks and the fittings necessary to connect to them are another story. The CGA has standardized a bewildering assortment of different combinations of thread counts, male and female fittings, RH and LH threads, yokes, nipples etc., so that each gas will have its own unique connector in order to make mixups less likely.

Adaptors are available for some of the less dangerous combinations, like putting a CO2 regulator on an argon tank, but not for the more dangerous ones - you won't find an adaptor that allows you to hook up an oxygen regulator to a hydrogen tank.

Most CGA fittings are also available individually, with universal NGT taper threads on one end, making it possible to make up just about any combination you want - even the dumb ones.

CGA fittings are available from most welding/gas suppliers. Western is one company that manufactures and catalogs an extensive line (see appendix for addresses).

Some gases have several applicable CGA fittings. For example, small portable medical 02 bottles generally use a CGA 870 pin indexed post or yoke valve (similar in concept to, but not interchangeable with, the SCUBA yoke system), and larger medical tanks as well as welding and industrial tanks use a CGA 540 threaded fitting. Often the only difference between medical and industrial gas fittings is that the medical ones are chrome

Table 1

CGA FITTINGS USED IN OXYGEN, AIR AND INERT GAS SERVICE

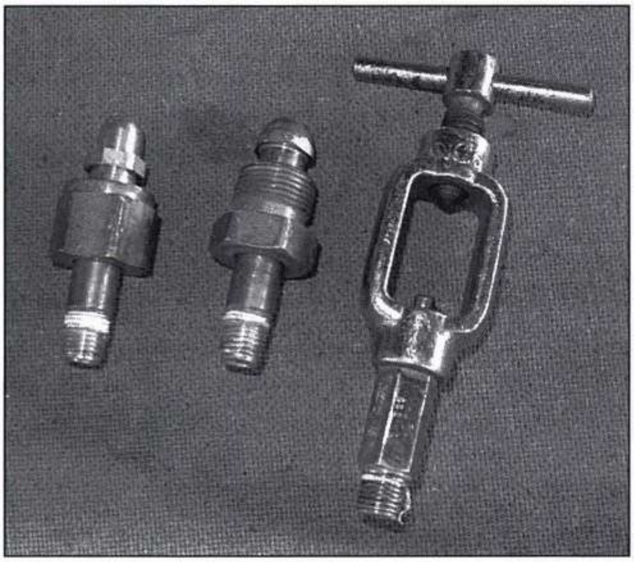
CGA280	Medical breathing mixtures
CGA 296	Industrial O2 Mixtures
CGA 346	SCBA (firefighting airpaks) up to 3000 psi.
CGA 347	SCBA high pressure up to 4400 psi.
CGA 500	Medical Mixtures
CGA 540	**Medical and Industrial Oxygen**
CGA 577	HP oxygen 3000 to 4000 psi.
CGA 580	**Argon and Helium**
CGA 590	Industrial air. Also used for premix nitrox, trimix etc. when purchased from an industrial gas supplier.
CGA 850	**Scuba yoke/A-clamp**
CGA 870	**Med. O2 Pin Indexed yoke**

Note: Fittings most commonly encountered in diving and aviation applications listed in bold type.

plated.

Most SCUBA tanks/regulators use either the familiar yoke or "A-clamp" system, or the newer screw-in metric DIN 477 #13 (230 bar) or #56 (300 bar) connectors to mate the regulator and tank. The other components of a SCUBA system, like gauges and regulator stages, are connected using O-ring sealed straight SAE fine thread fittings. The yoke/A-clamp interface actually has its own CGA number, CGA 850 but that doesn't mean you'll be able to buy adaptors from your local gas supplier - the two worlds guard their independence so rigorously that it's just about impossible to find adaptors to go from NGT to SCUBA other than from specialized dive shop suppliers.

The best way to make sense of the range of CGA fittings is to get the Western catalog, which has them all clearly illustrated. Knowing and using the right CGA numbers will also greatly enhance your credibility at the local welding/med gas supplier. Cale reports that if he calls a supplier and asks, say, for a medical O2 valve, he will almost inevitably be asked what he wants it for, then told he shouldn't be doing it. On the other hand, if he glibly asks for a CGA 870 1/2" NGT tank valve he'll usually get a straight answer.



CGA regulator side Fittings: CGA 540 (O2), 580 (inert gas) and 870 (medical O2, small tanks)

Internationally, the situation gets much more complicated - valve and connector usage tends to reflect old colonial and political spheres of influence, and are often far from logical, with neighboring countries using incompatible systems.

The pin-indexed 870 is used for smaller medical tanks over much of Europe and parts of the Pacific. For larger 02 tanks CGA 540 is used throughout North and much of South America as well as Thailand and the Phillipines. The UK, most former British colonies, many Arab nations, and many western Pacific Islands use the BSP "bullnose" connector. Europe is divided between the DIN 477, NFE 29, SMS 690 and UNI 4406 with the NFE being used in France and former French colonies, and northern European countries and many others worldwide using either the DIN 477 or SMS 690.

An excellent place to get information on the different international valves, connectors and adaptors, along with pictures to help identify them, is the DAN Europe webpage. DAN affiliates worldwide also sell adaptors for many of these connectors, and are often the best source if your local gas supplier can't help.

Economies

Why bother messing with O2 handling at all? Isn't it just asking for trouble?

The two main reasons are economy and obtainability (a distant third is the thrill of doing something forbidden). One may simply not be able to buy mixed dive gases or get an aviation set or medical tank filled locally. Or one may be able to, but only at an unreasonable price. I've heard prices for nitrox dive gas fills of everything from $6 to $25 for an 80 c.f. tank. A 250cf (7000 l) K or H tank of O2 costs about $25 to fill and holds enough O2 for mixing 15-20 tanks of EAN 32 before the pressure drops too low. Adding in the $3 for an air top-up, that still works out to only $4-$5 a tank for nitrox, and much less if one has access to an air compressor. If getting nitrox means paying $25 or driving a hundred miles, the math is pretty compelling, to say nothing of the convenience. Ditto for aviation use. If one can fill one's own tank, each fill will cost only a dollar or two. If your local FBO is charging much more than \$5 a tank, payback won't take long, even if you pay \$50 for a tank lease and \$50 or so for a whip.

With trimix, the cost benfits are even greater, because the gas costs are much higher, and it takes longer to do the mix. A dive shop - if one can even find one that does mix locally - is going to have to charge their usual markup on the gas, and some labor too, and that can easily double or triple the price. It's not the dive shop's fault - they are entitled to a fair profit for their time and investment. But this is one of those times when it can be a lot cheaper and not too difficult to do it yourself. Equally desirable is being able to protect one's supply. The only shop doing trimix in my area recently went under; local trimix divers must now drive several hundred miles for fills. Far easier to learn to mix their own! Especially because even the shops that do mix usually tend to do a batch once or twice a week, after the shop is closed, so getting a fill often involves two trips, and leaving the tanks at the shop until they get around to it.

Filling one's own tanks also allows more flexibility in tank configurations, since one isn't limited to what the gas dealer will fill, and can come up with some very cost effective setups for special purposes that simply cannot be obtained commercially. For example, a portable medical O2 tank costs about \$100 and holds 13 or so cf (400 l), enough O2 for maybe 20 minutes of treatment. If one has an old steel 50cf. SCUBA tank, a surplus SCBA tank, or similar recycled tank, it might occur that it could be put to good use as a backup emergency or aviation O2 tank, for the price of a \$15 valve. But one is unlikely to ever find a gas supplier who would clean and fill it with O2, so the only way to pull it off is to O2-clean it and fill it oneself (though a possible alternative would be to find a SCUBA shop servicing tech divers which would be willing to do it).

And finally, if one is into tech diving, one may find, as the tech agencies come up with more and more levels of certification in the quest to sell more courses, that the dive shop will refuse to sell the desired fill - high FO2 deco mixes especially - unless one has taken the "latest" course. Having the ability to bottle one's own cuts through all this potential aggravation.

Commercial Mixing

I was in a new dive shop the other day, and asked the owner if they were going to be doing nitrox. He said they really wanted to, but wouldn't be able to afford the setup for a while. "After all, just the mixing panel costs over \$10,000 with a Haskel and everything," he informed me somewhat condescendingly.

I was tempted to try and explain to him he didn't need a mixing panel at all at his level, and that only \$1200 or so for a whip, analyzer and hyperfilter would allow him to get his feet wet in basic PP mixing, but I didn't think it would do any good - he had that bright-eyed "I'm the dive professional here" look.

Besides, I've increasingly begun to feel that PP mixing, nifty as it is for us homebrewers, just isn't the way to go for a commercial operation. Any shop that is serious about selling nitrox really ought to do it right, and go with premix, sparing the customers the hassle and expense of O2 cleaning their tanks, and the inconvenience of having to leave them at the shop until the shop can get around to doing the fill.

The funny thing is, it doesn't even have to cost more. One can homebuild a continuous mixer for less than the cost of a whip, the analyzer is the same either way, and, since extra filtration isn't needed with premix, a three or four tank cascade for banking the premix can be assembled for about what a hyperfilter would cost.

The really neat about going this route is that, once a shop has the capacity to do walk-in nitrox fills, it usually finds that it's selling a lot more nitrox, and when it does, increasing capacity is simply a matter of adding more tanks to the premix cascade.

Chapter 2 Oxygen Cleaning

Equipment which will be used with high concentrations of O2 must, it is generally accepted in the industry, be "oxygen-clean". That is to say, carefully cleaned using non-combustible detergents and/or solvents to remove any contaminants that might create a risk of combustion when exposed to high pressures and percentages of O2. Commercial equipment made for O2 service, like medical O2 sets and aviation sets, comes already cleaned. If one is converting or adapting SCUBA or other gear not sold specifically for O2 service, industry practice is that it that it must be O2 cleaned.

There are two stages to O2 cleaning. First the gear must be disassembled and cleaned carefully, with non-flammable, non-toxic cleaners, to remove any trace of hydrocarbons (oil and grease) or any other potentially dangerous contaminants. Then any other potentially combustible parts - plastics or rubber compounds - must be replaced with O2-safe equivilents and lubed as necessary with special O2-safe lubricants rather than the silicone lube normally used on dive gear.

The 40% "Rule"

In diving circles the accepted rule has been that only gear that will be exposed to an FO2 (fraction of oxygen) of over 40% need be O2-cleaned. This "rule" originated with NOAA, and is somewhat arbitrary, being more a "rule of thumb" than a standard, however it has withstood the test of time. Not everyone accepts it - the CGA, NFPA and several of the tech diving agencies say anything over 23.5% - in short, anything richer than air.

Since partial pressure mixing of nitrox involves first filling a tank with the desired amount of straight O2, then topping it up with air, tanks and valves which will be used for partial pressure mix will be seeing, however briefly, high percentages of O2 and must be O2 cleaned, even though the final mix obtained may be well below 40%. Tanks which will be filled with premix nitrox <40% generally don't need to be 02 cleaned since they will not be seeing anything higher than 40%.

Dive regulators, on the other hand, usually don't require O2-cleaning for nitrox use regardless of whether it is partial pressure mixed or premixed use since they will not be seeing the high FO2's during the partial pressure mixing process. Nor do BCs, inflators or drysuits, despite a lot of jokes to that effect. Regulators that will be used with straight O2, or high FO2 nitrox deco mixes are another matter and should be O2-cleaned.

Keep in mind that O2-cleaning doesn't automatically make a device suitable for use with high FO2s - it just removes some of the more obvious hazards. Some gear - like titanium regulators or aluminum valves - just cannot be made O2 safe not matter how much you clean them. This is why liability-shy manufacturers will often describe their valves or regulators as being fitted with "O2-compatible" O-rings or grease, but stop short of calling the components "O2-safe".

Engineers use something called the "Oxygen Index" (OI) to detirmine how suitable materials are for use with oxygen. The OI is detirmined by putting a sample of the material in a pressurizable "bomb" chamber, and measuring what pressure of oxygen is necessary to keep the material burning once it has been ignited. Materials with an OI below 50 are generally considered dubious for use with oxygen.

Typical OI's for non-metal materials used in valves and regulators are:

Buna-N (nitrile)	18
EPDM	30
Viton	75
nylon 6	27
Kel-F	95

While it is easy to switch O-rings or grease to get a product that is more O2 compatible, it is not so easy to change the seat material in a valve or a regulator. This often puts a limit on how well one can be O2-cleaned.

And there are some devices that are just inherently unsuitable for use with high FO2s and no amount of cleaning will alter that. Recently a number of surplus Haskel nitrogen boosters were O2-cleaned by a vendor and sold to divers. At least two of them have been involved in conflagrations when 100% O2 was run through them. In one case the Haskel wasn't even being used as a booster - 02 was just being run through it from a cascade to a deco tank. The boosters involved had aluminum heads, which should have raised doubts in the minds of the users. And recently a titanium Atomic first stage combusted violently.

One question that keeps popping up is why 600 psi of O2 in a SCUBA tank should be more dangerous than 3000 psi (200bar) of air, when the air actually has a higher PO2. The answer seems to be that the potential for combustion is not exclusively the result of the PO2, but depends on both the PO2 and the FO2, and not necessarily in an intuitive fashion.

NASA did a lot of research after an Apollo capsule, which used a pure O2 atmosphere, caught fire on the ground during a training exercise, killing its crew. NASA concluded that any FO2 over 50% acted pretty much like pure O2, though it's hard to say if this applies equally to high pressures - the Apollo capsule was intended to be run at lower-than-atmospheric pressure, but was filled with O2 at atmospheric pressure to reduce stress on the capsule during the exercise.

Where do the contaminants come from? Some of them are left in the tank, regulator and fittings from manufacture. Others are things like greases and materials used in the valves, manifolds and regulators that are suitable for air but not for high levels of O2. Mostly, though, they come from the air with which the tank is filled.

Compressors need lubrication, and usually this lubrication is provided by oil not that different from the oil in the crankcase of a car. As the compressor is used, some of this oil migrates past the pistons and into the gas being compressed. Since compressors build up a lot of heat, some of the more volatile components of the oil also vaporize, and the fumes get sucked in. Well designed air systems use a number of strategies to avoid this. They may rely of non-toxic, non-flammable lubes, barriers between the lube and the air, high performance filtration, or a combination. These filters, though, are not perfect, and the standards for normal diving air allow for a small amount of hydrocarbons. The problem is that in the long term, these contaminants might accumulate in the filling system and in the tanks until they reach dangerous levels.

Generally, the quality of dive air is very good these days. But not always. Recently I was at a dive shop when two divers came in with some tanks to be filled. They hadn't been visually inspected for a few years, so the dive shop owner insisted on pulling the valves and taking a peek inside. What he found surprised us all - significant pools of a viscous dark liquid, probably oil (and very old oil at that) from a badly maintained compressor. Their last fill, they said, was from a part-time air station located behind a body shop and run by a non-diver who'd apparently seen a business opportunity and bought the compressor when the only dive shop in the area went out of business.

Now, if someone stuffed 500 psi (35 bar) of straight O2 in those tanks, would they have blown? Hard to say - but I sure wouldn't want to be the one to find out. Though it should also be pointed out that breathing air with oil in it is so harmful to the body that an explosion might be preferable to breathing the stuff.

I should mention here, however, that there is a counter view among divers, including some who have been actively mixing dive gases for years, and doing some very long and deep dives on them, that O2-cleanliness is a lot less important than has been thought in the past. As one diver/welder put it, "If oxygen was anywhere as dangerous as we've always been told, we would have all blown ourselves up by now"

Others point out that anything that is substantial enough to cause trouble - say an accumulation of oil as mentioned above, or a grossly overlubricated valve - is going to be readily visible, and that regular inspection will probably contribute more to safety than infrequent O2-cleanings.

One way or another, it seems clear that there are a lot of people doing partial pressure mixing of nitrox who are not using professionally O2-clean tanks or hydrocarbon free air and appear to be getting away with it. Does that mean you should?

Don't expect me to tell you it's OK. It's one of those things that you may get away with ten or a hundred times, but if on the thousandth time it blows up in your face you're going to feel pretty stupid in those last micro-seconds.

Rather, take it to mean one doesn't have to be overly intimidated. Oxygen cleaning, it appears, is not rocket science, as we've been led to believe in the past, but rather kitchen science - a matter of detergent, hot water and common sense.

It's worth noting that some of the most vehement members of the "O2-cleaning is for wienies" school, when cornered and forced to qualify exactly what they mean, tend to backpedal. What they actually seem to be saying is that O2-cleaning is usually not necessary with new or well maintained gear, when filled by someone with good technique. That's quite a difference.

The important thing is to use cleaning agents that will remove any hydrocarbons, but not contribute any themselves. Flammable solvents, obviously are out.

The Navy Dive Manual, the CGA, and other technical publications have traditionally leaned towards heavy duty solvents and detergents such as anhydrous technical grade trisodium phosphate, trichloroethylene and liquid freon, followed by rinsing with deionized water. These are hard to find, environmentally suspect in some cases, and may leave a bad smell in the tank that's almost impossible to get rid of.

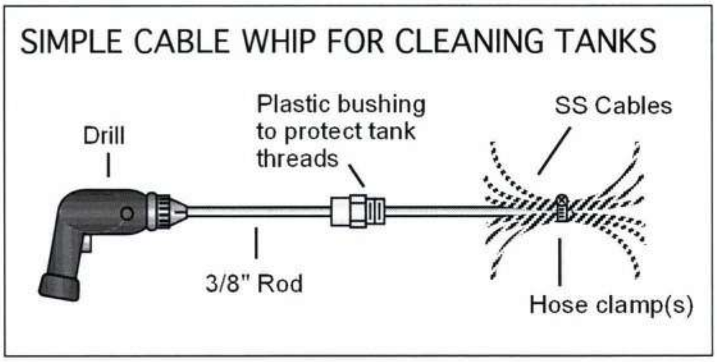
Fortunately, there are some much milder and more easily obtained detergents that are popular with tech divers and seem to do the job just fine. Two of the most frequently mentioned are Crystal Simple Green (the dye in the regular Simple Green difficult to get out) and Formula 409. These are both simply strong "tough job" household all-purpose cleaners, and other similar products should work just as well. There seems to be a slight preference for citrus based products, something to keep in mind when shopping if one cannot find either of the named products.

The detergents are diluted before use. Recent navy tests show that Crystal Simple Green is effective at dilutions (when used with hot water) of 25 to 100:1 . The lower dilutions can handle more contamination; the higher are easier to rinse out. Non-phosphate, biodegradable surfactants like Joy, Ivory, and Dawn can also be used.

The tank is filled with a hot solution of the detergent of choice, shaken, scrubbed, or tumbled, for at least 10 minutes, then thoroughly rinsed and dried.

Some sort of mechanical scouring action greatly increases the efficiency of any liquid cleaner, and will usually be necessary with tanks which have visible contamination inside. Even throwing in a few handfuls of pebbles, nuts and bolts, or a length of chain into the tank and sloshing them around with the cleaning solution will do a much better job than just the solution alone, but remember that anything that is going to go inside the tank must be scrupulously cleaned first to avoid contaminating the tank.

But there's a much better, and not much harder way. A simple drill-powered cable whip can be quickly and cheaply made from an 3/8" (10 mm) x 30" (75 cm) or so aluminum or steel rod withsome 16" (4 to 6 cm) lengths of 3/16" or so braided steel (perferably stainless steel) cable hoseclamped to the end, with a plastic bushing which screws into the tank to protect the neck threads. The bushing can be made by drilling out a plug such as new tanks are delivered with (most dive shops will have a bucket of



them out back) or a 1/2" NPT PVC pipe adaptor can be used - the thread is different but close enough that it will screw loosely into the tank neck.

If one has more than a one or two tanks, this whip will quickly become your indispensible buddy! In addition to cleaning tanks, it works great for removing light surface rust before taking a tank in for visual or hydro, or agitating acid cleaners.

The valve threads and shoulder area below them should be especially careful cleaned, since that is where old lube from the valve threads tends to concentrate. Old toothbrushes work great for this; I heated the handle on one and reshaped it to make it easy to reach the shoulder area. The wash should be followed by a very thorough rinse.

Cleaning tanks can be done better, and a whole lot easier, if one improvise a washing and drying stand that will hold the tank upside down and a few inches off the ground, so it can drain freely. Then the tank can be throughly rinsed by sticking a hose up inside and blasting it out with flowing hot water.

A few minutes of spraying an inverted tank will do a better job of getting detergent residue out than many repeated rinses done by dumping water in and swishing it around. If the sink has a sprayer one can usually unscrew the spray head from it and shove it up inside the tank. Otherwise an adaptors from the hardware store for hooking up a garden hose to a sink faucet, and a short length of cut-off hose will be necessary. The water should be between 110 to 140 degrees (60C), same as for a dishwasher. Steam cleaners are out, since they could just possibly overheat and weaken an aluminum tank., though some report good results with a pressure washer.

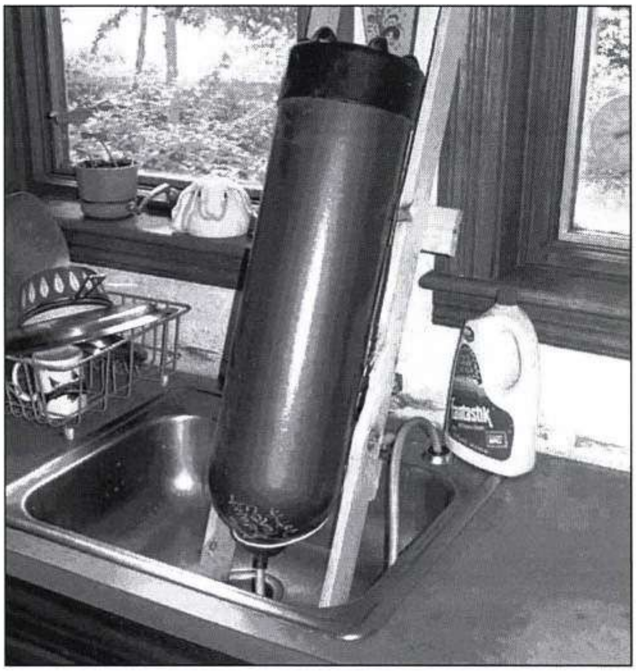
Then, after rinsing, the same rack can be used as a drying stand. Some airflow through the tank will greatly speed drying, and is essential for steel tanks to avoid rust.

It doesn't take much if the tank is still warm from rinsing; I use an old hairdryer loosely attached to a length of 1/2" conduit that sticks up into the tank. Others use air from a SCUBA tank, nitrogen, or even 02 which, being very dry, works almost as quickly as warm room air. It's not necessary to blast the tank out - just to keep enough flow to keep circulation from stagnating.

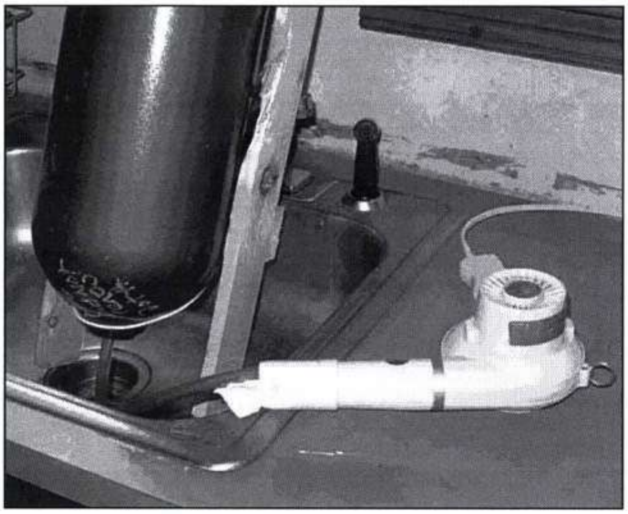
There's a product available from Global, Formula O, to prevent flash rusting of steel tanks which they list as being O2-safe, but it does not prevent rust in the long run, and drying the tank out immediately after rinsing while it is still warm will do the job just as well.

Remember that anything that goes into the tank - sprayer hoses, air pipes etc - should also be cleaned first, or they might re-contaminate the tank.

Air from an LP shop compressor should never be used to blow out a tank since it is usually filthy and can, in a couple of blasts, leave the tank more contaminated than it was to start with.



A washing rack doesn't have to be anything fancy, but it makes the job much easier



The same rack can be used for drying the tank

One of the reasons that water-based cleaners are preferred over solvent-based cleaners is because it is not enough just to dissolve a contaminant; if must be completely flushed out a too, and hot water is a lot cheaper and more environmentally friendly than solvent.

Be that as it may, there are a few jobs. like O2 cleaning gauges, where a solvent cleaner will do a much better job. Only non-flammable, zero-residue ones should be used. One such cleaner is trichloroethylene, most easily found in spray cans at auto parts stores under the CRC Heavy Duty Degreaser label. This is a nasty ol' non-environmentally-friendly chlorinated solvent and should be used sparingly, observing all the warnings on the label. How safe such products are to use in this application is entirely dependent on how completely the stuff evaporates after using, so anything cleaned with them should be given plenty of time to dry before being sealed or installed. Blowing out with dry scuba air will speed the process. Trichloroethylene is a poor choice for tanks because the smell is very difficult to get rid of.

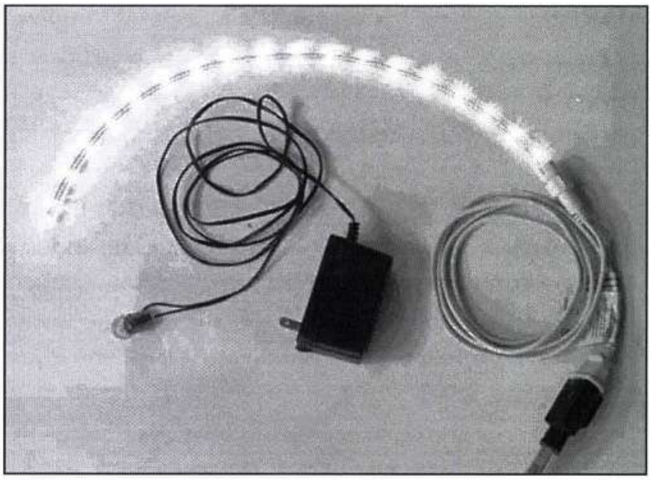
INSPECTION

After cleaning the tank should be carefully examined inside for any contamination that may have made it through the cleaning using an inspection light which can be dropped inside the tank.. Commercial tank inspections lights cost $50 - 70. I made my first one by soldering some wires to a flashlight or auto bulb. It runs off a recycled plug-mount transformer from some old electronic gadget, so I don't have to scrounge batteries.

You can make a much better light, almost identical to the $70 one Global sells, out of a decorative "rope" or "cable" light, which has a series of tiny bulbs in a plastic tube. The Light Tech #1002, which is available from Home Depot for about $10, works especially well, because it can be easily trimmed to any length.

The "official" way to inspect for hydrocarbons used to be with a UV or "black" light, since many hydrocarbons fluoresce under UV. The only problem with this is that while old-style mineral oils might, the contaminants that are most likely to be found in a tank or valve, synthetic compressor oil and silicone or O2-safe lube, usually don't fluoresce! So while a blacklight may tell if if a tank is dirty, it cannot tell tell you for sure that it is clean and should, as a result, not be relied upon.

Unfortunately, the CGA doesn't seem to be aware of this, and CGA Pamphlet G-4.1, which is the closest thing to the official word on O2 cleaning, says that black light inspection can be done in lieu of O2 cleaning, and tanks cleaned only if they fail it. THIS IS QUITE SIMPLY WRONG and potentially dangerous, and another reminder of how the



Tank Inspection Lights - homemade tail light bulb/tranformer, and a cable light.

The 100% Dilemma

In the early days of tech diving, when divers first started using high FO2s with conventional scuba gear there were many dire predictions of the carnage that would result. Since then, though, experience has shown that, if handled correctly, most scuba gear can be used with high FO2s with an acceptable, if not perfect, degree of safety. One exception seems to be the tank valve. There has been a steady stream of incidents involving combustion or near - combustion of standard scuba valves when used with 100% O2.

The culprit is the seat, not surprisingly, since it is the prime bottleneck and adiabatic hotspot. Just about all scuba valves use seats made of nylon 6, which, with an OI of 30, is marginal at best for O2 service. There's no clear pattern to these incidents. They can happen when the tank is being filled or when the valve is opened to use the gas, in the water or out. On a few occasions divers have actually had valves melt or blow off the tank, sometimes causing serious injury, but often there is no outside indication that anything has happened but the diver is alerted by a bad smell or taste, usually described as chlorine-like, to the gas, Or a valvewill be in for service and the seat is found to be charred, eroded, or completely missing.

Ironically, there is a much better seat material than nylon, Kel-F, which most valve manufacturers were using for their "nitrox" valves. Unfortunately just about all of them have recently stopped using Kel-F since it, while very unlikely to combust, puts out extremely toxic fumes if it does, while nylon, though much more likely to combust, doesn't put out as toxic fumes.

So as it stands, there is no scuba valve on the market which is really suitable for 100% O2, and anyone who wants to use 100% has no choice but to either try to scrounge some old Kel-F seats, or use nylon, but very carefully. This means cleaning the valves regularly, and replacing the seats frequently - NASA found that as seats wear and age they becomeincreasingly easy to ignite! And always opening the valves very slowly. Many techs recommend against using Thermo valves with 100% because they are very fast opening. Old, sticky valves are especially dangerous with high FO2s since they tend to open abruptly, creating a dangerous surge of O2. And always make a point of tasting your mixes and 100% fills before taking them diving!

There is some hope. The one good thing about the nutty new Euro M26 dedicated nitrox valve is that the EN144-3 standard requires it to be suitable for 100% O2 too, and there will probably be conventional M25 DIN valves using the same parts and layout that will be, if not ready for 100% out of the box, easily upgradable using the soft parts from the nitrox version. Aqualung already has several such valves, based on the old nitrox Z-valve they sold briefly in the US.

A similar situation exists regarding O-ring materials. While Viton is much less likely to combust than other materials, several reg manufacturers discourage using it because of the toxic fumes it gives off if it did.

CGA rules are often not a good match with SCUBA practice. Unfortunately, some of the dive agencies and tank inspection certification agencies defer to G-4.1 (probably because they have never actually read it!).

Rather than take it on faith, we smeared samples of silicone grease, Christolube 111, some old non-synthetic compressor oil, EZ1000 synthetic compressor oil, 5W30 motor oil and moly automobile grease on a metal sheet.

The only one to really fluoresce to the extent that it was hard to miss was the auto grease. The motor oil did fluoresce ever so slightly, so a carefull examination would probably have found it, and the non-synthetic compressor oil a little less. The others didn't fluoresce at all.

If you still have your heart set on a black light, cheap surplus ones are often available which can be modified to work as an inspection light, and cheap LED UV lights made for detecting air conditioning leaks are available at auto parts stores.. You want long wave ultraviolet, in the 340 to 400 nm range, which is, conveniently, what most LED black lights put out.

Valves

Reports have been coming in of so-called tech diving shops that have been O2-cleaning tanks, but not the valve. This is lunacy - it is becoming increasingly clear that the valve, not the tank, is the most critical component to be cleaned, since it combines an adiabatic bottleneck with a ready source of fuel (lubricants, seal and seat materials). The few O2 fires during PP mixing I have been able to get details on all seem to involve the valve.

Some sources recommend using a non-flammable solvent like trichlorethylene on the valve parts, since they have been exposed to grease, but the same cleaners as are used for the tank do the job just fine, especially if combined with mechanical cleaning in the form of a soft brush like an old toothbrush. Pipe cleaners and gun brushes are also useful for getting into tight places, especially if there is stubborn grease. Ultrasonic cleaners also work great for valves and regulators.

The valve should be completely dismantled, then precleaned by wiping with a paper towel or rag and using a wood or plastic pick to get any embedded dirt or old lube from the threads.

Then all the valve parts should be soaked in a warm detergent bath for at least 10 minutes. If the valve has been used, and shows any sign of corrosion, the metal parts should be soaked first in white 5% vinegar to remove the corrosion before the detergent soak.

After the detergent soak, the parts should be rinsed in warm water. A rinse bath is preferred to running water, at least for the final rinse, so that the rinse water can be checked.

Parts can be air dried, dried in an oven, or blown dry with air, nitrogen or even O2. If air is used it should be clean, dry SCUBA air, not air from a LP shop compressor - any air clean enough for PP mixing is fine for drying. If one is going to be doing many valves or regs an old SCUBA reg 1st stage fitted with a hose and a blowgun makes a handy rig. and can be run off leftover dive tank air.

After cleaning and inspection, the valve can be reassembled preferably using new soft parts - O - rings and HP seats - and O2-safe grease.

Parts that will not be immediately reassembled should be "bagged and tagged" - wrapped in plastic wrap or put in ziplock bags, with a label telling when they were cleaned and how. It's also a good idea to keep a log, recording the serial number of gear cleaned, the date of the cleaning, and the process followed.

The need to O2-clean brand new valves these days is debatable for less than 100% O2. Valves from both Thermo and Sherwood (the two largest valve manufacturers) are now coming through from the factory lubed with O2-safe grease although the manufacturers are not about to say this makes them O2-safe. There have been reports of conflagrations involving brand new valves, so many techs routinely O2-clean any new valve.

Regulators

The procedures for O2-cleaning a regulator are the same as for a valve. However a regulator is a much more complex piece of gear than a valve, and must be properly adjusted as it is reassembled. O2-cleaning of a regulator should therefore be attempted only if one has the knowledge and skills to rebuild it since the process is essentially the same.

Also, since regulators are out of the loop when the tank and valve are seeing 100% O2 during PP mixing, there really isn't any reason to O2-clean a regulator unless it will be used with mixes in excess of 40% although many nitrox divers who service their own gear just do it routinely just to be be sure.

Not too long ago most of the regulator manufacturers came out with dedicated "ntirox" models. The purpose of nitrox regulators has always been something of a mystery since special cleaning is not required for most nitrox mixes (bringing up the question, why don't they call them O2 regs?), however the rebuild kits for them should work fine for O2-cleaning the non-nitrox versions of these regulators since they have O2-safe parts, and the benefit of factory engineering in selecting them.

Nitrox regulators are a vanishing breed, though, as buyers become better informed and expect any regulator they buy to be nitrox-ready. Most manufacturers are quietly making their standard models more O2-tolerant. Many new regulators are coming through with O2-safe lube and soft parts though, as with valves, the manufacturers are coy about calling them O2-safe.

The need to O2-clean these regulators for use with high FO2s is extremely debatable, however, one should confirm that the lube used is O2-safe before running 100% through them.

Not all regulators can be O2-cleaned! Some, especially those with aluminum or titanium parts in the first stage, are inherently unsuitable for use with O2 because the actual metal can combust.

Regulators that have been O2-cleaned should be marked as such. Stickers and hose wraps for this purpose are available from various suppliers but an easier method is just to use florescent green tie-wraps, which are available from many hardware stores, electrical supply houses, and bargain tool stores.

Inspection

Inspection of the parts after cleaning to insure that the cleaning has been effective is a critical part of O2-cleaning. There are a number of different techniques.

The first should be a careful visual inspection of the both the parts and the rinse water. The parts should appear clean, with neither particles, oil slick, or detergent residue evident. As the parts are removed from the bath, they should be set down on a clean surface and examined for beading. If they are still oily, the water will bead almost immediately. If they are adequately cleaned, water will not bead for at least 5 to 10 seconds.

A refinement on this is the spray, or water break test, where distilled water is sprayed on the regulator parts using a hand pump sprayer. If the reg is perfectly clean, the water should spread and lie flat on the surface. Beading is a sign that some contaminants remain.

Then the parts should be wiped dry and examined carefully under a strong white light - a 100 watt bulb is about right. Used at close range, at a 90 angle to the eye, this can show up contamination that would be unnoticable to a casual examination.

The wash water and rinse water should be routinely examined after being drained or after the parts are removed using the light in the same manner. If there are particles in them, then it is likely that some particles still remain on/in the gear. Any oil slick or sheen on top of the water means that detergent levels were not adequate to emulsify all the hydrocarbons, and that, even if the part were adequately cleaned at one point, they may have been recontaminated as they were removed from the bath. If oil is present in the rinse water, it is a sign that the cleaning was inadequate, and the entire procedure should be repeated - not just the rinse.

Finally, a "shake test" should be preformed on the final rinse water. The principle here is that since a degreasing detergent bonds to the hydrocarbons, once all the detergent is gone from the tank all the hydrocarbons should be gone as well. Also, since detergent residue in the tank may be almost as dangerous as hydrocarbons, it is important that no trace of detergent is left.

A shake test simply means taking a sample of the final rinse water from the tank or rinse bath in a small test tube or jar, and shaking it vigorously for five seconds or so. If there's any detergent left, it will produce a foam or bubble ring where the water meets the edge of the container. If you swirl the jar a bit the bubbles will concentrate on the surface at the center of the jar, making it easy to spot even very small concentrations. Bubbles will also form in water which is free from detergents, but they will pop and dissipate almost immediately once the agitation is ceased.

The bubble test is surprisingly effective, and can reliably detect detergent residue in the 1 to 3 ppm range!

If the rinse water shows signs of detergent, then it follows that there is still detergent residue in the tank, and possibly hydrocarbons as well. The tank should be rinsed a while longer, and retested.

Lint free cloth, swaps, or filter paper can be used as a low-tech way to concentrate contaminants that are too dispersed to be otherwise detected. An area of the part in question is wiped, then the swab examined, under black light if available, otherwise with the naked eye. Cotton swabs should not be used with black light, since cotton will fluoresce on its own. This is an especially useful technique for inspecting areas that are not easily examined by eye, such as the inside shoulder of the tank.

Very small quantities of oil can be detected this way even without a black light by immersing the swab in hot water and watching to see if any oil slick or sheen appears on the surface.

In the time since I wrote the first editions of this book, nitrox has become mainstream, with the mainstream agencies and SCUBA manufacturers jumping on the nitrox bandwagon. As a result, more "official" information on O2-cleaning is available than was a few years ago.

Recently I've had the chance to go over some booklets on O2-cleaning put out by Global and by US Divers.

The USD booklet shows every sign of being written by lawyers rather than by SCUBA technicians. It suggests that gear to be used with nitrox must be cleaned using fresh cleaning solutions, rinsed with distilled water and carefully wrapped in plastic between each operation. The tech is to use powder-free latex surgical gloves, and replace them or clean them with alcohol whenever they become slightly soiled.

The punch line, is that after telling you all this, the booklet goes on to say that the gear so serviced may only be used for nitrox below 40%, and that PP mixing is forbidden!

USD says that their parent company, Air Liquide, did much testing before they'd allow USD to sell nitrox gear, and that they found that it was possible to initiate combustion in an air reg, with only a 40% mix! Details of the AL tests are, unfortunately, proprietary, so we can't know under just what conditions this happened, but a USD tech involved in the project told me it was in circumstances highly unlikely to be duplicated in real life, and involved very fast acting valves.

The Global publication, which is now available for free download on Global's website and highly recommended, is much more down to earth. Global recommends a proprietary cleaner of their own, #42100, which is described as a "mild organic citric acid", but says that 409, Simple Green, or Alconox SD-13 can also be used.

For new and clean tanks being given a precautionary cleaning, they recommend tumbling for 5-10 minutes using 8-10 lbs. (4 kg) of 4-5mm glass beads. Glass beads are not very abrasive, and their purpose here is to provide a scouring action without any actual removal of base material, and especially not of the protective oxide coating in an alu tank.

For old tanks showing any signs of contamination, rust, bayerite, or aluminum oxide dust, they suggest wet tumbling using standard tumbling abrasives - preferably the ceramic rather than aluminum oxide, since they are more uniform and predictable in their action - and tumble 2-3 hours for steel, and 30 minutes or less for alu.

This is all pretty much common sense, especially compared to the USD booklet. Since Global sells to dive shops, who should be expected to have tumblers (or if they don't, Global would be glad to sell them one) it's not surprising their recommendations are based on the use of one.

But while a tumbler makes it possible to do a good job of O2-cleaning tanks on a regular basis with a minimum of fuss, it's hardly essential, and a perfectly adequate job of O2-cleaning can be done without one.

Lubricants

One thing is very clear, that the silicone grease normally used for lubrication in SCUBA gear is not safe with O2, and that special O2-safe grease should be used. These sell for around $30 for 2 ounces.

Some tech divers report using standard silicon lube with O2, but since there have been numerous confirmed reports of fires caused by silicone lube and O2 it really doesn't make any sense not to use O2-safe lube in valves and regs that will see high FO2s.

In the early days of tech diving O2-safe lube was hard to find, but now many scuba regulator manufacturers are specifying its use, and even selling it.

Christo-Lube MCG 111 seems to be currently the product of choice, with Scubapro, Aqualung and Sherwood all recommending it. Krytox was once popular but DOW doesn't seem very interested in the dive market.

Interestingly enough, the reg manufacturers seem to be leaning towards these lubes not just for nitrox regs, but for across-the-board use on all regs and valves. The reason for this is not just to prevent mixups in the field, a USD rep told me, but because they feel that the new O2-safe greases are much better all-around lubes than the old silicones. Scubapro says in its service literature that only Christo-Lube should be used on its newer regs in order to "increase IP stability and maximize peformance."

Christolube's sinecure on the O2-safe dive lube market is being challenged by Aerospace Lubricant's Tribolube line. Tribolube 71 is a direct replacement for MCG 111, meets the same milspec, and is often a bit cheaper. Tribolube is aggressively wooing the dive market, with a line of complementary products including a solvent spray cleaner for removing O2-safe lubes and an O2-safe protectant spray, and very accessible technical support.

O2-safe lubes should usually be applied sparingly. The rule of thumb is that no build-up of lubricant should be visible on a properly lubricated part. The part should look shiny, but there should be no excess.

O-Rings

New O-rings, unless they come in a sealed package and are guaranteed O2-clean, should be cleaned in a weak warm water and detergent bath, and dried before being used in oxygen service.

Most sources have traditionally also stated that only viton O-rings, which are considered O2-safe, should be used in an O2-clean valve or regulator, but once again there is an ongoing debate in tech diving circles as to whether this is really necessary. Some say plain old Buna-N (nitrile) works fine (aviation practice, by the way, is to use nitrile for O2 systems), others say pure 02 will attack nitrile and they won't last nearly as long.

This is really an issue only with components which will be exposed to high-FO2s for extended periods of time. In the case of a valve that only sees 100% O2 during PP mixing, it is even harder to get very worked up about the need for viton, considering that the valve will only be exposed to it for a few minutes at a time. and usually at no more than 500 psi.

Why not just use viton anyhow, just to be sure? The problem is, viton introduces complications of its own. While viton is less likely to combust, when it does, it produces fumes that are extremely toxic, even in trace amounts. For this reason, several SCUBA regulator manufacturers have specifically recommended against the use of viton!

Also, off-the-shelf viton O-rings (especially, for some reason, the green ones) tend to be quite soft and there is a feeling that they often do not hold up as well as nitrile to wear and mechanical stress. Regulator manufacturers use specially formulated O-rings at key points, such as Scubapro's "Hyperthane", to tune the regulator for maximum performance. Usually these are harder compounds chosen for their ability to resist extrusion. Casually replacing these with generic O-rings in other material specifications may cause a noticeable degradation in regulator performance. This is especially a concern with piston first stages.

EPDM seemed like the perfect compromise when it started becoming widely and economically available. Several regulator manufacturers picked up on it, and a few of them even hinted that with EPDM and O2-safe lube the regs were good for 100% right out of the box.

Unfortunately, time has shown that this is not necessarily so. There have been a few instances of combustion in regulators with EPDM O-rings, and just about all the reg manufacturers have backed off from claiming the regs were OK for 100%.

Part of the problem with EPDM is that there are many different grades, and they vary quite a bit in how good they are. Some have O2 indexes almost as high a viton, and others little better than nitrile. This is no problem for a manufacturers who can spec exactly what they want, but it can be one for the diver or technician who has to take what he or she can get.

So while EPDM is probably the material of choice for nitrox regulators, and can probably be be (carefully!) used with high FO2s with a reasonable level of safety, I now tend to think that any reg intended specifically for 100% probably ought to have viton, at least on the HP side. Ditto valves which will be used at full tank pressure with 100% (as opposed to occasionally seeing 500 or so psi of 100% during PP mixing). And anyone using ANY scuba valve or regulator with high-FO2s should always be prepared for the possibility of combustion or tainted gas.

All this is a good reminder that tech diving and the use of high FO2s is still a relatively new, and evolving, field, in which there are often no clear limits or guidelines, and we must learn as we blunder along.

While many divers assume that any funny-color O-ring must be some trick composition and therefore O-safe, color is not really a reliable guide to O-ring composition. There are several industry marking codes, but they seem to be used only erratically. Most O-ring manufacturers will cheerfully dye O-rings any color a quantity buyer requests. Viton and EPDM O-rings often come in black though Apeks was supplying blue EPDMs at one point. Some studies have shown that black O-rings are less combustible than colored ones!

Global carries a large assortment of generic O-rings for use in regulators. Most of their nitrile O-rings are 70 or 75 durometer, and their viton O-rings 90. So those numbers make a good starting point for anyone shopping locally for O-rings. Another good source is www.air-oil. com which has a very wide range of O-rings on their website at very good prices.

If the reg manufacturer makes an O2 or nitrox kit for the reg that should be the first choice.

Incidentally, the only test I've seen (in Rodale's SCUBA DIVING magazine) that compared a nitrox and regular version of the same reg. found that the non-nitrox version performed measurably better. Was this just sample variation, one wonders, or do the "nitrox" components - which one assumes to be mostly to be viton O-rings - degrade performance?

One O-ring that it may make sense to routinely replace with funny-colored viton is the tank neck O-ring. Partly this is because it's the only O-ring in continuous contact with HP gas and thus the most likely to suffer from prolonged exposure to high PO2s.

Mostly, though, it's because some dive shops pumping nitrox have begun using this ring as an indicator of whether the tank/valve have "really" been O2-cleaned, and may refuse to believe it's been done if they don't see a funny colored O-ring there!

In conclusion, while the need for O2-cleaning is a subject for endless debates, it seems reasonable to, at the very least, give any tank and valve that will be seeing high F02s, even only briefly during partial pressure mixing, a good washing out, a thorough inspection, and replace the O-rings with new nitrile, viton or EPDM ones lubed with an O2-safe grease.

Stickers

The problem with doing one's own O2-cleaning, if one doesn't have fill capabilities, is convincing the shop that it's been done. Many tech dive shops enjoy perpetuating the notion that O2-cleaning is a black art as much as they like the additional source of income such ministrations provide, and are unwilling to accept the notion that it is something a customer can do for him/herself.

Telling them that the tank has already been cleaned at home will likely only lead to an argument and refusal. It's much easier just to show up with the tank properly stickered for having been oxygen serviced. But where to get the stickers?

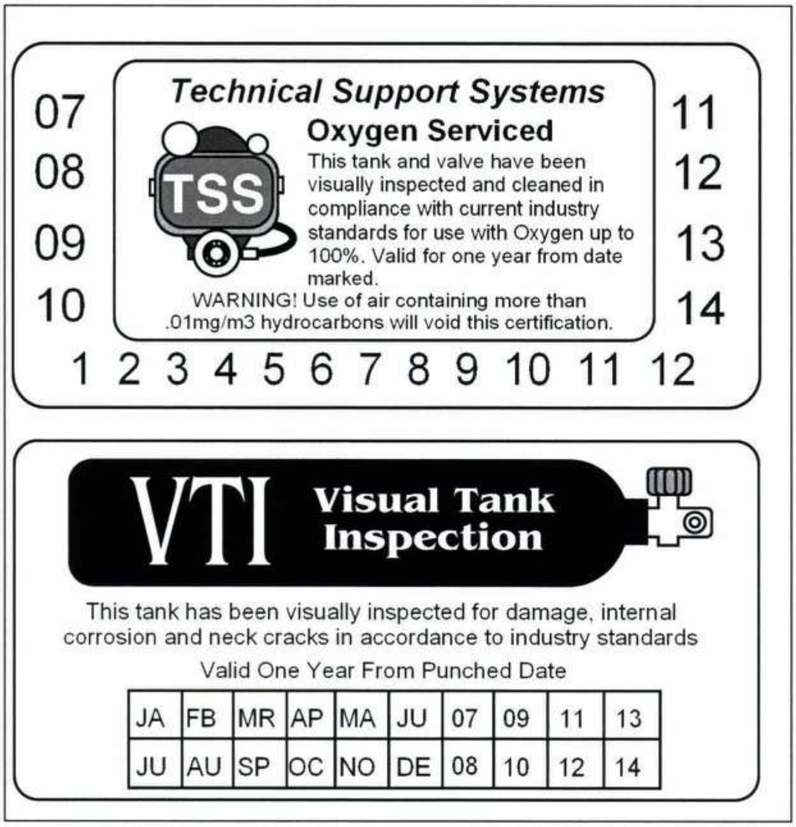
A very few shops will trust you to do it yourself, and some will even sell you O2-clean stickers - if you find one that will it's a good idea to stock up.

Note that stickers are really only a concern if one is getting nitrox fills from a shop and need to be able to prove it's been done. Most home mixers don't bother with O2-clean stickers on their tanks at all, because they only lead to troublesome questions when it comes to getting the tanks topped off. Far easier to keep the O2-clean status of the tank and the current mix in a separate logbook, bring the tanks in unencumbered with extra markings, and analyze the mix and tag the tank afterwords.

If one does need stickers, generic (no shop or agency name) O2-Clean and Visual Inspection stickers are also available from dive shop suppliers like Global.

The stickers I'm using now are from one of the tech agencies. They're pretty cute, because all they say is that the tank and valve have been "visually inspected and cleaned according to current TDI standards" without saying who did it or what those standards are, so an individual who does his or her own O2-cleaning can use them with a clear conscience.

Cale simply makes up his own stickers, using a computer draw program, and then prints them out



on a waterproof self-adhesive laser-printable label stock.

Cale resists the urge to get too clever or deceptive on his tank stickers. His simply say that the tank and valve have been cleaned and inspected in compliance with industry standards, both of which are true. He doesn't try to copy the stickers of any existing shop or agency since that would be dishonest. The two stickers shown are samples of his work.

I should make it very clear here, that the point in discussing how to make stickers is not to encourage anyone to fraudulently label tanks as being serviced when they have not been, but rather, to offer anyone doing their own O2 cleaning the means to mark the tank as so serviced. Oxygen cleaning, like tank inspection, is for everyone's safety, including your own, so cheating is foolish, shortsighted, and undermines the safety of the whole system.

It may also be criminal! While there is no legal requirement that tanks be O2-cleaned or annually inspected, putting an O2-clean or visual inspection sticker on a tank that has not been so serviced could be considered deceptive, and leave one liable if someone was injured as a result!

If one is doing one's own O2 cleaning, it is a essential to keep a log, recording the serial numbers of each piece of equipment cleaned, the date, and the methods used.

Incidentally, much of the above also applies to visual inspections. There is no legal requirement, or even uniform dive industry standard, for the inspection of tanks, and many dive store personnel doing visuals have no formal training or certification to do so. And paradoxically, I've heard from individuals who took the PSI course and then found local shops wouldn't accept their inspections!

All which leads to an interesting question - can a diver inspect his or her own cylinders? According to the DOT regs, there is no reason why not - it's not like hydro testing, where a tester must be licensed. Like O2 cleaning, tank inspection isn't rocket science. It's original intent was to see that the tank got, every so often, a quick common sense peek inside for gross defects, like cracks, contamination and serious corrosion. That being the case, there is no legal reason why divers who take the time to acquaint themselves with any of the appropriate guidelines - be they PSI, CGA, tank manufacturer, or agency - cannot "legally" do inspections for themselves though it is, obviously, only prudent for the novice inspector leave any borderline or 6351 "bad alloy" aluminum tanks to someone who has the special training and equipment necessary to safely inspect them.

Admittedly, the price of an inspection is small (or maybe that should be "was" - it's starting upward, and I know a few shops that are charging $30) but it can be an unnecessary aggravation, especially if you have a lot of tanks, or manifolded doubles that must be broken down to inspect, or are just tired of dealing with a dive shop that tries to use visuals as an excuse to gouge or enforce nutty standards - or doesn't know how to do a proper one.

Chapter 3
NITROX

The recent popularity of technical diving, that is to say diving which goes beyond the accepted limits of recreational diving, and involves use of mixed gases or decompression stops, has caused a surge of new interest in O2 handling.

Nitrox, also called EAN (enriched air nitrox), EANx and even SafeAir, is air which has had additional O2 added (or nitrogen removed, in which case it may be called denitrogenated air nitrox or DNAX). Used at medium depths, generally 130 feet (39m) or less, it can allow longer bottom times and/or shorter decompression stops by reducing the amount of nitrogen the diver is exposed to. The paradox is that while increasing the percentage of O2 lessens the N2 and hence the chance of DCS, it increases the chance of O2 toxicity, which is why rigid depth and time limits must be scrupulously observed. Much of the exploratory work on nitrox was done by NOAA, and the most common nitrox mixes, 32% and 36%, were originally known as NOAA 1 and NOAA 2 .

Straight O2, or "hot" nitrox mixes - mixes with a very high FO2 - are used for in-water decompression stops, since the higher levels of O2 speed the outgassing of N2 and shorten decompression.

Claims have been made that nitrox reduces narcosis, by reducing the amount of N2 is the mix. Most divers don't notice any difference, and current thinking, though scientific evidence one way or the other is sparse, is that O2 is just as narcotic as N2, so that replacing one with the other makes no difference with respect to narcosis.

Some studies have suggested that using nitrox instead of air makes a tank last about 8% longer!

One anecdotal benefit to nitrox that does seem to be real - though once again scientific evidence is lacking - is reduction in fatigue. Divers report being much less tired after dives when nitrox is used. I find the effect so noticeable on long drives home after a day of diving that I think I would use nitrox for that reason alone, even if it had no other benefits!

Since custom dive gas mixtures can be expensive or hard to find in many parts of the country, technical divers often find themselves transfilling and/or mixing their own.

It's not that hard. All that is required is the appropriate whip and - the most expensive item - an O2 analyzer for checking the final mixture.

Nitrox Mixing

There are four commonly used ways to mix nitrox: continuous blending, separation, by weight, and by partial pressure.

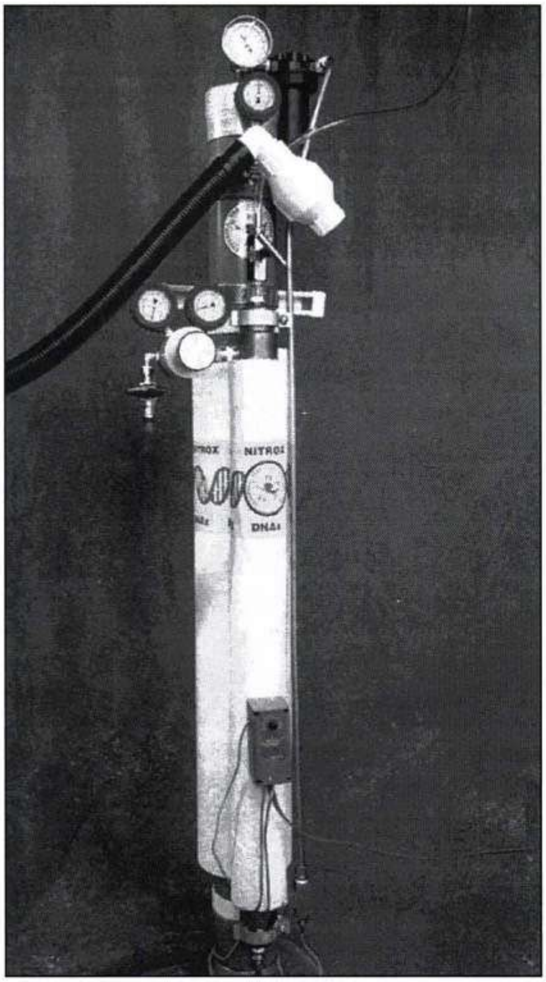
Continuous flow is the high tech way to do it. The gases are decanted, mixed, then recompressed into a storage bank, from which they can be transfilled into the dive tank. This kind of mixing used to be possible only with a sophisticated setup with a mixing board which incorporates the necessary flow meters, valves, analyzers and an O2 safe compressor to compress the resulting mix. However recently relatively low-cost continuous mixers have appeared that work with ordinary dive compressors.

Continuous flow mixing is also referred to as "atmospheric entrainment", since the gases are decanted to atmospheric pressure for mixing and then recompressed.

The latest innovations in the nitrox game are membrane and pressure swing absorbtion separators which allow filtering out some of the N2 from the air as it it is being compressed, making bottling nitrox as easy as filling a tank. But separators don't come cheap - at about $1000 per cf of compressor capacity - and also require an O2-safe oilless compressor for higher FO2s.

Mixing can also be done by weight instead of pressure. This is called gavimetric mixing, and ispotentially the most accurate method of all, since it eliminates all errors caused by heating and compressibility. The catch is it requires extremely accurate and expensive scales. Still, it is the preferred method used by most commercial gas suppliers.

A Continuous Mixer



A Membrane Separator from Undersea Breathing Systems

Partial Pressure Mixing

Partial pressure mixing is the simplest method of mixing. It means simply putting one gas in the cylinder, then the next, using the pressure to keep track of how much of each gas goes in - hence the name.

It's not as slick as continuous flow mixing, since in continuous flow mixing the mix is continuously monitored and analyzed as it is going into the tank. With partial pressure mixing there's no way to know exactly what the final mix is going to be until it is analyzed, and the mixer must learn to take into account factors like cylinder heating and gauge error.

On the other hand, it's a pretty straightforward business, and doesn't require much in the way of special hardware to do it. That makes PP mixing ideal for the homemixer, and it's likely PP mixing will be around for some time to come.

The O2 supply tank - usually a big 250cf (7m3) H or K tank - is connected to the SCUBA tank with the nitrox whip, and the the necessary amount of O2 to obtain the desired final FO2 transfilled from the big tank to the little one. While the main reason for adding the O2 first is that it's easier and avoids having to boost it, it is also desirable to do so since it keeps the PO2 that the valve will see as low as possible. Some mixers have suggested that adding it later would be safer, since the O2 would be diluted by the air already in the tank, but it is the valve we are most concerned with when it comes to adiabatic heating, and the valve will see a higher PO2 if the O2 is added after the air.

To avoid adiabatic heating the fill tank valve should be fully opened before the fill is commenced, and the valve on the supply tank end of the whip (or whip valve if so fitted) used to control the fill. It should be opened very slowly, and the system allowed to pressurize gradually, at the beginning of each fill.

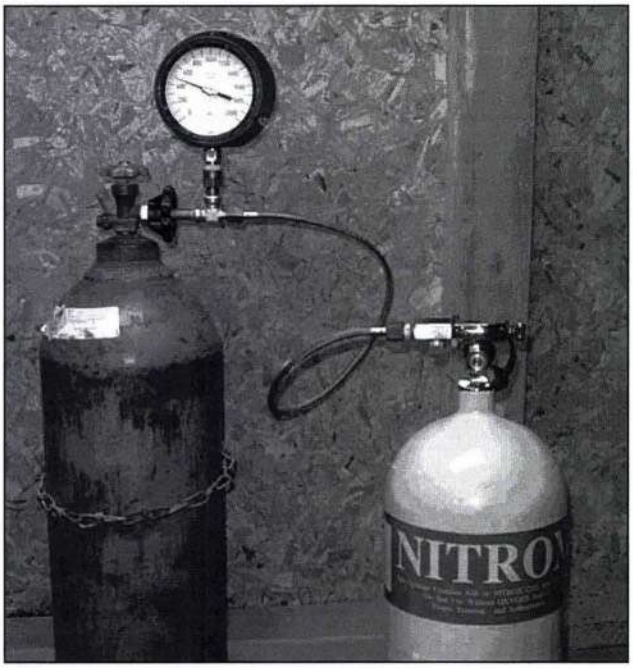
The transfer should be done slowly, at 60 psi (4bar)/minute or less, so as to minimize heating, both to lessen the chance of combustion and to keep the tank from heating up enough to throw off the pressure readings too badly. The home mixer actually has an advantage here, because he or she usually isn't in a big hurry, and can use low flow rates, let the tank sit and cool, then top it up to get the desired pressure.

After the O2 is added the tank is allowed to cool and the O2 pressure rechecked and adjusted if necessary to get it just right.

Then the tank is slowly topped up with air. There's a major difference to be aware of between adding O2 and adding air: when topping up with air, the tank valve should be kept closed until the whip is pressurized. If the whip is attached to the tank with the whip unpressurized, and the tank valve opened too quickly, a surge of O2 can go blasting up the (non-O2-clean and dirty) whip hose, possibly creating enough adiabatic heating to light the hose. This is especially a problem at dive shops that control the mix from a fill station panel rather than at the whip head since the whip is usually unpressurized when they start the fill, and there's a long run between the fill valve and the tank - one more good reason to cut the O2 with air before taking a primed tank to a dive shop.

Keeping the air fill rate slow lessens the chance of any possible problems if there are hydrocarbons in the air, and also keeps the tank from heating up and throwing off the pressure readings - 100 to 200 psi (7-13 bar)/min is plenty. Some mixers like to add the first 500 psi (35 bar) or so of air very slowing, at 60-100 psi/min (4-7 bar/min), to dilute the O2 down to safer levels, then do the remainder of the fill at a much higher rate to increase turbulence and hence mixing.

After the mixing is done, the contents are analyzed with an O2 analyzer to confirm that the FO2 is within tolerances, and the tank tagged to identify the mix and the date - a piece of 2" wide yellow plastic or duct tape and a Sharpie pen work well. Some mixers put a second piece of tape over the opening of the valve at the same time, to identify the tank as full.



Partial pressure blending using a whip

The usual limits given by the tech agencies are + or – 1%, meaning that if the target mix was 32% anything from 31 to 33% would be acceptable. Most mixers I know would be appalled if they were off by anywhere near a full percent, and aren't happy if they don't get it within 0.5%. Note that the purpose of analysis is not to find out what that mix is, but to confirm that it came out as intended - if the mixer has done the job right, the mix should be right on, and the analyzer is there only to provide redundancy.

O2 readings taken immediately after filling a tank may not be completely accurate since it may take a while for the gases in the tank to completely homogenized after air is added.

How long is a matter of some dispute. The NOAA manual, and a few of the tech agency mix manuals that follow its lead, used to say the mix tank should then be either rolled back and forth across the floor for an hour or allowed to sit for six hours to let the gases mix before being analyzed. Most mixers feel this is unnecessary as the turbulence created by the incoming gas mixes them almost instantly, and waiting five or ten minutes before analyzing is enough to finish to job.

Fortunately, there's no need to rely blindly on authority to decide who is right - since the mix should be analyzed both after mixing and before

Analyzing using the BC QR sampler from chapter 9.

The tank should always be labled with the current contents immediately upon being analyzed. Note tape on valve face to mark tank as being full.

using, a mixer will have plenty of opportunity to reach his or her own conclusion.

Anyone mixing should be keeping a mix log. Each mix should be logged so that any consistent error patterns can be noted and remedied.

One thing to watch out for - always measure the starting and finishing numbers for adding O2 with the same gauge, which will normally be the master gauge on the whip. It's easy to take the residual number on the worksheet and add the figure you've calculated for the amount of O2 to be added to it, to come up with the final pressure to which you should add the O2.

The problem with this is, if one has measured the residual using a spg or tank gauge, then uses this as the starting point to calculate what psi to add O2 to, and measures the O2 fill using the master gauge on the whip, there could easily be as much as 50 psi variation between them. While a 50 psi (3.5 bar) error on the residual mix number won't usually throw things off more than a fraction of a percent, a 50 psi error in the amount of straight O2 being added to the tank can cause as much as a 2% error in the FO2, which is unacceptable. So measure the residual mix with any gauge one pleases, but when it's time to add the

O2, the residual pressure should be rechecked once the whip is hooked up, using the master gauge, and the 02 fill-to pressure calculated using that as the starting figure.

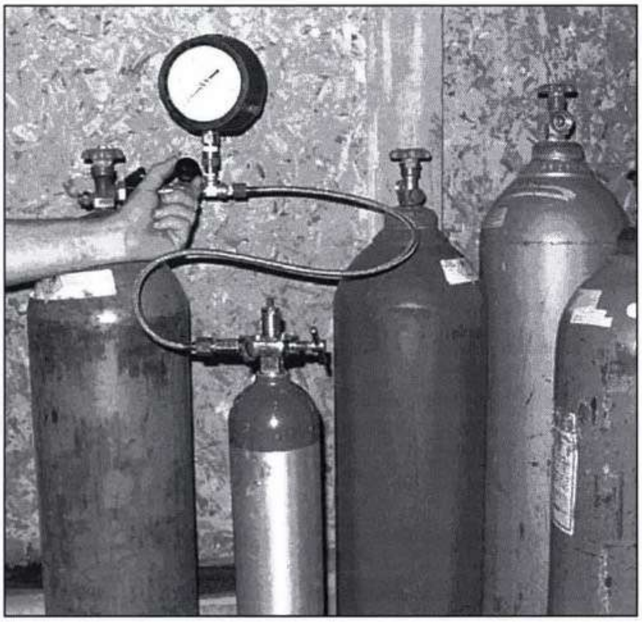
Mix should always be "tasted" or smell tested before using, since, should any combustion or vaporization occur in the mixing or boosting process, there will usually make the mix smell bad.

Filling Small Tanks

Priming small tanks with 02 present a special challenge. There are two reason why. The first is the obvious one, that their small size makes it very hard to keep the fill rates down - a valve opening that will produce a 60 psi/min (4bar/min) fill rate in a 104 will produce a 600 psi/min (40 bar/min) fill rate in a 12cf pony or portable avset tank! Even if there's nothing inside to catch fire to, that kind of fill rate could create enough heat to damage an alu tank or melt the valve seat.

The second is that the smaller internal volume of the tank reduces its ability to act as a "shock absorber" to lessen the adiabatic heating should one slip up while opening the valve.

Various sources recommend different ways to deal with this, such as mixing in a larger tank and transfilling the mix to the smaller one, or filling several tanks at the same time so the total volume is increased making the fill rate less volatile, but the most practical solution is just to be aware of the problem and keep the flow rates really slow - anyone filling small tanks on a regular basis should include a precision needle valve on the whip.



Good technique (and a reliable needle valve) are essential when filling small tanks

A regulator is also useful here, since the pressure can be increased in tiny steps, so the difference in pressure between the whip and the tank, and hence the flowrate, can be kept very small.

The same problems exist when transfilling straight O2 into a deco or aviation bottle, magnified by the fact that they are filled to a much higher PO2. Filling several bottles at once is the best option here, but since this usually will not be practical one may have no choice but to rely on a good valve, and a lot of caution and care.

Taking all this into account, it probably makes sense not to try to do mix or O2 transfills into small tanks until one has accumulated some experience filling larger ones.

How Much O2 To Add?

The place where a lot of home mixers get into trouble in partial pressure mixing is figuring out how much O2 to prime the tank with to get a desired percentage of O2.

The really dumb ones say "lets see, I want 32% nitrox, and it's a 3000 psi tank, so I'll add - let's see, 32% of 3000 is 960 – 960 psi of O2!

The slightly smarter ones figure, "I want to make 32% nitrox, but since there's already 21% O2 in air, that means I should add - uhmmm, 21 from 32 is .... 11% more O2! 11% of 3000 is 330 psi, so I'll add 330 psi of O2.

The first method is obviously totally bogus since it does not take into account the O2 already in the air. That diver would end up with something like 46% nitrox, and, very likely, CNS O2 poisoning.

The flaw with the second method is that it doesn't take into account the fact that the straight O2 one puts in the tank displaces air that will otherwise be in the tank, along with the O2 that would be in that air, so that the final mix would have less O2 that calculated.

In the second case, the diver put 330 psi, or 11% O2 to the tank. That leaves only 89% of the tank for air, so diver will end up with the equivalent of 89% of 21% of O2 from the air, which works out to 18.69%, along with the 11% of straight O2. Add them together, and it comes out to only a 30% mix.

Or to look at it in terms of cubic feet, let's call it a 100 cf. tank (just to make the percentages easier) and put 11% O2 into it. That's 11 c.f., which would leave 89 c.f. of air which at 21% O2 equals 18.69 c.f of O2, for a total of 29.69 c.f. of 02.

So in order to figure out how much O2 to add for any desired nitrox percentage one must take into account the O2 in the air. Fortunately, there's an easy formula that does so:

$$\frac{(FO2\ mix - FO2\ air)}{FN2\ air} \times \text{final psig} = \text{psi } O2$$

Where:

FO2 mix is the fraction of O2 desired in the finished mix.

FO2 air is the fraction of O2 in the fill air (usually 21%)

FN2 air is the fraction of N2 in the air (usually 79%)

final psig is the pressure of the tank once it is completely filled.

psi O2 is the amount, in psi, of O2 that must be added to the tank to give the desired FO2 mix

For example, for 32% (NOAA 1) nitrox in a 80cf/3000 psi tank you would have:

$$\frac{(32\% - 21\%)}{79\%} = \frac{11}{79} = 13.9$$

$$13.9\% \times 3000 \text{ psig} = 417.7 \text{ psi } O2$$

That means that to make 32% nitrox in a 3000 psi tank, one would simply put 418 psi of O2 in before topping it up with air to 3000 psi.

Notice that these calculations pay absolutely no attention to the actual volumes of gas involved. Since percentages are easier to work with, and psi easier to measure, than cubic feet, there's not really any reason to use cf in one's calculations except when it is desirable to know the actual volumes involved - to figure out how many fills can be gotten from an O2 supply tank, for example. To find volumes just multiply the size of the tank by the various percentages involved.

For example, to find out many cubic feet of straight O2 went into the the tank in the last example, since it was an 80cf tank, and took 14% of straight O2, one multiplies 14% times 80:

80 c.f. x 14% = 11.2 c.f.

Which means one could mix about 20 tanks of 32% nitrox from one 250c.f. tank of O2 (allowing a bit for waste and for the fact that not all the O2 in the big tank will be usable).

Notice too that the percentage to obtain any given mix is the same regardless of tank size and capacitie, but not the psi which must be calculated.

If the tank was, say a 2640 Scubapro + rated steel tank, and I wanted to fill it with 32%, then I would do:

14% x 2640 psi = 370 psi.

It doesn't matter when one puts in the O2 in, from the standpoint of getting in the right amount in the final mix. That is to say, if one puts the 370 psi into the empty 2640 psi tank then tops it up with air, or if one fills it with air to 2270 psi air and then tops it up to its rated 2640 psi with O2, one would still end up with 32% nitrox. In real life, one usually puts the O2 into an almost empty tank because it's easier, safer, and doesn't require a booster pump.

Notice too that that manifolded doubles are, as far as these calculations go, one big tank. If a single 2640 psi tank would take 370 psi, then two manifolded together would take 370 psi - not 740!! (anyone who doesn't understand why not probably shouldn't be reading this booklet for anything more than entertainment!).

The reader may have noticed a catch here. If one does not have the ability to do the air fill, then predicting exactly how much air will end up in the tank may be difficult. I know of one shop nearby that habitually underfills tanks. I've gotten 3000 psi tanks back from them with anything from 2650 to (just once) 2950 psi. Another shop, on the other hand, always does a slow fill to 3150, and the tank as it cools ends up consistently just a satisfying tad over 3000 psi.

The easiest solution is to go to the latter shop. But also keep in mind that a small difference can be simply taken into account when during dive planning. For example, to take a fairly extreme example, if I'd primed a 3000 psi tank with enough O2 to yield 32% nitrox, then gotten a lousy 2600psi fill, the resulting mix would be end up about 34% - fairly usable, unless I was planning on going to the max depth for 32%, and I'd be alerted to the problem when I analyzed the mix. But then, since I was down over ten percent of tank capacity, I might not have enough duration to justify using nitrox anyhow. So in real life, I'd probably just find a more reliable shop and top the tank off. Notice too that if one habitually overfill tanks (as some divers are rumored to do) that one must take that into account when figuring out how much to add, or mixes will be consistently off.

Mixture Creep

The old contents of the tank should always be analyzed before putting a new mix in, since leftover old mix can throw the new one off. If a new fill of nitrox is done on top of 300-700 psi (20-50 bar) of nitrox from the old fill and the old mix treated as air, then the final mix will have a higher FO2 than intended, since the old mix contains more O2 than air. This could, in some cases, produce an error of 2-4% , and even more if one had been using a high-FO2 mix.

If there is old mix, one has two options. The easiest is to empty the tank before refilling, but that's wasteful, and most home mixers can't stand the thought of wasting brew. Also, from a safety point of view, it is advantgeous to have as much old mix as possible in there since it cuts the 02, and lessens the chance of combustion.

The other is to analyze the residue mix in the tank and do the math to account for its effect on the final mix.

Actually, the calculations are easy - it's the same formula as for figuring how much O2 to add, but used this way it tells how much "extra" 02 is in the residual mix.

$$\frac{(FO2 - 21\%)}{79\%} \times \text{remaining tank psig} = \text{"left over" O2 in tank}$$

Where FO2 is the actual percentage of O2 in the tank,

and "left over" O2 is the O2 in excess to that in the air which can be applied to the next mix,

and 79% the amount of NO in air.

What this does is, in effect, divide what's left in the tank into 79/21 air and excess O2. The excess O2 can then be subtracted from the total amount of O2 that must be to be added to the tank to get the desired mix.

For example, suppose one has 600psi of 36% left in a tank:

$$\frac{15\%}{79\%} \times 600\text{psig} = 114 \text{ psig "left over" O2}$$

Then one can just subtract this from the amount of O2 that has to go into the tank to give the desired FO2. To use the first example, where it would require 418 psi of O2 to make a tankful of 32%, now one would put in:

418 – 114 = 304 psig

Of course if the residual mix in the tank is the same % as the new mix, you don't have to do this - just deduct the psig in the tank from the final pressure when you use the basic formula.

For example, if in the first example, one wanted to mix a tank of 32%, but the tank had 750 psi of old 32% in it, one could figure it like this

$$\frac{(32\% - 21\%)}{79\%} \times (3000 - 750) \text{ psig} =$$

$$\frac{11\%}{79\%} \times 2250 \text{ psig} = 313 \text{ psig}$$

Incidentally, one idiot I was talking to about this claimed that, if you reused the same tank long enough without compensating the mix would go on creeping higher and higher until would contain 100% O2! I asked him what was happening to the air the tank was topped with, and he looked confused.

Many people find the calculations intimidating. Dive gas mixing computer programs are available and can be a big help with trimix, but most of the time they are overkill for the home nitrox

WORKSHEET 1

MIX NO: 74 — FO2 target 32 % — FO2 actual 31.3 % — MOD 111"

Date: 7/13/95 — Notes: Doubles for Pinthis

NEW MIX	(FO2 Mix – 21) (32-21) = 11 / 79	=	.1392	X	2900 (Final tank PSI)	=	403	**PSI O2 necessary to achieve desired mix**
OLD MIX If any	(FO2 old m ix –21) 11 / 79	=	.1392	X	750 (PSI old mix in tank)	=	104	PSI O2 available from old mix, if any. Subtract from the above.
					Total		299	**PSI O2 to add to tank.**

A few details: "final psi" refers to the final fill pressure after the air is added. Normally this is the rated pressure of the tank - 2600, 3000, or 3500 psi, (180,200,230 bar) to name the most common. But if you are intentionally overfilling or underfilling the tank you need to be able to predict in advance the final psi to accurately calculate the amount of O2 to add. This is not really as much of a problem as you might think, since a few hundred psi in either direction will not throw the mix off by more than .5% of so - but don't take our word for it; try a few different scenarios for yourself.

If the leftover contents of the tank are air, one simply skips the "Old Mix" part of the worksheet. "FO2 target" refers to the mix you are trying to achieve. "FO2 Actual" is the mix you actually end up with, as measured by your O2 analyzer.

The worksheet doubles as a nitrox mix log - each page has space for three nitrox mixes. To use it, take the full-page master sheet at the back of the book, print it out, make a bunch of copies, punch them for a binder, and you've got a handy nitrox mixing calculator/log so you can track your mixes.

Table 3
OXYGEN PERCENTAGES FOR PARTIAL PRESSURE MIXING

For a final FO2 of:	add this much O2:	For 2640 psi tank:	For 3000 psi tank:	For 3500 psi tank:	Max Depth@ P02 1.4 ata:	Max Depth@ P02 1.6 ata:
32% (NOAA 1)	14%	367 psi	420 psi	490 psi	111'	132'
36% (NOAA 2)	19%	502 psi	570 psi	665 psi	95'	114'
40%	24%	634 psi	720 psi	840 psi	82'	99'
50%	37%	969 psi	1101 psi	1284 psi	59'	73'
80%	75%	1980 psi	2250 psi	2625 psi	25'	33'

*All depths in fsw.

mixer, especially if he or she doesn't keep a computer in the garage.

To simplify things, we've come up with a worksheet. It's designed to be used with a pocket calculator, to quickly figure out how much O2 to add to a tank for any desired nitrox mix, automatically taking into account any old nitrox mix left in the tank. It's a lot cheaper than using a computer, and probably faster, considering that it gives you automatic hard copy with no need to wait for a printer.

Anyhow, most of the time one does the same three or four mixes, so now that I've bored you with the math, here's the percentages all worked out for a few of the most common tank and mix combinations:

If one is doing percentages or psi's not in the chart, note that the chart is still useful, if only as a quick way to double check your results. For example, if one is filling a 3300 psi tank one knows the required psi should fall somewhere in between the figures for a 3000 psi and a 3500 psi tank.

Keep in mind that these numbers are only a starting point since they don't take into account heating of the mixture or compressibility (gases vary in how well they compress; a tank filled with 2000 psi of O2 will hold more cubic feet than the same tank filled with 2000 psi of helium). And then there'll probably be some gauge error. Until one has mixed and analyzed enough tankfuls of nitrox to get a feeling for how the variables fall, the process will be to a certain degree trial and error. Fortunately, as they say, "the proof is in the pudding" and in this case the pudding is an O2 analyzer that tells exactly what one has.

Scientists and serious gas mixers have a name for this uncertainty. They refer to mixing by the "ideal-gas" or "real-gas" method. This really applies more to heliox or trimix, where the compressibility of helium becomes a significant factor, but the difference is that in "ideal-gas" mixing one pretends that the gases involved perform in a perfectly linear fashion, where in "real-gas" mixing it's necessary to take into account the particular quirks of each gas in the mix to predict how they'll really behave. The Navy mixed gas manual, and some of the tech diving agency gas mixing manuals have much more on this subject, as does the trimix chapter that follows.

Most amateur mixers, one suspects, use what one might call the "ideal gas/real world" method, where they use ideal-gas assumptions modified by fudge factors learned by experience concerning factors such as temperature, compressibility and gauge error.

Table 4
AIR PURITY STANDARDS

	CGA D	CGA E	CGA F	CGA J	Navy/ NOAA	Fed. Spec. BB-A-1034	OCA (IANTD/ANDI)
02	--------19 – 23%---------				20-22%	20-23%	20-22%
CO	20	10	5	1	20	10	2
CO2	1000	500	500	0.5	1000	500	1000
Water		24					
Gaseous HCs	(not specified)			25	0.5 25	25	25
Oil mist and Particulates	5mg/m3	(not specified)			5mg/m3	.005m/l	0.1mg/m3

Note: all quantities in parts per million (ppm) unless otherwise stated.

Air for Nitrox Mixing

When partial pressure mixing nitrox, it is necessary to top up the tank with air after priming the tank with the O2. This is generally considered one of the two most potentially hazardous steps in nitrox mixing (the other being, of course, when putting pure O2 into the tank) since the incoming air is exposed, briefly, to very high FO2's along with heat created by the compression. The fear is that if there are any hydrocarbons in the air they could ignite. For this reason it is generally considered essential that only very clean, "hydrocarbon free" air be used in partial pressure mixing.

How free? There are a number of slightly contradictory standards. Plain old dive shop air is supposed to, at the minimum, meet the standards for CGA Grade E (on the CGA scale for air A is the lowest, not the highest). This is generally considered too dirty for partial pressure mixing.

The NOAA manual specifies air that meets Navy standards, which are fairly close to CGA grade E, and, interestingly enough, makes no distinction between air used for air diving or for gas mixing.

The tech diving agencies generally call for hydrocarbon free air, something variously referred to as "OCA" (oxy compatible air), "Nitrox Air", "Modified CGA Grade J" (regular CGA Grade J doesn't have a specification for hydrocarbon solids), or air meeting federal standard BB-A-1034.

The chart shows how they compare.

There's a couple of things to notice. One is that , while the big concern in PP gas mixing is the hydrocarbons contaminants in the air, the numbers listed under Hydrocarbons in air specs usually refers to gaseous hydrocarbons - like methane - and these are not usually the problem. Sometimes to make this clear they'll be called "Gaseous Hydrocarbons".

The hydrocarbons the dive gas mixer is most concerned with are the non-gaseous ones from the compressor. These are often listed as "Condensed mists and particulates" which can make it easy to overlook that they are also hydrocarbons, a mistake which could have serious implications if you were evaluating the suitability of air from a given compressor for PP mixing.

The particulate figure for BB-A-1034 is, for some reason, listed in mg per LITER, not per square meter as for all the others - do the math and, surprise, it works out to the same thing (at least it does for me).

Getting absolutely hydrocarbon free air requires, in most cases, an elaborate and expensive filter array, sometimes called "hyper" filters, especially in the case of an older or portable, compressor. These filter arrays are available from Lawrence Factor and Global among others.

Breathing air filters these days use a multi-stage approach to cleaning the air. Since filter media do not work well wet, the first step is a coalescing filter, or separator, to do the initial, crude, removal of moisture. Then the air is sent to a filter stack where it goes through a layer of dessicant to remove any moisture that got by the separator. After that it goes through a layer of activated carbon or charcoal which removes any odors, impurities or hydrocarbons.

A hyper filter is essentially just another filter stack, usually used in after, and in series with, the stock filter rather than replacing it, to add another level of filtration and, probably more important, redundancy. The hyper filter has the same stages as the primary filter, though the dessicant is usually 14x molecular sieve which traps oil and hydrocarbons in addition to water. Both regular and HP (high purity) carbon may be used to ensure complete filtration.

The media can be bought prepacked in cartridges, or in bulk. When bulk media is used it is packed into the filter stack, with the different media layers separated by felt pads. This allows customizing the filter to suit the needs of a particular installation, and is also cheaper.

Filters like this have relatively short lives, which are effected by a number of factors, including humidity, pollutants in the air, and how dirty the incoming air is. A filter must be carefully monitored to insure the quality of the air it produces.

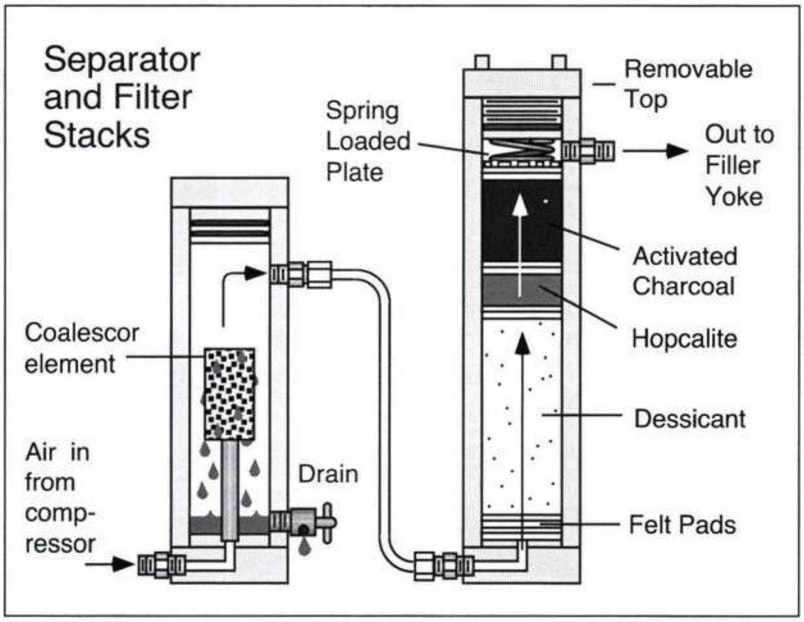
One of the reasons these filters are so expensive is that the air is being filtered after it is compressed, so the filter housing and all the other hardware must be able to withstand HP.

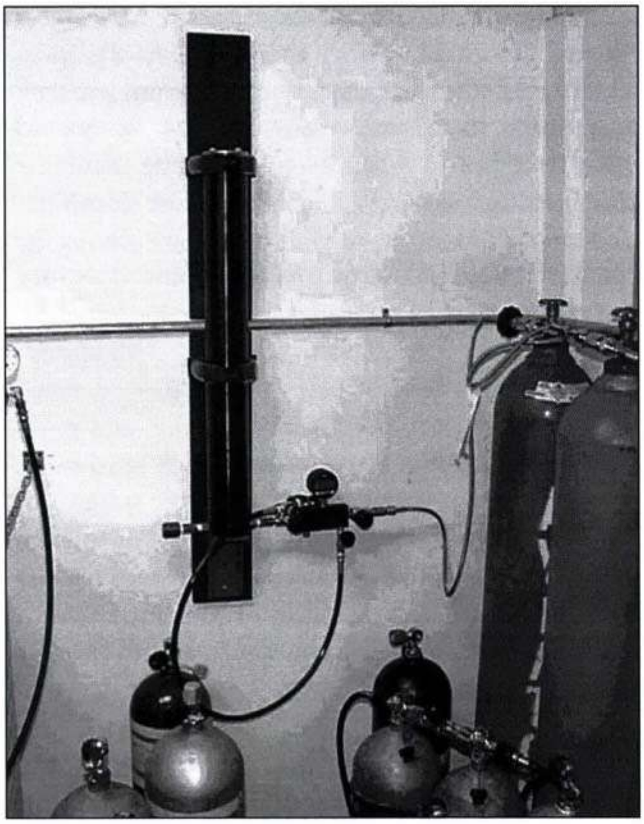
Some homebuilders, though, have built very effective low-cost hand-packed hyper filters using hydraulic accumulators, which can often be found surplus and are built to handle pressures in the 3000-6000 psi (200-400 bar) range.

Even the best filtration doesn't completely eliminate all the dangers of using a "dirty" compressor, since there remains the possibility that some O2 might back up from the tank and into the compressor, where it would encounter both oil vapors and extreme compression heating; a potentially dangerous combination. For this reason, mixing panels are always fitted with check valves to prevent a back flow into the compressor.

This is, obviously, particularly a problem anytime a tank is being filled directly from a compressor rather than via cascade or bank, and especially with portable compressors which tend to be dirtier and have less sophisticated filter stacks.

Small compressors create special problems. They often have tiny filters and older ones usually lack a constant backpressure, or priority, valve so that the filter and separator stacks are not always kept under enough pressure so they can do their jobs. Also, some of their manufacturers specify unrealistically long filter change intervals. As a result, they may be outputting air that is both dangerous to mix with and dangerous to breathe - inhaled oil can cause an unreversible condition called lipoid pneumonia! Anyone using one of these should make a point of familiarizing themselves with some of the unique safety and health issues involved.





Simple hyperfilter installation. The compressor is hooked up to it via the compressor fill whip, which goes on the SCUBA block fitting on the lower left of the filter.

One useful quick-and-dirty air quality test every diver should know is the "handkerchief test" - take a clean white handkerchief, rag, or the tail of a tee shirt, put it over the filler yoke outlet, and blow some air through it. Any visible moisture, oil, or other contaminants deposited on it mean that the filter is not doing its job. This is a very crude test - it will not tell you if the air is good, only if it is inexcusably bad. And it won't detect CO. While you are at it, sniff the air. While CO has no odor, it is often accompanied by combustion byproducts that do, and can tip you off that something is seriously wrong.

Topping off from a cascade is always preferable to a compressor if one is doing PP mixing. The fill can be done at a safer, slow rate, rather than at the compressor's pace, and has a chance to cool. Any oil mist will hopefully condense as it does, and, with a little luck, settle into the cascade tanks and never even make it into the tank being filled.

When this book was originally written, there was little agreement in the tech diving community about just what the air standard should be for PP mixing. Everyone agreed it should be pretty clean, but just how clean was not clear. A few of the agencies tried to evade the issue by calling for simply "hydrocarbon free air", or something called "modified Grade J" which was basically J without any hydrocarbons.

After that things settled down and there was a consensus on the "modified Grade E" shown on the table, that is to say, air containing no more than 0.1mg/m3 of oil, or "nitrox air", "O2 clean air" or OCA as it is increasingly referred to.

This was of some interest to the homemixer, because, while that's only a 50th of what is allowed in normal Grade E diver's air, it's still a more realistic standard than the "totally hydrocarbon free air" called for by some of the agencies. More to the point, many dive shops that do not mix gas or use special filtration routinely produce air that clean.

However, recently a number of people who ought to know have been heretically suggesting that even plain ol' grade E air is plenty good enough - if it really meets the grade E standard. Dick Rutowski, "the father of nitrox", has been insisting so for years. And one air test lab tells me that about 80% of the air they test from grade E systems actually meets the higher OCA standard.

Like the virtues of O2 cleaning, the dangers of explosion from using less than totally hydrocarbon-free air are hotly debated among the tech diving community. It appears they are probably less than they have been generally taken to be the in the past, and many people even seem to be mixing nitrox using just standard dive air.

A number of posts on the various tech/SCUBA forums on the net over the years have challenged anyone to cite a single verifiable case of a tank combusting or exploding from dirty air during partial pressure mixing (though there is the whip incident alluded to earlier). No one has been able to cite one that I have heard of. Nor have several people in the tech industry I've communicated with (most of them, it should be made very clear, are quick to say they do know of such cases, but are just unable to pin down the facts about them). What fires do occur seem to happen when the O2 is being added.

If one lacks the means to fill the tank oneself, one is faced with an ethical question. Tell the dive shop that there is oxygen in the tank, or just drop the tank off and try to look innocent? If one tells, the shop will probably give one a hard time and refuse to fill the tank out of exaggerated concerns for liability or understandable concerns for their own safety.

Many home mixers who wish to placate their consciences while not creating unnecessary hassles compromise by not letting on to the shop what they are doing, but find a shop that has very clean air. The dubious ethical reasoning behind this is that if a shop boasts about how clean their air is, then blows themselves up forcing filthy air into an O2 primed tank, it's their fault.

Others top off the tank with as much air as possible using another SCUBA tank, on the theory that this will lower the FO2 enough that topping off the tank will pose no possible hazard to the dive shop.

This is a very worthwhile precaution, and is highly recommended, since it transfers whatever even slight dangers that might occur in the topping-up stage from the innocents at the shop to the mixer, where it belongs. Since one tankful of air will be enough to dilute the O2 for several tanks of nitrox, it adds only slightly to the total cost of each tank of nitrox.

The best thing to do, obviously, is to find a shop with very clean air, and come clean with them about what one is doing.

It's important to realize that the fact that a shop mixes nitrox doesn't necessarily mean they'll give hydrocarbon free air when they fill an "air" tank; one more reason why it is a good idea to communicate. Since the filter arrays necessary to produce absolutely hydrocarbon free air are

The ultimate solution - a homemade compressor by Ken Swain. The pump is militrary surplus, once used for high altitude air sampling, and the filter stack a surplus SS aircraft hydraulic accumulator.

expensive to maintain, some shops have a bypass rigged so they use the expensive filters only when they are doing gas blending. On the other hand, many other shops that do gas mixing use hydrocarbon-free air for all their fills.

And then, there are many shops that don't even do gas mixing that have air that is virtually hydrocarbon free, simply because they have very good or well maintained compressors - one lab, which does air analysis for many dive shops, reports that about 85% of the air they analyze from non-O2-safe filter systems meets the requirements for nitrox air. These shops are a good bet for anyone doing home blending since, as they are not selling nitrox themselves, they won't regard the home mixer as competition - or analyze the tank to see what's in it. How to tell? Look around for some recent air analysis sheets for their compressor. Any air station should be having regular tests done on their air; a good shop will usually have the most recent results posted.

Note also that having clean air is only half the battle when trying to avoid the dangers of topping off O2; it is also important (and just how important is hard to say with any certainty) that

We should all be so lucky.........

the air be added slowly. A shop with very clean air that slams the fill in is not a good prospect for topping-off primed tanks, one more reason to come clean and reach an understanding with the dive shop rather than doing fills on the sly.

A 1990 report on air quality requirements for nitrox by Mastro and Butler suggests checking for hydrocarbons by swabbing the inside of piping leading from a compressor with a clean swab, then examining it for oil under a black light. While such tests are too subjective to be completely reliable, they can be done easily in the field.

It's hard to read the Mastro/Butler report without getting the feeling that the minute quantities of oil in a breathable but not totally hydrocarbon free air like Grade E are a problem only if allowed to build up over time. That is to say, that the quantity in any one charge of air is unlikely to be enough to be a concern.

This is an interesting tidbit for anyone homebrewing nitrox, because it suggests that regular O2 cleaning can - to a certain extent - offset the home mixer's lack of absolute control over the quality of the air, since in this kind of PP mixing the tank is the only part of the gear that sees high FO2's and where hydrocarbons could present a problem. Regular O2 cleaning of the tank and valve could remove any accumulations before they reach the danger point.

It also suggests that fears that an O2-clean tank will "lose its virginity" as a result of one or even several fills of non-nitrox air are unfounded.

Also, it's worth noting that if anything bad is going to happen, it's by far most likely to occur while the O2 is being transfilled into the tank - not later when the tank is topped up with air. In the few reports of tank fires in the course of PP mixing I've been able to find, the fire has always started while the O2 was being added, in tanks which - one assumes - had been previously contaminated, rather than in tanks where dirty air was put on top of O2. However, just because it hasn't happened or doesn't happen often doesn't mean it won't, O2 being the perverse and unpredictable gas it is, and if a diver was to have a tank or whip combust during a dive shop top-up, he or she would be faced with some serious liability and credibilty issues.

As nitrox, and nitrox homebrewing, becomes more common, many shops, especially those in the nitrox business themselves, have become suspicious of anyone bringing in doubles or big singles. They figure that, since they have invested the money to be able to pump nitrox, anyone not buying it from them is robbing them. Some will insist on analyzing any techie-looking tanks before filling, which can be embarrassing. For this reason, many homebrewers find it "safer" to to get their fills at shops that do not do any mixing themselves and are unlikely to have analyzers.

Some shops use a shortcut method. As one dive store owner told me, "When a customer comes in for a fill and I think he may have O2 in the tank, we blow off some gas and watch the expression on his face. If he screams or winces, we empty it all the way." Stoicism is a useful virtue!

On the other end of the spectrum, there are shops - especially in Florida - that. rather than get paranoid or paternalistic, simply provide O2-clean air, charge a reasonable price for it, and don't worry about what the customer may be up to. There are a few such mixer-friendly shops elsewhere - John Allen's shop, on the outskirts of Philadelphia, gets $45 for a year's worth of unlimited, O2-clean air.

Chapter 4
TRIMIX

Back in the 1930's it was found that replacing the nitrogen in a diver's breathing mix with helium made it possible for the diver to function at much greater depths than possible on air, since helium is much less narcotic than N_2 and, when used to replace the N_2, virtually eliminates narcosis.

Actually, the original impetus to using helium in diving was the belief that it would radically shorten decompression times, based on the fact that helium's diffusion rate is about 2.6 times faster than N_2. In practice it was not so simple - the problem is, while helium is outgassed faster than N_2, it is also absorbed faster, so on shorter dives - those with a bottom time of less than two hours - using helium actually increases deco time, at least, according to traditional tables.

However, He was found to have other advantages. In addition to eliminating narcosis, helium, and mixes containing helium, are much easier to breathe under pressure since the helium is so much less dense. This, in turn, can lessen fatigue and CO_2 retention, both which can be a contributory factors in narcosis and DCS.

More speculative, and less proven, is the belief among many techdivers that helium is "easier on the body" than air. Trimix divers, like nitrox divers, generally report feeling much less fatigued at the end of a long dive than they would after an equivalent dive on air. Explanations vary, are hotly debated, and are too complicated to go into here, but it seems clear that using trimix may save wear and tear on one's body as well as on one's mind.

Helium is quite expensive compared to other compressed gases, though, so heliox mixes are used mostly by government and commercial operations, who can afford it, and usually with rebreather-type apparatus that reuse and conserve the helium.

Deep diving sport divers found they could get many of the advantages of heliox at a much lower cost by adding helium to air to reduce rather than eliminate the N_2. Since the mix contains N_2 from the air as well as O_2 and He, it became known as Trimix.

Since N_2 is still present, narcosis is still a concern, but can be kept at manageable levels. And decompression schedules, at typical tech diving bottom times, are easier on trimix than they would be on heliox.

A few years ago, trimix was the cutting edge for recreational tech divers. Now it is getting to be relatively commonplace.

Divers may be hearing a lot more about helium in the future. As tech and extended range diving become more popular, there is a war currently being waged in the tech diving community over the future of deep air diving. Traditionally, the tech agencies have regarded deep air as the first step beyond recreational diving, and most of them insisted that anyone wanting to learn trimix must first complete several deep air courses. As a result, most would-be techdivers did their first deep dives on air.

A rebellion against the agencies, spearheaded by Florida cavedivers, is promoting the doctrine that deep air is unacceptably dangerous, and, given the availability of trimix, senseless and "farm animal stupid". They make an analogy to drunk driving - no matter how often a drunk may drive while intoxicated, and how skillful the drunk may be at doing it, he is still impaired, less able to deal with emergencies, and much more likely to have an accident, than if sober.

The diver who thinks he or she can learn to tolerate narcosis, they say, is fooling him or herself every bit as much as the drunk who thinks he can learn to drive safely while intoxicated. For proof, one need only look to the long list of deep diving fatalities, a list which includes some of the tech community's most most experienced and proficient divers.

While trimix has traditionally been used most ly for dives below 200' (60 m), "hyperoxic" trimixes, sometimes called "triox" - that is to say, trimixes containing elevated levels of 02 comparable to nitrox - are increasingly being used for dives in the 100-200' (30-60 m) range - at least they are in the US where He is cheap.

Triox is interesting stuff, if only because using it makes you realize how much more narced you are most of the time than you ever realize. One experienced tech diver was telling me about how just for the heck of it he decided to see what all the fuss was about. He mixed himself a tank of 32/30/38 and did a penetration dive on a 120' deep wreck he'd done over 500 air dives on - and was amazed to find himself noticing a wealth of details he had no recollection of ever seeing before.

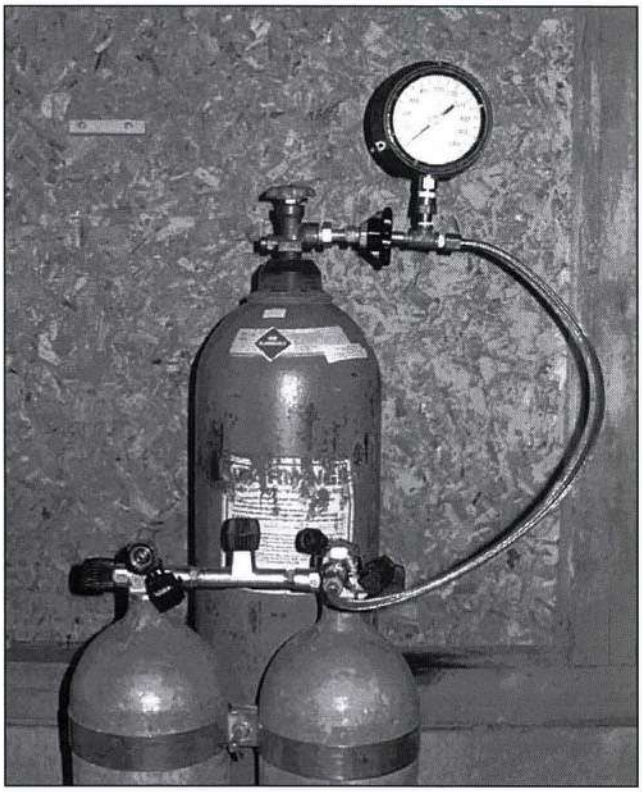
Most trimix is usually mixed much the same way homebrew nitrox is, by partial pressure mixing in the dive tank. Since helium is inert, the process is actually slightly safer than mixing nitrox. Combustion is not a concern while adding the helium and the dangers of dirty air substantially reduced since the O2 in the mix is already cut with the helium before the tank is topped off with air. However, the initial step, transfilling the O2 into the tank, is just as dangerous as with nitrox, so air quality (to keep the tank from becoming contaminated) and keeping the fill rate slow are still just as important as with nitrox.

While the actual mechanical process of mixing is essentially the same, there are several critical differences between mixing nitrox and mixing trimix that the would-be mixer should be aware of.

The first is that, since there are three variables instead of two, the calculations and mixing procedures are that much more complicated.

The second is that, since the amount of He that must be added is usually much greater than the amount of O2, and is usually added after the O2, the He must be added to a much higher final pressure than O2 typically is in nitrox mixing. As a result, a booster or a He cascade is pretty much a necessity, unless one is willing to throw away most of the contents of each supply tank - hardly a practical alternative, since He costs 2 to 10 times as much as O2.

Even with a cascade, divers mixing trimix often



Adding the helium using an O2 whip with an adaptor find they cannot get as much mix in a tank as they'd like, since He comes in (generally) 2200 psi tanks. Without a booster, one is realistically unlikely to get more than 1800 psi or so into a tank, and that only if there are enough tanks in the cascade to get a reasonably high final pressure - which means at least four. When high PHe mixes are required, as a result, many divers simply put up with not filling the tanks to full pressure, rather than use a weaker mix.

And finally, the tolerances are much stricter for trimix than nitrox. The + or – 1% tolerance usually used for nitrox mixing isn't good enough for trimix, especially low-FO2 mixes for deep dives. Most good trimixers aim to get their mixes spot on, or at least accurate to a tenth of a percent.

Compressibility is also a much greater concern for trimix than for nitrox. The compressibility factor for helium is much higher than for air - about 7% at 2200 psi/70° (150bar/20°C) - and there is no easy way to analyze a mix for He content as there is for O2 (though this is changing).

There are really two separate, if overlapping issues when it comes to the accuracy of a mix; the FO2, and the N2 to He ratio. The problem with the latter is that since there is no cheap way to measure it the way there is for O2 so that it's harder for the tri mixer to track his or her mixes and come up with a personal fudge factor for correcting for compressibility.

Fortunately, the FO2 is the only percentage which is really critical. A 5% error in the FO2 - and that would be a gross error by any standard - could put a diver in serious danger of oxtox or compromise a deco schedule. A 5% error in the amount of He, on the other hand, - as long as the FO2 was OK - would only mean a diver would be exposed to a level of narcosis slightly greater or less than planned. Dr. Bill Hamilton, the deco specialist, has been quoted as saying that even a 10% error in the N2 to He ratio would not be terribly significant.

Actually, there's no excuse for even a 5% error. If the gases are added according to the calculations, and the FO2 measures within the target range, then the He to N2 ratio should, by inference, be acceptable too.

However, that isn't going to happen if the mixer doesn't take into account compressibility. If a trimix is prepared by adding O2 to an empty tank, then He, and topping up with air based on ideal gas calculations, one can expect the final mix to contain approximately 10% more oxygen than the intended (note that this is 10% of the desired FO2, not 10% of the total; if one is aiming for a 12% mix, the error would be 10% of 12%, or about 1%, not 12% plus 10% = 22%).

The 1971 U.S. Navy Diving-Gas Manual (not to be confused with the U.S. Diving Manual Part 2) has procedures for dealing scientifically and precisely with compressibility when PP mixing, but they are complicated enough that almost no one bothers to use them.

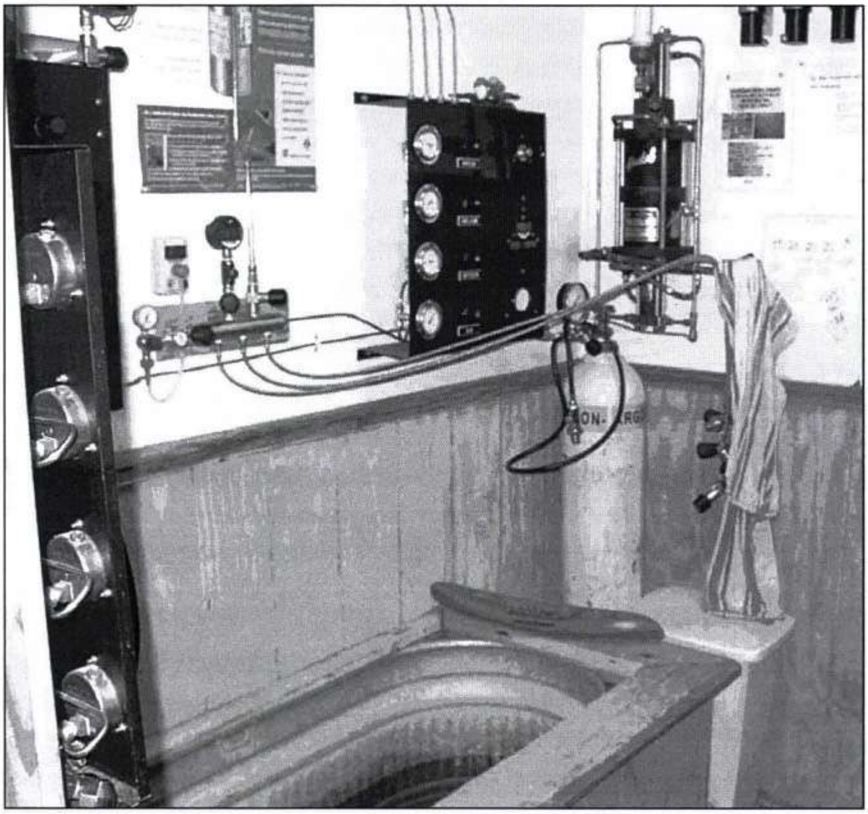
Indeed, the more recent U.S. Navy Diving Manual Part 2 (Mixed Gas) acknowledges this, saying, "An awareness of the differences in the compressibility of various gases is usually sufficient to avoid the problems which are often encountered when mixing gases. When using the ideal-gas procedures which follow, a knowledgeable diver should add less O2 than called for, analyze the resulting mix and compensate as necessary".

In short, fudge.

The almost universally accepted way of doing so in the techdiving community is to add the O2 first, and simply put in 10% less than the ideal gas calculations call for. Since the compressibility of He in the 2000-3000 psi (130 to 200 bar) range is about 10%, this pretty well does the trick. As one gains experience, one may want to adjust the figure slightly in either direction.

Some sources say the O2 should be added first, preferably to an empty tank and that if the tank is not emptied, the total pressure in the tank after the O2 is added but before the He goes in should be below 1000 psi for the 10% fudge factor to be effective. Others say it makes no difference which order the gas is added which would logically appear to be the case.

Compressibility problems increase with temperature. The homebrewer is actually in a better position than a commercial operation to deal with heat relat-



A trimix mixing station, complete with a Haskel booster.

ed compressibility problems, since the homebrewer isn't tying to crank out mix and can afford to wait for the tank to cool between each step, then top it off before going to the next step.

Since there three variables instead of two, that is to say, O2, He and N2 instead of just O2 and N2, a much greater range of possible mixtures exists than with nitrox, which is why it is important to get competent instruction before messing with trimix. Many divers mix and dive nitrox without formal training and do just fine. The odds of doing so with trimix, though, are much less - mostly because using trimix assumes incurring some serious deco obligations with all the attendant problems and risks, and involves much more complicated gear configurations and task loading.

The most basic trimix is probably 17/17, aka "poor man's trimix"; air to which helium, but no additional O2, has been added. Mixes like this are more properly called "heliar" since they consist of just air and helium, to distinguish them from more sophisticated trimixes.

Many techdivers consider 17/17 a pretty wimpy mix, since it extends the END only by 20% or so, and the reduced FO2 actually increases the deco time at the relatively shallow depths this mix would normally be used. They feel it isn't really worth bothering to do a trimix that's less than 30% He. Considering that He is much more expensive than O2, and that anyone with the technical capability to mix 17/17 could just as easily mix a proper trimix, it's hard to understand the purpose of the mix.

Adding O2 as well as He allows tailoring the mix much more precisely to the intended use, since the the FO2 can be selected to combine some of the deco advantages of nitrox with the narcosis-lessening effects of heliair.

By adjusting the amount of He and O2 it is possible to tailor the mix to give any desired combination of END (equivalent N2 depth) and PO2. Normal procedure is to pick an FO2 that will give the maximum acceptable PO2 at the maximum depth of the dive, then decide what END can be tolerated (usually something in the 100' to 130' range, though though some go as much as 185') then calculate the amount of N2 that must be replaced with He to obtain that END.

For example, let's take a dive to the Doria, at 240', with a max PO2 of 1.4 ata and a 100' END.

First one figures the depth in atmospheres, remembering to add in 1 ata for atmospheric pressure.

$$\text{Total pressure ata} = \frac{\text{depth}}{33\text{ fsw}} + 1\text{ ata}$$

$$\frac{240\text{ fsw}}{33\text{ fsw}} + 1\text{ ata} = 8.27\text{ ata}$$

Then divides that total pressure by the target PO2 and

$$\frac{1.4 \text{ ata}}{8.27 \text{ ata}} \times 100\% = 17\%$$

then the N2:

$$\text{total pressure} = \frac{(\text{ depth fsw })}{33} + 1 \text{ ata}$$

$$\frac{(\text{ 100 fsw })}{33 \text{ fsw}} + 1 = 4.03 \text{ ata total pressure at 100 feet}$$

PN2 = total pressure x .078
0.78 X 4.03 ata = 3.14 ata PN2 at 100'

3.14 ata/ 8.27 ata = .38 = 38%

If the PO2 is 17%, and the FO2 is 38%, then the balance of the mix, 45%, will be He. So the answer is a 19/45/38 trimix (or a 19/45 as such mixes are usually referred to, omitting the FN2).

For a deeper dives, the FO2 may be reduced until the mix doesn't contain enough O2 to support life at the surface. Then another mix, called a travel mix or gas, is necessary to get the diver down to the depth where the increased pressure makes the PO2 adequate, and back up again at the end of the dive. Usually, the travel mix will be a nitrox in the 50/50% range. Even when a travel mix isn't absolutely necessary, a trimix diver will often use one, simply to take advantage of the deco advantages of using a higher O2 mix whenever possible. Then, for the final deco stop, the diver will often use straight O2.

There are, obviously, a lot of variables. For a shorter, lower exertion dive, one might choose to dive a higher PO2 to reduce deco time. For a longer dive one might want a lower PO2 to guard against oxtox. Divers doing demanding tasks, like cave mapping, may go with an even lower END. Price and availability of He can also radically effect one's choice of an END.

It might be worth mentioning here that there are many in the tech diving community who think it is foolish to use the END to measure the narcotic potential of a mix, since it is beginning to appear that O2 is at least as narcotic as N2. Rather than calculate the END - equivalent nitrogen depth - they suggest calculating a slightly different usual END - equivalent narcosis depth - based on the total PP of the N2 and O2 rather than just the N2. Support for this position remains at this time mostly anecdotal, as few scientific studies have been done comparing the narcotic properties of O2 and N2, but few serious divers would dispute the notion.

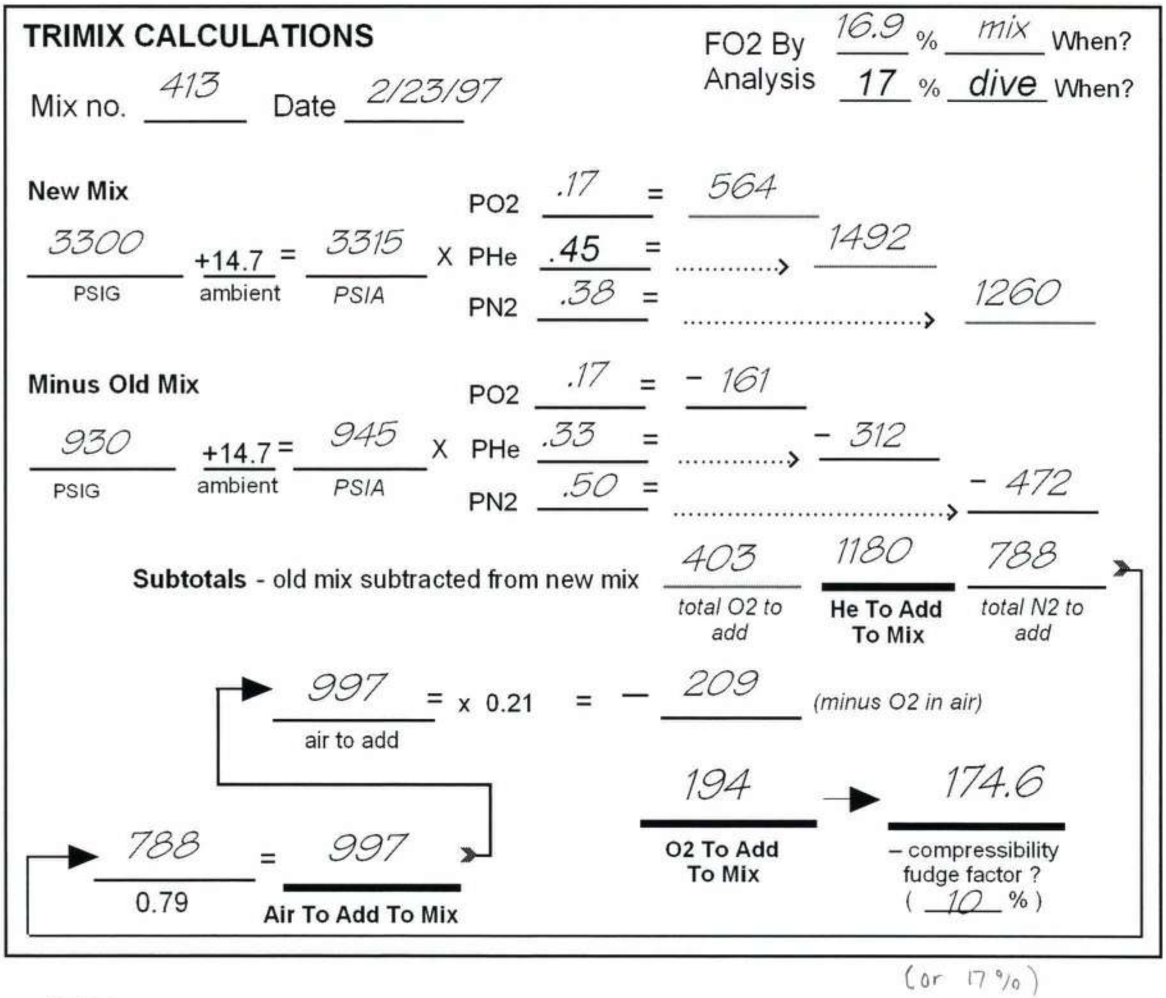
After the percentages have been calculated, the next step is to figure how much of each gas to put in the tank to get the desired mixture. Computer programs are available that do this, including several freeware and shareware programs and spreadsheet templates, the better of which even compensate for compressibility. It isn't hard, though, to do with a pencil and a pocket calculator. Even if one has a mix program, it's still worth getting to know the calculations, since they provide an easy way to double check a computer, especially if the figures it provides seem suspect.

The sample worksheet shows the Doria mix in the previous example on top of some old 17/33.

Once the mix is done, one comes to the big problem with diving trimix - no easy-to-use tables exist for diving the stuff. That isn't really surprising, since between bottom mix percentages, travel mixes, switchover points and so forth there are an almost infinite range of variables possible for each trimix dive, and, using print tables, you'd need a separate table for each one. Divers using trimix usually use custom dive tables worked out especially for that dive. This isn't as big a deal as it sounds - there are several reasonable priced programs for desktop/laptop computers such as Decoplanner or Abyss that make it easy to "cut" a custom set of tables for each dive, and also may do the gas mixing and OTU calculations as well.

The wide range of variables in trimix diving, both in the bottom mix itself and in the choice of mixes for travel and deco gas means that one is not likely to soon find a trimix dive computer that will make trimix diving as easy as nitrox computers have made diving nitrox. For a start, a trimix computer must be able to handle not only multiple mixes, but also allow changing mixes on the fly. As of this writing, there is only one very expensive limited production trimix computer that can do this, and another has just been announced that will sell for about $1000.

However many extremely experienced tech divers object to the notion of a trimix computer. They feel that a complete understanding of deco issues is essential to the safety of anyone doing deco dives, and that the only way to acquire this is by cutting one's own tables, and trying numerous "what if" scenarios to learn what works and what doesn't,



Notes:

- psig means psi gauge, which doesn't include the ambient. Psia means psi absolute, which does. If one wants to ignore the effect of the residual gas in an "empty" tank, just ignore the ambient step and treat the psig as psia - it'll throw the mix off just a tiny bit depending on what's in the tank. Actually, for any but the most critical mixes it really doesn't really much difference. But don't believe me - do the numbers both ways on a few sample mixes, and decide for yourself.

- Starred values 0.21 and 0.79 are for air. If the tank is being topped up with nitrox, simply substitute the appropriate values.

until one can almost work out the tables in one's head.

They also point out that gas management is an integral part of planning a dive, and that a computer, while it can tell you how long you've been down and how long it will take you to reach the surface, can not tell you if you have enough gas to make it.

Another problem to be aware of with trimix is that, since helium transfers heat about 6 times faster than air, trimix is not a very good insulator and is not the best choice for inflating drysuits. That means carrying an extra tank, usually a 6-12 cf. pony, for dry suit inflation.

Some also say that wetsuits are unsuitable for trimix diving, since they do not provide enough insulation to keep a trimix diver warm, given the higher conductivity of He, but the current feeling is the gas inside a diver's body has a fairly negligible effect on heat loss, and that a wetsuit diver will not be significantly colder on trimix than on air.

TRIMIXING

Apart from the tank and contents, it doesn't take much new in the way of hardware to get into trimix if one is already doing nitrox. If one isn't, it makes sense to get some experience with nitrox first since, while the process is similar, mixing trimix is more complicated and hence offers more opportunities to screw up.

The same whip as is used for nitrox can be used for trimix with the addition of an adaptor.

The O2 is added first, at 60 psi (4 bar)/min as for nitrox, including whatever fudge factor one is using for compressibility. Then the tank allowed to cool and the amount of O2 adjusted. It's usually a lot easier to keep the flow rates low enough that the tank doesn't heat, than let it get too hot and have to wait for it to cool.

The He is added, and the tank allowed to cool and the amount of He fine tuned. Then the contents are analyzed after being allowed to sit for a while to make sure the gases are completely mixed.

How long does that take? Good question. He is notoriously more reluctant to combine with other gases than O2 is, and, while some mixers report no problems, others say they see significant changes from one O2 analysis to another - in either direction - for as long as a day after the mix is done! Some mixers even recommend deliberately using a high rate of fill for the last few hundred psi of He (relative tank pressures permitting) in order to mix up the tank contents. Others say either roll the tank for an hour or let it sit - lying on it's side to discourage stratification - for 24 hours before expecting an accurate analysis. This is probably overkill, but's something each mixer can decide for him or herself.

The reason for analyzing the mix now, midway in the mixing process is that it is the last time it will be possible to get a good measurement of how much He is in the tank, since there's no easy way to directly measure the FHe. At this point, since there's nothing but O2 and He in the tank, measuring the FO2 will also find the FHe, and if the proportions are right at this point, they should still be correct after the air is added.

If the analysis comes out right, the tank can be topped off to the desired final pressure with air. Then the mix is allowed to sit for awhile, the FO2 analyzed again, and any necessary corrections - usually limited to adding more air - done to get the mix just right.

After one has done enough trimix to get a feel for it, this process can be speeded up somewhat - fudge factors can be modified to account for both compressibility and heating.

Record keeping and labeling are especially important for trimix, since, while a nitrox mix can always be identified by analyzing the FO2, there's no cheap way tell the FHe of a mix once it leaves the mixing shed.

It is also highly recommended that anyone mixing trimix use a check list, and write down the starting and final pressures at each step, and verify at the start of each new step that the valves are in the right position and that the starting pressure is the same as the final pressure was at the end of the last step. There have been cases of people doing fills with the valve in the fill tank closed or only partially opened, who mistook the line pressure for the tank pressure, George Irving on Trimixing:

GAS MIXING LESS THE BS

Let's assume all bottles are correctly marked - that means MOD only, horizontally, in three inch high letters , on either side of the upper bottle in the orientation of the tank. All tanks turned off, all regs parked. To deploy, we locate the bottle by MOD, we remove the reg and put it in our mouth, we then relocate the bottle by MOD, and turn if on. If we can breathe, we are breathing the right gas.

Now, mixing. First put two pieces of tape or one GUE split tape on the empty bottle. Hook up to either gas, but I do helium first since I want my oxygen addition to be more in the middle of the operating range of the gauge, but it can be done either way. Figure the correct amount of helium for your mix considering coefficient of expansion and heat expansion. Helium will need about 17% overfill to get the % you seek. Let's say we want 50% and we are filling to 3000. Fill the tank first to 1750 to get to half, but then add another 10% or so for heat expansion, so go to a total of 1900 roughly. It should cool back to 1750 or so. No sense getting real anal here, the heat expansion is simply equal to the ratio of absolute temperature change, using the Kelvin scale - just guess at it. Turn the bottle off, but do not remove the whip until you have written down the contents of the tank and the date. Now remove the whip .

Now, add the oxygen. Keep in mind that it will be heated and expanded, but not too badly. Go a little over your intended amount but not too much. Calculate this independently of the helium, and add it without regard for the "pressure" of the helium. If you added the oxygen fist, keep in mind that it will have expanded as well from the heat of the helium filling and be giving you a higher overall helium pressure reading than you really have, so add a touch there if that is the case over and above the other two reasons. Do not remove the whip until you have written down the new gas added and the date. Analyze it if you please, to solve for the helium later to satisfy yourself.

Now add the air, unless that was heliox and we are done. Immediately analyze the gas and write the analysis on the other piece of tape or the split tape, write the date on it as well, and take the original tape off the tank and cover the valve with it to indicate that the tank is full. Do not move the tank until this is done. Obviously , the analysis should jive with the MOD. To dive the tank, you can remove the tape so as not to litter (and obviously the only thing we go by in water by is MOD) , but if you do not use the tank, retape it and the valve, rewrite the contents and date, and transport that way, including partially full tanks that you intend to reuse (I reuse my deco tanks for two dives usually, so I may write some thing like "2000 psi 50% 10-18-00") . If you use it and are not going to reuse it, it is now assumed that the tank has some amount of that gas in it, but can not be used again unless reanalyzed, so is not retagged. It can not be stored full without a tape, and it can not be transported full without a tape. Doubles can not be stored untagged if they have gas in them, and if that mistake is made, dump the partial gas and remix rather than adding to a mix. A lot of people fool themselves this way on the helium %.

(George Irving is the Project Director of the Woodville Karst Plain Project (WKPP) and an outspoken advocate of DIR diving. He, along with Jarrod Jablonski, holds the world record for cave penetration, over 18,000' at a depth of 300', and has been mixing his own gas for years.)

Mixes should always be tagged immediately upon analyzing

and added little or no gas to the fill tank.

Helium likes to leak. It's high diffusion rate allows it to escape through spaces that will hold other gases. There has been some speculation over the years as to whether it is possible for the He to leak out of a tank selectively, leaving the O2 and N2 behind, with many anecdotes told, but no proof either way, and the general feeling among mixers seems to be it's not a real concern.

Topping Up Old Mix With Air

Occasionally divers doing serious diving in a spot where mix is not available, will find it expedient to top up a partially used tank of mix with air to get a low octane trimix which, while far from optimum, is still better than air.

This is common practice on multi-day boat trips to deep, distant wrecks like the Andrea Doria, where the boat has a compressor but no gas mixing facilities. Calculating the percentages in the topped-off mix requires a slightly different set of formulas than mixing does. This worksheet shows how its done, and has the advantage that one can take it along to remote locations where one might not want to risk taking a laptop.

To use our earlier example, for example, if one dove a 17/45/38 trimix the first day, and observing the rule of thirds, returned with 1100 psi (73 bar), topping with air would give a 20/15/65 mix for the second day.

Note that this worksheet can also be used if you are topping up with nitrox, simply by substituting the appropriate valves as for the nitrox mix sheet.

Actually, there's another even better strategy for dealing with this situation, assuming one has two or

TOPPING UP OLD MIX WITH AIR

O2 By Analysis 20 % mix When? 19.8 % dive When?

Mix No. 219 Date 8/21/97

1100 (PSI old mix) X .45 (FHe old mix) = 495 — 3300 (final fill pressure) = .15 (**FHe Final Mix**)

1100 (PSI old mix) X .17 (FO2 old mix) = 187 (PO2 old mix)

3300 (final fill pressure)
— 1100 (PSI old mix)
2200 (PSI top up air) X 0.21 = + 462 (PO2 top up air)

649 (PO2 total final mix) — 3300 (final fill pressure) = 19.6 (**FO2 Final Mix**)

more sets of tanks (a fair assumption if one is diving the Doria).

Fill one set with the optimum mix for the dive, and prime the other with a "double strength" mix. For example, using the same example of a 240' (72 m) Doria dive, one might pack a 20/80 heliox in the spare set. After the first set is used, the hi-test mix is transfilled into the first set of tanks using a tank balancer whip. Then both sets are topped off with air, producing a mix in the 20/40/40 range.

It's not quite that easy - some fiddling may be necessary to get the numbers just right, and compensate for old mix in the tank. But it sure beats diving deep air - or lugging around a zillion tanks. It's also possible to do a triple-strength mix this way, if one doesn't need too high an FHe, by using a 10/90 or so.

The same stunt will, obviously, work equally well with nitrox. Note that it would be madness to do this without owning one's own O2 analyzer! The mix must be fine tuned, and doublechecked immediately prior to use.

Anyone trying this should make damn sure that the tanks are marked so there is absolutely no chance that anyone might mistakenly use them before the mix has been diluted, lest their last words be "Oxtox!", in a very squeaky voice.

Divers who dive conservatively, and follow the rule of thirds, will often find themselves after a day or two of diving with several sets of tanks, each containing a third or more of residual mix - too much to throw away, but not enough to do another dive with. If the diving is being done where new mix is unobtainable or prohibitively expensive, it would be nice to be able to consolidate the contents of several mostly used-up tanks into one usable set.

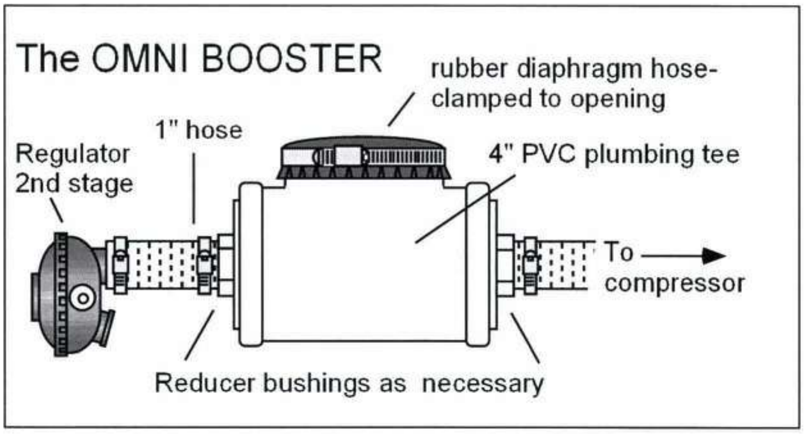
Normally, this a a job for a booster pump, but divers have often wondered if there isn't some way to use a compressor to recompress the gas so it can be recycled.

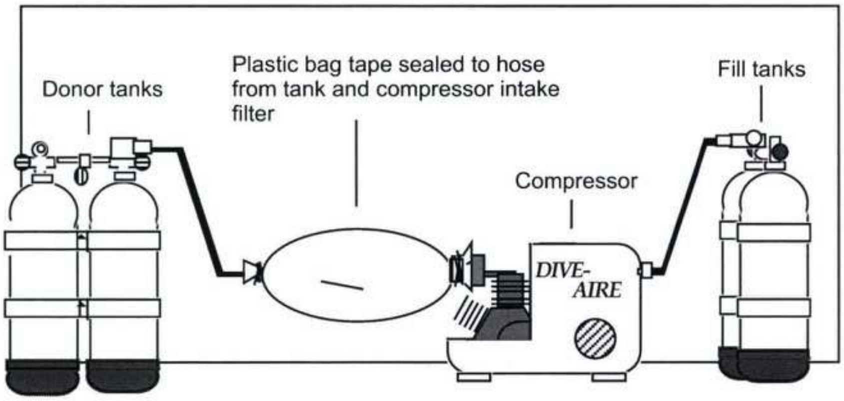
Actually, it's surprisingly easy. The problem is to match the flow of gas from the tank to the capacity of the compressor so that the compressor intake will see only normal ambient pressure. Overpressure or underpressure in the intake tract of the compressor can cause problems, and most compressor manufacturers warn against it.

There are two methods of doing this that seem to work pretty well. One is to use an old double hose/single stage dive regulator as a demand valve to feed the old mix into the compressor. The other is to use a large plastic bag as a bellows/reservoir between the tank of old mix and the compressor, and manually operate the valve to feed the gas from the tank into the bag.

The regulator method has the advantage of being automatic, but it's a bit fussy - the regulator's response may not be fast enough for the compressor, and too powerful a compressor may overbreathe the regulator. Getting this to work can take a lot of fine tuning, making it more appropriate for a permanent installation. The reason for using the old double-hoser, incidentally, is that the combination of single-stage reduction, large bore ambient hoses and the big diaphragm seems to give it a faster response time - single hose regs just don't seem to do the trick.

There's a way to do the same with a single hose regulator, Michael Fisch's DIY Omni Booster. It uses the single hose regulator with the exhaust valve opening sealed shut, which is attached by the mouthpiece stub to a 4" (100 mm) PVC plumbing tee. The other side of the tee connects to the com-





successfully in the jungle with garbage bags and duct tape, though if one is doing it regularly it might be worth putting together a more durable setup.

The more improvised the setup, though, the greater the chance that the final mix will be somewhat diluted with extra air that has managed to slip in, but analyzing the O2 content should detect any problems in this respect.

pressor intake, and the remaining opening covered with a diaphragm made from a sheet of inner tube rubber stretched drum tight. The idea is that the tee acts as a buffer chamber, and the diaphragm both evens out the fluctuations and gives a visual indication of whether the flow is adequate. If it starts getting sucked in, then there is not enough flow, but if it starts bulging out too far there's too much flow.

One drawback to this method is that the 2nd stage is being asked to cycle many times faster than it was ever designed to do - 1200 to 3500 times minute rather than 20 or so - so to reduce the load on the damand valve the 2nd must be adjusted so it is freeflowing a bit. If this is not done, the rapid cycling of the valve can chew up the diaphragm in a few minutes! I still prefer the bag method, but the Omni Booster has many enthusiastic users.

The bag method is simplicity itself, and seems to work very well. Even better, it can be done anywhere with a minimum of special gear - in the field, using a portable compressor, or at a cooperative dive shop. The bag is acting both as a buffer to even out the fluctuations in supply and demand, and as a very simple, easy-to-read flow gauge (one can see by looking at the bag if it is getting too full or too low).

By regulating (manually, that is) the flow of gas to keep the bag full, but not too full, the flow of gas from the tank can be matched to the compressor's demand. Since the bag is acting only as a flexible barrier between the gas and the surrounding atmosphere, it is under minimal load and doesn't have to be particularly rugged - the process has been done

The smaller the compressor, the easier it is to do, since a large compressor will require high flow rates and can empty the bag in a couple of seconds if whoever is operating the tank valve isn't paying attention.

A couple of cautions: these methods are for recompressing old mix, and **not for boosting straight O2 or high FO2 mixes**. Compression creates a lot of heat, and the oil in the compressor can combust in the presence of HP O2. This could cause fire or explosion, but it might also happen without even being noticed, and create deadly CO. Compressor temperature should be watched carefully, since mixes don't always dissipate heat the way air does.

Reconciling the Supply Tank and Fill Tank Pressures

The small scale mixer, who may be using a single supply tank rather than a cascade, and nary a Haskel in sight, will often have to deal with reconciling the contents of the supply and mix tank, in order get the pressure low enough in the mix tank so the pressure in the supply tank will be enough to do the fill, while avoiding having to throw away any more old mix than is absolutely necessary.

This is a problem that the commercial mixer, with a Haskel and/or cascade, and a customer paying for the gas, usually does not have to deal with, and, as a result, is often neglected in mixing courses. The Navy Dive Manual Part 2 has a formula for the purpose, but makes the dangerous assumption that the two tanks will always be the same size.

For example, suppose one wants to mix some 32% in the doubles shown in the nitrox worksheet, but the pressure in the "H" 02 supply tank is down to 1250 (86 bar), and there's 750 psi (52 bar) of residual mix in the doubles. According to the worksheet, the new mix will need 299 more psi of O2. On the face of it, one is out of luck, but since the H tank has a lot more volume than the doubles, a 1 psi rise in the doubles will not produce an equivalent drop in the supply tank.

There's probably some homungous formula for calculating it, but I find it easier to break the process down, as on the worksheet.

Note that, for this purpose, it isn't necessary to take into account if the tank is going to be overfilled since one is only concerned only with the comparative volumes of the two tanks, and that can be done simply by comparing the psi/cf ratio for both tanks.

Note too that space is provided for a safety margin. Since transfer rates tapers off to almost nothing as the pressure in the two tanks near each other, and since tanks - supply tanks especially - vary in subtle ways and don't always hold exactly what they are claimed to, it's a good idea not to plan on not cutting too close to the line, and having a little extra pressure in the supply tank - at least 25 psi.

Metric users, who are already accustomed to thinking of tanks in terms of their actual "water volume" capacities, can get the ratio simply by dividing the volume of the supply tank by the fill tank(s).

In real life, I doubt anyone actually does the math very often since it's pretty easy to work out in one's head. I keep a chart out with my tanks, which lists the compensation factors for all the dive and supply tanks sizes I use, and do the rest of the figuring in my head.

This is my own chart, included only as an example. Since tank sizes vary quite a bit around the country, to say nothing of the world, this chart should be taken only as an example, and anyone needing a similar chart should work it out for themselves.

RECONCILING SUPPLY AND FILL TANK PRESSURES

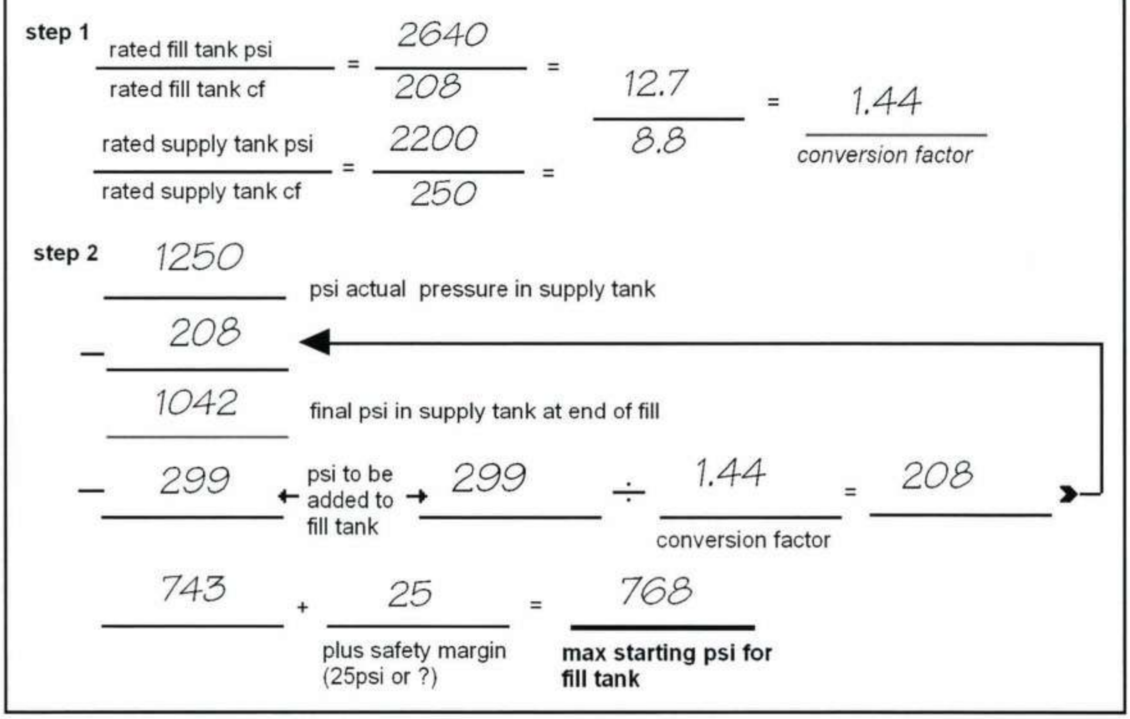


Table 6

Transfill Pressure Conversions Factors:

250cf/2200psi	300cf/2200psi	360cf/2200psi	Tanks	
8.8 psi/cf	7.3 psi/cf	6 psi/cf		
11	14	17	alu 30	100psi/cf
6.8	8.2	10	alu 5O	60psi/cf
5.4	6.6	8	alu 63	48 psi/cf
4.3	5.2	6.3	alu 80	38 psi/cf
3	3.7	4.5	LP95/98	27 psi/cf
3.4	4.1	5	alu 100	30 psi/cf
2.8	3.4	4.2	LP 104	25 psi/cf
5	6	7.3	HP 80	44 psi/cf
4	5	6	HP 100	35 psi/cf

Note: for double, halve the conversion factor given for the single fill tank size.

Emptying, Evacuating and Purging Tanks

We talk about emptying tanks, but what we usually consider an empty tank actually has 14.9 psi (1 bar) of gas left in it. When we do our mix calculations we can always take this into account, by adding the 14.9 psi (1 bar) to our gauge readings and calculations but with nitrox it usually simply isn't enough to make a difference.

Occasionally when mixing a trimix with a very low FO2, it will be desirable to empty the tank completely, so there's no chance of the residual mix in the tank throwing off the final mixture. Since gauges tend to be less accurate at both ends of the scale, it can be difficult to accurately take into account small amounts of residual fill - far easier to simply empty the tank and eliminates one more possible source of error.

In a well equipped filling station this would be done by evacuating the tank by applying a vacuum to it, then starting the fill into the completely empty tank. Since it's impossible to get an absolute vacuum, the normal procedure is to vacuum and prime the tank several times when a really pure or accurate fill is desired.

While this is beyond the capacity of most home mixers or dive shops, one can get almost the same effect, if not as quickly, by purging the tank.

To purge the tank, empty it to atmospheric pressure, then put a modest amount of the new gas, say, 30-100 psi (2-7 bar), then empty it again. What one is doing is diluting the old contents, then draining, then diluting again, so the old contents are eventually almost completely replaced by the new contents. If one is curious how well this works, it's easy to work out the math.

Put 30 psi (2 bar) in, and the old contents are diluted 2:1. Drain it back to ambient, and it will only contain 1/3 as much of the old contents as it did before. Fill it again to the same pressure, and that 1/3rd is diluted again so it only makes up 1/9th of the contents, and so on, and so on. Filling to higher pressures will do the job faster; using lower pressures and more cycles will make more efficient use of the gas.

Is it really necessary? Most of the time, no. After all, 14.9 psi (1 bar) of air would amount to only 1/2 of 1% of a 3000 psi (200 bar) fill, and only 21% of that would be O2. If you were mixing, say, a 14% O2 trimix in that tank, it would add only .1% 02 to the mix.

If one really needed to be able to vacuum tanks, simple siphon vacuum pumps, which connect to a faucet and run off water pressure, are available from laboratory supply companies, and oilless motor driven vacuum pumps turn up in surplus catalogs fairly frequently for around $50. It wouldn't be hard to use one of these pumps, simply by adding a "T" and a shutoff valve leading to the vacuum pump to a standard fill whip. The catch is, some of these pumps are not particularly clean. If the pump should stop before the valve is closed, the vacuum in the tank would reverse the flow, sucking into the tank any contaminants in the line and the pump or, in the case of the faucet pump, water. A one-way check valve might be a wise addition.

Adjusting Bad Mixes

Most mixing manuals give tips on how to fine tune an existing batch of mix, should the analysis show it didn't turn out quite as intended. There's no trick to it, really - one just analyzes the bad mix, then recalculates using the target mix and residual numbers, just as for PP mixing in a tank partially filled with old mix.

What bothers me about this is that the point of using an O2 analyzer on the mix is not to find out what the mix is - one should already know that - but to confirm that it came out as intended. Or, put in another way, to provide redundancy. The O2 analyzer isn't supposed to be the ultimate authority, but rather to provide a second opinion. As such, it is only meaningful only if it agrees with the first (the one derived from the gauges and fill calculations). Should the two disagree, it means that either the analyzer or mixing practices are off. It doesn't tell which one.

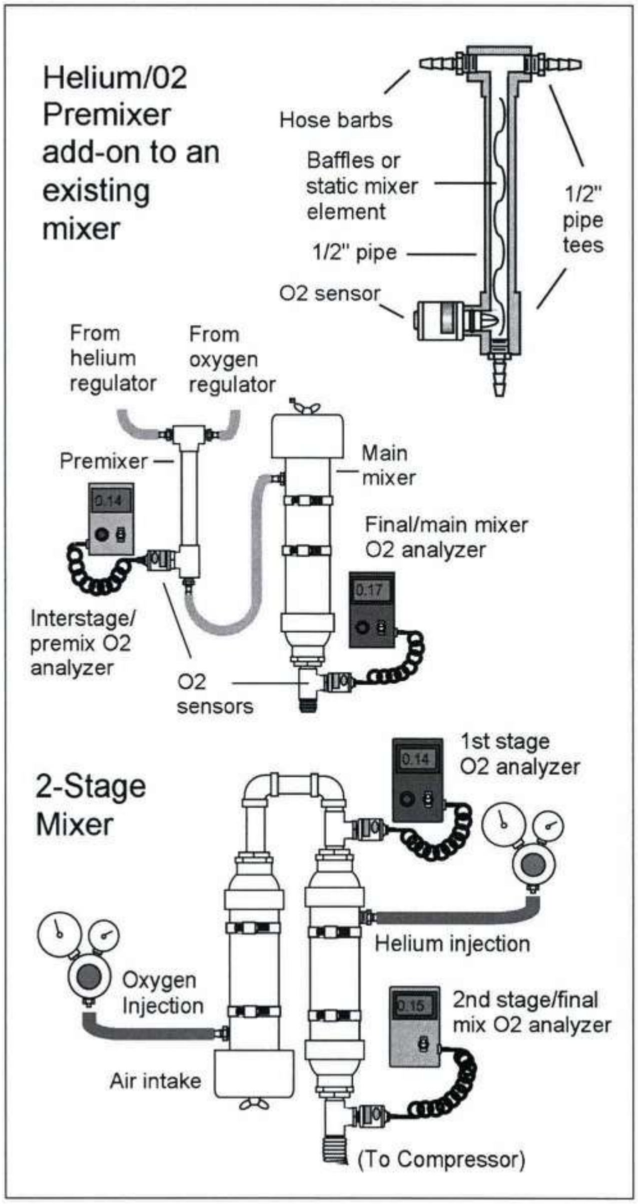
If one starts fiddling with the mix on the basis of the analyzer, then one is admitting that one's gauges or calculations aren't to be trusted. Yet of the two - the gauges/calculations or the analyzer, the gauges are arguably the more accurate. By tweaking the mix based on the analyzer one may be adding to the error rather than eliminating it.

That being the case, if the mix doesn't analyze as it should, and there's no clue as to why it doesn't, the safe thing to do is dump the old mix, double-check the calibration of the analyzer, and start over.

There are two exceptions to this. One is if multiple analyzers and sensor are available, so the analysis can be cross checked. If several analyzers/sensors agree, then it's reasonable to conclude the problem was in the mixing.

The other is if one goes back through one's calculations or mix check list and discovers where the mistake occurred, and that mistake matches the error found in the analysis.

In the latter, it makes sense to try and save the existing mix since you've settled the descrepency. In the former one can also proceed and doctor the mix, but if it was me I'd still be real curious about why it didn't come out the way it was supposed to the first time.



Continuous trimixing without a He analyzer (see page 110 for details).

Chapter 5
100%

100% FOR DECOMPRESSION

100% O2 or high-FO2 mixes are usually used for decompression by serious divers.

The old rule of thumb was that stops shallow enough to be done on 02 (which usually meant 20' of less) could be halved if done on O2 rather than air. The current availability of good deco software makes this sort of approximation obsolete, but it demonstrates the very real advantages of using O2 for deco.

O2 for deco is carried in a separate tank, usually something in the 20-40 cf range. It used to be the fashion to hang the deco 02 tank on a shotline from the boat, or carry it to the bottom but leave it where it could be picked up on the way back, but after a number of well-publicized accidents in which wreck divers couldn't find the line or the O2 tank for some reason and got bent or worse for lack of O2 it has gone somewhat out of fashion. Many ocean tech divers carry their deco gas with them through the entire dive; cave divers still drop their deco bottles because they know that they will be returning that way, or not returning at all. For both wreck and cave it's also considered good practice to always carry enough backgas or bottom mix to complete a full deco in case one's O2 for some reason should not be available.

Deco O2 is usually tranfilled into the deco bottle in a the same manner as O2 is transfilled for partial pressure mixing, using the same whip. However, since more 02 is going into the tank, and to a much higher final pressure, extra caution should be used to keep fill rates and tank temperatures from getting too high.

It's also very difficult to fill a tank this way to anywhere near its rated capacity since SCUBA tanks are rated (usually) for higher pressures than O2 supply bottles, and the situation worsens as more O2 is taken from the bottle.

If a full cascade is available, pressures in the 1800-2200 psi (120-145 bar) are possibly available - adequate, but a bit irritating if one is using higher pressure deco bottles. Shops catering to serious techies will often have a booster and be able to fill to higher pressures, but this can add to the cost considerably.

For the home mixer probably the easiest solution is to live with the reduced pressure, and use a large enough tank to give adequate duration with less than a full pressure fill, though an extra O2 supply tank or two for a mini-cascade really helps.

Be aware that using 100% O2, and especially 100% O2 at full tank pressures of 2000 - 3000 psi (135 - 200 bar) as opposed to the lower pressures experienced in PP mixing greatly increases the potential dangers involved in O2 handling! This is especially true when using modified or adapted gear like scuba equipment rather than dedicated gear designed for O2 service. Factors like hose, seat and O-ring material come into play, that may not be a major concern at lower pressures.

Trashbag boosters should never be used with

100%, or anything above 40% unless with an oil-less O2-safe compressor. Boosters not specifcially made for O2 should also be approached with caution - there have been several reported fires (and, in one instance, a tank explosion!) involving homemade and adapted boosters. In several cases the booster involved was a genuine Haskel, but one made for boosting nitrogen which Haskel says should not be used with O2, but had been bought surplus and "O2-cleaned".

SURFACE-SUPPLIED O2 FOR DECO/RECO

Sometimes it is advantageous to use surface-supplied O2 for decompression, or even in-water emergency recompression.

Boats catering to serious techies will sometimes have an "oxygen bar", consisting of a horizontal bar which can be hung beneath the boat, equipped with multiple SCUBA second stages supplied with O2 from the surface.

Setup like this requires a special setup with a standard dive reg 2nd stage (or full face mask) in the water connected by a long hose to an O2 supply in the boat.

There are two ways to do this. One is to use SCUBA gear exclusively, and simply add a long (50-100'/15-30m)) SCUBA 2nd stage hose to the reg so the tank can be left in the boat. The other is to use a med/industrial reg as a 1st, on a big medical or industrial tank, as covered in the emergency O2 section, and use either a custom long hose with the appropriate SCUBA and NPT fittings, or a stock long SCUBA hose and a SCUBA to NPT adaptor to connect the SCUBA 2nd stages.

If a long SCUBA hose isn't available, it's possible to use other sorts of hoses. The fittings to mate the hose to the second stage are hard to find new, but can be had by cannibalizing old SCUBA hoses. The fittings can be re-swaged onto the new hose if an appropriate swager and ferrule can be found, or simply held on by a hose clamp.

Many divers use welding hose (in the case of siamesed hoses, the two can be split apart) without problems, but others say they add a foul smell to the O2.

A check valve should be fitted to guard against suddenly loss of pressure and mouth or mask squeeze if the hose should break, or the tank be inadvertently disconnected while in use.

The regulator should be capable of outputting in the 160 to 200 psi (11 - 14 bar) range to accommodate standard SCUBA 2nd stages. Many O2 welding regulators will not work since they don't have enough range.

The SCUBA tank and 1st stage has the advantage of being quick, easy and cheap - as long as one has some spare regs around. The med/industrial reg has the advantage of using standard O2 tanks so it isn't necessary to transfill the O2 into SCUBA tanks, with all the attendant problems and costs. And using an med/indust tank allows much larger quantities of gas to be carried.

Also, the med/indust reg is adjustable, so the output can be tweaked to compensate for depth - otherwise, with the 2nd stage at 20', and the 1st stage on the surface, the IP will be running 10 psi (.8 bar) low, which is enough to throw off the tune of many 2nds.

Two important caveats: having surface-supplied O2 available does not obviate the need for a diver to carry enough gas to complete the dive profile, since the surface-supplied rig must be regarded as potentially fallible. And in-water recompression to treat DCS is a very controversial and exacting procedure which should not be attempted without a full understanding of the issues involved.

OXYGEN FOR EMERGENCY FIRST AID TREATMENT OF DIVE ACCIDENTS

Oxygen has been found to be an extremely safe and effective treatment for most diving related medical emergencies, especially DCS (decompression sickness, or the "bends"), with virtually no contraindications. DAN (Divers Alert Network, a non-profit dive safety/medicine organization) has aggressively promoted its use in such cases and offers courses in its proper administration. It is not within the scope of this booklet to give instructions for the emergency use of O2, and anyone interested in learning about it is strongly advised to take the DAN course or an equivalent.

While the extreme value of O2 in treating dive emergencies is well established, O2 sets are generally found only on commercial dive boats, as the $400+ price tag of an "official" O2 set keeps them out of the reach of the average diver. This is regrettable, because much diving takes place far from both commercial dive operators or medical facilities, and dive accidents occur regularly where O2 could be a lifesaver but is not available.

One of the original purposes of this book was to, by making divers aware of some low cost, alternatives to commercial medical O2 outfits, increase the availability of emergency oxygen among the diving community.

A Basic Medical O2 Set: a tank, regulator with flowmeter, and a throw-away non-rebreather mask

Overview

A basic emergency surface treatment O2 set consists of a tank of high pressure O2, a regulator to reduce the pressure, and a mask. The mask is usually either of two kinds: constant flow, which, like the name says, is fed by a constant flow of oxygen, and a demand mask which works like a SCUBA regulator to deliver O2 only when the user inhales. Demand masks are expensive, though, at about $200 - which effectively doubles the cost of an O2 set.

Constant flow masks are much cheaper, being plastic throw-away items, and are more suitable for use on an unconscious or badly injured person. However, in order to obtain high percentage of O2 from them it is necessary to set the 02 flow wastefully high. Demand masks are considerably more expensive, but deliver the highest percentage of O2 with less waste.

There are several other kinds of masks used in medicine and aviation - partial rebreathers and nasal cannulas - which do not deliver a high enough percentage of O2 to make them appropriate for serious emergency use, and especially dive emergencies.

Medical O2 tanks and regulators made specifically for the purpose are readily available, for about $400, though lower cost sets can often be improvised using SCUBA, aviation, or other gear, and used medical O2 gear is often available cheaply on Ebay.

Most dive boats have a minimum emergency O2 setup consisting of a medical O2 reg and a 12 to 20cf (350-700 litres) bottle. Since 02 is most effective when used promptly, one is often faced with a paradox: if one puts someone on O2 before it is absolutely clear they need it, one often will never know if it was necessary!

That is to say, O2 administered promptly will often completely alleviate minor DCS, to the point where it will be impossible afterwards to ever know if the symptoms were real or just imaginary. That should be good news, but the catch is most dive boat operators don't want to break open their 02 set just because someone may be feeling a bit odd, and most divers would hesitate to ask them to do so. Both because of the expense and hassle of having to refill the tank and replace the mask afterwards, and because conventional wisdom is that when someone shows any sign of DCS whatsoever all diving should be halted so they can be rushed to shore for treatment at the nearest recompression facility.

As a result, divers are often reluctant to confess to symptoms for fear of ruining everyone else's day, and dive boat operators sometimes unwilling to take immediate action, preferring to wait until the symptoms are so pronounced as to be unmistakable. Similarly, a diver turning up at a hospital emergency room and demanding to be put on O2 instantly may find him or herself having to wait, then argue with a doctor who is unfamiliar with DCS and unwilling to admit it. Unfortunately by then things may have gotten to a point where no amount of 02 will fix things and a trip to a chamber will be necessary.

For this reason, serious dive boats, like those doing wreck/tech diving, will often carry a large, 122 - 250 cf. (3-7 m3) 02 bottle plumbed for several demand masks or, more likely, old regulator 2nd stages (with long hoses, the same combo can also be used for surface supplied O2 deco gas). With a rig like this anyone showing the slightest hint of trouble can immediately be put on O2 without unnecessary fuss, or the expense and drama of breaking out the med set, simply by handing them a mask, while the situation is being evaluated.

This is one more advantage of having your own O2 set - you can use it whenever YOU feel it might be beneficial, without having to negotiate with the dive boat captain or paramedics.

Oxygen Masks

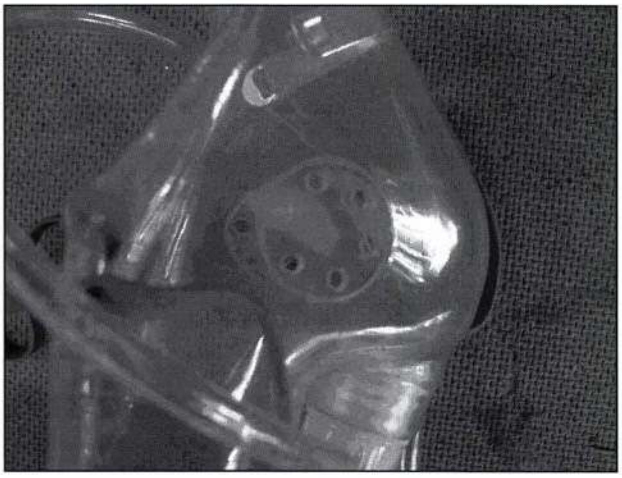
If one chooses to assemble one's own emergency medical set, one should be aware that many of the oxygen sets on the market - medical and aviation - are set up for supplemental O2 rather than giving the user the 100% O2 recommended for treatment of dive emergencies. To get anywhere close to 100% O2 it's necessary to have either a demand mask or a non-rebreather mask as opposed to the nasal cannulas or partial rebreather masks often used in medical or aviation practice.

This is not usually a problem, since med non and partial rebreather masks are usually throwaways, meant to be used once and discarded, and as a result sell for only $5 or so. They can be bought over-the-counter without a prescription from a medical supply or medical gas dealer, and from many drugstores.

It's important to get the right one, though - a NON- rebreather mask - since partial rebreather masks are much more common, and look almost identical to a non- rebreather . The main difference is that the non-rebreather has a one way flapper valve between the reservoir bag and the mask.

Non-rebreather masks, incidentally, usually come through these days with a flapper valve on only one of the two exhalation ports; the other one is left wide open. The reason for this is that EMT's would sometimes hook an unconscious patient to a non-rebreather mask and then either set the flow too low, or not notice when the tank ran out. Result - one seriously hypoxic patient at best.

The opening is supposed to allow a little air in so the user won't smother if the O2 runs out. The drawback is, the port acts like a built-in air leak,



Built-in leak on a non-rebreather mask

making it impossible to get 100% O2 with these vented masks - 80 to 95% is the best they can do - and it requires wastefully high flow rates to do even that well.

This is not a problem in most medical situations where 100% O2 is not vital, or where the O2 supply is unlimited and one can afford to run high flow rates to make up for the "leak", but is significant in DCS treatment where supply is limited and the closer one can get to 100% the better.

It's fairly easy to refit one of these masks with an extra flapper valve taken from another mask or improvised from a bit of plastic or rubber. Doing so trades the safety margin the air port provides for the proven benefits of a significantly higher percentage of 02. But anyone doing so should be aware of the issues involved, and be damn sure anyone using the mask is carefully monitored. And remove any signs that the mask was tampered with before the inquest!

It's also easy to just cover the hole with a thumb or finger, either the victim's, if he/she is functioning, or the provider's. This has the advantage of being somewhat fail-safe (if the victim passes out, or the provider leaves, the hole will be left uncovered) and requiring no modifications that might be difficult to explain later on. The hole can be covered and uncovered as the victim's breathes, so that the finger acts as the missing one-way valve.

The importance of a good, tight fit for the mask itself cannot be overstated, if the full benefit of the O2 is to be derived. The mask should fit tightly for a good seal, and be rechecked frequently while in use to see that it hasn't come loose. It may be necessary to hold the mask firmly in place to maintain the seal. The flimsy elastic band that comes with most throw-away med masks is not up to the job when one is trying to obtain as near to 100% O2 as possible.

Demand masks are another matter altogether. A medical O2 demand mask is functionally identical to a SCUBA 2nd stage, in that it flows only when the user inhales. They are desirable whenever the victim is able to use one since they provide a very high FO2 with very little waste. Many suppliers will refuse to sell them to anyone without medical training, though, since they usually come with a manually triggered positive pressure button that allows one to literally blast O2 under pressure into a non-breathing patient's lungs. In the hands of someone without extensive training (and that means more than just the basic DAN course) this can be very dangerous, for obvious reasons.

DAN has specially modified demand masks made for its O2 kits that omit the power button, and these are recommended for anyone without medical training Unfortunately the cost of either the DAN or normal versions keep them out of many divers' O2 kits.

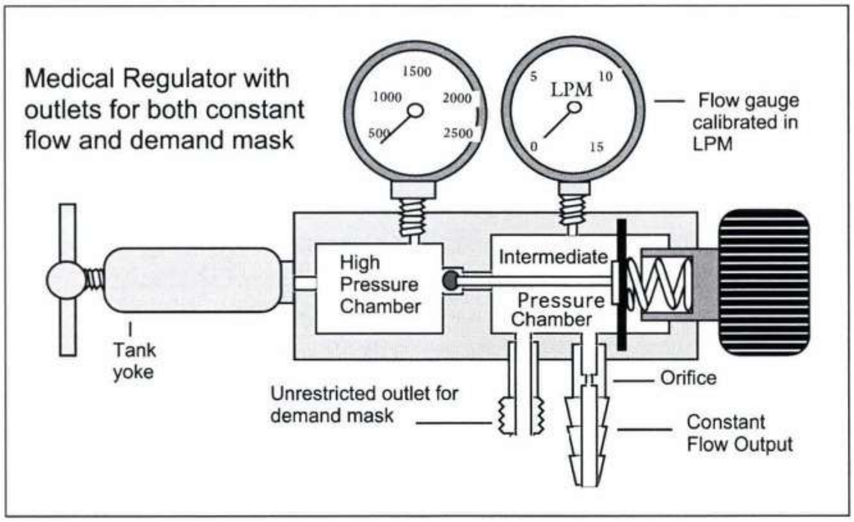
As a cost-effective substitute, divers putting together an O2 set often use an old SCUBA 2nd stage as a demand mask. Since there are a lot of old ones kicking around which can be had for almost nothing, they make a reasonable budget alternative to a proper medical demand mask.

The 2nd should be tuned for the easiest possible possible breathing, even to the point of slight leakage. For medical use, a full face medical mask covering both the nose an mouth, such as the Tru-Fit™, is preferred since it prevents the patient from diluting the FO2 by breathing air in through the nose.

It is possible to adapt a medical mask to a SCUBA 2nd stage by using bits of plastic plumbing pipe, heated in boiling water and reshaped as necessary, as an adaptor. Most medical O2 equipment, like pocket masks and the Tru-Fit™ mask used on demand masks, are made with a 22mm o.d. and 15mm i.d., so any adaptors should conform to those sizes.

If a normal SCUBA mouthpiece is used, it should be used with a noseclip to insure the person being treated gets as close to 100% O2 as possible.

The purge button can be used - accidentally or intentionally! - to give the victim an extra jolt of 02, in the manner of a medical demand mask which has not had the DAN modification. This is a very controversial subject, and was debated at



length recently on the Techdiver mailing list. The cautious argued that SCUBA reg purge valves give unpredictable and often violent flow, and that using it so could cause serious harm to a patient. Others (including at least one doctor) argued that if the patient wasn't breathing the patient would soon die anyhow, so it was worth the risk.

Oxygen Sets

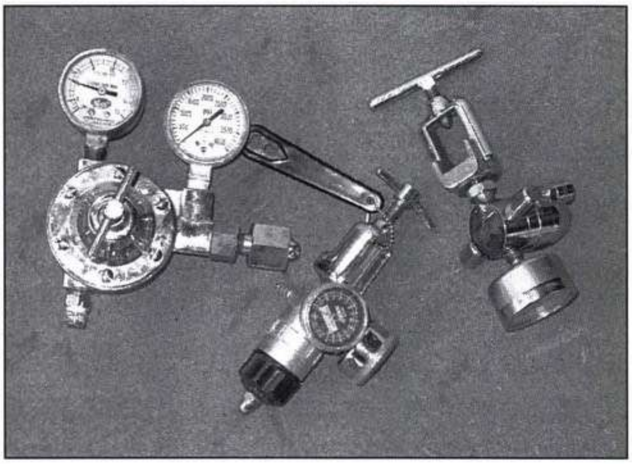
When it comes to putting together a emergency oxygen treatment set, there are three basic choices: standard medical gear, converted SCUBA equipment, or improvised sets such as welding tanks or converted aircraft sets. Gear fetishists and anal compulsives will sneer at the latter choices, and insist that for emergency gear, only the best, purpose-built equipment will do, but anything that will deliver O2 will be better than nothing, and if the choice is between an improvised outfit or nothing at all, the improvised set is the clear winner. Also, even if you have an "official" med O2 set, cobbling together an extra tank can greatly increase the duration, and hence safety, at little additional expense.

A barebones med set can be put together for about $100 with some judicious shopping, figuring $40 for a used reg, $50 for a med tank, and $5 for a non-rebreather mask. A plastic toolbox made to go under the seat of a pickup truck, for another $12 or so, makes a perfect case being long enough to fit a med O2 tank.

The O2 sets DAN sells are very nice, if a bit expensive, and configured specifically for dive emergency use. I used to think they were overpriced, but after using a couple I've changed my mind - you are getting what you pay for, and they are very good sets, with some useful extras, like a waterproof fitted Pelican case and an expensive demand mask that a bare bones med set won't have. But nice as these extras are, they are not absolutely essential and a cheaper set will do the job just as well 95% of the time, and almost as well the other 5%.

If your oxygen set will be used on others than oneself, though, and especially in a commercial situation, that is to say, if one is instructing or operating a dive boat, then one should probably make a point of using standard medical gear, if only for liability reasons. That's why serious dive boats, even if they are carrying a big multi-user O2 bottle, will also always have a standard medical O2 set tucked away.

If it's for one's own use, of course, anything



Medical regulators come in many sizes and configurations, not all of which are suitable for SCUBA emergency use

Hard plastic washer, somewhat the worse for wear, and a Bodok seal.

goes.

An O2 set can be multipurpose. I use my little tank flying and throw it in my dive bag when I go diving. An O2 cleaned SCUBA tank/regulator combo can be used both for in-water deco or surface treatment use (though a spare tank of O2 should always be kept in reserve for strictly emergency use).

Some O2-provider courses insist one should always ask the person being treated, preferably in front of witnesses, if they would like O2, and then make them put the mask on themselves, in a crude attempt to absolve oneself of any possible liability.

As repellent as it is to think about playing games like that at such a time, it's probably especially worth doing if you are using an improvised O2 set or non-medical O2 - saying something along the lines of "This is just my deco O2 and not an official medical O2 set, but oxygen will probably help your situation, and if want to use it you are welcome to it". Then let them put the mask on themselves if they are able to, giving them whatever help as is necessary.

Personally, though, if someone is too far gone to play such games I am going to give them O2 - any O2 - and damn the consequences, and I hope that if I am ever in a similar situation someone will do the same for me.

Medical Regulators

Medical O2 regulators can be found either with the CGA 870 post valve or the CGA 540 threaded style. Usually, the 870 is used on portable sets and the 540 on stationary ones meant to be used with big tanks, but not always. I ran into a cute little medical O2 set in a surplus store with two D tanks manifolded together and a tiny CGA 540 med reg.

Since home O2 sets are often used by older people with breathing disorders, they turn up used fairly often. I've bought them at flea markets and junk stores for $5 to $20, and suppliers who handle surplus and used medical gear will often have them in the $25-40 range.

If one is considering buying a med reg, keep in mind that they come in different output ranges, The most common ones are 8 and 15 lpm, but you'll also run across 1/2, 1, and 2 lpm versions. Only the 15 lpm models are suitable for emergency dive O2 treatment use (though in a pinch an 8 lpm reg can usually be cranked up high enough to give 15 lpm even though the needle will be pegged or out of the marked range). It is not hard to convert many of the others though it is usually more cost-effective to get the right one in the first place.

One other thing anyone using a CGA 870 post valve tank and reg combo should know is that the washers used to make the seal between them are not as well retained as they are on other HP gear, and are easily lost.

The hard nylon ones (usually green) are only intended to be used once There's nothing more frustrating than lugging your O2 set around for a couple of years, then find when you actually need it that most of the gas goes hissing out around the seal. Plus they harden up when they get cold, making it even harder to get a good seal., Anyone who thinks SCUBA yoke valves are klutzy should try getting an old, used, washer on an 870 to seal on a cold day - you can waste a lot of O2 this way. The hard washers have also been implicated in several fires.

New washers are included when a med tank is refilled, but if one is using a non-standard tank, refilling a med tank oneself it'll be necessary to get some spare washers from a med gas dealer.

Table 2

Oxygen Flow/Pressure Through a no. 77 drill (0.46 mm) orifice

Flow (lpm)	3	5	8	10	12	15
Pressure (psi)	10	25	55	75	90	120
(bar)	.7	1.7	3.8	5	6	8

Note: these numbers are based on actual measurements taken on several old medical flow gauges, and should be regarded as only approximate.

There's a much better choice for a CGA 870 washer, the Bodok seal, which uses a captured O-ring which can be reused with impunity. It's by far the better of the two for making a trouble-free seal, but doesn't stay put as well, so one should always have a few spares on hand regardless.

Med regs generally come set up for one or both of two modes of delivery - to supply an adjustable flow of oxygen calibrated in liters per minute to a constant flow mask or cannula, or to provide an intermediate pressure suitable for supplying a demand mask.

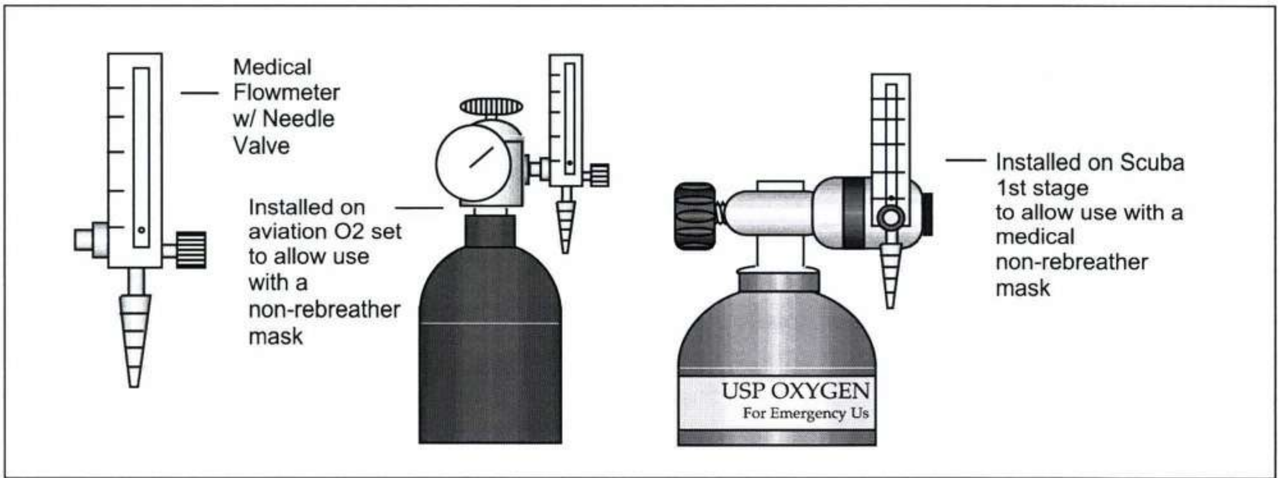
Usually, they come set up either for constant flow only, or for both.

Actually, the main difference between the two is not in the regulator itself, but in how it is plumbed. A regulator intended for use with a constant flow mask or cannula usually has a precision orifice in the output side that limits flow. Since the flow through the orifice will depend on the pressure the orifice is exposed to, the flow through the orifice to the mask can be set very accurately by adjusting the intermediate pressure in the regulator.

To measure the flow, the regulator has a flow gauge calibrated in liters per minute (lpm). This flow gauge is actually just a pressure gauge calibrated so it will read correctly when used with the matching orifice, the size of which is marked on the gauge face. Most commonly this will be .018" (.46 mm), or the size of a no. 77 drill.

A med reg using the orifice/gauge method of flow control can be converted to a different flow rate by replacing the gauge and the orifice, or the existing orifice drilled out and just the gauge replaced.

Some medical sets use a vertical column flowmeter and needle valve to adjust flow rather than a matched gauge and orifice. These flowmeters are useful because they can be added to almost any kind of regulator - SCUBA, industrial or medical - to allow them to be used for emergency O2 administration. The flowmeter has a



Medical regulator with a DISS port added to the LP port to take a demand mask

transparent column with a ball that moves up and down in it to indicate the flow. While this is potentially more accurate and reliable that the orifice/gauge combo, both methods have their disadvantages. The flowmeter must be mounted upright to read accurately, and may be hard to use in a pitching boat or moving vehicle. The gauge/orifice combo, since it reads intermediate pressure rather than actual flow, will still register normal flow if the hose is pinched or blocked, even though no O2 may actually be getting to the mask.

Newer med regulators may have no gauge or meter at all, but are adjusted simply by turning a calibrated knob marked for the different flow rates.

Regulators made for use with a demand mask are equipped with another type of outlet, called a DISS (Diameter Index Safety System - there are different sizes for each gas) outlet on the high pressure side of the orifice to give unrestricted flow at the regulator's intermediate pressure to the demand mask. They can be told apart because the constant flow outlet will usually be a tapered push-on type connection, while the outlet for a demand mask will have a threaded or QR union to cope with the higher pressures. The DISS outlet often includes a neat self-sealing valve that opens automatically when a mask is connected. Some med regs have several DISS outlets for multiple patient use, and one with both a DISS and metered orifice can usually be used with both kinds of masks simultaneously for treating multiple victims.

It's handy to be able to use either system on a diving emergency O2 rig, since a demand regulator will make more efficient use of the gas with a conscious user, but a constant flow non-rebreather mask is desirable in order to treat an unconscious or badly injured victim.

Fortunately, it's not hard to convert either kind of reg to the other, given a few brass fittings and a little imagination. To add a demand mask (or a scuba 2nd stage) to a metered flow medical regulator, one must tap in somewhere upstream of the orifice and add an outlet for connecting the demand stage. Since the orifice is usually located in the fitting that the tube to the mask connects to, you can add a tee fitting between it and the regulator, or you can remove the flow gauge (which is actually measuring the intermediate pressure) and put a tee between it and the regulator. If one wants to keep the "official medical" look, buy a chrome tee from a medical O2 dealer.

If one is going to be using an med. demand mask, the appropriate DISS fitting will also be required. For use with a SCUBA second, the tee can be equipped with a shut-off valve, or simply capped when not in use.

Aviation Oxygen Sets for Emergency O2

Small aircraft use a variety of portable or built-in 02 sets for high altitude use. Sometimes you'll run into these at airport fleamarkets or surplus stores. The portable oxygen sets are usually easily adaptable to emergency use by simply by adding a non-rebreather mask.

The emergency O2 set I take along for casual diving has aviation ancestry; it's a very lightweight 11c.f. emergency O2 bottle with an integral fixed pressure regulator that was originally part of a small pressurized Cessna. It's purpose was to supply the four passengers with a twenty minute supply of supplemental O2 in the event of a pressurization failure - the lightplane version of "in the event of an emergency, oxygen masks will drop from the ceiling".

Since the regulator is not adjustable, I added a $5 surplus flow meter/needle valve so it can be used with a conserving cannula or non-rebreather mask without wasting O2.

Converted SCUBA Gear

If one is using a scuba tank and regulator for an emergency oxygen rig it's necessary to go the other way. As mentioned earlier, a standard SCUBA reg second stage will make a perfectly usable demand mask for a conscious, functioning patient, but it is essential to have the ability to use a non-rebreather mask for treating someone who is seriously injured. That means adding some way of reducing the flow to the standard 15 lpm. Since the intermediate pressure on a scuba reg isn't adjustable as on a welding or medical regulator, doing so is a good bit more complicated. In order to get the right flow, one must measure the intermediate pressure and make an orifice that will give the desired flow at that pressure. Or one can just cobble up a needle valve or flow meter/needle valve combo which can which can be connected to the regulator's LP port using an adaptor like those shown in the appendix. Sharp-eyed readers will notice an amazing similarity between a dive regulator so modified and the homebuilt sampler described later on in this book; they are essentially the same thing, and the same one can be used for both purposes.

A flowmeter is handy, but in a pinch one can simply adjust the flow by eye, by cranking it up until the reservoir on the non-rebreather mask completely fills between breaths, and never goes below 1/3 full as the user inhales. But this is something best learned in a DAN O2 Provider or other emergency treatment course and beyond the scope of this book.

One can also buy an adaptor, consisting of a SCUBA yoke and a CGA 870 post, that runs a medical regulator off a SCUBA tank. This is a handy adaptor to have if one is into tech diving, even if one already has a med set, since it would permit continuing treatment using any available SCUBA tanks filled with deco O2 or even high-FO2 nitrox mix once all the 100% was used up.

Anyone handy on a lathe can also turn a little bottle cap size adaptor that will slip inside the med reg yoke and adapt it directly to a SCUBA yoke. One must keep in mind when using these adaptors that most medical O2 gear is intended for 2000 psi (140 bar) tanks and it may not be advisable to run them off a (full) 3000+ psi (200+ bar) SCUBA tank.

One major advantage to using an old SCUBA tank for emergency treatment O2 is that it will have so much more capacity than a standard portable med tank that if there is any question as to the flow rate one can afford to be generous.

If one is going to use converted SCUBA gear for emergency O2, it doesn't make any sense to buy it new. A $25 steel 72 and a junk $30 unbalanced piston regulator, O2-cleaned, will do the job as well as a brand new 80 and $400 worth of regulator.

If a SCUBA tank and SCUBA valve/regulator are used for emergency O2, the tank MUST BE CLEARLY MARKED as containing O2 for emergency surface use, so there will not be the slightest chance that someone might try to dive with it - a mix-up which has claimed a number of lives in the tech diving community. It's not enough just to label it O2, since there are many idiots with and without C-cards in their wallet who still think O2 is what divers use.

When discussing using SCUBA gear for emergency O2 treatment, the question comes up of whether, if no straight O2 is on hand, but nitrox is, it's worth using nitrox. A recent issue of the DAN magazine, ALERT DIVER, touched briefly on this, and concluded that it is.

While 100% O2 is, of course, the ideal, any additional O2 over what is in air will increase out-

Any oxygen is better than none

gassing of N2. A basic nitrox mix - say 32 - 40% - administered via a demand or non-rebreather mask, or SCUBA regulator, would give the person being treated an FO2 similar to what they'd get from the nasal cannulas or simple 02 masks commonly used to administer supplementary O2 in hospitals. With a higher FO2 deco or travel mix - like 50/50 or 80/20 - the benefits would, obviously, be even greater.

Welding Sets And Other Improvised Sources of Emergency O2

If one already has a small 02 welding tank - like the 20 or 50 c.f. tanks that are the only tanks most gas suppliers will sell outright, and are sometimes found in mail order catalogs, one might wonder why not just use it for emergency O2 as well rather than buying a whole new outfit.

There's no reason not to, assuming one has no compunctions about breathing welding O2. All that's necessary to adapt a welding tank and regulator for use as an emergency O2 source is a mask and some way of adjusting the flow. This can be done simply by adjusting the regulator's output pressure, or one could buy a proper medical O2 gauge calibrated in liters per minute and matching orifice from a medical O2 supplier. Or make an orifice and label the rig somewhere with the appropriate psi settings to obtain the desired flow - once again, usually 15 lpm.

Since welding tanks and the larger medical tanks both use the same CGA 540 valves, medical regulators are also available that will screw right on to a a welding tank. Or one can buy or make an adaptor to run a more common CGA 870 med reg on the CGA 540 tank.

In an emergency one can use a welding set with a medical mask without any modification at all simply by sliding the plastic hose from the mask over the tip of the welding torch and using the regulator knob or O2 valve on the torch to adjust the flow. We did this a little while ago to treat a friend who managed to get mild CO poisoning working in his garage, as a stopgap while we called the doctor. It's not a bad idea to disconnect the acetylene tank, just to be on the safe side.

It's also possible to hang a spare dive regulator second stage off a welding or industrial regulator and use it as a demand mask.

Since many welding O2 regulators won't deliver much more than 80psi (5 bar) or so, and most dive regulators are designed to work with an intermediate pressure of 125-150 psi (8-10 bar) the regulator second stage may have to be tuned to work with the lower pressure, and not all seconds will have the range necessary to achieve this. Swapping fittings on the O2 regulator takes just a minute, so it can still be used for welding. The really nice thing about this kind of rig is that it's got some serious capacity compared to little 7 to 13 cf (1.5-3 liter) portable med sets.

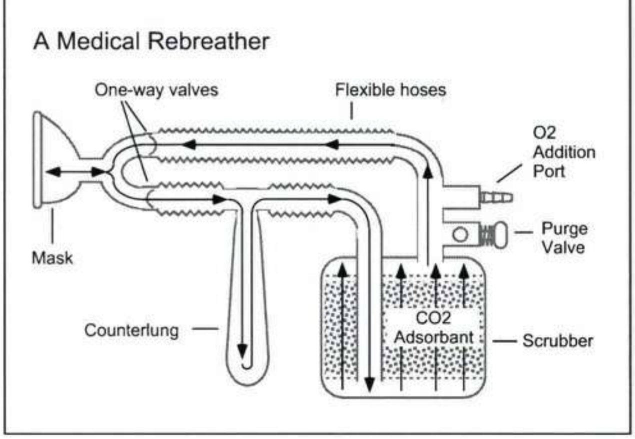
If one does put together an improvised emergency treatment O2 set, it should be placarded prominently with directions for how to use it, just in case the owner is not around - or is the one being treated. I've got the directions for mine printed on a sheet of paper which I put in a plastic cover and taped to the tank so they won't get lost. I also usually leave my emergency set up for an unconscious user, with the non-rebreather

DAN RemO2 Medical O2 Rebreather

mask rather than a demand mask in place, so it can be put into use with one twist of the valve, on the theory that in the most extreme emergency that will be the mode that'll most likely be needed; in less extreme circumstances there'll be time to change over as required

Rebreathers for Emergency O2 Adminstration

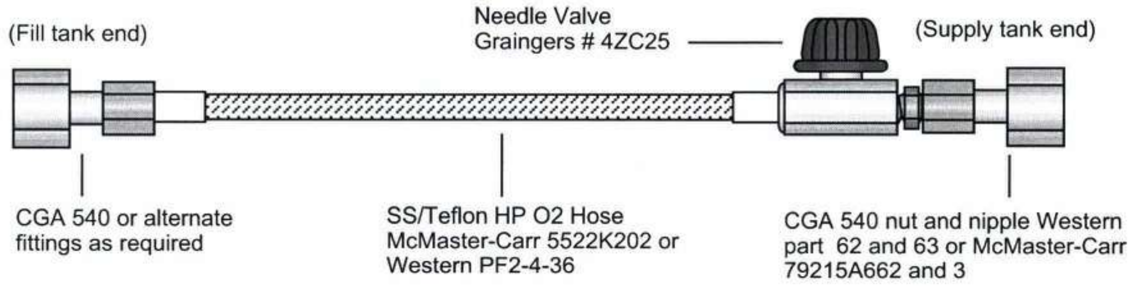
Breathing O2 from an open circuit apparatus is very wasteful, since only about 4% of the inhaled 02 is actually metabolized, and the rest is exhaled and wasted. Rebreathers (not to be confused with partial-rebreather masks) are closed circuit O2 breathing systems that use a filter called a "scrubber" to remove CO2 from the exhaled gas, so the O2 can be breathed over and over again. Additional O2 is added as necessary to replace the O2 which has been consumed. Since virtually nothing is wasted, rebreathers make very efficient use of gas, and a rebreather will typically give 6 to 10 times as much duration from a tank of 02 than the same tank would give with an open circuit mask.



DAN has recently come out with a $195 rebreather option (though DAN is somewhat coy about coming out and calling it a rebreather) designed to be used with their medical O2 kits called the RemO2 (for remote location O2) which gets 6 hours out of a standard super-D tank.

Looking at the DAN rig, it appears to consist of about $30 worth of medical O2 parts in a $40 Pelikan drybox. Medical gear, though, is notoriously overpriced so this is probably an exaggeration. And when you consider that to get similar duration would require a 80lbs or so worth of expensive tanks, the DAN unit is a bargain. However, it would not be hard for anyone with some knowledge of rebreathers to come up with a similar rig for much less.

Rebreathers, though, have one very terribly serious catch to them, which anyone using one, be it DAN, other, or homebuilt, must be very aware of. The trigger that makes us breathe is not lack of O2, but excess of CO2. Remove all the CO2, as an RB does, and it is possible, if significant nitrogen is left in the loop, for a person to breathe and rebreathe the same gas, until there is not enough O2 left in it to sustain life, at which point the person will pass out and eventually die, often quietly and without ceremony, and without even being aware that anything is wrong. Once the O2 stops flowing, a rebreather abruptly tranforms itself from an efficient life support machine to an equally efficient euthenasia device - in fact, Hemlock Society types have been known to recommend a



modified rebreather (sometimes referred to as a "debreather") as a painless means of suicide!

For this reason, any rebreather being used for emergency treatment should be purged regularly and monitored extremely closely, to insure that the patient is receiving adequate O2.

AVIATION USE OF 02

Oxygen is required by the FAA for flightcrews in non-pressurized aircraft for extended flights above 12,500' (3756 m) and any flight above 14,000' (4200 m). The FAA also recommends, but does not require it, for flights above 10,000' (3000 m) day and 5000' (1500 m) night.

Many pilots use it for lower altitudes, and believe that it lessens the fatigue one often feels after flying which is caused, in part, by mild oxygen deprivation. Tests have shown that night vision is especially sensitive to even mild hypoxia, and can be significantly improved by use of supplemental O2 even at relatively low altitudes.

While larger unpressurized aircraft usually have built-in oxygen systems, pilots of smaller aircraft often use portable units.

These cost in the $400 to $600 range, depending on how big the tank, how many users, and whatever other bells and whistles they include. Medical O2 sets can also be easily adapted for flight use.

Since most av and med sets hold typically only 10 to 30 cf., a pilot using one of these portable sets is put in the position of frequently having to buy very small amounts of O2, which, as has been pointed out earlier, can be very expensive. This has driven many pilots who regularly use O2 to seek ways of filling their tanks themselves.

Most portable aviation O2 sets come with tanks using special dedicated valves and/or regulators so they are not swappable at refill time. That's one advantage to using a converted medical O2 set - it gives the option of either having your tank refilled or swapping it.

There's a catch to swapping, though. Most aviation sets come with aluminum tanks, which are much lighter (and prettier) than steel tanks (though some steel aviation sets use lightweight steel tanks that weigh very little more). But some gas dealers are phasing out aluminum tanks for medical O2. That being the case, if you get an aluminum tank, and would like to stick with aluminum, you may have to have your tank refilled rather than swapping it, or else call ahead to see if your gas dealer has an aluminum exchange tank in stock or can set one aside for you.

Also, medical O2 refills for small tanks tend to be fairly expensive, at $10+ a hit. Fills at airports can cost anything from $5 to $50. If your airport is at the higher end of the scale, or simply does not have O2, this can provide a powerful incentive to fill your own.

A basic refilling station for av O2 will cost a bit over $100 - about $50 for a one year tank lease, $40 or so for the whip, plus the cost of the gas. For more efficient gas use you'll need more tanks, at $50/yr. each - see the discussion of cascades in the Hardware chapter.

The whip for refilling aviation O2 tanks can be much simpler than one for mixing dive gases, since one will usually be trying to get as much into the tank as possible, and not to meter out an exact amount, making a gauge not essential.

Transfilling O2 into aviation tanks may be simpler than mixing gases for diving, but it is potentially more hazardous for two reasons:

– It involves filling straight O2 to a much higher final pressure. All the hazards of O2 increase with pressure.

– Portable aviation tanks tend to be smaller - usually in the 11-22 cf range, and small tanks are much harder to fill, since their small volume gives them less ability to absorb surges, and makes it difficult to keep flow rates low (40-60 psi/3-4 bar/min) enough for safety. For this reason it is essential to have a precision needle valve on the whip, rather than relying on the tank valve.

Incidentally, since glider pilots regularly use O2, and tend to use smaller portable sets, one is much more likely to get a reasonably priced, hassle free refill at an airport serving gliders than one serving bizjets. Another alternative is a dive shop that caters to tech divers and is set up to do O2 fills on the spot.

Since a portable aviation O2 set can be used for emergency medical treatment, it's only fair that it should work the other way around. The catch is, for the most efficient aviation use, a trickle flow of supplemental O2 is all that's needed, not the flood that is used in treating diving emergencies, and most medical regulators don't allow for such precise adjustment without modification.

Traditionally, aviators have used heavy rubber or plastic partial rebreather masks. These were too expensive to be casually discarded, and were reused, which was not terribly sanitary. Pilots began using cheap throw-away medical masks instead, and then discovered medical nasal cannulas.

These medical masks and cannulas existed in a gray area for a while, since they were not approved by the FAA for aviation use. Eventually, some of the O2 set manufacturers got them approved for flight use, and now they can be used without reservations.

The latest thing is the conserving cannula, which has a small reservoir that stores up the O2 between breaths so that a lower flow rate can be used. Each time you inhale, the cannula delivers a slug of O2 that, being inhaled first, goes, in theory, to the bottom of the lung where it is most efficiently used. Using a conserving cannula can increase the duration of an O2 tank by a factor of four, making them well worth their higher cost.

Upgrade kits are available for med and older av sets which allow the use of conserving cannulas. The kits usually consist of a precision flow gauge, needle valve and conserving cannula, and cost about $80 per user. The cannula alone costs around $25.

Flow rates with a convention partial rebreather mask or non-conserving cannula go from approx. 1.5 liters/minute at 12,500' (3756 m) to 2.5 at 20,000' (6000 m). With a conserving cannula they range from .35 liters/minute at 10,000' (3000 m) to .6 lpm. at 18,000' (5400 m), the highest the FAA permits conserving cannulas to be used. Aviation flowmeters are usually calibrated by altitude rather than lpm, with a dual scale on units intended for use with both masks and conserving cannulas, so one simply sets the flow for the altitude. Some older av sets do not have a flow meter at all, but have an orifice which delivers a fairly wasteful constant flow of 2 or 3 lpm. These are intended for use only with masks, but can be converted to use conserving cannulas using the same basic parts as are used to convert a medical set.

The latest thing in aviation O2, the EDS (Electronic Demand System), uses sophisticated electronics to meter out the O2 as efficiently as possible. An EDS can get 10 hours of supplemental O2 out of a tiny 180 liter "A" cylinder. But the systems cost about double what a regular aviation set costs. They are especially popular with glider pilots, where space and weight are at a premium.

Chapter 6
BUYING IT

Oxygen is usually bought from a welding/industrial/medical gas dealer. There may be one near you, otherwise, most of them service large areas and there's likely to be a least one offering regular delivery and pick up (usually, at a charge) wherever one might live.

One nice thing about having it delivered is that the truck drivers are usually less picky than the people behind the counter back at the shop. Anyone trying to pull a fast one - like swapping a non-standard tank, or sneaking an extra tank that's out of hydro into the rotation - is more likely to to get away with it on a pickup than if they take it to the store.

There are three grades of oxygen you are likely to encounter in the U.S.; Grade A Aviator's, Grade B Medical, and Grade C Technical.

Welding O2 is usually grade C. You'll hear a lot of conflicting information on what the differences are between them, but one thing is sure; they all come from the same tank at the gas plant.

As the representative of one aviation O2 set manufacturer said, when he told me to just use welding O2 if I couldn't find aviator's, "there may be 1/2 of 1% in it which isn't O2, but whatever it is, it won't hurt you."

Actually, if read the CGA and USP specs, you'll find that welding O2 is, at least on paper, purer than medical! USP standards require that medical O2 be only 95% pure, while welding O2 must be at least 99.5% (any dirtier and it won't do consistent welds). That's really just a technicality because cryo O2 is very clean, and most suppliers bottle the medical stuff to the same standard as the welding, and it would be very hard to find medical O2 as impure as the USP permits.

There are differences. Depending on who you talk to, you may be told that the difference is that there's more paperwork for the medical gas, that they flush the filling lines more carefully, or that they vacuum purge the medical tanks of old gas before filling but not the welding ones.

One supplier told me that they are required to test each batch of med O2 but not the welding stuff. "Have you ever had a batch that failed the test," I asked him?

"No", he said, "Never. And I've never heard of anyone who did."

The truth seems to be a mixture of all the above. Breathing O2 must be tested for purity, on a batch by batch basis, and records kept for traceability. The tanks must be vacuum purged to remove any leftovers before being refilled.

Whatever the difference, it doesn't seem to add up to very much, because there is almost no difference in price between welding and medical O2.

Aviator's O2 is usually the most expensive, mainly because so little of it is sold compared to the other two. The only difference between medical and aviation O2 is that the aviation stuff is tested and certified to have a lower moisture content. This is important if an aircraft's O2 tanks and plumbing are mounted outside the cockpit and exposed to the chill of high altitudes, but has little advantage for a portable O2 set that will be kept inside a heated cabin. Note that this doesn't mean it actually is any drier, just that it is tested to meet the dryness specs. My supplier tells me that virtually all their O2 meets the aviator's dryness standard, and the only time they ever reject a bottle is once in a blue moon when a just-hydroed tank has a tiny bit of moisture left in it.

Still, most aviators use it because the name is right, and many divers use it just because it is certified breathing-grade O2 that can be bought without prescription hassles.

One of the funny things about aviator's O2 is that the price varies between dealers much more than the price for the other grades. I never paid much attention to aviator's O2 when I was having no trouble buying medical O2, especially because the local gas dealer quoted me a price for it about double what other grades were selling for. Then, after that dealer started insisting on a prescription for medical O2 I did some shopping and found another dealer who sold aviator's for only a dollar or so more than welding. I went back to the first dealer and asked why they were so high; this time they admitted their plant wasn't set up to do aviator's, and the price they had quoted me was based on getting it from another dealer, which really jacked it up.

The same dealer, it turned out, was selling large amounts of medical O2 to a dive shop. I asked if the shop had a prescription, and was told no.

"I thought you just told me you couldn't sell it without a prescription," I muttered.

The guy thought for a minute, then said "They're using it for diving."

"So am I"

The guy looked stumped, then called his boss over. "Well, they're, like, a distributor," he told me. " It's OK for us to sell to distributors"

He noticed me looking skeptical, and added "I could show you where it says so in the regs, but it would take too long to look it up."

Don't expect logic in the gas business!

So whatever tiny differences there might be, there are a lot of divers and pilots breathing welding O2, and I've yet to hear of a single problem caused by "bad" 02. A few diver's who use aviator's O2 complain that it drys out their throats much faster, but my gas dealer laughed when I told him.

It's also worth noting that while the first edition of the NOAA Dive Manual, which one would expect to be pretty conservative, said that Grade C was not suitable for breathing, the current edition says it is "safe for breathing but may have an objectionable odor, and for that reason should not be used in diving". I haven't ever run into any objectionable odor myself yet; if one does, changing suppliers will usually cure the problem.

And my 1960 copy of the Linde Oxy-Acetylene Handbook says unequivocally that "All Linde oxygen is of such high purity that, in addition to industrial uses, it is suitable for human consumption in the treatment of respiratory and other diseases".

One will hear people claim that welding O2 is more likely to contain contaminants, especially acetylene that may have leaked in from the other tank. Or that the filling lines may have been used for other gases and not properly purged.

This is highly unlikely - just about any contaminant that could cause harm should one breathe it would be a much greater danger to the gas company when they fill the tank. Acetylene, especially, would be a disaster, since it spontaneously explodes under pressure. If a gas plant put 2000 psi (130bar) of O2 on top of acetylene, they would be the first to know about it - KABOOOM!

One difference that does exist concerns vacuuming the tanks. Medical tanks are vacuumed before they are filled to suck any remnants of the old contents, just in case anything bad has, by some unlikely chance, gotten in. Welding tanks are not always. Some people report they have been able, when having their own tanks filled with welding O2, to request that the tanks be vacuumed, and many gas suppliers routinely vacuum all O2 tanks. Ask!

Since there is no significant difference in price, there's no point in not using medical or aviator's 02 - whichever one can obtain cheapest and with the least hassle. But if if they aren't available - because the gas dealer insists on a prescription or has crazy pricing - or one already has a supply of welding O2 and doesn't want the expense and/or complication of more tanks, there doesn't seem to be any compelling reason not to use the other stuff.

While gas is normally sold in leased tanks, most gas suppliers will also rent tanks by the day. This is useful when one is on an extended dive trip - bring along your whip, get a short-term rental on a few tanks, and mix your own.

Gas dealers aren't necessarily the only place to get O2. As the cryogenic oxygen has become more common, many large users of O2 - like factories, big welding shops and hospitals - have their own substation for filling tanks. If you have access to one of these where you - or a buddy - work, it may be possible to get privately owned tanks filled with absolutely no hassle, as easily as getting a SCUBA tank filled. Since bulk O2 doesn't cost much, it'll probably be much cheaper than getting it from a gas dealer, and maybe not cost anything at all.

We had one guy in the area a few years back, a real cowboy, who had a big welding shop. He used so much O2 that the gas company obligingly set him up with a little substation - a cryo O2 tank and the plumbing to gasify and pump it. He'd sell to anyone, and didn't give a damn about hydros or bills of sale. If the tank looked funky or was long out of test, he just wouldn't put as much in it. Filling by ear, we called it. Then his marriage broke up and the shop went bust. But it was great while it lasted, and lot more fun than dealing with the prigs down at the local gas supplier (who actually, believe it or not, wear cop style uniform shirts with American flag patches on the shoulders!).

Pharmacies often carry O2, but only the smaller medical sizes. Handy if one needs to swap a med tank in a hurry (assuming, that is, they are willing to do it) but not much use if one needs a couple hundred cf for mixing.

Another alternative better suited for filling small emergency or aviation tanks is a dive shop that does gas mixing. They're more likely to be set up to do it on on the spot, and, and it very likely will cost less than from a medical/industrial gas dealer. This works especially well for non-standard configurations, since a tech dive shop will be able to fill it on the spot and may be more likely to have the adaptors to do it.

Is It Legal To Buy O2?

Which brings us to the law. Is it legal to buy O2 for use as a breathing gas? The answer is definitely yes, unless you are talking about med O2, in which case it is probably, but you may have a hard time proving it.

First of all, there's no law against breathing O2 - even 100%.

Medical O2, it's true, is usually sold by prescription, but that is mostly a technicality to do with medicare and insurance reimbursements.

Until recently this was all subject to federal law, but then a few years back the feds decided to hand the authority back to the states. When federal regulations covered it, there were exemptions for emergency use and small quantities. But many of the states never bothered to update their laws, so in many cases it was just about impossible to even figure out if there was any law. The law in my state, for example, defines a prescription drug as "a drug which under federal law is required .. to be labeled with one of the following statements:

a) "caution federal law prohibits dispensing without a prescription"

b) "caution federal law restricts this drug to use by or under the order of a veterinarian..."

But federal law nowhere required medical oxygen to be so labeled! Instead, the Food, Drug and Cosmetic Act, in the Good Manufacturing Practice section says only that medical O2 should be labeled "for administration only by personnel properly instructed in oxygen administration or by licensed practitioners". And there is some question as to whether this is law or only guidelines.

So, in my state at least, medical O2 didn't seem to be a prescription drug by law.

In some states, like Florida, divers and dive industry people were able to get the law changed to specifically permit the purchase and administration of O2 for dive emergency use.

Then out of the blue the FDA issued a new set of guidelines to clarify the whole mess. According to this latest (9/97) policy (which turns out to be a rehash of a 1972 policy) oxygen now must be labeled as follows:

"For emergency use only when administered by properly trained personnel for oxygen deficiency and resuscitation. For all other medical applications, Caution: Federal law prohibits dispensing without prescription"

There doesn't seem to be any clear definition of "trained personnel". The FDA told me it was up to the state to set standards, and very few states apparently have done so.

The FDA seems to think it was clearing things up with this new policy statement, but it raises as many questions as it answers. By saying "for all other medical applications," it leaves non-emergency, non-medical applications - like gas mixing - still in limbo. One suspects many divers will just go ahead and buy it whatever they need under the emergency use policy

One thing to remember, since no one in the gas industry seems to know for sure what the law really is, let alone where it is written down, there's quite a bit of room for creative bullshitting and if one sounds confident one can often prevail. The new policy has been sent to the CGA and the state pharmacy boards, which hopefully will be communicating it to all concerned, so possibly gas dealers will be hearing about it; if not, and you have trouble buying med O2, suggest the dealer contacts the CGA.

Other grades of O2, like aviator's are not considered drugs at all and can be freely bought. There is, unfortunately, no "Diver's Grade" O2. Actually, there is an "environmental O2" mentioned in the federal regs, which is exempted from the labelling requirements. It is essentially just USP breathing O2 when sold for non-medical uses, "for use in space capsules, deep submersibles etc." according to the regs. I have never found a dealer who actually carries it, and most have never even heard of it (if you ever should find yourself trying to buy some, be sure to tell them it's for use in a space capsule!).

If one is going to be quibbling over the legal status of O2 with a gas supplier, it might be worth mentioning here that USP does NOT mean prescription. It simply means that a product conforms to the standards given in the United States Pharmacopoeia. The baking soda you can buy at the super market is marked USP, and all Linde O2, welding included, was for many years marked USP.

Oddly enough, the problem of buying med O2 has always been worst when it comes to getting little emergency bottles refilled. Buying large quantities of med O2 for gas mixing is rarely a problem. I know mixers who have no problem getting three or four H tanks of med O2 delivered right to their garage, but get hassled by the same dealer when they try to get a little A tank filled.

There is, you may have noticed, a wonderful absurdity to the O2 regs, even as revised. Since all O2 comes out of the same vat at the plant, it's hard not to start wondering at what point plain-old-O2 becomes Prescription Drug O2. Probably at the moment it is put into a container labeled such. That being the case, one has to wonder if it looses that status when it leaves the container. Or if using "environmental" O2 therapeutically would be a violation of law!

One thing that does seem to be clearly and unequivocally illegal is to refill medical O2 tanks that still bear medical O2 contents labeling, since this would constitute "unauthorized manufacture of a prescription drug". For this reason, if one is using a medical O2 tank for non-medical purposes, the medical O2 label should be removed.

This is one of those "crimes" that it would be very hard to prove anyone did, unless they did it openly or boasted about it - you have been warned!

BUYING HELIUM

Helium is usually available from the same med/industrial gas suppliers as O2, and all the information elsewhere in this book concerning tanks, leases, and the eccentricities of gas suppliers in regards to O2 is equally applicable to He.

Not too long ago, the US was the sole supplier of helium, with the US government maintaining a tight hand on the supply in case another war ever made it necessary for us to float a fleet of blimps and dirigibles on short notice. This made He expensive or unavailable in much of the world. Now sources of the gas have been found in Africa and Russia as well, and the US government has realized that if war comes we don't have any blimps to inflate anyway. This has resulted in a loosening of the supply, and made it much more available, though often still expensive.

The big question the would-be trimixer faces is what grade of helium to use since there doesn't seem to be a standard, universally available USP breathing grade the way there is for O2.

Rather, there are several extremely pure and correspondingly expensive grades used in analytical work, some dirtier industrial grades, a USP medical grade, and a "balloon grade" and low end welding gas which may actually be ungraded crude helium with substantial amounts of other gases mixed in.

The chart show how they compare at my local gas supplier:

Helium is often referred to by the number of 9's in its purity rating. Chromo grade is "Six nines", UHP "five nines" and Zero, HP and Industrial "four nines" - and USP "two-nines".

Prices given are based on buying 5 to 10 tanks a year. One will notice that the prices in the table are a little inconsistent. That's partly because the list combines information from several sources, but mostly because there doesn't seem to be any hard and fast price list, but the price quoted seems to depend somewhat on the mood of the salesperson at the moment.

I get a feeling, pricing He at different suppliers, that He is sold differently than O2 - that most He buyers tell the supplier what they need, then haggle a price rather than choosing from a list of standard in-stock grades and prices.

I was told that UHP and Balloon were their

Table 5
TYPICAL HELIUM GRADES AND PRICES

Grade	Purity%	02 ppm	hydrocarbons	Price (260cf K tank)
Research (aka Chromographic)	99.9999	<1	> 0.5	$150
UltraHighPurity	99.999	<5	>0.5	$100
Zero Grade	99.995	<5	0	$80
High Purity	99.995	<5	<1	$50
Industrial	99.995	<10	<1	$63 (300cf "T" tank)
Commercial	99.5	<10	not spec.	$50
USP	99.0	<10	not spec.	$50
"Balloon"	"Able to float a balloon"			$45

(ungraded - typically 98-99% but no guarantees) biggest seller - always a question always worth asking, since one may get a better deal on a grade they do a lot of than on a grade they rarely handle.

The USP grade deserves some comment. We think of medical grades as being super-pure, but actually it is the dirtiest of all the graded He. As the lab man at the supplier told me, "It's a junk grade".

This brings up an interesting point. The fact that a particular grade of gas is sold for human consumption doesn't necessarily mean it is safe for diving use, since breathing a gas under pressure multiplies the effect of any impurities. A level of impurities that would be acceptable in a gas intended for use at one atmosphere could be dangerous at ten.

Actually, as with O2, the differences between the lower grades aren't as much as they appear. The lab man told me that even though the USP specs say it only has to be 99.0% pure, their stuff actually meets the commercial standard, and usually greatly exceeds it. While there's no hydrocarbon spec for the Commercial and USP grades, he told me it would be in the same range as the other grades since there are no significant differences between how the grades are handled at the plant.

Most gas suppliers get they get their He the same way as they get their O2 - liquified, in big cryo containers. They decant it and do whatever tests, paperwork, and tank vacuuming is required to qualify it as the desired grade. But everything - from the Research to Balloon grade (usually) - comes out of the same tank. So the actual differences between the grades are - often - very slight.

Older sources like the 1st edition NOAA manual make a distinction between oil and water pumped helium, and specify that only the water pumped is suitable for breathing. My supplier says this is no longer an issue - that all his helium is water pumped, and his analysis seem to bear this out. And the current edition of the NOAA manual no longer makes the distinction. But this may not be true everywhere, and this is something that should be carefully checked with the supplier, especially abroad.

Grade names and analyses will vary from supplier to supplier, and the counter staff will often not be able to explain the differences, or if they attempt to, may often give erroneous info.

Any gas supplier with its own plant will have a lab somewhere, and that's the best place to look for the answers. If the shop won't get the lab on the phone, then the best strategy is to get the number for the supplier's plant or main office, then call them and ask for the lab.

My gas supplier has a local store, but they've also got an toll free number for the main office at the plant. The main number is on the tank stickers and invoices; I call the main office or lab first whenever I need info, then just tell the guys at a local store what to get me.

So what grade to use? The NOAA manual says QVL (quality verification level) G, a five-nines grade. The Navy Dive Manual says type one (gaseous) Grade B (respirable), a four-nines.

Navy Standards for Helium

Purity	99.997%
N2 and argon	5 ppm
H2O	9 ppm
Neon	23 ppm
Hydrocarbons	1 ppm
Hydrogen	1 ppm
O2	3 ppm

Many mixers would say this is overkill, and many tech divers - such as the WKPP cave team, probably some of the most accomplished non-professional deep tech divers in the world - seem to use commercial grade helium for their mix. The dirtiest grades, at 1 ppm total hydrocarbons (and note this is total hydrocarbons, and includes oil, not just gaseous hydrocarbons as on the air chart) far exceed the standards even for air to be used in PP mixing.

It is interesting to note that main difference between the industrial and the HP seems to be the industrial is more likely to be "contaminated" with a tiny bit more O2. This is important in analytical work, but hardly a problem for the gas mixer, who will be adding O2 anyways, and the extra 10 parts per million isn't likely to throw off the mix.

That being the case, it seems that any graded He one is likely to buy in the US is probably adequate for diving.

"Balloon grade", which is not really a grade, or ungraded welding He is a more dubious proposition. While my supplier told me his usually runs 99% pure, the NOAA manual warns that ungraded helium can run as much as 15-50% not-helium. I mentioned that to the labman he agreed it was possible; the only test for balloon grade, he said, is whether it will float a balloon - literally; the gas is tested for flotation.

Also, some suppliers also cut their balloon grade with air - apparently as a safety measure, to keep kids from going hypoxic when they inhale the stuff to make their voices squeaky and this may even be required by law in some places.

On the other hand, most suppliers get their balloon grade from the same cryo tank as the other grades, and many - including mine - don't cut it with air. The balloon grade my suppler sells, they tell me, is pretty much the same as the USP, the only difference being, in the words of the lab man, "we give the balloon tanks a single quick vacuum and the USP tanks two thorough ones".

So that particular supplier's balloon grade might make it a good alternative to the other grades, especially because balloon grade can be obtained with a minimum of hassles just about anywhere. But I'd want talk to the plant where they bottled it, and check it with my O2 analyzer before I did any mix with it!

In some areas where a lot of commercial diving goes on one may be able to find He specifically bottled for dive use. The only thing to watch out for here is that dive He sometimes is premixed with 10% O2, to guard against hypoxia in the event of a systems failure on the mixmaster. Once again, checking your He with an O2 analyzer before using it is a worthwhile precaution.

There's another potential problem to be aware of. Since He is inert, and not often used as a breathing gas, it isn't treated with the strict segregation that O2 is. The same CGA valve fitting as is used for He is also used for nitrogen and argon and a supplier may switch a tank from one gas to another.. This creates the remote possibility that a tank supposedly containing He may actually contain something other gas. Since welding shops and dive shops catering to tech divers will often be stocking both He and argon, and maybe nitrogen for drying tanks, He should always be tested before being used for mix.

There's an easy way to do this - the "sniff test". Crack the valve, take a whiff of the stuff and say a few words. If your voice is high and squeaky, it's He. If it isn't, it's something else.

There's one other thing about buying helium that anyone looking to buy it for dive gas purposes should know - some suppliers are, for liability reasons, reluctant to sell He if they know it is going to be used for diving, and especially by individuals rather than businesses.

In Florida recently, after the deaths of several techdivers in a highly publicized trimix training accident, one of the major industrial gas chains announced that they would no longer sell He to divers.

I was surprised to find, as I was researching this chapter, that my local supplier has the same policy! The salesperson told me they had no problem with selling anyone any amount of He as long as they didn't know it would be used for diving, but that if they did, they would have to refuse to sell it - the compressed gas industry version of "Don't ask, don't tell".

This being the case, it is probably prudent not to volunteer what the gas is for, and instead leave the impression that it will be used for a less controversial purpose, like welding or analytical work - or filling balloons.

Cale (who one must suspect simply enjoys being devious) when asked what he will be using the gas for replies blandly that it is for an experimental and proprietary manufacturing process, details of which he cannot divulge until the patent is secured!

Gas suppliers are usually much more willing to sell it to a business than an individual, so if one does not have one, or if it is too obviously dive related, a letterhead shop might be in order - see the appendix for more info.

Exchange It or Fill It?

It is, these days, almost impossible in many parts of the country to get an 02 or He tank refilled rather than exchanged for a full tank. Just about all gas suppliers now work on an exchange basis. A few will take your tank and fill it, on special request, but it usually takes a week and costs extra.

I bought a portable flying O2 rig with a dedicated tank/regulator a while ago with the idea of using it both the rare times I fly high enough to benefit from O2, and the rest of the time leaving it in my dive bag as an emergency O2 setup. The catch, it turned out to be almost impossible to get filled. The med/welding supply dealer wouldn't touch it since it had oddball aviation fittings and wasn't swappable, and the FBO at the local airport wanted $25 for contents plus $65 an hour labor to fill it - for a 11 c.f. tank!

I made an adaptor to fill it from my big tank, but if I hadn't been able to do so it would have been near worthless. The odd thing is, that same set is still being sold by many flight shops, although there are now other aviation O2 rigs on the market that use more compatible components.

If one owns one's own tank (or has an orphan tank of dubious pedigree) this can create a dilemma when it comes to getting if filled. On one hand, if they swap it for a full one, one is relieved of the responsibility of maintaining it. But if it's swapped, the bill of sale (and you do have one, don't you?) no longer matches the tank in one's possession, and at some time in the future it may be hard to prove that the tank is legitimate. Anytime, then, one swaps a privately owned tank there should be a clear understanding with the supplier about ownership. I know one fellow who took his privately owned tank to be filled and swapped it without difficulty; a year later he got a bill for tank lease. When he asked what was going on, he was told in their view he'd never owned the tank, they'd given him a year's free lease for "turning in" an orphan tank. What could he do? The tank they'd given him when he swapped his was clearly marked "Property of" the gas dealer's, and he had no paper to show it had ever been otherwise.

The company I'm using now, on the other hand, when they exchanged my welding tank was willing to give me a letter stating that I owned a tank outright. I suppose if someone in this situation wanted to be absolutely safe they'd get the old and the new tank's serial numbers on the invoice each time they got a tank filled, so they'd have a paper trail back to the original bill of sale.

Some tanks one should never swap. The fat little "Jumbo D" tanks that come in DAN emergency kits are very rare in the industry, and anyone who foolishly swaps one for a more common size will probably never see another - hard luck if one has one of those lovely Pelican cases designed to fit it.

Many suppliers also won't give out an alu tank if one is turning in a steel, or will charge a surcharge for doing so and, if one has an alu med tank, one should avoid being talked into swapping it for steel. Be cautious about about accepting any casual assurances they might give - if they say, "just take this tank for now and we'll give you the right one next time" be sure to get it in writing.

Chapter 7
TANKS AND VALVES

Tanks come in all different sizes and may be either bought or leased from the gas supplier. The little tanks one usually finds oneself lugging about, dive tanks, emergency medical tanks, and aviator's O2 set tanks, are usually sold outright. The big tanks one uses for welding or filling other smaller tanks from are usually - but not always - leased from the gas supplier. If one is mixing nitrox, or refilling aviation or med tanks, at least one big tank, most likely a big 244 - 250 cf "H" or "K" tank will be needed.

While SCUBA tanks are generally referred to by their capacity in cubic feet (at least in the US - metric divers refer to tanks by the liquid volume and rated pressure, as in " a 12 litre 300bar tank") medical and industrial tanks are usually referred to by a letter code. Medical tank contents are usually given in liters, and industrial tanks in cubic feet.

That can make it hard to figure just how much any given tank actually holds. The table gives most common sizes.

DOT 3A, 3AA and 3 AL tanks come in a myriad different sizes and shapes. They all meet the

Table 7
COMMON COMMERCIAL OXYGEN TANK SIZES

Designation	Material	Capacity litres	Capacity Cubic Feet	Approx Duration For emerg. use*
A	alu	180	6	14min
C	alu	240	9	18min
D	steel	350	11	24min
D	alu	400	13	27min
E	steel	625	20	42min
E, Jumbo D	alu	700	22	47min
X	steel	1500	40-50	100min
M	steel	3.5m3	125	
G	steel	6.5m3	225	
H	steel	7m3	240	
K	steel	7m3	250	
J	steel	8.5m3	302	
T	steel	9.5m3	337	

Notes:
- Exact capacity and designation may vary with suppliers!
- Some suppliers prefix medical sizes with MO eg. MOD etc.
- M. G, H and J are large, non-portable tanks.

same standards, and are more or less interchangeable in each pressure rating group - that is to say, there's no legal or technical reason why you couldn't put O2 in a CO2 tank, or CO2 in an air tank (as long as you didn't exceed the pressure ratings, of course). However, industry practice, especially in the smaller sizes, is to use different styles of tanks for different gasses. An individual doesn't have to be bound by these conventions, but should bear in mind that if one doesn't have the capacity to fill the tanks oneself it can cause trouble since a gas dealer may balk at putting a gas into a tank they believe is inappropriate. Also, it may be necessary to change the valve since the CGA, as explained earlier, has different valve configurations for each gas. But changing the valve may not help you at the gas dealer - they may say "Hey, look! Some idiot put a O2 valve on a CO2 tank," and refuse to fill it.

Aluminum O2 Tanks

Aluminum medical O2 tanks are cool looking; bright polished aluminum with a shiny green accent ring around the shoulder. They won't rust if you leave them on a dive boat, and they are lightweight which is great if you are going to take them flying. Many of us who use medical O2 tanks go out of our way to get our hands on them. This is not always easy - when you swap a tank at fill time many suppliers will try to give you steel for alu, but charge a hefty premium to go the other way!

Also, some of the big gas suppliers are getting away from using aluminum tanks for O2, and a few won't touch them at all. I've heard two explanations. One is that aluminum oxide corrosion flakes could combust within the tank, and the other is that the tanks are very susceptible to overheating when refilling, and this can cause tank failure.

The green paint around the shoulder of an aluminum O2 tank, apparently, is not there simply to color code the tank O2 green, but is a special heat sensitive paint that discolors if the tank is overheated, signaling that it was time to chuck the tank.

It takes surprisingly little heat to damage an aluminum tank - anything over 350 degrees (180C) is verboten according to NOAA. A few years back there was a rash of tank explosions after a tank repainting firm used a baked-on finish on aluminum tanks, and neglected to hydro test the tanks afterwards.

Be this as it may, these problems, like most tank failures, almost always occur when the tank is being filled, so however much they may concern the gas supplier, they don't really have to concern the rest of us - unless we are refilling aluminum tanks. If one is, then the secret is to take it very slow and, and maybe use a water bath that completely immerses the tank.

Incidentally, steel tanks have their dangers too. A CGA Safety Bulletin (SB-7-92) mentions a number a tank explosions in the offshore diving industry resulting from salt water getting inside steel cylinders. When the cylinders were refilled, the combination of salt water and high PO2's led to greatly accelerated corrosion. Apparently these were industrial cylinders that were being used underwater and allowed to completely empty before being replaced. Never allowing a dive tank to empty completely, and giving it an internal inspection before refilling if one accidentally does, are two of the most basic safety rules of diving; they would, it seems, apply doubly to tanks used in O2 service.

Lease or Own?

The easiest way to buy O2 (or any other compressed gas) is to call the nearest dealer, set up a tank lease for how ever many tanks you need, and have them deliver the gas. If you are using a lot of gas, the cost of leasing tanks will not be that much in proportion to what you are spending total on gas.

But if you are using only a few tankfuls a year, the cost of tank lease can be significant. In the larger sizes, most gas suppliers won't sell tanks outright, but only lease them. Not so many years ago lease prices were pretty reasonable - and why not? Tanks don't really cost all that much, and they last just about forever (the other day I noticed the manufacture date on a helium tank we had was '33!). Then the gas suppliers realized they had the customers by the balls and started jacking up the prices to the point of absurdity. The more bastardly ones also even charge something called "demurrage" (short term rental) - if for some reason you have an extra tank of theirs for a few days.

Lease on an O2 tank, say a 250 - 340 cf (7-9m3) tank, as of this writing run between $20 and $75 a year depending on the supplier, how many tanks you take, and how long the lease runs. There are significant price differences between suppliers, so it's worth shopping around before you lease a tank. Be sure to take to price for refills into account - cheaper gas can offset a more expensive lease and v.v., though I've found the place with the cheapest gas usually has the cheapest leases for some unknown reason.

Gas dealers have such crazy pricing, especially for small users, that you really have to shop around, and check and doublecheck everything they tell you. The guy who inspects my car just got a notice of a 50% increase from the company he was leasing from. He was bitching about it to another customer, who had a couple of tanks leased from the same company, and had gotten the same notice. They got comparing notes, and found that one was paying double what the other was, for exactly the same thing! He called the company, and the guy there said, "No sweat, we'll give you the same deal he's got".

A few gas suppliers will still sell tanks outright. This can be a real money saver in the long run, but brings its share of hassles too since many gas dealers will refuse to fill privately owned tanks, or charge a premium for doing so. A 250 cf. (7m3) tank bought outright goes for about $200. With tank leases running about $40 a year, that's only a five year payback, and by the end of those five years tank leases will probably have doubled again, and one will own a tank outright that will go on saving money year after year, and if not needed any more can be easily sold since it will have good papers.

There are also a few companies that specialize in selling tanks only, any size, and don't deal in gas at all, which sell new and reconditioned tanks for considerably less than a gas dealer will. These tend to be located in big cities, and the easiest way to find them is in the Thomas Catalog, which can be found on the net and in most libraries.

There are smaller size tanks for most gases which are commonly sold outright by everyone. When they need filling you simply swap them for a filled one. The price you pay for the fill includes a charge for service so the gas company, not you, worries about hydros and valve service. Since these tanks are industry standard sizes, any gas supplier can swap your tank for a full one, and there are no hassles about proving ownership or finding the right dealer for your brand of tank.

Since when you buy one of these tanks they just grab you one out of their rotation stock, your "new" tank is really a used one - there's no advantage to buying new if you can find a second hand one somewhere else. I've bought a couple at flea markets. Tank suppliers, like the one mentioned in the appendix, who sell tanks rather than gas, often sell both new and reconditioned tanks. If one is going to be swapping, get the reconditioned one and save a few dollars.

The catch is that the smaller sizes commonly sold outright don't hold much - the largest welding tank my former supplier would sell outright held only 40 cf (1250 l) and the largest medical O2 tank only 20cf (625 l). And it costs almost as much to fill a small tank as a large one. So these tanks are not much use if you are doing gas mixing or av refills. They are, though, good for emergency 02 setups since there's no rent to pay on them and they (hopefully) will not have to be refilled very often.

A 40 cf (1250 l) welding O2 tank, incidentally, costs about the same as a 13 c.f. (400 l) medical tank, making it an interesting alternative for anyone setting up a emergency kit for a dive boat or club with some serious multi-user or extended duration capacity.

Gas suppliers vary a lot in how flexible and helpful they are. I've got a big old welding O2 tank which the local shop wouldn't fill since they discourage customer-owned tanks. I was getting desperate enough to consider printing up my own bill of sale, Cale-fashion, when a friend who runs a body shop suggested another gas supplier. They came, swapped my tank for a full one without a murmur and didn't even complain that the old one was out of hydro.

The other day I called the first gas dealer (just because they are a lot closer) to get a price on a medical O2 valve. Why buy a valve, the guy asked. Just bring the tank down and he'd swap it for a new tank with a good valve for the price of a fill. I explained the tank wasn't a standard one, and probably wasn't swappable. He said it didn't matter - they'd swap any tank. Actually I didn't have a valve at all. I was looking for one to make an adaptor out of. But I didn't want to try and explain that to him.

I dug out an old CO2 tank I'd bought back from the dump, took it down, and, to my amazement, they swapped it. Then the next time I went in they refused to refill it without a prescription!

Can't figure them out, but the moral seems to be, anytime you are trying to pull something, it's worth trying several suppliers to see who feels helpful that day.

Orphan Tanks

Occasionally one will run into tanks for sale with questionable pasts. Sometimes they are leased tanks which were never returned to the rightful owner, but often they are tanks that were sold outright back when that was more common, or tanks left in the field when a compressed gas supplier went out of business.

Since these tanks can often be had for less than the price of a year's lease, they would seem to be, on first sight, a real bargain. But whether these "orphan tanks" are worth anything to you depends on how tolerant a gas supplier one can find. Many gas dealers operate on the theory that if one can't absolutely prove ownership of a tank, then it must be theirs, never mind that they have absolutely no claim to it. Linde tends to be the hardest to deal with; other vary. If one does buy such a tank, be sure to get a bill of sale for it, preferably on a commercial letterhead.

If you can get the original bill of sale made over to you, so much the better. Legitimate bills of sale for privately owned gas cylinders are worth their weight in gold, since without them the tank may very well be useless.

Always call a gas supplier and find out their policy before you bring in a privately owned tank. Better yet, call two or three times, letting some time pass in between calls, to make sure you get the same story each time. Some will try to claim a tank of dubious background on the spot, insisting it must be stolen (then often as not they'll re-collar it and use it themselves, but that's another story).

Cale when confronted by an orphan tank without its bill of sale (after confirming, of course, that it is not a stolen one) simply grinds the name off the collar if it is a well known one, and makes up an "original" bill of sale on his computer ("Acme Welding Supply") and laser prints it.

One gas delivery man I heard about, when someone tried to swap a tank with a collar bearing the name of a rival company, sputtered indignantly " I can't possibly take that."

Then he added "Grind the writing off the collar, throw some paint on it and I'll swap it next time".

There's another technique that some folks, who already have a legitimate lease on some tanks, use for dealing with orphan and privately owned tanks that's sleazy but a little less so that making a bill of sale: slipping the orphan tanks into the rotation with the "good" ones.

Most (but not all) gas dealers have, in addition to their own properly collared and marked tanks, a fair amount of old tanks accumulated by one means or another, that still bear the names of the other companies (or have no name on the collar at all) and as a result, they are not alarmed when a tank turns up with another name on it.

So what they do is simply return the orphan tank in place of a leased one, with the result that they have one more tank in stock than they have a legitimate lease on. When one terminates the relationship with that company, simply keep the extra tank(s). It's an easy if not totally legit way to turn a one-tank lease into a cascade.

Cale says this works especially well if the tanks are being picked up rather than exchanged at the shop, since the truck drivers are usually much less picky than the counter staff, and anyway by the time it gets back to the plant it will be mixed in with all the other tanks and no one will be able to say with any certainty where it came from. But it's unlikely they'll care - they'll just go on using it with all the others.

If the driver does notice it, and yells "Hey, this isn't our tank" Cale just says "Oh, you've got the wrong tank - yours is over there."

The main possible catch to this is that there are a few uptight suppliers who maintain stables of identically marked tanks, amongst which a stray will stick out like a sore thumb. These suppliers, obviously, are not good candidates for pulling this shuffle. The easiest way to tell is to keep an eye on the tanks that come through from that supplier and see how much variety there is.

Cale has a friend with a welding shop who has slipped several dozen tanks for friends into his three tank rotation; they usually tip him an extra $5 per fill for his trouble. It runs up his volume so he gets a better rate, the supplier sells more gas, and so everyone is happy.

Most gas suppliers consider a tank lease as giving the lessor the right to possess one tank, but don't care what - that is to say, when a tank of O2 is used up, it can be swapped for one of He.

This gives the low budget mixer a little room for experimentation. For example, if one has only an occasional need for trimix, it is possible (with good timing) to finish off a tank of O2 by priming some tanks with O2, then swap it for a tank of He, and finish the mix, then use the rest of the tank to prime the next set of tanks, swap it for an O2 tank, and finish the fill.

However, since most suppliers will short term rent extra tanks at small charge, if one has an orgy of mixing planned it's usually easier just to rent the necessary extra tanks. The per day charge will be more than on a lease, but since the tanks will only be needed for a few days it can be very cost effective, especially if it avoids returning a half-full tank.

Cale, or course, came up with a new and devious way to profit from this. He's been gradually slipping more and more tanks into the rotation with his one-tank lease, but alternating between He, argon and O2 so he gradually has built up a mini-cascade of each.

The obvious flaw with this method is that it requires keeping close track of which tank is which, and Cale's friends are all waiting to see what happens when he slips up and returns an empty O2 tank when he was supposed to have only a single He.

Cale's days of fun may be coming to an end. The latest batch of O2 he got had little lumpish things cemented on the shoulder of each tank. The delivery man explained that they are transponders, that can be read with a dedicated scanner, and will allow automatically tracking each tank.

Recycling Tanks

As mentioned earlier, there's no reason why one cannot use a proper pressure tank to hold a gas other than what it was originally intended to hold, as long as it can handle the pressure. Often one can pull it off for no more than the cost of a new valve or an adaptor.

Sometimes a likely tank will turn up at the dump or a flea market. As fire departments switch to the new, lightweight high pressure composite tanks, a lot of old steel air tanks from SCBA portable breathing sets like the Scott and Survivaire are turning up at junk and surplus dealers. I bought one for $2 at a scrap yard the other day, and a local surplus shop has a whole rack of them for $10 apiece. These are high quality lightweight 2100 psi (140 bar) steel tanks holding 50 to 70 cf, and come with a variety of valve and neck thread configurations.

With a little adaptation and cleaning they can make a good aviation, deco, or emergency 02 tank, But the catch with these, and any other "recycled" tanks, is that this works only if one is going to be able get them filled, or can fill them oneself as most gas dealers won't touch them since they are not "official" O2 tanks.

The SCBA tanks usually have a CGA 346 (compressed breathing air) thread on the valve. This can be adapted to CGA 540 using an adaptor (Western 827), or one could make an adaptor to put a CGA 870 stub on it for use with a med O2 regulator, or simply replace the valve with a proper CGA 870 or 540 valve depending on one's needs.

Anytime one uses a tank underwater not specifically made for the purpose one must keep in mind that diving is hard on tanks, especially steel ones. The only tank finish that can be counted on to really hold up in salt water is galvanized zinc. However, it is rarely feasible or cost effective to have used tanks galvanized.

Many steel dive tanks came new with plastic finishes that tended, once breaks in the finish developed, to retain water beneath the finish and actually promote rusting. Tanks not intended for dive use usually have just a single coat of enamel that doesn't offer protection enough for in-water use. The problem, then, if one is refurbishing an old tank, or converting a new, non-dive tank for dive use, is what to put on them that will offer some protection. Regular paint just doesn't work very well - it scrapes, or even rubs off, and and the salt water seems to go right through it.

The only finish I've ever found that seems up to the job is a rustproofing paint sold on the auto restoration market called POR-15. It's a moisture cured urethane primer which can be applied, by brush or spray, directly over rust, pitted or bead-blasted metal (it doesn't like going over smooth new steel or old finishes). Properly applied, and topcoated with either regular paint or, even better, the matching POR-15 topcoat, it is the closest thing to an indestructible finish that can be applied without special equipment.

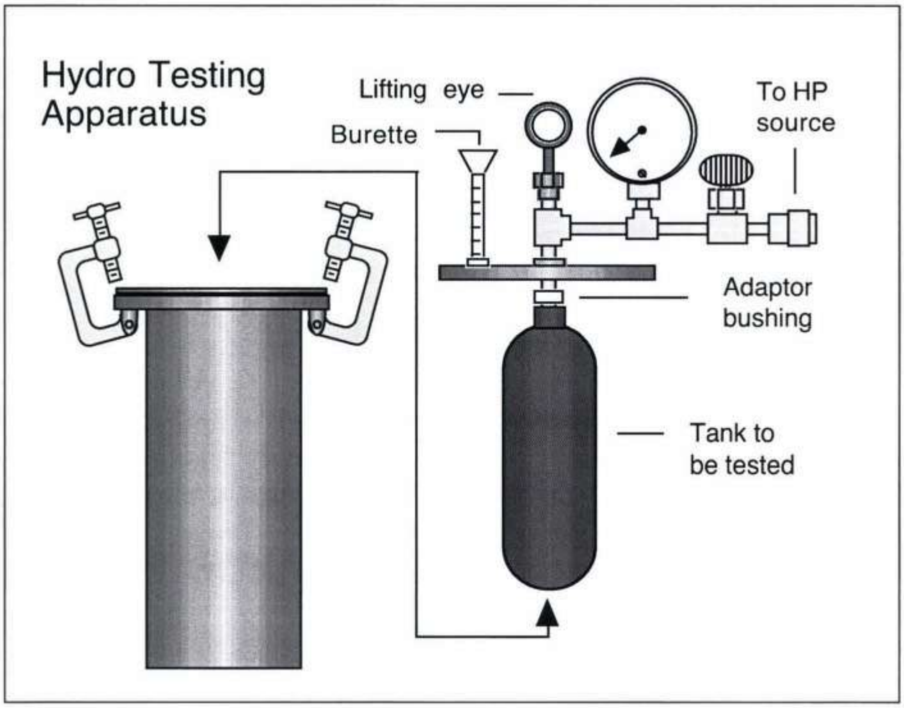
Another finish that many divers report good luck with is ZRC brand cold galvanizing paint. While not as rugged as POR-15 is is easier to touch up, and especially good for recoating galvanized tanks.

Obviously, this only applies to a tank being used underwater. For an emergency treatment, aviation, or storage tank, any paint will do, but it's a good idea to use the standard colors assigned to each gas; in the case of O2, green.

Hydro Testing

High pressure tanks must be periodically pressure tested by a qualified shop, usually every five years. If the tank passes, the date of the test and some markings identifying the shop are stamped into the metal on the shoulder of the tank. This makes it easy to tell if a tank is currently "in hydro", or when it was made - just look at the newest and oldest dates.

Hydro testing isn't just a matter of overfilling a tank and seeing if it bursts, as legend would have it. The tank is filled with water then placed in a water filled test chamber with a calibrated burette on it. The chamber is sealed and the tank is pressurized to 5/3's (usually, but not always - some HP steels are tested at 3/2s) of its rated pressure. The tank's expansion is noted by measuring the amount of water displaced into the burette as the tank fills. Then the pressure is let out of the tank and the contraction measured by noting the level in the burette. If the residual expansion left after the tank has been depressurized is more than 10% of its maximum expansion, the tank fails. The reason for filling the tank with water when it's tested is to reduce the explosive potential should it burst. This concept confuses some people, but its pretty simple. The explosive force in a filled tank is a function not of the pressure alone, but of the pressure and volume of the gas it contains. Since liquids are incompressible, by filling the tank completely with water it is possible to pressurize it



with little or no volume of compressed gas, hence very little explosive potential.

When one takes a tank to a dive shop for a hydro, they will usually take the valve off, take a peek inside, then send it out to a shop that specializes in hydro testing - usually the local fire extinguisher shop. Then when it comes back, the dive shop takes another peek, puts on the valve, a new O-ring, a VIP (visual inspection) sticker, and fills it - usually for about $25.

If you are really looking to save money, you can cut out the middle man, and take it to the hydro shop yourself. Look in the yellow pages under Fire Extinguishers to find one near you, then call to find if they do hydros on the premise. If they do, they'll usually they charge $10 - 15 a tank, and maybe a bit less if you have a bunch of tanks and/or a business card.

Sometimes they'll take the valve off for you, but they usually won't put it back on again. If that's a problem for you, you probably shouldn't be contemplating doing anything mentioned in this book.

You don't get a new O-ring, a visual inspection sticker, or a fill. If you're doing only one or two tanks, it's usually well worth extra money to let the dive shop handle it. But if you have a lot of tanks, or oddball ones, it can be a lot easier to go directly to the hydro shop and the savings can really add up.

As far as the visual inspection sticker goes, I've found most dive shops don't hassle me about a visual on a tank with a fresh hydro, since they assume it was visually inspected when it was hydroed (as it was, but most hydro shops don't have dive stickers to put on) but even if I have to pay the dive shop for a visual and a fill, I still save about $10 per tank.

It pays to check out a hydro shop before letting them at your tanks. There's a dive shop nearby that fails almost every old steel 72 they test. Since other shops don't, it's pretty clear that the shop must be doing something wrong. But try to point it out, and you'll get a lecture. You'd have to be insane to take a steel tank there considering, but divers keep doing it. If they would only ask the shop before leaving the tank about what kind of failure rates the shop had they would be warned, since the shop makes no secret about its aversion to older steel tanks.

The other scary thing about this is that once a tank has been failed by an authorized hydro station, under the regs, that tank is dead. It's illegal to even test it again! So if a shop mistakenly or incompetently fails your tank, there's no appeal.

This almost happened to a friend of mine when he took six steel tanks to a shop and had them all fail. Fortunately, the shop didn't obliterate the markings (as they are required to do, under the DOT regs) but just stuck stickers on them saying they'd failed. My friend, knowing the statistical odds of six tanks failing at the same time were infintesimal, peeled off the stickers and took them to another shop, where they all passed!

I should mention here that the DOT regulations only apply to tanks used in commerce. It is completely legal, according to the DOT, for an individual (or a shop, for that matter) to fill privately owned tanks which do not have a current hydro! Nor are the tanks in a non-commercial stationary cascade required to be hydroed. This isn't to say it's a good idea not to, just that, by the letter of the law, it's not required.

The 10% Overfill + Sign

One aspect of hydro testing that has caused a lot of confusion is the + rating. Steel tanks marked ICC or DOT 3A or 3AA may be legally filled to 10% over the pressure rating stamped on them, as long as they have been hydro tested for the higher figure, and this noted by marking them with a plus sign (+) stamped after the hydro date (an interesting historical note is that this was originally conceived as an emergency measure during WW2 when tanks were in short supply).

Many "experts" will tell you that the + rating can only be done when the tank is first hydroed upon manufacture, and only applies to the first five years of the tank's life. THIS IS NOT TRUE! The DOT regulations make no distinction between the first and subsequent hydros. A tank can be plus rated for as long as it will pass - in fact, a tank that passes the basic test but fails to qualify for the + rating can still be used at the lower pressure. My big welding O2 tank has been + hydroed ever since it was made, way back in 1940.

The catch is, to do the 10% the tester has to know the tank's REE - Rejection Elastic Expansion - number. These are stamped on all newer tanks, but may not be available for older tanks. If the REE is available, qualifying for the "+" requires just one extra step, subtracting the permanent expansion from the temporary expansion, and comparing the result with the REE.

Although many SCUBA shops routinely do a 10% overfill on all steel tanks, others will not do it without seeing the plus, so it's well worth making the effort to find a hydro shop that will do the plus test - especially because the advertised capacity of most steel tanks is based on them being filled to the + standard!

A "steel 72", for example, without the overfill actually holds only 65 c.f. (now you steel 72 users know why you seem to run out so fast compared to your buddy with an alu 80!).

It is dangerous to assume the hydro shop will automatically + test and eligible tank. If one doesn't insist, they probably won't. And if they say they'll "see if they can do it" or other vague promises, they probably won't. Worse yet, if they skip the + rating on one hydro, it may be impossible to ever get it done again (though once again, there isn't anything in the DOT regs to forbid it).

Another occasional source of confusion at inspection time concerns burst disks. Some dive shops will tell you that they must be routinely replaced when the tank is hydro tested, or in some cases, even during yearly inspection.

This simply isn't so. It's just another hustle to make a bit more money off you. Not that it's not a good idea to occasionally replace them, but there's no law that says they have to. If a shop insists, ask that they point out to you where it says so in the regs, and good luck to them.

Incidentally, according to the DOT regs, some categories of tanks that are not likely to be exposed to corrosives (which rules out SCUBA tanks, obviously) need be hydro tested only every ten years, as long as they are hammer tested each time they are filled! These tanks are marked with a star after the test date.

The hammer test consists suspending the tank and banging it with a hammer, the way auto mechanics tested crankshafts in the pre-magnaflux days, and listening to the note the tank gives off. A cracked tank (or crankshaft) will give off a false note; a good one will ring like a bell.

Cale, who hates to spend money having tanks hydroed unless he absolutely has to, has been known to do a quickie semi-hydro check of used tanks that are not be going to be frequently refilled (for example, when he's setting up a random old 1800 psi (120 bar) 20 cf. (5 l) tank to use as an extra emergency O2 tank) by filling them with water (after giving them a careful visual inspection and hammer test), and pressurizing them to 5/3 of their working pressure from a 3000 psi SCUBA cylinder.

While this is probably safer than just going ahead and filling a tank of uncertain history without testing it, it's no substitute for a real hydro since the stretch and recovery of the tank aren't measured and anyhow the tank still isn't legal. Anybody rash enough to try this should be damn sure to remember that every bit of airspace left unfilled with water dramatically increases the explosive potential should the tank let go, and the further away from the tank one can be when it is pressurized the better (Cale uses a long HP hose and keeps a concrete wall between him and the tank! Oh, and he lives out in the country, a long way from the next house).

Neck Cracks

A new wrinkle in the used tank situation is sustained load cracking (SLC). Older aluminum tanks made of the 6351 alloy have a problem with cracks forming at the neck. If the cracks aren't caught in time, the tank can explode upon filling, usually "banana peeling", and do a great deal of damage. Newer tanks are made of 6061 which does not seem to have this problem.

The dive industry has known about this problem for a long time now, and a neck crack inspection, which is done with a special magnifying dental mirror and a flashlight, is part of the recommended inspection procedure for aluminum tanks. Since the cracks develop very slowly, and are readily visible, this was considered adequate. There is also an electronic device, the V+, that uses magnetic eddy currents to detect cracks.

Recently, though, an aluminum tank exploded at a Florida diveshop. The owner of the shop immediately began calling for all dive shops to refuse to fill any alu tanks that had not been V+ inspected. A lot of people in the diving community felt that this was premature, and that the problem was not that the visual neck crack inspection was inadequate, but that too many dive shops had been skipping it altogether. A lot of shops that didn't really believe the V+ machine was necessary got pressured into buying them and then they too, anxious to recoup their investment, started refusing to fill tanks without a V+ sticker.

Inspecting for neck cracks using a penlight and magnifying mirror

All this was bad new for many divers who had taken a PSI or similar course expecting to be able to inspect their own tanks, since now they found they needed a $1000 machine.

Another thing worth noting is that while most dive shops that have one use the V+ on all alu tanks, Luxfer says that they have never seen a case of sustained load cracking on a tank made with the later 6061 alloy, and that the V+ machine should not be used on later tanks as it will often produce a false negative!

While I may sound a bit skeptical about the V+ machine (and it is interesting to note that the word is that Luxfer was returning about 30% of the condemned tanks sent in by dive shops, when Luxfer techs could find nothing wrong with them!), NECK CRACKING IS NO JOKE. Anyone inspecting aluminum tanks should learn the appropriate technique, buy the necessary tools (PSI sells the mirror for about $15), and do it every time the valve is off the tank).

Tumbling

If a tank is really scuzzy inside, and especially if it shows rust pitting, the shop may recommend tumbling. A tank is tumbled by partially filling it with chunks of abrasive compound and putting it on a motorized stand that rotates the tank at about 60 rpm. Most shops that hydro test tanks can also tumble them, at a cost of $10-20. Drill-powered abrasive whips are also available, though usually only from dive shop suppliers like Global, that do a good job on light surface rust.

Cale has been known to tumble his own tanks if they aren't too bad. He dumps in a bunch of small pebbles he screened from his driveway and cleaned, then screws a bit of pipe into the cylinder and chucks it on to his big old 16" Hendee metal lathe then lets it tumble for a couple of hours at a very low speed. Seems to do the job.

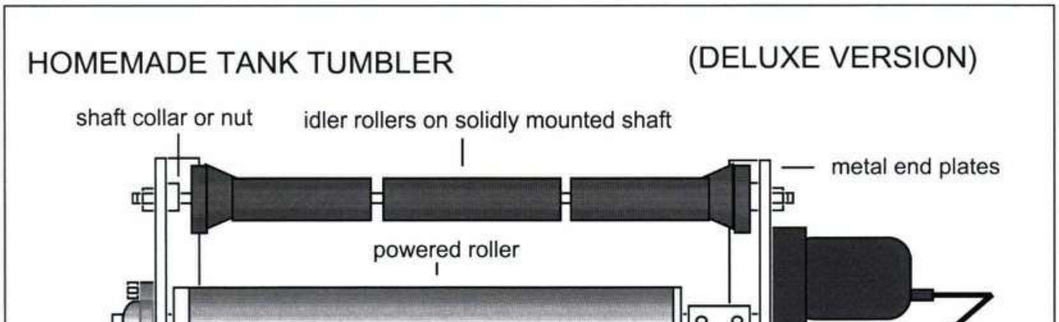
Cale, and many others, use pebbles because they are cheap and available. I've always wondered how effective they are. PSI did some tests to find out just that, doing extended tumbling of tanks using both pea gravel and aluminum oxide chips. After 15 days of tumbling at 28 rpm, the pebbles removed an average of .0015" (.04mm) of wall thickness. The aluminum oxide chips took only 7 days to remove .003" (.08 mm) From this one can conclude that pebbles work fine, though they take about 4 times as long - hardly a problem for the home tumbler who only has to do a few tanks and is not particularly in a hurry.

The other thing interesting about this test is the amount of material removed - 7 days is a long time to tumble a tank, and with the faster-cutting chips, only .003 was removed, from a tank with an average wall thickness of .180" (45 mm). That's only about 1.5%, and suggests a steel tank can endure quite a bit of tumbling without being significantly weakened.

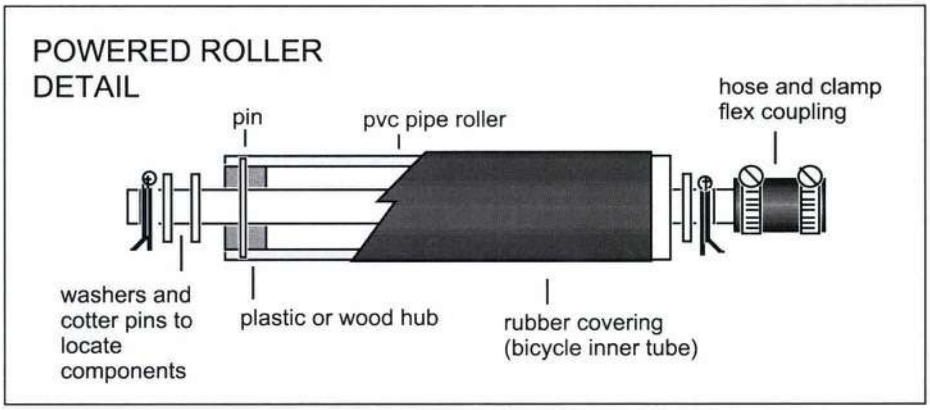
Some folks get anal about keeping their tumbling media clean. That's a mistake. As the tumbler turns, a slurry will form, of abrasive dust from the media. This slurry is what is actually doing most of the work - without it, the tumbler will not cut nearly as quickly as without it. That's why a tumber always seems to do so little in the first hour or two of running with a clean fill of media.

Commercial tank tumblers usually consist of two or more rollers set in a frame. One roller is powered by an electric motor, and the other is a free turning idler. The tank rests between them. Commercial tumblers cost in the $200-500 range, so it's not surprising that many shops and individual divers have found it worth the effort to build their own.

The frame can be made from two metal end plates, 1/8" or so thick, with tie rods holding them together. The idler rollers turn on a solidly mounted steel shaft, which can double as a structural member. Plastic rollers made for conveyer use, and self-lubricated plastic bearings designed to fit standard size tubing are available from most bearing supply/power transmission supply houses, and a row of small wheels also works.



The motor is the key component, and the rest of the tumbler pretty much must be designed around it. The tank speed should ideally be something in the 35 to 70 RPM range. Reducing the speed of a standard motor that much using belts or gears usually requires two stages of reduction and a jackshaft, so it's much easier to use a gearmotor that incorporates the necessary reduction gearing.



It takes a fair amount of power to run a tumbler - the motor isn't just spinning a balanced mass, but is rather continuously lifting the weight of the abrasive - about 25 lbs. (11kg) worth, for a full sized tank. The motor should be something in the 1/4 to 1/2 HP (4 to 8 amp at 110v) range.

New, gear motors like this cost around $200. Fortunately, they are are fairly common on the surplus market. Surplus Center, for example, has several suitable ones priced in the $40-90 range.

The motor should be rated for continuous use - many gear motors are intended for only intermittent duty and will not be happy running nonstop for the extended periods required for tank tumbling.

The powered roller can be made using off-the-shelf drive components, or by fastening a length of PVC plumbing pipe over steel shaft, using a wood or plastic hub at each end and pins or set screws to lock the roller shell to the shaft. One end of the assembly turns in a flange bearing mounted to the end plate, and the other end can be connected directly to the gearmotor's output shaft using a simply sleeve coupling. To improve the grip, the roller should be covered with rubber. I've used radiator hose or pieces cut from a bicycle inner tube. Some fine tuning is necessary to keep the tank centered. Commercial rollers are available which have flanges, as in the diagram, to locate the tank. Otherwise, the rollers can be built up bands of inner tube rubber so the tank rides in the center. Or the roller shaft can be mounted in a slot for adjustment. As a last resort, a stop - one of those nail-on hard nylon chair sliders mounted on the frame will keep the tank from getting scraped up.

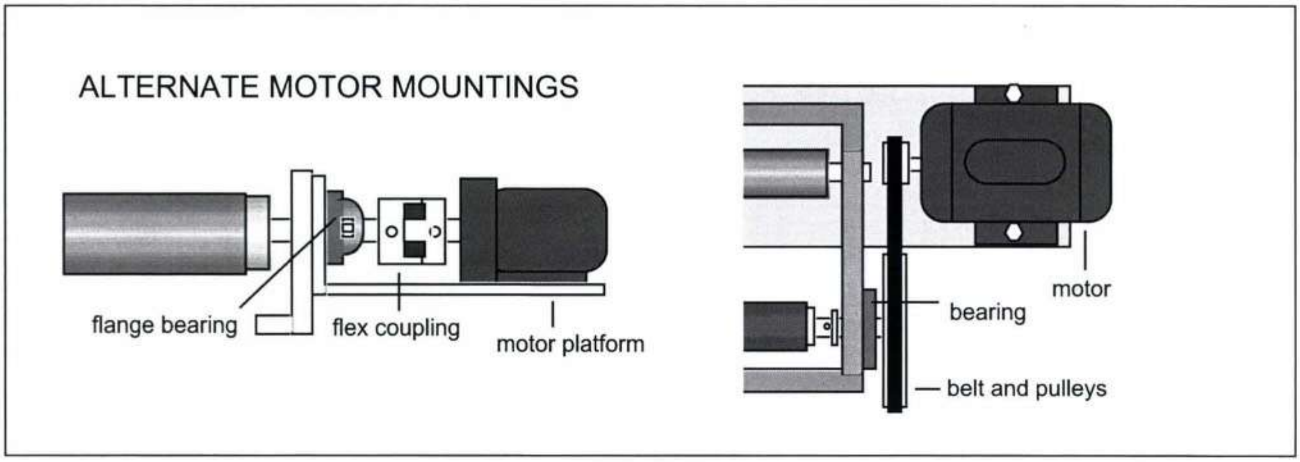
The speed at which the tank rotates is determined by the speed of the roller and the ratio between the diameters of the tank and the driven roller, so the motor should be selected before making the roller.

For example, given a 2" roller, a 150 RPM gearmotor, and an 8" diameter tank, the roller will turn at the same RPM as the motor, but, since the ratio between the tank diameter and the roller diameter is 4:1, the tank will be turning at only 37 RPM - just about right.

If the powered roller is made fairly large, say 3" or larger, and the motor is powerful enough, the frame can be extended, and a second freewheeling roller can be added on the other side, so two tanks can be tumbled at once.

If the roller is too small, it won't have enough grip to reliably turn the tank, Anything smaller than 1" should be avoided, and something a bit larger is preferable.

In addition to the shafts holding the idler(s), one or two tie rods will be necessary to join the two end plates. These can be steel rods with the ends threaded, or spacers made of 1/2" or so pipe (15mm), with threaded rod running through them. A tumbler like the one described above will still cost between $50 and $100, but will be suitable for full time operation.



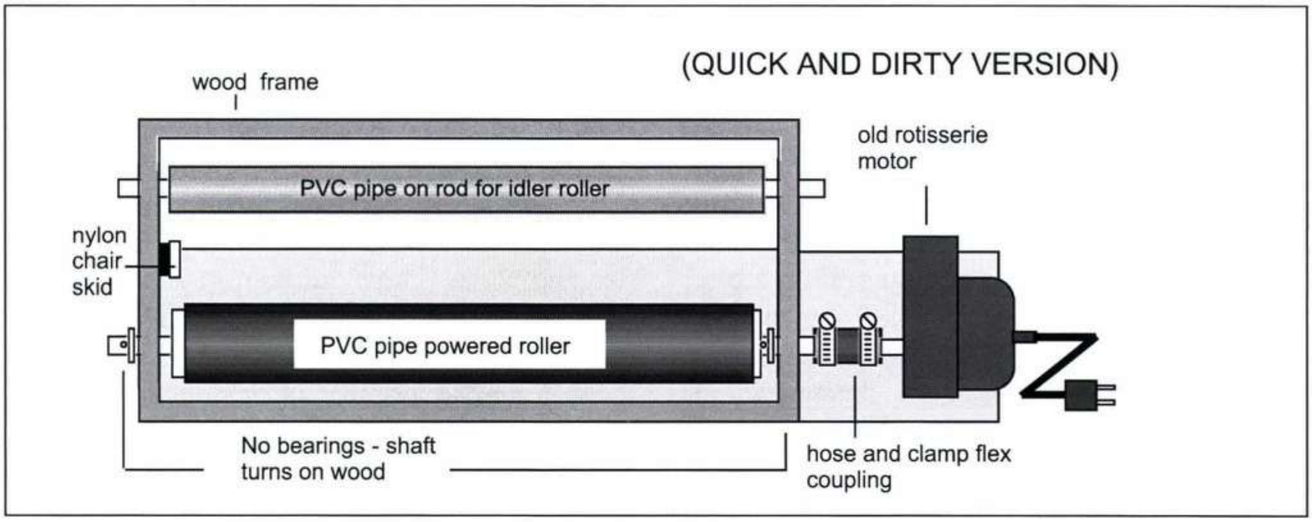
If it is necessary to tumble just a few tanks, it's possible to make quick and dirty tumbler, using a simple wood frame, with holes drilled in the ends for the shafts, which turn on the wood without any bearings. The idler shaft can be a simple length of PVC plumbing pipe slipped over a steel shaft or threaded rod. Cotter pins and washers, rather than nuts and shaft collars, can be used to locate the shaft and rollers.

The motor is still the key, though there are several cheaper alternatives to a proper gearmotor. I've seen an old rotisserie motor from a charcoal grill used successfully, and lighter-weight gearmotors in the 2 to 4 amp range often turn up surplus and may be strong enough to do the job.

If one is really determined to avoid buying a gearmotor, it's possible to get a fair amount of reduction in one stage using cheap die-cast pulleys, which can be found at most hardware stores. A 1725 RPM motor with a 1.5" (35mm) pulley driving an 8" or 10" (25 cm) pulley on the roller will bring the roller speed down to 300 rpm or so. With a 1" (25mm) roller, this will give a tank speed of about 75 rpm with 7"-8" (20cm) tanks which is a bit on the fast side but usable. Using a 12" (30cm) or 14" (35 cm) pulley would bring the speed down even further, but require mounting the motor even further off to the side to get adequate belt wrap on the small pulley.

If one takes this route, a proper flange or pillow bearing will probably be necessary, at least on the drive end of the powered roller.

Note that if one makes a quick and dirty tumbler it can easily be upgraded bit by bit if it ends



up getting more use than anticipated - the holes in the end can be sleeved with cheap nylon or delrin plain bearings, or proper flange ball bearings. The motor can be upgraded, or all the moving bits moved to a proper metal frame. Since the rotation speeds are so low, one doesn't have to worry about balance or vibration or catastrophic failure, and can improvise with impunity.

Global puts out a very useful booklet on tank tumbling, which is recommended to anyone who would like to know more.

Tumbling in conjunction with some detergent and hot water is the way to go if one wants to get a tank really clean inside, since the abrasive scrubs the inside of the cylinder in a way liquid alone cannot. However, if it just rust one is after, tumbling dry is more effective. Glass beads are often used with detergent and water, as these are less aggressive than abrasive chips, but add a scouring action.

Aluminum tanks generally should not be tumbled, at least not by amateurs, except for a brief cleaning tumble, since they are much softer. Since they don't rust, all tumbling accomplishes is removal of the protective aluminum oxide layer. If for some special reason they must be tumbled, it is important to use the right abrasive.

You may be wondering why I bother to go into such detail about tumblers in a book about gas mixing. The reason is that steel tanks, especially those used with higher FO2 mixes, will frequently be found when annualled to have light surface rust on the inside. This is not a serious problem, and can be easily removed by a brief tumbling. The catch is, many dive shops will insist that the law requires that any tank which has been tumbled must be hydro tested afterword.

This simply is not true. There is nothing in the DOT regs that requires it. There is a CGA publication which suggests hydro testing tanks after tumbling, but it is not one of the CGA publications which has been indexed into law. More to the point, the publication is clearly referring to industrial tanks which have been badly abused and require extended tumbling involving substantial removal of metal to remove deep pitting, not the kind of touch-up tumbling common with SCUBA tanks to remove light flash/surface rust.

However, convincing a dive shop of this can be well nigh impossible, so many divers with a heavy investment in steels find it safer - and cheaper - to do their own tumbling, and present the tank to the shop at visual time clean, and keep their mouths shut if asked any questions.

Overfilling

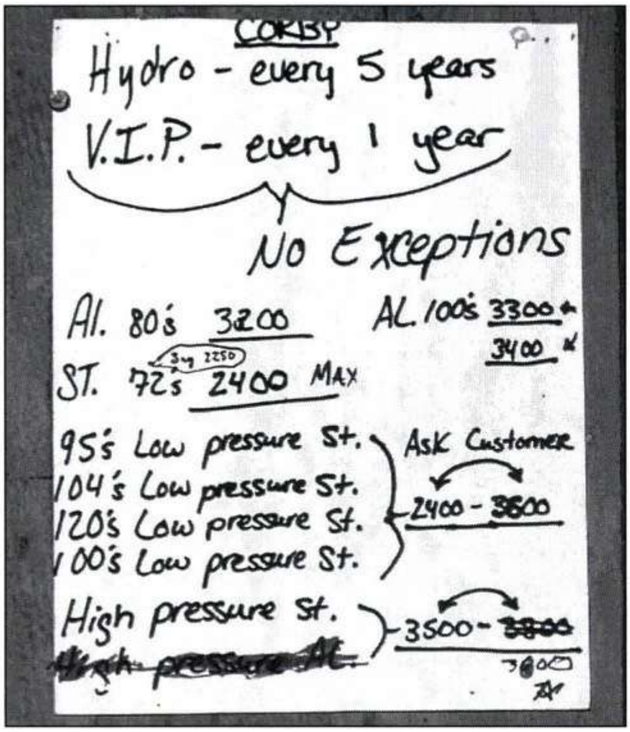
Some divers, especially cavers, regularly overfill their tanks. LP 3AA tanks in particular. It's a tempting proposition - instead of spending the big bucks, and putting up with the extra weight and bulk that oversize tanks entail, simply pump the extra cubic footage into one's existing tanks.

The catch is, of course, that doing so means one is exceeding the tank's rated pressure. Most cavers don't care. They've seen a lot more people die from running our of air than from exploding tanks, and anyway many will tell you that everyone they know has been doing it for years without a hint of trouble.

Critics of the practice say nonsense, by overfilling you are endangering yourself and others, dramatically shortening the life of your tank, and - worst of all - breaking the law!!

Habitual overfillers respond that the DOT standards for tanks are incredibly overconservative, intended for industrial tanks which will be filled daily, manhandled and abused, and still are expected to last for decades in commercial service.

Actually, there's quite a bit of truth to this. Steel tanks are good for a certain amount of fill cycles before they lose their resilience and fail hydro. Just how many depends on the fill pressure - the higher the fill pressure, the less cycles before they fail. Overfilling a tank radically - up toward the burst point - can cause permanent deformation and eventual or immediate failure. But stay below that point, and there are a wide range of pressure/cycle options available that offer a reasonable compromise between function and safety.



Ah, Florida......

A steel tank which is good for 10,000 fill cycles at 3000 psi might be good for 40,000 cycles at 2000 psi. That's until it fails hydro, incidentally, not until it explodes. There's no "right" pressure or magic formula to find it, rather just a matter of judgement and politics in balancing how long the tank should last versus how much it can hold. The ICC/DOT has done this for us in the USA very conservatively.

Divers are unique among compressed gas users, in that we have to carry ours around on out back, and depth and decompression issues make it difficult to swap tanks whenever we need more air. That being the case, the advocates of overfilling say, trading off tank life 10 or 20 years in the future for extra capacity right now makes sense in many specialized situations. Especially because tank life, even at overfill pressures, is measured in many thousands of cycles, far more than most privately owned tanks will ever see.

Some vendors even seem to be acknowledging this in a wink-nudge fashion. OMS, which sells Faber LP steel tanks, notes in their catalog that the tanks are rated for 2640 psi (2400psi plus the "+", 180 bar), the test pressure is 4000 psi (275 bar), the minimum burst pressure in excess of 6400psi (440 bar) - and then casually mentions that Faber rates the tank for 10,000 fill cycles at 4000psi (275 bar)! That's the equivalent of hydro testing the tank every day for 30 years. I haven't seen any such figures on tanks made by Pressed Steel, the other major supplier of LP steel dive tanks, but one imagines they'd be similar.

Note that the all the discussion above is about STEEL tanks. Aluminum tanks, it cannot be overemphasized, handle stress very differently than steel, and absolutely CANNOT be overfilled in the same extravagant fashion as some divers overfill steel tanks.

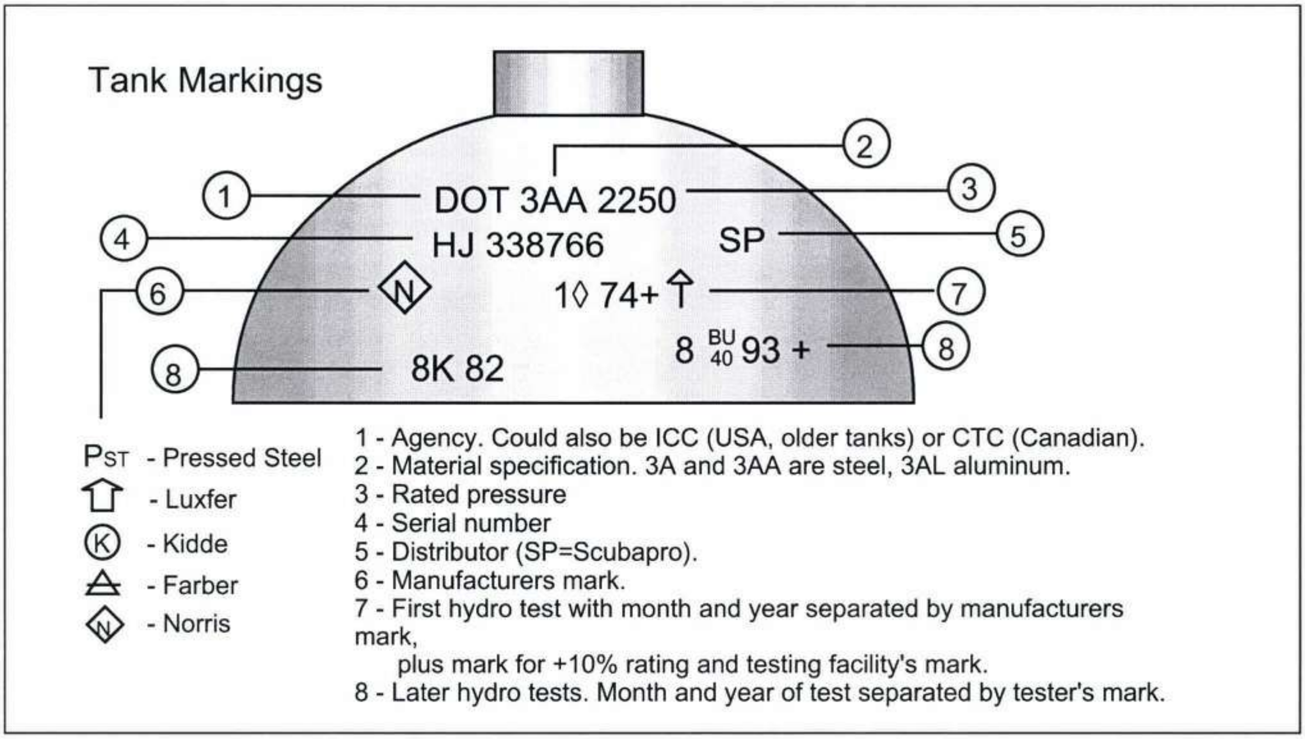
Aluminum does not stretch and recover like steel, and fatigues very quickly when overstressed! Alu tanks depends on rigidity rather than resilience for their strength. The line between overfilling and not is, as a result, a very narrow one for aluminum as compared to steel, and to cross it almost guarantees catastrophe. All the same, many divers routinely fill alu 80's to 3500 (240 bar), but very few would dare go higher.

Tank Codes

Tanks come marked according to material specification and pressure rating. 3A and 3AA are the usual codes for steel tanks. Aluminum ones are usually marked 3AL.

Sometimes you'll come across some oddball ones. I ran across an O2 tank at an airport flea market that looked brand new but bore a 1950's manufacture date and was marked ICC3HT1850. Not a good buy - the 3HT means it must be scrapped after 4000 fill cycles or 15 years! And then there are some early aluminum SCUBA tanks manufactured under special permits or exemptions, whose manufacturer did not renew them with the DOT, and which cannot ever be hydroed or filled again even though there's nothing wrong with them..

For some unknown reason, tanks in the U.S. are rarely marked with their capacity. So how is



one supposed to know the capacity of an unknown tank? If it's apart for for cleaning or inspection, take a tip from Archimedes and simply fill it with water and measure how much it holds. Then you can figure the capacity easily as long as one knows that one gallon equals .1337 cubic feet, and one fluid ounce equals .00104

For example, suppose a tank holds 1 gallon, 1 pints and 3 ounces.

That's 147 ounces:
147 x .00104 = .153 cf.

But this, of course, is the capacity at one atmosphere of pressure - that is to say, how much gas the tank would hold unpressurized at sea level, or the "water capacity" as it is usually called. To find its cf capacity at its rated pressure, which is usually what one is after, it is necessary to figure out how many times the gas will be compressed inside the tank, by converting its working pressure into atmospheres. Let's say it's a 2100 psi (145 bar) tank:

$$\frac{2100 \text{ psi}}{14.7} = 143 \text{ atmospheres}$$

.153 cf x 143 ata = 22 cf

Otherwise, you'll have do some mathematics, figuring on a wall thickness of 3/16" for steel and 1/2" for aluminum.

Take for example, a 5 1/4" x 22" 3AL1800 (aluminum 1800 psi) tank I bought back from the dump.

The first step is to find the area of the circular section of the tank.

It's O.D. is 5 1/4", so , subtracting an inch for the wall thickness (2x1/2"=1") gets an I.D. of 4 1/8".

(actually, I start with the circumference, then divide by π (3.14) to get the diameter, since it's more accurate when one doesn't have large calipers)

That needs to be divided by 2 to get the radius, so I can find the area using πr2 :

3.14 x 2.1252 = 3.14 x 4.5 = 14.18 sq. in. area of tank section

Then I measure the length, measuring only the actual full width section of the tank, ignoring the neck and end domes (if any). This comes out to

19" which is multiplied by the area to get the total volume:

14.18' x 19" = 269 cu.in.

$$\frac{269}{1728} = .156 \text{ cubic feet.}$$

$$\frac{1800 \text{ psi}}{14.7} = 122 \text{ atmospheres}$$

.156 cf x 122 = 19 cf.

Or about the same as a Jumbo D.

Keep in mind that you can easily run a 10- 15% error when you calculate a tank's the capacity this way, even assuming you do the math right, so don't stake your life too closely on the results!

Metric users don't have to go through all this hassle - their tanks are rated in bar, and marked for working pressure, test pressure, and water capacity. To find the volume one just multiplies the pressure times the water capacity.

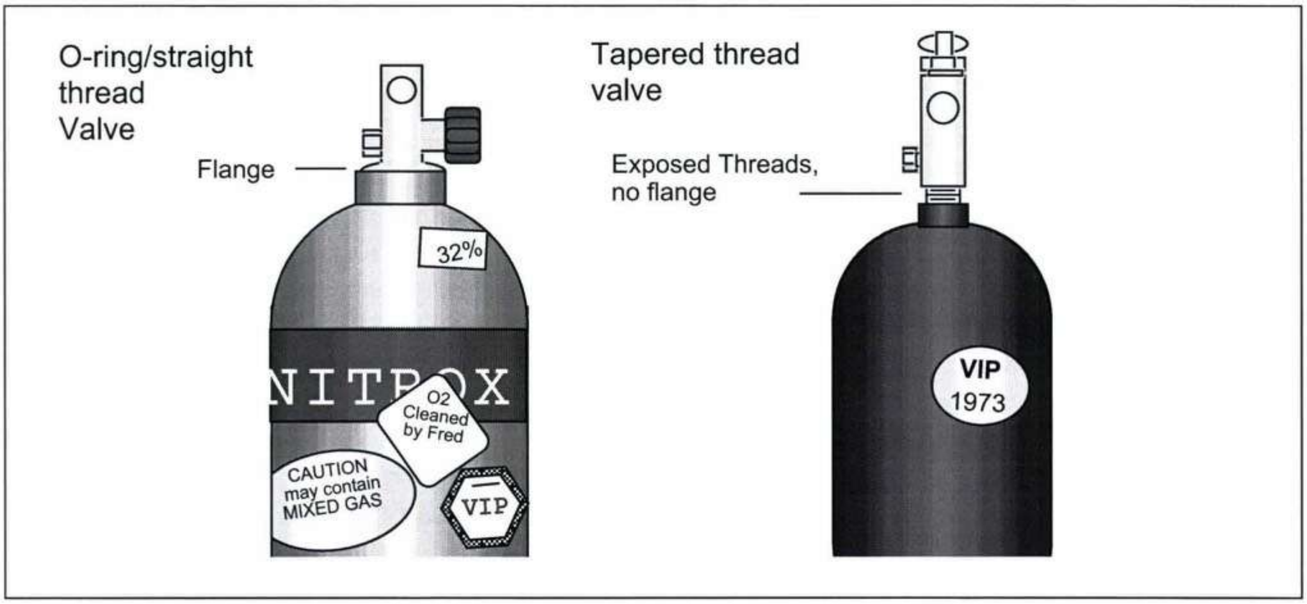
VALVES

The valves for compressed gas tanks usually come in one of two different varieties: tapered NGT threads and straight threads. With the exception of newer steel SCUBA tanks, steel tanks generally use tapered thread valves, and aluminum tanks generally use O-ring sealed straight threads. Steel bottles may have either kind, but aluminum always have the straight threads.

It's usually easy to tell the difference just by looking at them. The SAE valve will have a flange covering the neck of the tank and the tapered thread valve will have exposed threads on the valve protruding above the tank neck. If one is trying to figure out what kind a valve a bare tank requires, a straight thread tank will have a recess at the top of the threads to accommodate the O-ring and a taper thread tank won't.

Most straight threaded valves are 3/4" - 14 NPSM (National Pipe Straight Mechanical, if you must know). HP steel tanks like the old Genesises are another variant, 7/8-14 NFT, and European tanks usually are metric 25/2.

Probably the rarest SCUBA valve of all is a 1/2" straight thread valve. These were used on a few SCUBA tanks made by Kidde in the 60's, if you have one of these valves without a tank, or tanks without a valve, good luck finding the other. These valves are much sought after because they can be used to convert a aluminum medical O2 or whip cream tank for use as a pony or argon bot-



tle.

One thing to be aware of is that straight threads are described by the actual diameter of the threads, where NGT, like NPT, are described by the nominal I.D. (inner diameter) of the pipe they are used on. The threads on a 1/2" taper thread valve will actually measure about 3/4".

The danger is that one can - loosely - fit a straight threaded valve in a taper thread tank (and sometimes force a taper thread valve into a straight thread tank). If one uses enough teflon tape one might not even notice the mismatch. In neither case would the threads be properly engaged, and if the tank was filled the valve would probably blow - if it held air at all - with enough force to do some serious harm.

What if one wants to put a SCUBA valve on an old steel tank - for a stage, argon/drysuit, or pony? New SCUBA valves with 1/2" taper thread are just about impossible to find (although Sherwood used to run off a batch from time to time). Older steel dive tanks, however, used these valves, and they are fairly sought after by serious divers for just that purpose. These valves are easy to spot because they are usually post valves, with a tiny (since it must fit through the reg yoke) valve knob on the top of the valve rather than a big knob on the side like newer valves. Most dive stores that have been around for a while will have a few lying around in the back room (if they haven't been cleaned out by low-buck tech divers). These valves (like just about all valves) are brass, and extremely delicate in the area on each side of the recess where the O-ring for the regulator goes. It's extremely easy to wreck the valve by putting a wrench on the wrong spot.

Non-SCUBA tank valves are available from most gas suppliers, but the price can vary wildly from one dealer to another. I've been quoted between $15 and $60 for a new CGA 870 valve, and anything from $12 to $45 for a CGA 540. Once again, as is usually the case in the gas biz, it really pays to shop around.

Tapered thread valves have to be really tight in the tank to hold gas for long periods - a local industrial gas dealer earnestly told me 2500 ft/lbs of torque (350 kg/m), but I think he slipped in an extra zero. I just tighten them until they don't leak (using a sealant like teflon tape, of course).

Straight thread valves are much are much easier to deal with than taper thread, since the O-ring, and not the interference of the threads, holds the pressure in and the valve need be tightened only just enough to keep it from coming loose.

Valves, taper threaded especially, can be very hard to loosen, especially if it's been years since they were last disturbed, all the more because it is so hard to get a good hold on a round tank without messing it up. Even if you have a vise big enough to grab a 7 or 9" (28-36 cm) tank, clamping it in one risks damaging tank. An old inner tube or piece of leather will protect the tank.

Nylon and plastic "soft" strap wrenches are available for about $15. As a last resort, most shops doing hydro testing have hydraulic tank grabbers that grab a tank tightly enough so that a good-sized wrench and cheater bar can be used.

Straight threaded valves need no sealant, since the O-ring provides the seal, but should have just a little lube on the threads to keep them free and, especially for aluminum tanks, to act as a dielectric barrier to discourage dissimilar metal corrosion. Use the same lube as used on the O-rings - silicone or O2 safe, depending on what's going into the tank.

Tapered thread valves need a sealant. There are special O2-safe sealants, but most everybody seems to use just plain teflon tape. Some suppliers carry O2-safe teflon tape. Apparently the difference is that great care is taken to see that no oil gets on the tape in the manufacturing process, but it's debatable whether, considering the tiny quantities involved, it really makes any difference. It's good practice, though, to avoid leaving bits of tanks inside the tank or plumbing. Correct practice is to wrap the tape only 1 1/2 turns, and not on the first 3 threads at all, so as little as possible is actually exposed to the O2.

Burst Disks and Safety Plugs

All but the smallest tanks are required by US DOT regs to have safety plugs on the valve to let off pressure before the tank explodes should the tank be grossly overfilled or caught in a fire. Older valves usually have lead filled blow-out plugs. Newer valves have frangible burst disks; tiny disks made of thin metal, and retained by a hollow plug. Frangible burst disks come in different thicknesses and rated for different pressures; they are intended to burst at about 150% of the tank's working pressure. This is something to watch out for when switching valves between tanks; a burst disk from a 3000 psi (200 bar) tank used on a 1800 psi (124 bar) (151 bar) tank would offer little protection, while a burst disk intended for a 2200 psi tank used on a 3000 psi tank could let go at anytime.

It's a bad idea to remove the burst disk just to look at it - any time the burst disk is removed, the entire assembly is supposed to be replaced. Actually, the major troublespot is the little washer which makes the seal, which is usually copper, and cannot be counted on to work more than once. But the washers are rarely available separately, forcing one to buy the entire assembly. If one does reuse a burst disk, it should be replaced facing the same direction as it was originally, so any bulge points outward.

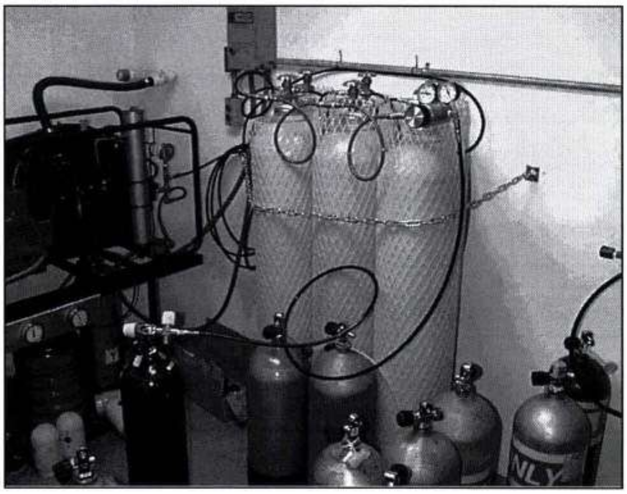
Burst disks have a bad habit of occasionally letting go for no reason at all, generally (at least in the retelling) at the worst possible time. Tech divers, especially cavers, who have a special dread of hearing that sudden whooosh that means all their air is going up in bubbles, have been known to double up on burst disks, or replace them with a thicker one made of shim stock, so they cannot let go accidentally. One should be aware, if one is considering doing so, that doubling up the disks will not simply double the burst rating, but for all practical purposes completely disable it, as well as rendering the tank illegal under DOT regulations. Since, as mentioned earlier, most cavers can point to many people who have died in caves for lack of air, but very few who have been killed by exploding tanks, they undoubtedly feel the trade-off is well worth the risk. It's also worth mentioning that the USA is just about the only country that requires safety plugs on SCUBA tanks.

Cascades and Haskels

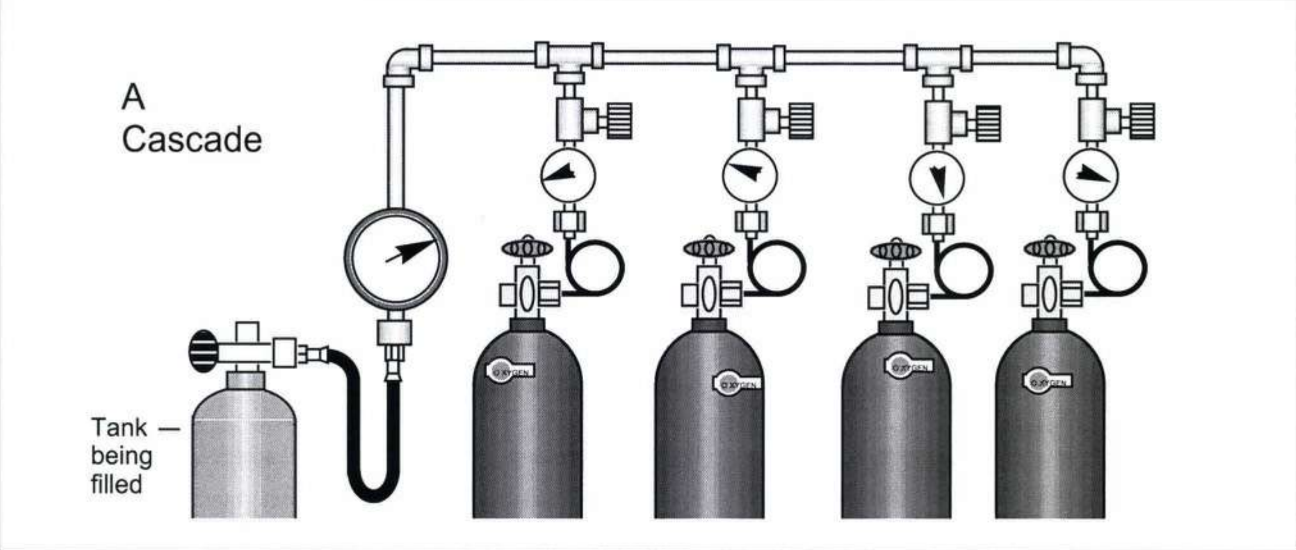
A problem with filling one tank from another is that, courtesy of Mr. Boyle, the pressure in the big tank goes down as the little tank fills, and one can never get the pressure in the little tank as high as it was in the big tank. Each time the little tank is filled the pressure in the big tank drops in proportion to how much gas volume has been taken from it, which reduces the amount of usable gas that can be put in the little tank. As a result, after filling a few tanks one will often end up with the supply tank still almost full of expensive gas, but at too low a pressure to be of any use.

There are two ways the pros deal with this. One is by using a "cascade" - a series of several donor tanks which are used in sequence, starting with the oldest, lowest pressure tank, and working up the newest, highest. That way the tank with the highest pressure is used, in effect, only for topping up and hence maintains a high pressure for much longer. As the pressure in each tank drops and the first tank in the sequence is used up, each tank drops a notch, and the new tank takes its place at the end of the cascade.

The tanks in a cascade can be used separately,



A 6-tank Air Cascade



or plumbed together to make the job easier. Many dive shops use a cascade of big air storage tanks to fill dive tanks so they don't have to run their compressors so often. Usually they are permanently plumbed in parallel with a separate gauge and valve for each tank so they can be switched between simply by opening and closing the valves. If one really wants to get fancy, automatic "sequence" valves are available from Aqua Environment that sense the pressure of the cascade and fill tanks, and automatically switch from one cascade tank to the next as the pressure in the fill tank builds!

On a simpler cascade such as many homemixer use the tanks are not be connected at all, but each tank used in turn by simply moving the whip from one tank to another.

The only catch to a cascade is it takes a bunch of tanks to make one, which multiplies the cost. However, even a two tank cascade can allow much more efficient use of the contents, and, if one is using more than a few tanks of O2 a year, should repay the cost of an extra tank lease.

The necessary hardware to hook up a cascade - valves, lines and gauges - can be bought either from an HP gas supplier that carries the Western or a similar line of fittings, or from specialized SCUBA shop suppliers.

While having a separate valve and gauge for each tank is a great convenience, it adds considerably to the cost and complexity, and many cascades do without them. The tanks are simply plumbed in series, and the tank valves used to control the fill. However, without a separate valve for each tank downstream from the tank valve there is no way to equip each tank with its own pressure gauge. Without separate pressure gauges the only way to find out how much pressure is in each tank is to open the tank valve and read the pressure on the main gauge, so having individual tank gauges can save a lot of fiddling with the valves.

One mixer I know has come up with a clever way around the problem - he's made a set of movable magnetic labels for the tanks to mark them in the order they are to be used, from least full to fullest. Each time a fresh tank is added to the cascade the tags are moved over one tank. Note that there's no need to keep track of the pressure - just the order in which they should be used. It's a neat and effective solution, and could be done just as easily with tags hung on the valves, or sticky labels.

Professional setups using a lot of tanks often simplify things a bit by grouping several cylinders together in banks, so one valve and gauge serves several tanks.

If one is mixing dive gas, especially nitrox, falling supply tank pressure isn't really a problem since one will be putting the gas in first then topping the tank up with air from a compressor. Achieving high pressures in the tank being filled is really only an issue when filling aviation tanks, deco tanks for diving, or refill emergency treatment bottles and want to get the full rated capacity. The latter, emergency treatment bottles, usually aren't much of a problem since they need refilling so infrequently. I just make it a point to top up my emergency bottle whenever I get a new full O2 tank in. If the timing doesn't work out to do that, I go over to a friend's shop where the turnover in tanks is high enough that there usually is a full one around, and top it off there.

It is a problem when one is mixing trimix. He comes in tanks at a pressure of about 2150 psi (150 bar) - my gas dealer only guarantees "somewhere between 2000 and 2200 psi".

BOOSTERS

Another way to get full pressure in the tank being filled is to use a booster pump. This is a special pump designed for boosting the pressure of compressed gases. Haskel is the best known manufacturer of these pumps, so much so that the name is often used generically to refer to any booster pump. The secret to the Haskel-style booster pump is that it is not trying to compress the gas from scratch, but only boost the pressure of gas that is already compressed.

Booster pumps are most commonly composed of two linked pistons, a small one that does the compressing and a bigger one that drives it, and is powered by air from either a HP or LP compressor. Most boosters are driven by LP shop line air and boost HP gas, so the two sides are strictly isolated from each other, but some, often called "amplifiers", use the same HP gas to drive them as is being boosted. These work fine with air, but are expensive to use for boosting gas since most of the drive gas gets wasted in the process.

Boosters are definitely fun and useful gadgets, but are expensive - $4000 or so, enough to put them out of the range of most of us (though they can occasionally be found used for much less).

There are also boosters that work like regular compressors and are powered by electric motors, but for some reason they seem to be less common in dive circles. And if you look in an older edition of the US Navy dive manual, you'll see a wonderful cast iron booster pump which is powered by two men, one on each side of a eight foot long rocker bar.

Cale keeps insisting he is going to build a booster pump using a cheap surplus hydraulic cylinder. It's an interesting notion, but I'll believe it when I see it.

Boosting oxgyen can be particularly dangerous, both because the dangers of combustion increase as the pressure goes up.

Haskel specifies 5000 psi (330 bar) as the upper limit for boosting O2 with its boosters. However that assumes the boosting will be being done into dedicated. purpose-designed tanks which is rarely the case in the dive world. Most wise divers would hesitate to boost O2 above 3500 psi, and the tech agencies usually say 3000 to 3200.

Actually, there's a third approach to the dropping pressure problem, and that's just to live with it - to use tanks with more capacity than is necessary so they will still be effective with partial fills. My little aviation set, using conserving cannulas, will last 25 hours on one fill. That means I can do a heck of a lot of flying on an only quarter full tank. An old steel 50 or 72 dive tank, filled to 1000 psi, can provide for a half hour deco stop, or several hours of surface O2.

Notice also that, unless one has access to a booster, there's not much point in using HP tanks for O2. Since O2 comes in 1800 to 2200 psi (124-150 bar) tanks, there's no way to fill a 3000 psi (200 bar) tank, let along a 3500 psi (240 bar) one, with O2 to anywhere near capacity with O2 without one, so without a booster one might as well save some money and put those old LP tanks to work.

Chapter 8
THE HARDWARE

WHIPS

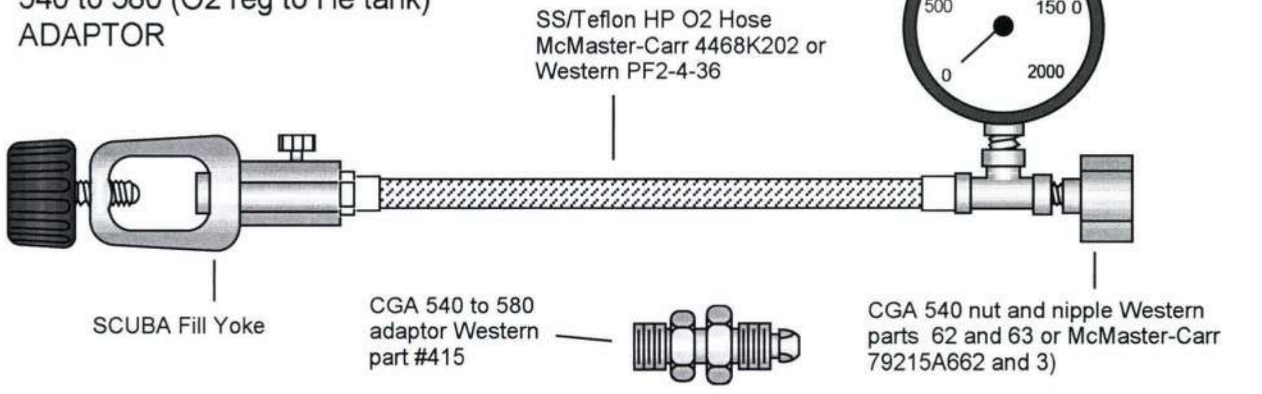
Forget those sick fantasies of SM chicks in tight skin2 wetsuits - we're talking tech. To transfer compressed gases from one tank to another you need some sort of connector - a pipe or hose - with the appropriate fittings on each end to accommodate both tanks. If the connector is rigid, it's usually called a manifold. If it's flexible, it's called a whip. Semi-flexible connections made of copper tubing (.065" thick wall, not the flimsy stuff you can buy at your hardware store) called pigtails (because they are bent in a circle, like a pig's tail, to allow more flex) are also often used, but don't really work all that good for tank filling unless you will always be hooking up to the same size tank in the same position.

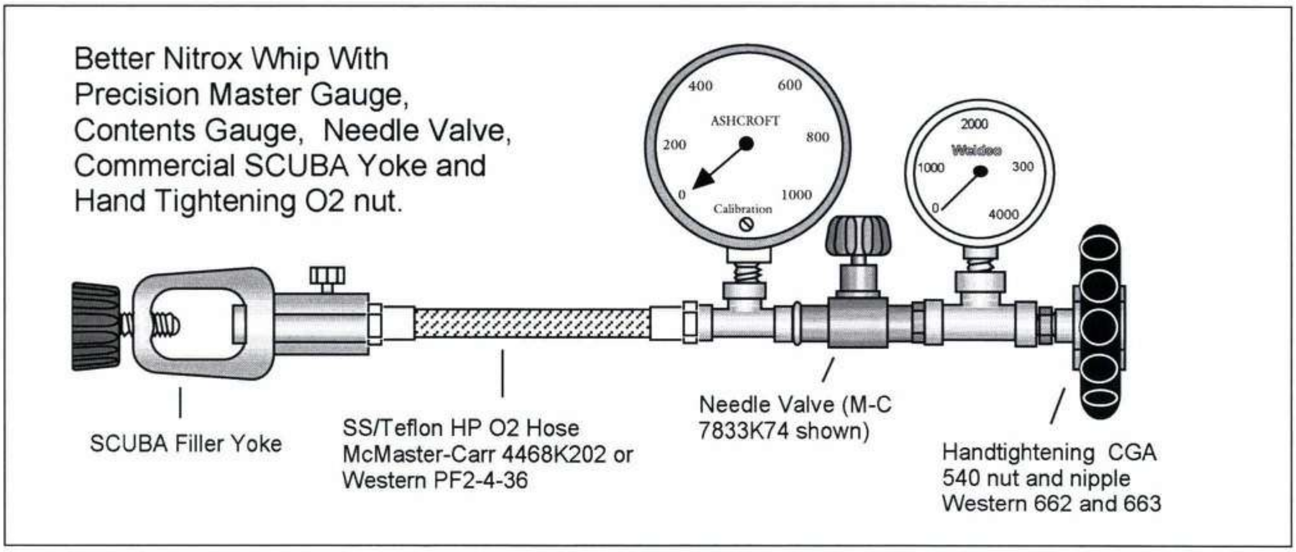
Whips are sometimes available ready-made from gas dealers or dive suppliers. A basic O2 to SCUBA whip from Global goes for about $100. The catalog description cautions it is not suitable for nitrox mixing since the gauge is not precise enough, but many homebrewers would disagree. Global's "official" nitrox mixing whip, with precision gauge and other bells and whistles goes for $750, or a tad under $1000 with a digital gauge.

Whips can also be easily made up from parts, usually for much less than a ready-made whip costs. The supply tank-side fittings can be bought from a welding and gas supplier. These carry lines of fittings such as Western's, or can order them in.

Aviation O2 fittings to fit specific oxygen sets can usually be ordered from the manufacturer, or through a large distributor like Aircraft Spruce.

BASIC NITROX WHIP WITH CGA 540 to 580 (O2 reg to He tank) ADAPTOR





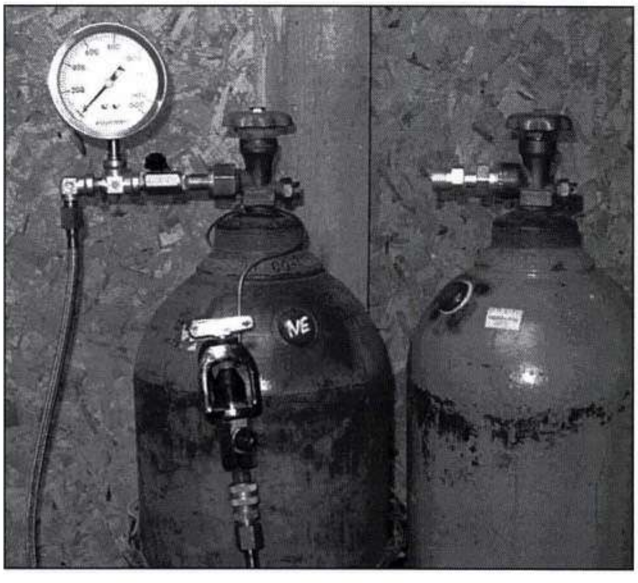
The specialized SCUBA fittings like the tank filler adaptor are most easily bought through a dive shop though, if the local shop is uncooperative, there are several other alternatives.

The critical part on any whip, whether home-made or commercial, is the hose, since it has to be able to both flex and handle the pressure. Hardware/auto store tubing won't do - we're talking serious pressure here. A good starting point for a professional quality home-made whip is a braided stainless steel/teflon hose like McMaster Carr's 4468K202 which has 1/4 NPT threads on the ends, and sells for about $15 for a 3' length. Western and other suppliers have similar hoses, but M-C is usually cheaper, cheap enough that it really doesn't make sense to use anything less, though rubber hoses rated for O2 are also available such as SAE 100R7.

An alternative to NPT fittings on hoses are 37º JIC fittings. These are flare-type fittings, and very useful when a line will be done and undone occasionally since they make a tight, reliable joint without needing any sealant and with only modest tightening. They also act as a swivel, to allow tightening the hose without rotating it which is useful when running a hose between two fixed objects. Most JIC hardware is carbon steel, and unsuitable for O2 service, however Graingers lists SS JIC-to-NPT adaptors and M-C has brass JIC and NPT U-Build fittings for braided SS hose.

It's important to understand that there is no such thing as a completely O2-safe hose, and that hoses are probably the weakest link in most O2 blending setups. At the White Sands O2 seminar mentioned earlier the remark was made that they had yet to find a hose that they couldn't light up at will with HP O2!

The one drawback to braided SS/teflon hose is that it is liable to kink and eventually fail if allowed to bend too sharply. The usual way this happens is when the filler yoke is allowed to fall or hang



Hose savers. An elbow and a hanger hook. Note the tiny needle valve on the whip, and the adaptor on the He tank.

unsupported. I see a lot of mixers precariously balancing their yokes on the tank and/or regulator, why, I don't know, because it only takes a minute or two to make a hook that goes around the neck of the tank to hang the yoke on. I use brazing rod because I like brass, but welding rod or coathanger works fine. Hose strain can also be reduced by putting an elbow where the hose meets the tank fittings, so the hose points downward rather than horizontal.

Cale has, probably just out of sheer perversity, been known to use hydraulic hose for whips, and even on one occasion a flexible grease-gun hose! A ready-made 3' 1/4" hydraulic hose with a burst pressure rating of 11,000 psi (760 bar) costs about $8, and may be a lot easier to find on the spur of the moment than a proper HP O2 hose. The catch with using them for O2 service is that there's no way to know how compatible the materials are for O2 service. Even if one knows someone else who is successfully using one with O2 that doesn't mean one will necessarily get away with it - different compounds are used by different manufacturers, and some might be more combustible than others. Also, combustion isn't the only process that O2 speeds up. It can accelerate oxidation (duh!), rotting, and a bunch of other things. A material that may seem to tolerate O2 perfectly well in the short run may fall apart a few weeks later.

Also, the manufacturing or testing process may have left contaminants in the hose and fittings, so they must be scrupulously cleaned before use regardless of one's feelings about O2-cleaning in general (and don't even think about using a used hydraulic hose, no matter how much it's been cleaned!). And lastly, hydraulic hoses almost always have steel fittings. All in all, something better avoided, at least for O2.

The SCUBA side tank filling yoke (or DIN filler adaptor) is a specialized SCUBA part. The easiest way to get one is from a SCUBA shop supplier . Global sells a tank filling yoke with bleeder valve, their part no. 45050, for about $50 and list a number of other permutations such as DIN valve fillers as well as complete whips in many configurations.

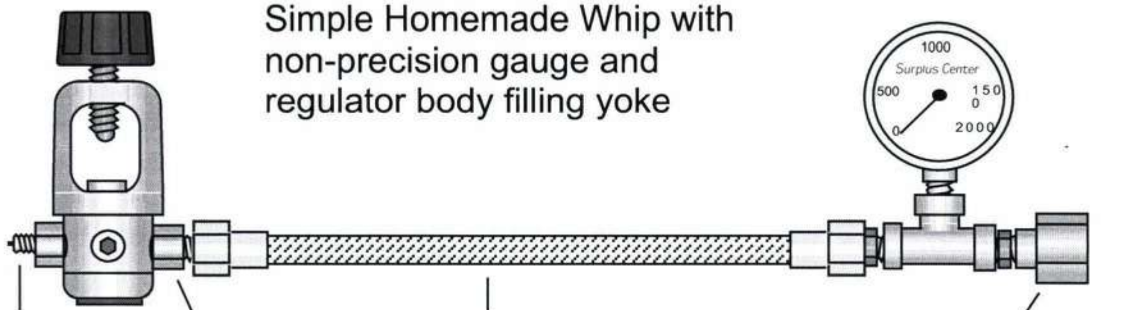
Another way to get a SCUBA filler yoke is to cannibalize a tank pressure checking gauge, which is basically just a filling yoke and bleeder valve with a gauge attached, or one of those "tank equalizer" whips which have two yokes on a hose for filling one tank from another. Either one of these second hand should cost less than a new filling yoke, and if your dive shop is giving you a hard time about selling you a filling yoke they are easy to buy since all the mail order SCUBA suppliers carry them.

If one is going to be using a whip a lot, it pays to use good components. They make the job easier, and lessen the room for error. As in everything, there are shortcuts one can take, but one takes them at one's own risk.

Rather than buy a dedicated scuba tank yoke

Cale's Kamikaze Whip - weld and mix at the same time! A lot of O2 has gone through this rig, but the steel fittings on that hydraulic line still make me nervous.
A setup like this (but with a proper hose, please) could be used with a continuous mixer, to allow PP and continuous mixing from the same tank without swapping connections.

Simple Homemade Whip with non-precision gauge and regulator body filling yoke



and oxygen tank connector, Cale uses an old SCUBA regulator first stage (which he has perfunctorily O2-cleaned) for the SCUBA end of the whip. He made a SAE/O-ring to NPT taper thread adaptor to hook the hose up to the HP SPG port of the SCUBA regulator. The other end of the hose he screws into the HP port on his welding regulator where the HP gauge usually goes. He has also been known to make filling yokes from defunct old first stages by taking the yoke nut or retainer, drilling it out with a 7/16" drill, and cutting 1/4" NPT threads in it.

It's kind of foolish to try and save money on the O2 tank end of the whip, since the right fittings (Western part no. 62 and 63 or MC #79215A662 and 3) cost just a few dollars. But Cale had a spare O2 reg he'd found at a flea market lying around and saw no reason to spend more, especially because it came with gauges already attached.

But this strategy - using a regulator as an improvised fill adaptor - can come in handy for one-shot jobs. Cale on several occasions reports successfully using the same method, unscrewing the HP gauge from a medical regulator and screwing in an HP hose in its place - to refill a medical tank when he didn't have the proper adaptor.

Just to make the circle complete, he also has a little bottle cap sized adaptor he made on a lathe which lets him use a medical regulator on a SCUBA tank.

The bad thing about filling methods which require undoing and redoing tapered thread connections is that each time they are undone a few more scraps of sealant, teflon tape, or other contaminants can find their way into the system. For that reason, among others, they cannot be recommended on a regular basis though they can be a useful kludge in a one-off or emergency situation.

If one is buying CGA 540 fittings for a whip that will see a lot of use, it's worth considering spending the extra money for "hand- tightening" connectors. Regular CGA 540 connectors use a brass nipple which fits into a matching brass socket, and a hex "inlet nut" to tighten them together. The connection is metal to metal, counting on the resilience of the brass for sealing. The usual practice is to tighten them with a big wrench, check the connection with Snoop or soapy water, and tighten them some more, repeating the process however many times is necessary until they stop leaking.

Hand-tightened fittings like Western's have a seal set in a grove at the tip of the nipple, like propane gas grill fittings, and a handwheel instead of a hex nut, so they can be fastened and unfastened without using a wrench. Hand tightening tank fittings are a real convenience on any whip which is going to be moved around much, though with the slight disadvantage that the seals can wear out or fall off and put the whip out of commision until a replacement is found.

When a dive regulator first stage is used as a filler yoke, there's got be some way to bleed off the residual pressure before disconnecting. Commercial filler yokes have a bleed valve specifically for this purpose. If a SCUBA regulator is being used as a yoke on a temporary basis, a first stage can simply be left connected, and the purge button used to bleed the system. But for full time dedicated use this is inelegant and clumsy and a dedicated bleed valve is pretty much essential.

Just about any small valve able to handle 150 psi (10 bar) or so will do. Commercial fill yokes use a simple valve machined into the body. Hard to do after -the-fact, but any valve capable of handling the pressures involved will do the job just as well.

One can also buy, at any hardware or plumbing store, a little fitting which has a tire-style Shrader valve in an NPT threaded adaptor. These are used for pressurizing and bleeding heating and pump systems, but make great bleeder valves.

Note that these valves are not adequate for HP use! If one is used Cale-style as a bleed on a reg body, it should always go on the low pressure port of the reg, to bleed the reg via the intermediate chamber, so the valve is not exposed to full tank pressure.

Incidentally, should one ever need such a thing, it's worth knowing that high pressure Shrader valves do exist - they are used on aircraft landing gear struts and should be available any place that services small aircraft. Aircraft Spruce has them rated for 2000 psi (138 bar) for about $2, and 3000 psi (200 bar) versions exist. Aircraft components are usually rated extremely conservatively, and can generally stand, for brief periods, higher pressures within reason, though deliberately overloading of any components is of course to be frowned upon.

Trimix Whips

For trimix, the same whip can be used as for nitrox with the addition of a $10 CGA 580 tank to 540 reg adaptor (Western part 415). If one goes this route, a nice refinement is to use a hand-tightened O2 fitting on the nitrox whip, and a wrench-tightened 580 to 540 adaptor. The adaptor can be left semi-permanently on the He tank, and the whip moved easily from the O2 tank to the He tank. Keep in mind that a hand-tightening nut can only be used with the matching soft tip or O-ring style nipple since it doesn't create enough force to reliably seal a metal-to-metal joint.

If a dedicated He whip is desired, it can be made as for the nitrox whip, by substituting the CGA 580 nut and nipple (Western parts 92 and 15-3) at the tank end for the CGA 540 specified for O2. Since the helium is inert, a plain rubber HP air hose or hydraulic line may be used instead

O2 whip being used for trimixing with the addition of a CGA 580-to-540 adaptor between the tank valve and the whip. Note the hand-tightening nut and braided SS/teflon hose.

of the more expensive teflon/SS hose recommended for O2.

Aviation Oxygen Whips

Refilling aviation O2 tanks may require some oddball dedicated fittings from the manufacturer. Mine, for example, uses a filler valve very much like a oversize Shrader tire valve. I made up an adaptor out of a hardware store brass fitting and an O-ring but wouldn't advise this to anyone who isn't experienced at this sort of thing. Most av sets, though, use standard fittings, usually CGA 540.

Anyone planning on filling their own aviation tank should look into this before buying one. Some adaptors - like Scott's - are outrageously expensive, and one is unlikely to find them anywhere but at an airport. Using industry standard CGA fittings rather than special dedicated aviation fittings is a definite plus since it means you'll be able to get the tank filled in a lot more places.

An aviation whip can easily be assembled using the same hose mentioned earlier with the appropriate fittings on each end. Western will also sell you a hose, part no. PF-63 that already has the CGA 540 fittings on each end. Since it's quite a bit more expensive that the plain hose, and makes it difficult to change the fitting on the end should it ever be necessary, I prefer the built-up version as shown.

Gauges

Mixing nitrox and trimix also requires a good master gauge on the whip, though some home mixers have been known to use their SCUBA SPG's. Large face, precision (calibrated) gauges are highly recommended, but a number of home mixers report consistently getting within 1/2% on their mixes using just an ordinary SCUBA or welding gauge.

A 2500 psi (170 bar) to 3000 psi (200 bar) gauge works best. some nitrox mixers prefer to use a lower range gauge, since they are usually adding only 400 psi (25 bar) or so to a tank that has maybe 700 psi (50 bar) of old mix in it, and using a 1500 - 2000 psi (100-133 bar) gauge gives better resolution in those ranges. The catch to using the lower pressure gauge, of course, is that if one inadvertently cranks the tank valve open too far and the gauge sees the full tank pressure it may blow the gauge sky high - ask Cale how he got the scar on his eyebrow.

Precision gauges are expensive, at around $400 new (though new surplus ones are often available, though rarely O2-clean, for less than half that from C&H Sales).

Mixing is a lot more pleasant with a large face gauge, since the graduations are smaller, making it easier to read small differences. And anyhow, the choice doesn't have to be between big expensive and cheap little. There are also cheap big gauges, and they are what I tend to prefer, offering as they do a good compromise between price and accuracy.

Most of the big analog mix gauges in the tech catalogs are precision gauges. Precision gauges are guaranteed to meet certain accuracy standards, and their calibration can be traced back to the bureau of standards. That gives the impression that big equals expensive. However, there are plenty of decent big, non-precision gauges available, especially from surplus dealers, and the price is cheap enough that's there's no reason to put up with a tiny one. I'm currently using a SS case 2000 psi 4" gauge that cost $12 from Surplus Center.

The only catch is it's hard to find larger size gauges which are cleaned for O2 service without paying a lot extra. Most of the homemixers I know don't worry too much about whether a gauge is specifically marked as cleaned for O2 service, as long as it's new and shows no visible signs of oil or other contamination inside. Any contamination that can't be seen, they figure, just isn't enough to cause serious trouble.

It's sometimes possible to O2-clean a gauge, using the same detergents as are used for tanks and regs, by shooting the detergent into the HP opening with a syringe, then repeating with rinse water until all traces of detergent are gone. The catch is getting all the liquid out again, since the bourdon tube of a gauge is both small and convoluted. It can be done, though, by purging the gauge, pressurizing and depressurizing it repeatedly, so the escaping pressure drives out the water.

A lot of the surplus gauges in the right pressure range are filled (or have plugs so they can be filled) with fluid to dampen the movement. Usually these are filled with glycerine, which is fine with 02 - in fact, some boosters and other HP O2 gear use it as a lube or sealant. However some may be filled with mineral oil or kerosene, so one it is essential to know which before attempting to use a filled gauge in O2 service.

The trick, top-of-the-line setup is a digital electronic master gauge. These sell for $600+. Digital gauges. like O2 analyzers, usually will read out in tenths, and even hundredths. Compared to an analog gauge, where each division on the dial may be as much as 10 or 20 psi (1 bar), it's hard not to be impressed.

It's important to understand that the accuracy of a digital gauge is a function of the sensor, not the display. The fact that the meter reads out in tenths doesn't mean much unless the sensor can differentiate that finely. As often as not they can't.

Digital pressure gauges are, actually, usually quite accurate, commonly to about 1/4 of a percent. That could work out to as much as a 2 - 5 psi error over the range the gas mixer will be most concerned with - more than good enough for our purposes, but not that much better than a good analog gauge, and certainly not good enough to justify putting very much weight on the tenths of a psi.

Shops like digital gauges because they are easier to read from a distance - handy if one is trying to mix gas and run a shop at the same time. But for the rest of us, they just don't have any advantages commensurate to the cost.

A cut-rate alternative to a new digital gauge is to use an old air-integrated dive computer as a master gauge. These incorporate very accurate digital pressure gauges, and are often available used as divers trade up to nitrox computers. Many an old Phoenix has ended up as part of a mix panel, with a AC adapter to control its notoriously voracious appetite for batteries.

Gauges should be handled with care, analog gauges especially. Commercial nitrox mixing whips often have separate run of hose leading from a tee on the whip to the master gauge, so it can be wall mounted and spared any rough handling when the tanks are connected and disconnected.

One hears occasionally of home mixers who figure if they have a good enough gauge they wouldn't need an analyzer. This is dubious logic - the purpose of the analyzer is to backstop the gauge (and your calculations!) and in doing so, provide redundancy in making sure the mix is what it is intended to be. Even the best gauge in the world can start acting up, and without an analyzer there's no way to know it.

Whip Valves

Nitrox whips may or may not include a valve. Home mixers often make do with the tank valves to control the flow and most of the time this works fine. A needle valve on the whip is, while not essential, quite useful. Mainly, it frees the mixer from having to rely on th uneven quality of the supply tank valves. Most of them work fine, but every so often one will encounter one that grabs, catches, and then goes from off to wide open with a single tug. Using one's own valve to control the fill eliminates this variability. Also, using a fill valve on the whip allows adding a separate gauge for monitoring the supply tank contents.

If a valve is included on the whip, it should be one that allows very precise control of the flow, since adiabatic heating caused by abruptly pressurizing the system is one of the better documented dangers in O2 handling. This means a good quality, smooth-operating needle valve, not a gate, ball or other fast opening valve. Valves like this suitable for HP O2 tend to be expensive, $50 and up, if a suitable one can't be found used or surplus.

M-C's 7833K74 looks promising to, for about $20. The brass version is rated to 3000 psi, and has viton seals. Top quality Swagelok and Parker valves can often be found at cheaply on ebay. There are too many variants to list part numbers here; get a catalog before you start bidding.

If a whip valve is fitted, the valve on the fill tank should be wide open before filling is commenced, to lessen any bottlenecks that can cause adiabatic compression. I start by checking that the whip valve is closed, then open the fill tank valve all the way, then doublecheck that the whip valve is shut, open the tank valve partway, and begin the fill using the whip valve.

Quick Release HP fittings. ISO Series B and Parker ST.

Check Valves

Check valves are spring loaded valves that go in a pressure line and allow the gas to flow in only one direction. They are useful but not essential on a mixing whip, where they can prevent backflow if the supply tank pressure is too low, but are absolutely required anytime the air supply is integrated with the O2 whip, as on a mixing panel, to prevent O2 from backflowing through the filters and into the compressor. They are also highly desirable anytime there are tanks of different kinds of gas plumbed together, to keep the gas in the higher pressure tanks from accidentally feeding into the lower pressure ones.

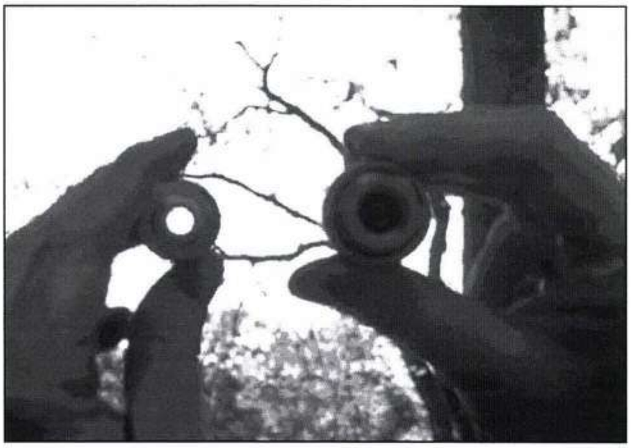
Quick Release Fittings

Parker, Swagelock, Aeroquip and others make HP quick disconnect (QD) fittings that allow lines and fittings to be quickly connected and disconnected.

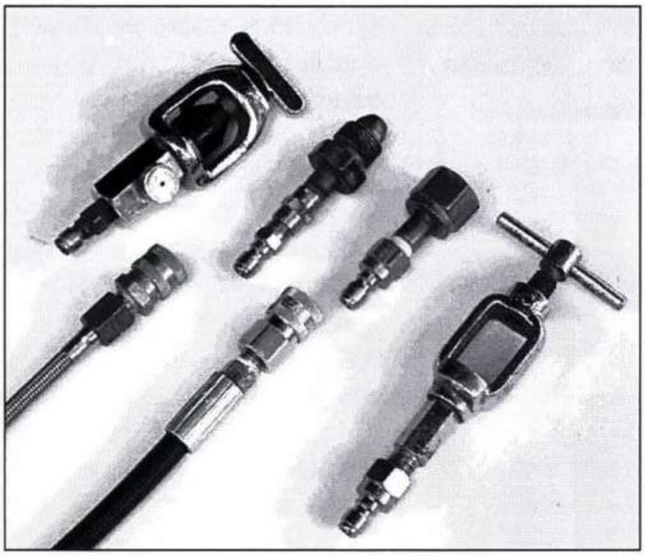
QDs can be very handy for setting up whips or mix panels so they can be quickly reconfigured - for example, I have them on my all-purpose traveling whip so I can change quickly switch one side from SCUBA to CGA 540, and on my homemade booster so I can quickly change both the input and output gases.

QDs are also great for mounting delicate components like a precision or electronic gauge, since they allow quickly removing the gauge so it can be protected when the whip or panel is being transported or O2-cleaned.

There are several standard industry interchange groups for these fittings, so that QDs made by different manufacturers can be used with each other. Some of these groups are really intended for use with fluids and not gases, and may leak slightly when used with HP gases. They are available in steel and SS, and sometimes brass, and with and without built-in shutoffs on either or both sides so it is not necessary to plug the



The Parker ST-series QR (left) has a straight-through path, others usually don't.



QRs can save a lot of time and teflon tape by making it possible to change quickly from one tank fitting to another.

unused port. However the ones with the valves have convoluted paths, which make them, along with the steel ones, a dubious choice for O2 use.

My current favorite is the Parker ST series (sold by McMaster-Carr as High Flow Pneumatic/Hydraulic Hose Couplings). These have no valves and a straight-through, unconvoluted bore, making them a good choice for use with O2, along with an accessible and easy to replace O-ring seal (a –111 in the 1/4").

The female sockets are available in brass and SS, both rated for 5000 psi, the brass for a bargain $4, and SS a not-so-bargain $28. The male plugs come in steel. brass and SS ($2/$8); however M-C doesn't carry the male plugs in brass so you have to get them from a Parker distributor.

You don't necessarily have to use the SS female with the SS male plugs; I (as do a number of commercial mixing panels) use the brass or SS plugs for O2, but may use the steel plugs with air or inert gas when I'm too lazy to look for brass ones.

ORIFICES

When it comes to handling HP gases, orifices are just about the cheapest, simplest form of insurance around. An orifice is simply a tiny hole - say, 1/32" (.8mm) - drilled in a plug and placed in the gas path to limit flow. On an 02 whip an orifice can guard against runaway fills and greatly reduce the fire hazard should the whip break or an 0-ring let go. An orifice can also, by slowing down the flow, make precise partial pressure mixing much easier should one not be using a precision valve.

I'm a big fan of orifices, ever since an acquaintance had a memorable "learning experience" while filling a landing gear strut on a small plane. These struts are built like hydraulic cylinders, but filled with a combination of oil, for damping, and highly pressurized N2 to provide springing. He was using a home made "strut bottle" - a 2100 psi (140 bar) N2 tank with a valve but no regulator, and accidentally opened the valve to far. The blast of HP N2 extended the strut so quickly that it blew apart, firing the upper section like a mortar shell through the wing and on up, smashing a hole in the sheet metal roof of the hanger!

His Mk2 version incorporated an orifice, and he hasn't had any trouble since. SCUBA gear too routinely incorporates orifices on the HP lines so that a blown gauge or hose won't instantly empty the tank.

To give the most protection the orifice should be located at the donor tank end of the whip. Since the orifice will have full tank pressure on one side and often much less on the other, it must be firmly and solidly held in place, preferable by good, full depth taper threads. Trying to hold an orifice in place with an inadequate or interference fit may simply result in the creation of an impromptu pneumatic .44 magnum.

Even with a very tiny orifice, the flow rate will vary according to the upstream pressure. Medical regulators, as covered earlier, adjust the flow this way, using a regulator with an adjustable output pressure and a pressure gauge calibrated in liters per minute. The gauge must be used with the right size orifice in order for it to read correctly, and that orifice size is usually marked on the gauge face.

Flow Through An Orifice Formulae

For finding the flow through a given orifice at a given pressure:

$$Q=11PuD^2$$

For finding the diameter of an orifice to produce a desired flow at a given pressure:

$$D=0.3\sqrt{\frac{Q}{Pu}}$$

Where
Q is the flow rate in SCFM
Pu is the upstream pressure PSI
D is the diameter of the orifice in inches

For example, suppose you want to make a BC sampler, to give a flow of 0.14 cfm (4 lpm) from a 140 psi intermediate pressure:

$$D=0.3\sqrt{\frac{0.14}{140}} \qquad D=0.3\sqrt{0.001}$$

$$D=0.3\ (.03) = .009''$$

When the downstream pressure is more than one half the upstream apply the following corrections:

<50%	1.00
60%	.90
70%	.65
80%	.46
90%	.33
95%	.23
98%	.14
99%	.10

For gases other than air multiply Q by:

Helium	2.6
Nitrogen	1.0

Sometimes it is desirable - when making a gas sampler, say, or when building a constant flow semi-closed rebreather, to use an orifice to obtain a precise metered flow.

This requires some calculations to figure how big to make the orifice for a desired flow and pressure. Fortunately, there's a couple fairly simple formulas for figuring it out.

Sub-Sonic and Sonic Orifices

One of the interesting (and often handy) things about flow through an orifice is that, if the ΔP - the difference between the upstream and downstream pressure - is high enough, then the flow, as it reaches the speed of sound, "sticks", and isn't effected anymore by the downstream pressure. This is very useful if you are designing a semi-closed rebreather or similar device, and want the volume of gas delivered to be constant regardless of depth.

Orifices working this way are referred to as "sonic" orifices, and orifices running at slower speeds as "subsonic". Calculating the gas speed to find out if an orifice is sub sonic or sonic sounds intimidating, but it is anything but - the rule of thumb is that the flow is sonic as long as the upstream pressure is at least double that of the downstream pressure.

The same formula can be used to figure either sonic or subsonic flow given the pressure and orifice size. A correction factor is used if the flow is subsonic, and other correction factors are necessary for gases other than air.

Keep in mind that these formulae will only give a rough approximation. There are too many variables that effect flow through an orifice - how deep it is, how the edges of the entry and exit are finished, etc., for a formula to give exact results. The actual flow should always be measured, and the formula used only as a guideline. If a flow meter isn't handy, the orifice can be calibrated by bubbling gas into an upside-down, water-filled container.

Precision orifices like these are almost always used along with a regulator - it wouldn't make much sense to try and run one at full tank pressure, as the output would vary too much as the tank pressure dropped, defeating the point of using a precision orifice.

Plugged Orifices

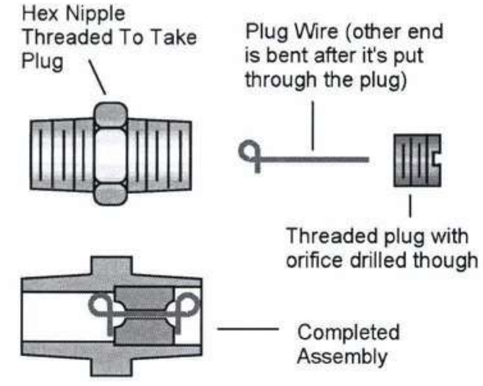
The problem is, for an orifice to be useful in many of the sorts of applications covered in this book, such as a sampler, it must be so tiny that it cannot be easily drilled without specialized equipment - to give the recommended 2-4 lpm flow for an O2 sampler running off a typical 140 psi (9.5 bar) 1st stage, the office would have to be only about .005"! By way of comparison, the smallest drill available in most hardware stores is a #60, which drills an .040" hole.

There are several ways around this. Several companies sell ready-made precision orifices which work quite nicely. Maxtec, for their one-piece analyzer, uses a .005 ruby orifice from Bird. Norgren makes a similar product, which comes in .002 increments and sells for around $20. These orifices, like the ones used on the Draeger SCRs, are often made of a synthetic stone like ruby because it laser drills cleanly, and erodes much less over time than metal orifices.

However, for a quick and dirty version, there's an old trick that works quite nicely. Rather than trying to drill a preposterously tiny hole, drill the smallest hole you can conveniently drill, then plug it most of the way by running a wire through it (with the ends bent over so it won't blow out). If one were to take the #60 drill mentioned earlier, the smallest size the amateur is likely to use successfully (using a drill press, that is) and stick an .039 wire through it, the remaining opening will be just about equal to a .005 orifice. If the flow needed further adjusting, the wire could be stretched or filed to fine tune the fit, or a smaller or larger wire used.

To calculate the flow from such an orifice, just calculate the area of the hole and the plug using $\pi r2$, subtract the area of the plug from the area of the orifice, figure the equivalent diameter for that area and plug it into the flow formula.

It doesn't take much to clog so tiny an opening (though the wire-plugged orifice seems to be more resistant to clogging than a simple hole since a single particle can't plug it and the wire tends to vibrate with the flow, which helps dislodge any blockage) so some sort of micron filter before the orifice is desirable.



There are gauge snubbers - compact $10 fittings with a sintered metal filter inside - from McMaster-Carr that would seem to be ideal for this purpose, though the directions warn that they are not intended for use as filters. I suspect the reason for not using them as filters is the limited filter area which would clog quickly if used to filter large volumes of questionable gas, however, they seem to work fine in this application.

An alternative to an orifice is to use a needle valve. Precision "instrumentation" and "metering" needle valves are available that can be adjusted down to flow rates comparable to microscopic holes, though some way of locking the setting will be necessary unless it is to be calibrated every day. The needle valve should ideally be one intended for use with gases - ones made for fluids usually don't allow fine enough adjustment.

Flow Fuses

There are also fittings, usually called "flow fuses" which are made so that they permit a moderate flow, but close if the flow gets too high. They would seem to be a very good thing for an O2 system, should a meltdown or line rupture occur. Unfortunately, most of them have flow ratings much too high to be of any use in gas mixing applications. Aqua Environment makes an adjustable one that can be adjusted down low enough to be useful, but it's aluminum, and hence questionable for use with 02.

OTHER FITTINGS

If one is cobbling up any sort of custom gas handling setup, one will need, in addition to any special SCUBA or CGA fittings, a whole bunch of plain old taper thread fittings like elbows, connectors and pipe nipples. Brass the material of choice, since tolerates O2 well and doesn't spark or create chips or flakes that might. Also, it looks prettier and doesn't rust. The easiest place to find these is in the plumbing section of a hardware store.

Are these fittings up to the pressure? Good question. Most hardware store clerks will give you a funny look if you ask what the pressure rating is for their brass fitting. Most everyone I know uses them, at least in the smaller sizes, without much hesitation for pressures up to the 3000 psi (200 bar) range, but I've always had some lingering question about how foolish we are being to do so.

I finally tracked down some specs for one common hardware store line of brass fittings, and found they are rated for only 1200 psi (83 bar) regardless of size.

The interesting thing, though, is that while the service pressure is that same 1200 psi for the whole line, the burst pressure rating is 15,000 psi (1035 bar) for 1/8" (3mm) and 1/4" (4 mm) fittings, and only 5000 psi (345 bar) for anything larger. That suggests that, in the smaller sizes at least, these fittings are very conservatively rated and explains why they seem to handle high pressures with such aplomb. The steel fittings in the same line are rated for 3000 psi (200 bar), with a 15,000 psi (1035 bar) proof rating in sizes up to an inch or so.

The Western catalog shows some brass fittings that don't look very much different from the better hardware store variety, and lists them as good up to 3000 psi (200 bar), and in some cases 5500 psi (380 bar) Above that, they say, use steel. Are the Western fittings better quality, or are they just rating them for a higher percentage of the burst pressure? Hard to say, but since they don't cost much all that much more, why not use them?

Global also carries a full line of fittings, and recommends brass for up to 3000 psi (200bar) and SS for higher pressures.

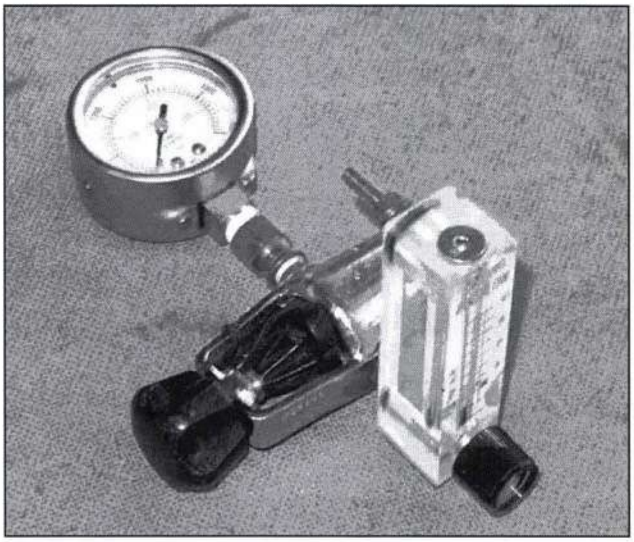
There's not really much point in using fittings much bigger than 1/4" (6mm) if it can be avoided, not only because the smaller they are the stronger they are, but it's good to keep the volume of the manifolds and whips as low as possible to limit the explosive force and flow rates should something let go. At the low flow rates one should be using for tank filling and gas mixing, 3/16" or 1/4" is plenty.

Cale used to use hardware store fittings almost exclusively, but believed the secret was to select them carefully. To demonstrate, he liked to show off three 1/8" brass tees he picked out of the same bin at the local hardware. One was machined from solid, with the wall thickness a reassuring 5/32" (4 mm). The other appeared to be forged and very solid, while the third was crudely cast, with the holes drilled off-center and a crack already starting along a casting line.

I say "used to" because Cale has recently discovered that there's a busy black market in used and surplus Cajon, Parker and similar valves and fittings on Ebay, and Cale cannot resist a bargain. Gorgeous HP SS fittings are gradually replacing all his nasty old hardware store brass - the ones that haven't already exploded, that is.

Active components, like valves and gauges, that have working parts, are another matter altogether. While many will withstand much more pressure than they are rated for, using them so is a crapshoot and cannot be recommended.

So three things to remember when selecting fittings:



Cale's Swiss Army Knife - it's a sampler, a filling yoke, a tank pressure-checker, and an emergency O2 regulator! Note $5 surplus flowmeter/needle valve combo

- the smaller a fitting is (usually) the higher the pressure it can handle given similar threads and wall thickness (note the brass fittings mentioned earlier are all rated for 1200 psi (830 bar) but the smaller ones have much higher burst pressures than the big ones. Similarly, a 1/4" (6mm) hydraulic line typically has a burst pressure of 11,000 psi (760 bar) where a 1/2" (13mm) may be as low as 8000 (550 bar).

- the smaller a fitting or line, the less compressed gas will be contained in it at any time, hence the less explosive potential should it let go. When it doubt go small.

- don't fudge. Use fittings that are designed to work with each other. Don't try to force incompatible fittings together, or trust teflon tape to do the work of properly fitting threads. If threads must be cut to make or mate custom fittings, be sure the hole bore is the proper size to assure full thread depth and that the threads are properly formed.

Speaking of teflon tape, it probably worth mentioning here that a good paste thread sealant (O2-compatible, if used with HP O2) will run circles around teflon tape when it comes to sealing a chronically leaky joint - especially on stainless steel, which isn't as compliant as brass, and often will not seal well without extra help. Stainless also tends to gall when tightened dry, so if a sealant isn't used, the threads should always be lubed with a dab of O2-safe lube, tapered fittings especially - in fact, using a bit of lube will often allow SS fittings to be tightened so well that no sealant will be necessary.

Regulators For Mixing

A regulator makes a very nice addition to a mixing whip, since instead of having to stand there fiddling with the valve while the pressure inches up, one can simply set the output to a tad below the target pressure. This is especially useful because otherwise, if one is doing a lot of mix, there's a tendency to keep cranking up the fill speed. Do this long enough, and one day one will inevitably run into a contaminated tank or over-lubed valve, and the fireworks will begin.

In most of the few authenticated reports of combustion during PP mixing that I've been able to find, it is hard to avoid the conclusion that the mixer simply cranked the O2 on too hard and fast, and encountered adiabatic combustion. 70 psi/min (4.5 bar/min) means 5 to 8 minutes for the average nitrox O2 transfill. Filling more than a couple tanks at time could easily drive me to take my chances with shortcuts.

The only problem is finding the right reg, since it must be O2-compatible and have a very wide output range - ideally, something like 0 - 1500 psi (100bar) or more so it'll have adequate range for adding O2 over old mix. The O2 regs one is most likely to come across used or surplus tend to be welding and med regs, and rarely output much over 150 psi (10 bar). Suitable regs bought new cost in the $150 - $250 range.

That being the case, for the home mixer, a reg like this is a luxury. Still, they do turn up for less, so it's worth keeping one's eye open. I bought mine new-surplus, in an electronics surplus shop of all places, for $18.

Many of the used regs one will run across with the proper output range will be inert gas regs. It is easy enough to change the inlet fittings for use on an O2 tank, but there's not way to know how suitable the internals are for use with straight O2 (or how contaminated they are). This leaves one with a choice of attempting to home - O2 clean the reg, or taking it to a welding supply where you'll probably be told it can't be done. All in all, it's probably easier to keep looking for a "real" O2 reg with the right range than try to cobble something together, though many mixers report successfully O2-cleaning and using second-hand inert gas regs.

O2 regs usually appear identical to other gas variants within a given industrial regulator line, though I notice in the Purox catalog, that their dedicated O2 regs now include a "unique patented internal baffle design to suppress internal forces in the even of a burnout".

Mixing Panels

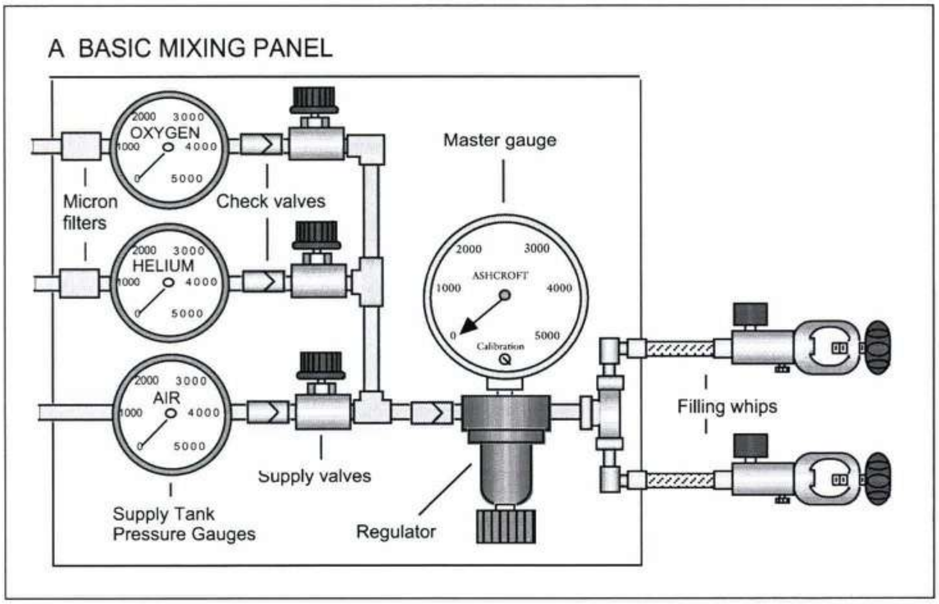
The next step up from a whip is a mixing panel. Mixing panels allow integrating the O2, air and He filling steps so that the same master gauge is used for all the gases. Panels are usually used whenever a lot of mix is being done, and a compressor is located on the premises, so it can be tied in to the panel. But not always - some divers have built very elegant panels into Pelican boxes, for use in the field as an alternative to a simple whip.

Many different variations are possible. Some panels incorporate O2 analyzers, flow restrictors, booster pumps or other refinements for increased safety, accuracy or convenience. The panel shown includes a regulator, but many panels make do with valves only. If a cascade was being used for any of the gases, the valves and gauges for the cascade could be incorporated into the panel for convenience.

Nice portable mixing panel in a case. QRs, I notice, are Parker STs.

The panel shown is set up to do trimix as well as nitrox (the same panel, obviously, can be used for both). A nitrox-only panel would be exactly the same, minus the contents gauge and plumbing for He. It makes sense, if making a nitrox-only panel, to leave room for the additional parts needed for He so it can be easily added at a later date.

Usually the mix panel isn't used for plain air fills, to avoid using up the hyper filters or contaminating the lines. The air feed comes from the hyper filters, and another set of whips not feeding from the hyper filters is used for air fills.



CONTINUOUS NITROX MIXERS

Newcomers on the mixing scene are the Nitrox Stick and similar devices such as the Quick Air.

These are relatively low bucks ($1000-$2000 without the analyzer) continuous ambient entrainment devices that squirt some 02 into the air before it is sucked into the compressor, so that the compressor outputs ready-mixed nitrox.

Basically this just takes a mixing chamber with an O2 feed near the intake and an O2 sensor at the exit.

In between the two the chamber is baffled to provide a "tortured path" to create enough turbulence to thoroughly mix the O2 with the air before it reaches the sensor or the compressor. This ensures that the sensor can get an accurate reading, and lessens the chance that a slug of straight O2 might make it into the compressor, causing combustion or worse.

The O2 is supplied via an adjustable regulator so the output pressure can be adjusted in order to obtain the desired FO2.

Continuous mixers like this have a couple of very real advantages over PP mixing. The main one is they eliminate the need to transfill 100% O2 at high pressures and the attendant risks - the O2 is decanted via a medical or industrial O2 regulator, and is at ambient pressure when the mixing is done, so the fill tank, valve, and filling hardware never see straight HP O2. This being the case, super-clean air is not required and tanks don't need to be O2-cleaned.

Since the O2 is decanted to ambient before being recompressed, the mixer makes it possible to use more of the contents of the supply tank.

Continuous mixers are expecially nice for topping up, since it is possible to add some nitrox on top of a partially full tank regardless of how much pressure is left in the O2 supply tank.

If one hase access to a compressor, a continuous mixer is definately the way to go - they make blending nitrox as quick and easy as filling a tank.

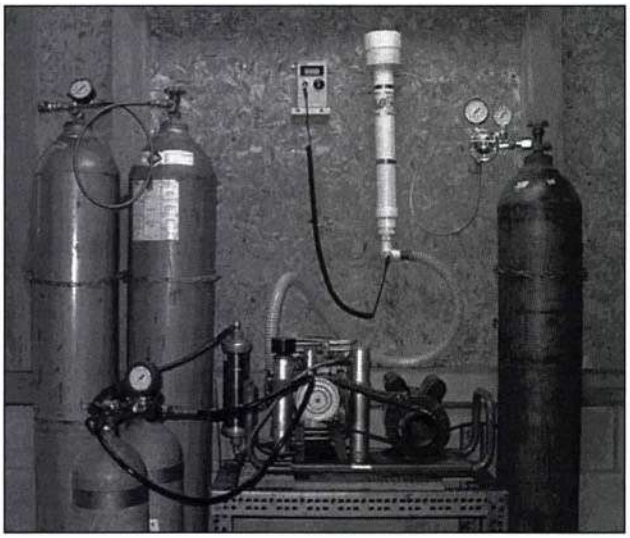
Their one limitation is that they can only be used for mixes in the normal recreational range - since the O2 is going through the compressor, FO2s in excess of 40% can result in combustion, and there has been at least one case of a compressor exploding so violently that it blew itself through the wall of the building!

I was skeptical when these devices first appeared, because it seemed to me that the output volume of a compressor would vary enough as the tank pressure increased to make it difficult to produce a consistent mix. It turns out, though, that the volumetric output of a multi-stage HP compressor is relatively uneffected by the output pressure, so that these devices work quite well.

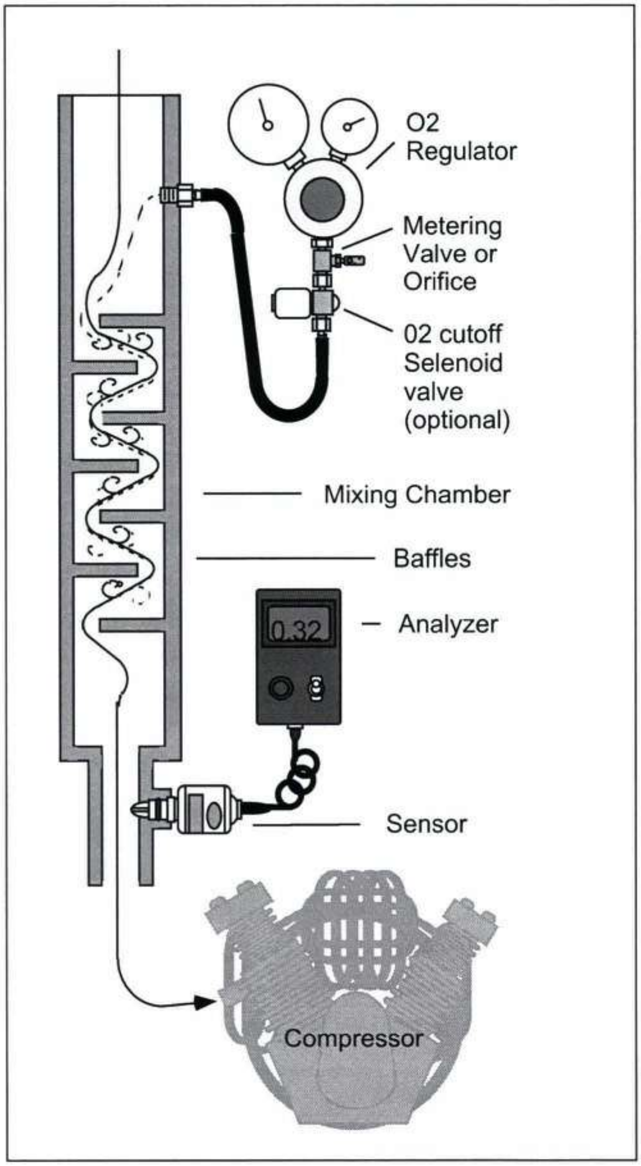
When continuous mixers first appeared there was also some concern about them harming compressors, and some people insisted that they should be used only on oil-free compressors.

The compressor manufacturers have given mixed messages as to how advisable it is. At one time both Coltri and Bauer were on the record as saying that running up to 40% O2 through their compressors would not effect the warrantee as long as a proper nitrox-compatible oil such as EZ-1000 was used. Bauer, though, seems to have changed its mind since then, and now says that using a continuous mixer will void the warrantee. Be that as it may, thousands of people all over the world are happily continuous mixing with standard compressors, most of them probably Bauers, and remarkably few incidents have occured. Coltri, Alkin and Eagle don't seem to have any problems with it, and it's also worth noting that membrane separators run nitrox into a compressor in exactly the same way as continuous mixing does, and there are a number of companies making membrane separator setups that also use standard compressors, from both Bauer and Coltri.

This is not to say that the units are idiot proof. or will suffer fools! There are several very real dangers anyone operating a continuous mixer



A Continuous Nitrox Mixer In Operation. Note the two-tank mini-cascade on the left.



Continuous Mixer Schematic

should be aware of.

The main one is that, since oxygen mixes start getting scary at the 50% mark, the 40% limit should be taken very seriously, and anyone who needs 50% or higher should not try to use a PP mixer to produce it (although it is possible to prime the tank with 100% as one would for PP mixing, then top off with 40%, which is often easier than PP mixing higher FO2 mixes from scratch).

The other is that if oxygen should is turned on and allowed to run for a while before the compresor starts, or if the compressor is allowed to stop then restart while the oxygen was running, the compressor could fill with pure O2 and combust. Hyper filters don't address the problem, since they are downstream of the compressor. Some of the commercial units have a solenoid cutoff valve on the O2 line that stops the flow of O2 should power to the compressor be interrupted The ideal would be to hook an analyzer directly to the solenoid, so the compressor power or O2 flow would be automatically cut if the O2 spiked. Such systems exist, but they are not cheap. So far the only mixers I've seen that will do this use modified old medical analyzers that have adjustable high/low alarms that can be tapped to trigger the solenoid.

A magnetic starter, which prevents the motor from restarting should power be interrupted is also valuable, especially in areas subject to frequent outages.

However, regardless of how many safety devices are attached, a unit like this should not be used unattended, and simply keeping a close eye on the unit while it is in operation is your best protection.

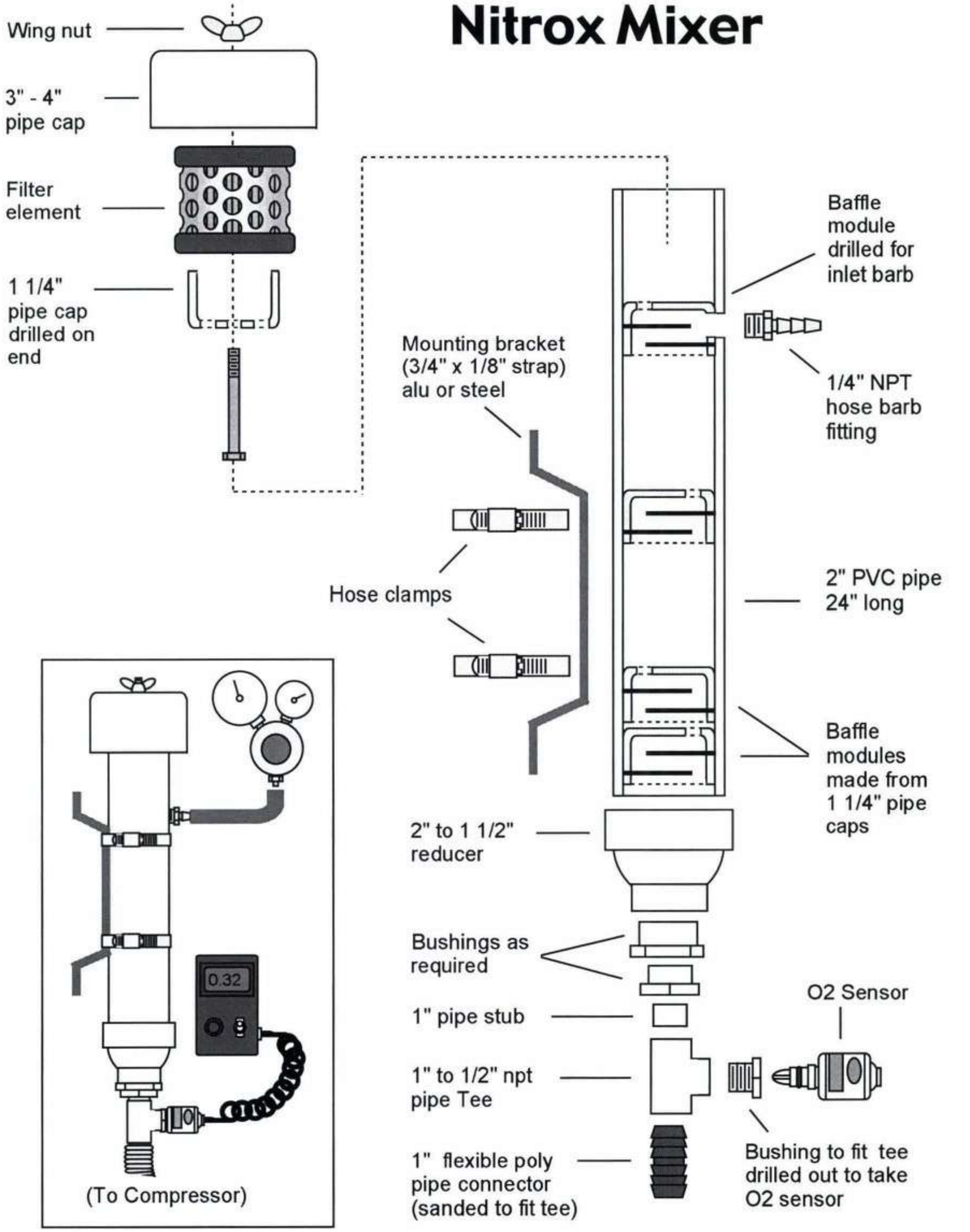
Another danger to be aware of is that if the compressor is an older one, and especially one that was run on mineral oil, it may have enough carbon buildup to combust in the presence of the extra O2 if the compressor gets too hot. So most sources advise cleaning the valves and the condensor coils on an older compressor, and converting it to O2-safe synthetic oil, before using it for continuous mixing. And, as with any mixed gas, always sniff test the mix before use!

Building One

These are ideal devices for homebuilding - even the commercial offerings have a distinctly homebuilt look about them, being glued and hose clamped together from everyday hardware store plumbing fittings.

Most of their cost is for the regulator and analyzer hardware (and doubtlessly product liability

A Continuous Nitrox Mixer



insurance). Since suitable used medical and industrial regulators are very common items in surplus stores and flea markets, and the homebuilt analyzer described elsewhere in this book will work just fine, it's possible to homebuild a continuous mixer for a fraction of the cost of a commercial unit.

Just about any adjustable-ouput regulator can be used, as long as it can provide enough volume for the compressor being used. Two stage regulators are nice, since they have a more stable output, but not really essential.

The output must be equipped with an orifice (though some units use a vertical column flowmeter and needle valve instead) in order to allow regulating the flow by adjusting the output pressure.

The size of the orifice depends on a number of factors, mostly how big the compressor is and how much pressure your regulator is able to output. The bigger the orifice, the lower the output pressure setting that will produce a given mix. If the orifice is too big, then the output pressure range required may be so narrow that it will be difficult to accurately adjust the regulator. Also, regulator output may be erratic at very low settings. Too high and it'll waste gas because it won't be able to run the supply tank down as low. I like to size the orifice so the mixer produces 40% nitrox at an output pressure of 40-50 psi, since this gives enough range on the gauge to set the mix easily, but allows using almost all the O2 in the tank.

Orifices are available from M-C and other industrial suppliers, in a range of sizes and configurations. The orifice size should be something in the area of .020 (.5mm) for a 3 cfm machine to .040 (.1 mm) for a 7 cfm.

Actually, my current setup just uses the orifice that was already on the regulator, a 0-15 lpm medical reg, which works just fine for my little 3 cfm compressor. If a stock medical orifice is too small, it is often possible to increase the flow by diddling the orifice with a pick or bit of wire to open it up.

I replaced the LPM gauge with a big 4" 0-100 psi gauge, which makes it easier to adjust output precisely.

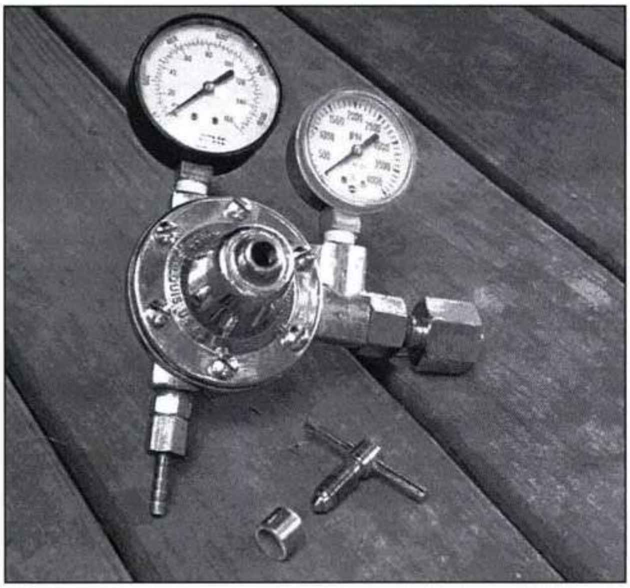
Some continuous mixers put the orifice right at the mixer, so the O2 is sprayed in under pressure, figuring the extra turbulence will ensure a better mix, but putting the orifice on the regulator allows using random low pressure hose and fittings between the regulator and the mixer, and seems to work just as well.

A needle valve can be used instead of an orifice. which eliminates a lot of trial-and-error, but it should be one that can be locked to hold the setting - M-C #4955K13 "tamper-resistant needle valve" would work nicely, since it has a locknut to lock the adjustment.

The Nitrox Stick, which uses a lockable metering valve, uses a clever variation on this intended to make the rig a little safer. When the unit is first placed into operation, the operator completely closes the metering valve, then starts up the compressor, cranks the regulator output pressure up as high as it will go, then gradually opens the metering valve to produce the highest FO2 output the operator is comfortable with - usually a little over 40%. Then the metering valve is locked, and the compressor output pressure used to adjust the mix in the normal manner, the idea being that it will now not be possible for anyone to accidentally crank up the output high enough to produce an unsafe mix.

The only problem with this is it pushes the pressure necessary to get a desired mix up unecessarily high, and thus lessens a mixer's ability to make full use of the supply tank's contents. An easier way to achieve the same protection might be to make a sleeve to limit how far the output adjustment knob on the regulator could be screwed in.

The mixer itself is built of PVC plumbing pipe and fittings. There's no right way to do the baffles - whatever works, works. One of the earliest of these continuous mixers actually used a little bouncing ball in the air path, and others have used little propellers or squirrel cages. These are probably overkill. The Nitrox Stick uses an off-the-



A simple spacer sleeve, or even a stack of washers, on the adjustment screw can protect against setting the output too high.

shelf "static" or "motionless" pipe mixer which can be had for $60-200 depending on material (PVC or SS) and size. These are lengths of pipe with twisted ribbon baffles inside which are really made for mixing liquids, but seem to do a fine job on gases, while adding minimal resistance. If I was building a mixer for commercial use, that would see a lot of service, I would probably use one of these mixers rather than build my own baffles. And some DIYers report good results using Whiffle golf balls for baffles.

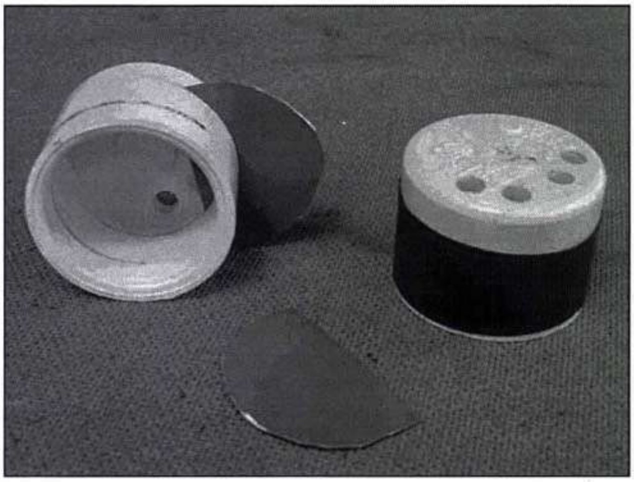
My mixer uses baffle modules made of pipe caps and sheet metal (aluminum flashing or flattened tin cans work fine) just because they are cheap, easy to make without special tools, and can be added or subtracted easily to get just the right amount of baffling. The caps should be wrapped with a little tape for a snugger fit if necessary, or can be cut to take O-rings.

I drilled a 3/8" (10 mm) hole in the side of one of the baffle modules, opposite one of the baffles, then put it in the stack even with the O2 inlet hose barb fitting before screwing the barb in, so the barb once screwed in would hold it in place, the idea being to deliver the O2 into the flow at a point of maximum turbulence.

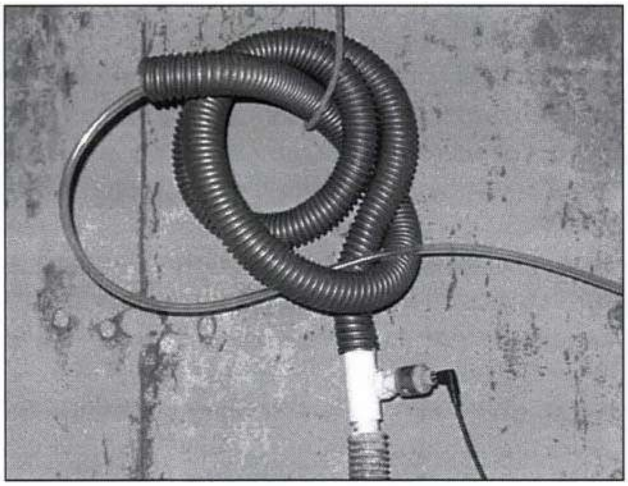
The important thing in designing baffles is to be sure that there is no continuous path through them. The incoming charge - all of it - should be mixed and remixed with itself with no exceptions. I've seen some homemade continuous mixers which are heavily baffled, but with a continuous gap between the baffles and the chamber walls - not good, since the O2 can remain stratified and "creep" along the wall, and the sensor give an unrealistically high or low reading depending on where it is positioned in relation to the O2 flow.

Too much back pressure is not a good thing either - the clear path through the baffles should always be roughly equal in area to the intake tract of the compressor. The back pressure can be tested by inhaling through the mixer - there should be no more resistance, and preferably less, than breathing through a decent quality SCUBA regulator (1-2" H2O) - or by hooking up a manometer or magnahelic gauge to the sensor port.

Some homebuilt mixers don't even bother with baffles. A number have been made out of nothing more than a length of corrugated vacuum cleaner-type hose. A straight piece of pipe with a filter and O2 injection are attached to twenty feet or so of looped hose leading to a tee with the sensor on it, the idea being that the corrugations and bends will provide enough turbulence to homog-



Baffle modules are pipe caps with alternating slots hacksawed in them to take metal baffles.



Quick and Dirty Corrugated Hose MIxer. The hose before the tee is a bit too short to provide good mixing.

enize the brew. A few even do without the lead-in pipe, and just stick the tube from the O2 regulator a foot or so down the corrugated tube. It's tempting, on a minimalist mixer like this, to mount the sensor on the compressor itself, but this isn't a good idea since the vibration can damage it - it should be at least a couple feet from the compressor, and connected to it via a flexible hose.

The example shown doesn't make any pretence to being the ultimate or the end-all. It's just one of a zillion possible variations that will do the job. I tried to come up with a design which would be both easy to make and easy to describe. One thing I do not like, that some mixers use, is stainless steel or brass wool or scouring pads, since there's always the possibility that some bit of them may be sucked in, and damage the compressor. It's a good rule to use nothing inside the mixer which is small enough that it could get sucked into the compressor.

The sensor fits into the side port of a PVC pipe tee. I used one that has a 1/2" threaded NPT port on the side, and bored out a PVC 1/2" plug to take my sensor. The Teledyne sensor I use has an O-ring sealed adaptor that fits into a 15mm hole (a 19/32" drill works fine).

Keep in mind that the mixer doesn't have to deal with much pressure, and that leakage upstream of the sampler simply doesn't matter since the end is wide open. The mixer will run fine without cementing the fittings together, too, so there's no reason to cement it together until it's been run long enough to know that it works. Leakage downstream (towards the compressor) of the sensor is much more significant than leakage upstream, since downstream leakage will undermine the sensor reading.

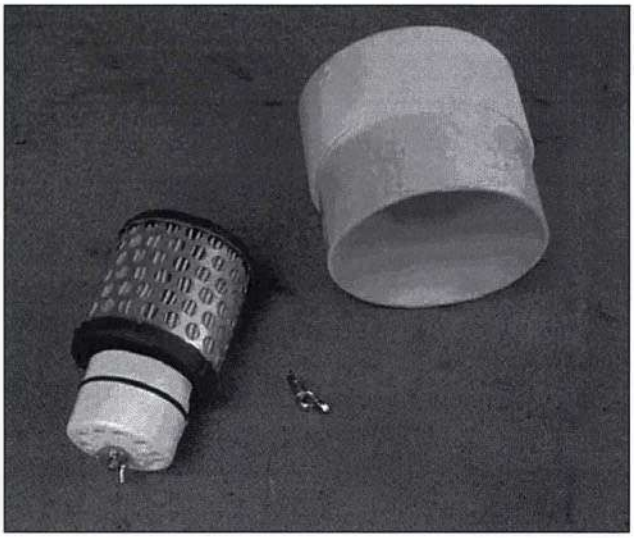
The mixer works fine on my 4 cfm compressor, and should be good up to 8 cfm or so. For a larger compressor it might be desirable to scale up the design somewhat.

My mixer incorporates a filter, but this wouldn't be necessary if my compressor had an "L" filter that allows hooking up a hose from the compressor filter to a remote intake. If would also be possible to use a complete filter assembly from an industrial supplier like McMaster-Carr or MSC, or even J.C. Whitney. If no filter is used at the mixer end the mixer should probably still have at least a screened inlet to keep crud, small objects, insects and rodents from being sucked in - the Nitrox Stick uses a SS screen 100 mesh sump filter intended to double as a flash screen.

My filter assembly is made of PVC pipe fittings and a Briggs and Stratton #5026 filter (just because it was the right size and easy to find anywhere). It's mounted on a pipe cap like the ones used for the baffle modules, which just slips in the tube. The pipe cap should be wrapped with tape for a snug, airtight fit; I got fancy and cut mine to take an O-ring. Srtips cut from a bicycle inner tube can also be used.

Using The Mixer

The single most important rule is not to not turn on the O2 until after the compressor is running, and to turn the O2 off before stopping the compressor. Otherwise the danger is that the mixer and hose will fill with near-100%, and blow the compressor when it starts. Also, the regulator output pressure should be turned down before opening the O2 tank valve, to guard against the possibility that the regulator may be set too high,



Air filter assembly made by sandwiching a small engine filter between two pipe caps.

and deliver a spike when the tank valve is opened.

Those precautions aside, continuous mixers are pretty straightforwards. Once one gets a feel for the gadget, it's usually easier to adjust the mix by using the O2 pressure rather than the sensor. If one tries to adjust the mix using the sensor, it's too easy to wind up "chasing" the sensor, overcorrecting in one direction and then the other.

Once a mixer is up and running, the easiest thing to do is to mix couple of tanks of nitrox, logging the pressure (or flowmeter) setting used for each one and the analyzer reading while the mix is being done. Then, after the tanks have sat a while, analyze the contents and compare the results to come up with a correction factor to use in setting the mix. It's pretty common to find a descrepency between what the analyzer is reading while the mix is being done and the final reading when the tank is analyzed, and even the best commercial mixers will often be off by about 0.5%. However, anything over 1% is usually an indication that the baffling is inadequate to homogenate the brew, or that there's leakage downstream of the sensor.

While you're at it, log how long it takes your compressor takes to fill the tank in 500 psi increments. If there's a big difference between the first and the last it means your compressor does not deliver a very consistant output over the fill, and it may be necessary to work out another compensation factor to use when doing top-ups. This is no big deal - just a matter of remembering to crank up the flow a tad more when doing top ups on an almost full tank.

Continuous Trimixing

By adding a second feed for He, it's possible to pump trimix with a continuous mixer. Normally, this requires a special He analzyer, as discussed in the next chapter.

However, I should mention that there are divers who are using continuous mixers for trimix without the benefit of a He analyzer.

There's at least two ways to do this. One is to calculate the He flow rates necessary to get the desired mix with the compressor being used, set the flow using a He-calibrated flow meter (or one calibrated for air or O2, and multiplying the reading by 2.6), then run off some trial tankfuls and check the starting and finishing pressures in the supply tank to see how well reality matches theory and working out a table of flows for each mix.

This requires some complicated math because it's necessary to deal with gas volumes rather than just pressures, and there are several jokers in the deck, like compressibility and the fact that gas suppliers can often tell you only approximately what the capacity of their tanks is. It's a lot safer if there's a He analyzer nearby that can be used for the initial calibration, and to check an occasional batch with. And each batch should routinely be doublechecked be reference to the starting and finishing supply tank pressures and volumes.

A better way is to make a premixer, basically just a smaller version of the main mixer, to blend the O2 and He before they are injected into the main mixer, and put another O2 anlyzer between the premixer and the main mixer. Since the premix contains nothing but O2 and He, the amount of He can be read simply by subtracting the %O2 from 100.

A little math is necessary to find the right O2 to He ratio necessary to produce the desired mix. First one figures how much of the final mix O2 will come from the air, and how much must be added. For a 17/45, for example, one gets:

(21/79) x 38% = 10%   17% – 10% = 7%

So it will be necessary to add 7% O2 and 45% He, which adds up to 52% of the total mix. Given these numbers one can calculate the percentages of both gases in the premix:

$\frac{45\%}{52\%}$ = 86.5% He $\frac{7\%}{52\%}$ = 13.5% O2

That means a 13.5/86.5 premix, so adjusting the flows so the premix O2 analyzer reads between 13 and 14%, and the mixer O2 analyzer 17%, should produce the 17/45/38 mix.

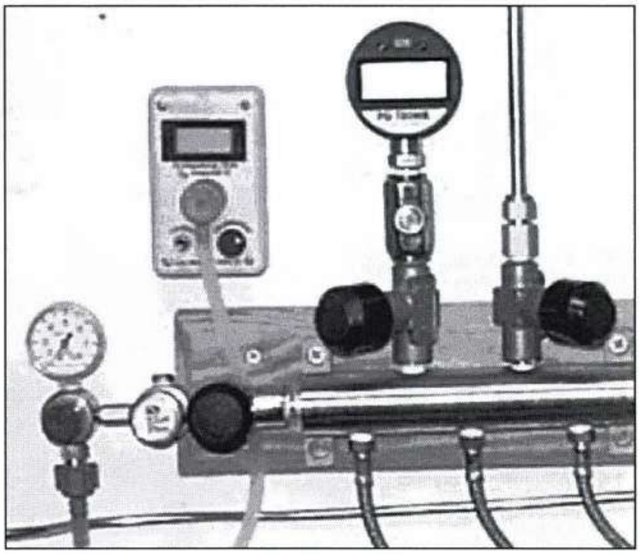
Since there's a lot more leeway in the PHe than the PO2 neither method is a totally suicidal endeavour, though both are certainly not something to be approached casually and without a full understanding of the issues - and math - involved.

Upstream and Downstream O2 Sampling

Continuous mixers usually use an upstream analyzer- that is to say, the one mounted on the mixer, before the compressor - so the mix is analyzed before it goes into the compressor, which gives the operator at least a fighting chance of catching it if the O2 gets too high before something blows. However, a downstream analyzer, that analyzes the mix after its been through the compressor, will provide a more accurate reading of what is really going into the tank.

Sampling the mix downstream, when it is compressed, requires special, expensive sensors able to function at pressure. An easier way to do it is to use a standard analyzer like the one used for the upstream sampling, with a step-down regulator to reduce some of the mix to ambient and trickle it through the sensor. Doing so requires an extra regulator and a flow reducer, though the same bleed could also be used to feed a CO detector.

Actually, the setup is exactly the same as is used to sample mix from a tank, only it's permanently installed on the HP side of the compressor, so a



A Downstream Analyzer. The adjustable output medical regulator on the end of the HP compressor output manifold feeds a dedicated analyzer

cheap old medical, industrial or balloon regulator can often be used. Compressed Air Specialties Inc. sells a nice $60 non-adjustable 150psi (10 bar) regulator rated for 5000 psi (330 bar) regulator that is perfect for the purpose

A downstream sensor is a real luxury, and few continuous mixers have one. However, it does makes calibrating a new mixer much easier since it isn't necessary to fill a tank to find out what the rig is outputting. It's possible to improvise one temporarily for calibration purposes by making up a simple sampling tee to go on the compressor fill whip so the output FO2 can be read directly.

It's not even absolutely necessary to have two analyzers - the same analyzer can be switched back and forth (taking care to plug the hole in the mixer when the sensor is not installed) and the readings from both positions compared.

An interesting subtlety worth noting in passing - since the upstream analyzer on a continuous mixer will be reading ambient air, and the downstream analyzer air that has been dried by going through the compressor and filters, in humid conditions there will always be a difference between the two readings equal to the correction factor on the Analox chart.

Chapter 9
ANALYZERS AND SENSORS

Overview

Analyzers and sensors are a major part of the mixing game, because anyone mixing dive gas absolutely MUST have some way of analyzing the mixture for O2 content, both immediately after mixing, and before use. There are a number of gauges made for this purpose, such as the OxySpy, Miniox and Handi, which are available from tech dive gear dealers, medical suppliers, and some mail order dive houses.

Two things are necessary to analyze mix - the analyzer and a sampler. The analyzer consists, usually, of a analyzer box, with the gauge in it, and a separate sensor that plugs in to it.

The sampler consists of whatever hardware is necessary to decant a trickle of mix from the tank and immerse the sensor in it. Usually this breaks down into two parts - a tank adaptor or regulator with some kind of a flow restrictor, and a concentrator or sampling tee that the sensor plug or screw in to, and that directs the flow at the sensor.

A Commercial Analyzer from OMS - that flowmeter looks awfully familiar!

Not too long ago this was done mostly using borrowed medical and industrial hardware The usual setup was a Miniox or similar analyzer, a medical sampling tee, and a tank sampler made from a SCUBA filler yoke, a regulator and a vertical column flowmeter. The price of all the hardware really could add up, and smart divers soon started hanging surplus flowmeters on old SCUBA first stages.

Since then, as more gear has made specifically for SCUBA has appeared, things have gotten a bit simpler. The bulky sampling tee has given way to compact concentrators like the Maxtec and the yoke and regulator samplers have been superseded by compact reducers that snap on a BC hose QR. Increasingly, SCUBA O2 analyzers are building the sensor, and maybe a flow reducer too, right into the analyzer box. The latest analyzers to hit the market, like the Expedition and the OxySpy, don't use a flowmeter at all - you just crack the tank valve slightly and hold the analyzer up to the valve opening.

However, all this sophistication costs money. The good news is that it's possible to build an analyzer and sampler for a fraction of the cost of a commercial unit using parts easily available from a number of sources.

The OxySpy analyzer reads directly from the tank so no sampler is necessary.

ANALYZERS

Oxygen analyzers generally use a galvanic cell for the sensor. A galvanic cell is, in effect, a little fuel cell with a lead anode and a gold plated cathode and some electrolyte gel that, when exposed to O2 fuel, creates a small current of electricity, usually in the 0-20 millevolt range. The higher the fuel concentration, the higher the voltage produced. The electronic gauge portion of the Miniox is actually little more than a digital voltage meter (DVM) which has been calibrated so it reads out in percentage of O2.

Since the commercial analyzers are essentially nothing more than a custom calibrated DVM with an $80 sensor attached, it might occur to anyone already owning a (good) DVM just to buy the sensor and use their DVM with it, doing whatever calculations are necessary to convert the volts to %. It works, though at the cost of introducing one more layer of possible error into the process.

How about using a $25 automotive O2 sensor? The notion keeps popping up, but I haven't heard of anyone actually doing it. There are a couple problems. For one thing, automotive O2 sensors are intended to measure the small amounts of O2 that make it through the combustion process so it questionable whether they'll even function at the much higher levels found in dive mixtures. For another, they are designed to work HOT - like exhaust system hot. There's usually even a time switch in the fuel injection system that cuts the sensor out of the loop until it has had a chance to heat up. I suppose one could use a blow torch to preheat it......

Later cars use three wire sensors which have a built-in heating element to heat them up almost instantaneously for faster and more consistent readings; one of these, I suppose, could be rigged up to a 12v source. This might solve the heat problem but, since three wire automotive sensors cost pretty near as much as the proper mine safety/medical O2 sensors like the Teledyne, and probably won't give nearly as good results, it's uncertain what the point of this exercise would be.

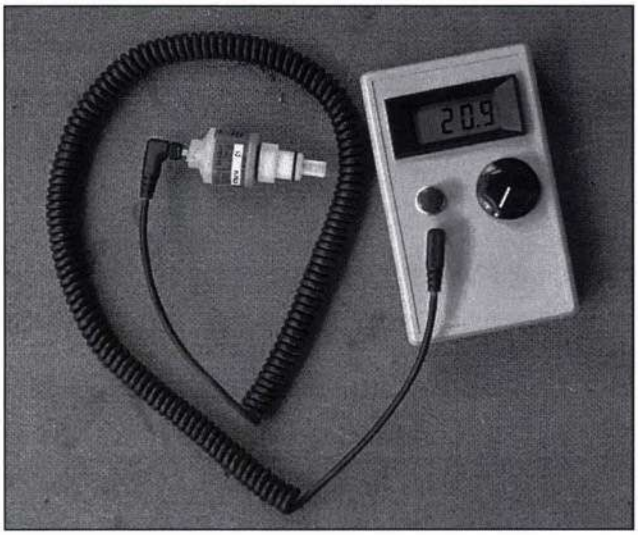
Since the sensor is the heart of an analyzer, if one is trying to save money it makes sense to use a real sensor and save money elsewhere, by using a DVM or other gauge.

To use a DVM, hook it up to the sensor, then sample a known reference mix - usually air, for obvious reasons. Then divide the reading by 20.9, the percentage of O2 in air, to find the % per mv for that particular sensor. Then run some 100% O2 through the sensor. You should get a reading of 100 X your conversion factor. Actually, it is very common for the 100% figure to be a little off, since sensors are not completely linear, but if it is off by more than say, 2%. something may be wrong with your setup.

Once the conversion factor has been established, sample the mix you want to analyze, and multiply that reading by the conversion factor just obtained.

For example, suppose a sensor's reading on air is 11.7 mv, then:

$$\frac{11.7}{20.8} = .5625 \text{ volts per \% O2}$$



An OXY HACKER Analyzer

That means a 36% nitrox mix should measure:

36 x .5625 = 20.25mv

One can quickly doublecheck this by using a bit of common sense. Since 36% is almost double 20.8%, a 36% mix should read a little less than double 11.7mv, and it does.

Suppose you are trying to mix 36% nitrox and after mixing it you analyze it and come up with a reading of, say, 18.58 mv.

By dividing it by .5625 you can find out what the % of O2 is:

$$\frac{18.58}{.5625} = 33.03\% \text{ O2}$$

The only thing to remember is, as anytime you use reciprocals, is to keep them straight. In the last example, it wouldn't be too hard to get mixed up and instead do:

$$\frac{.5625}{18.58} = .0030\% \text{ O2.}$$

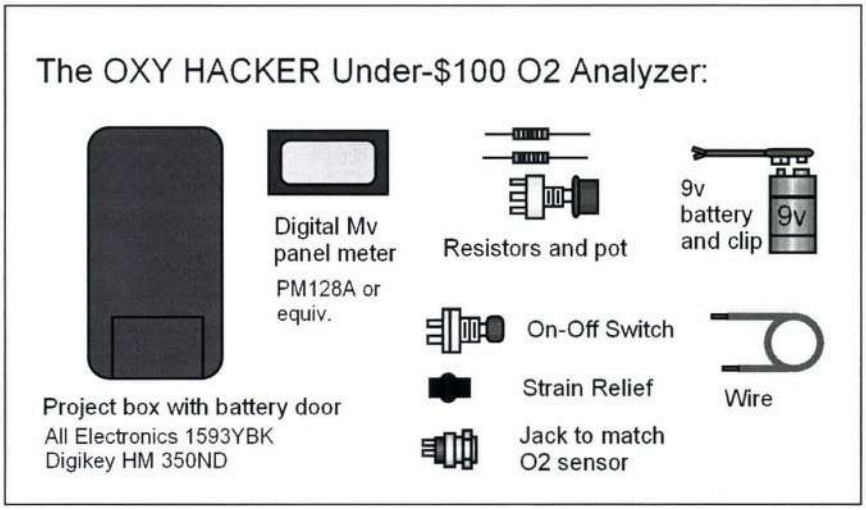
The answer is obviously wrong enough that common sense should alert one to the error. BUT in this particular case the answer is otherwise close enough that if one does math like I do, one might be tempted to assume the decimal point was in the wrong place and go off thinking there was 30% O2 in the tank. Oh well, it probably wouldn't be fatal.

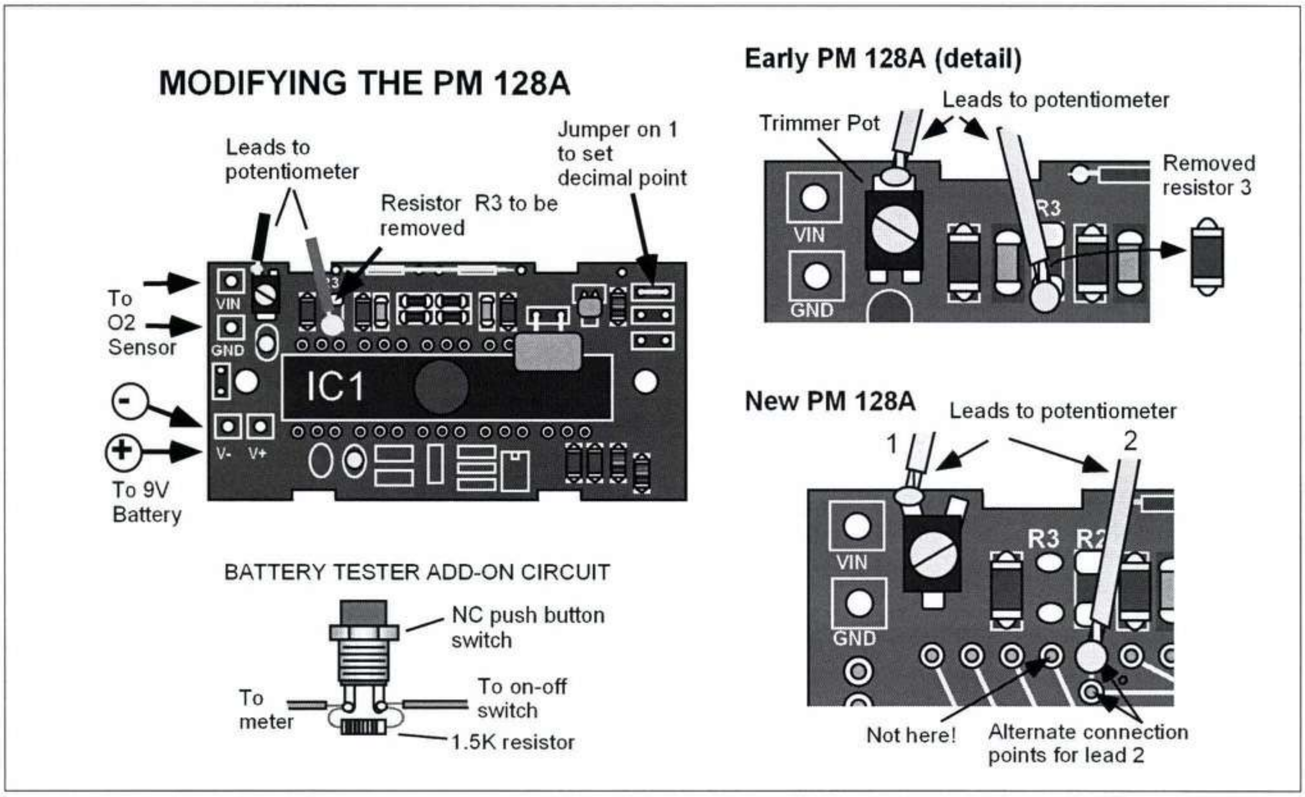
This kind of DVM analyzer must be "recalibrated" every time it is used, by sampling air and doing the math to find the current coversion factor, since an O2 sensor's output will vary slightly from day to day, and as it ages. It's also a good idea to crosscheck the results against a "real" analyzers whenever possible, or on known mixes other than air.

The OXY HACKER Analyzer

All that math is just an invitation to error. A much better alternative to using a DVM is to buy a cheap off-the-shelf digital millivolt meter, mount it in a case with a battery, and have your own home made analyzer. The meter can be recalibrated to read directly in percent O2, so it acts just like a commercial analyzer, and no calculations are necessary.

It's both surprisingly cheap and easy to do. Since the panel meter contains all the electronic you don't have to be an electronics wonk to do it, though it helps to know how to use a soldering iron.





When the first edition of this book came out there was a lot of scepticism as to whether a $10 panel meter and could really do the job of a $300 Miniox - everyone was still so brainwashed by the black art and rocket science mystique that surrounded O2 and nitrox that it seemed too good to be true. Since then, though, thousands of OXY HACKER readers have built them, with uniformly good results, and countless cross-checks against commercial analyzers in the field have shown the homebuilt ones to be every bit as accurate and reliable. The homebuilt version has other advantages. You aren't stuck buying the manufacturer's sensors, but can shop around for the best deal, since the analyzer can be recalibrated to work with any sensor on the market. And if you drop the analyzer in the water or it just stops working, $12 or so worth of parts will fix anything that could possibly be wrong with it.

The original plans given in this book were for using either of two panel meters, the DMD3500B and the PM128. Availability of the DMD3500 is spotty, and the PM128 has been superseded by a newer version, the PM128A which is available from a number of electronic suppliers for about $10, and is the panel meter of choice at this time for building an analyzer (plans for converting the older versions, in case you have one, are still available on our website).

The PM128A differs from the old version in that it uses SMD (surface mount) resistors instead of the old style wire ones. Just to confuse things a bit further, there seem to be two versions of the PM128A, which differ slightly in layout - the diagram above shows how to identify and modify both.

There have also been reports of vendors relabeling completely different meters by other manufacturer as PM128As. The real thing is made by Colluck in Hong Kong. If you order a PM128A, and it doesn't look like the meter in the pictures here, then it is probably not one, and the directions here almost certainly won't work!

Suppliers and products come and go, so it's a good idea to check the UPDATES section of our webpage before you go shopping for parts.

There are many other similar-appearing panel meters on the market, but each of them uses its own unique circuitry, and, while most of them can be converted given some trial and error, the directions given here will work only with the PM128A!

The PM128A is a panel meter, which means it's intended to be installed on a panel, so the guts are exposed in the back, and it must be mounted in a case. The exact size and shape doesn't matter, but it should be at least 2 3/4" wide to fit the panel meter, 1" deep, and 4" or longer to allow room for the other components. Plastic project boxes are available from electronic shops and catalogs that even have a little battery compartment built in which make a very professional looking job of it.

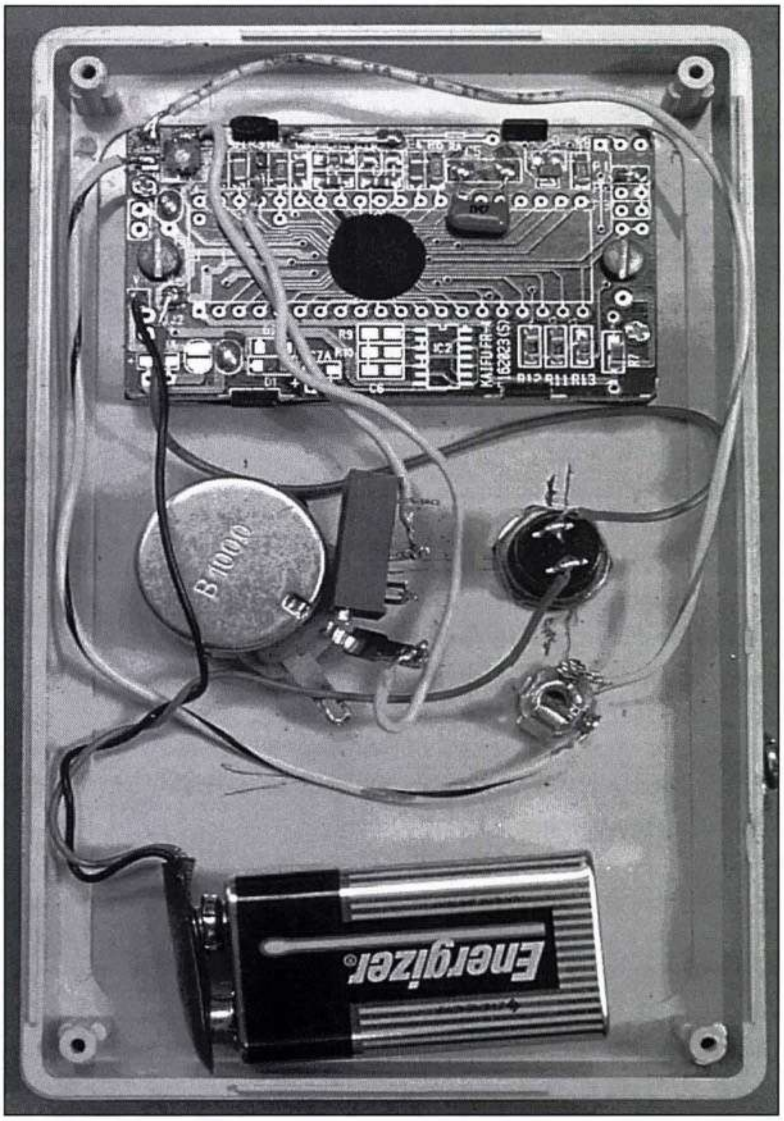
For those who don't like digging around in the bargain bins of surplus electronics shops, Oxycheq has a kit based on the plans in this book, that includes all the necessary parts and a Teledyne sensor for about $100.

Modifying the PM128 Panel Meter

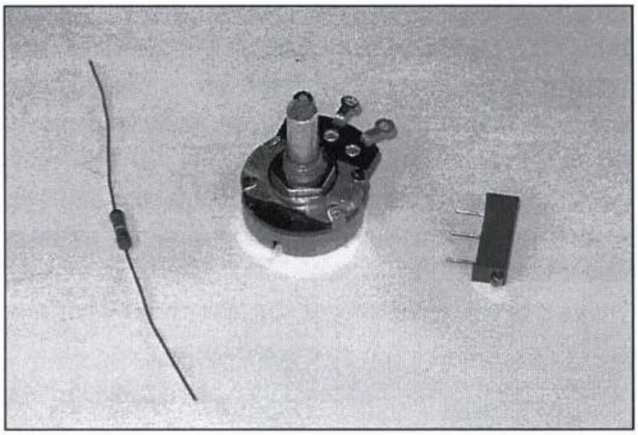
The PM128 is modified by removing one of the SMD resistors and replacing it with an adjustable resistor, better known as a potentiometer, or "pot" to allow calibrating it so converts the MV into % of 02. A fixed resistor is added in series with the pot to offset the range. Since the pot will be used to calibrate the analyzer each time it is used, it is mounted in a hole in the box with a knob on the outside, so wires must be soldered to the board and connected to the pot.

Begin by removing resistor no. 3 as shown in the diagram. Removing SMD's is a little trickier than removing old style wire resistors since you can't snip the leads and remove each side separately. The easiest way is to use two soldering irons together like pincers to simultaneously heat both sides and pick up the resistor. If only one soldering iron is available, the resistor must be gently pried off while heating one side at a time. Be careful not to leave the soldering iron on either side too long, or you may heat up the circuit board enough to damage something - it only takes a second or so to heat the solder until it lets go.

The two leads that will connect the calibration



The complete analyzer seen from the back. Note the blue trimmer pot - this is used in place of the series resistor, and allows easy calibration and recalibration of the analyzer to work with any sensor. Note too that the battery would normally be in the battery compartment.



A resistor, potentiomenter, and trimmer pot

pot go more-or-less where R3 was. A 6" piece of wire lead is soldered to the upper or upper left hand leg (depending on which 128A you have) of the trimmer pot on the meter board.

The other lead gets connected to the lower of the pads where R3 went. However, it may be easier to solder it to either of the two little round solder pads below R2, which connect to the pad, as shown in the diagram. Note that this is NOT THE ONE DIRECTLY BELOW R3.

The leads will be very brittle at the point where they connect to the board once soldered, so care should be taken not to flex them too much while assembling and testing the analyzer since this can either break the lead or damage the board. If you have a hot glue gun, a dab of hot glue where the lead is soldered to the board will act as a strain relief to keep it from breaking.

The pot and the fixed resistor are doing two overlapping but different jobs. The value of the pot determines the calibration range available - that is to say, whether its 0.16 to 0.25, or 0.10 to 0.30. What we are looking for is for the analyzer, when connected to the sensor and reading air, to have a range of about .18 to .26, so that there is space on either side to compensate for different sensor or reduced outputs as the sensor ages. The exact range doesn't matter - get it too wide and the analyzer will be a little fussier to calibrate, get it too narrow and you may not have enough range to calibrate it when the sensor ages without going inside and changing the fixed resistor.

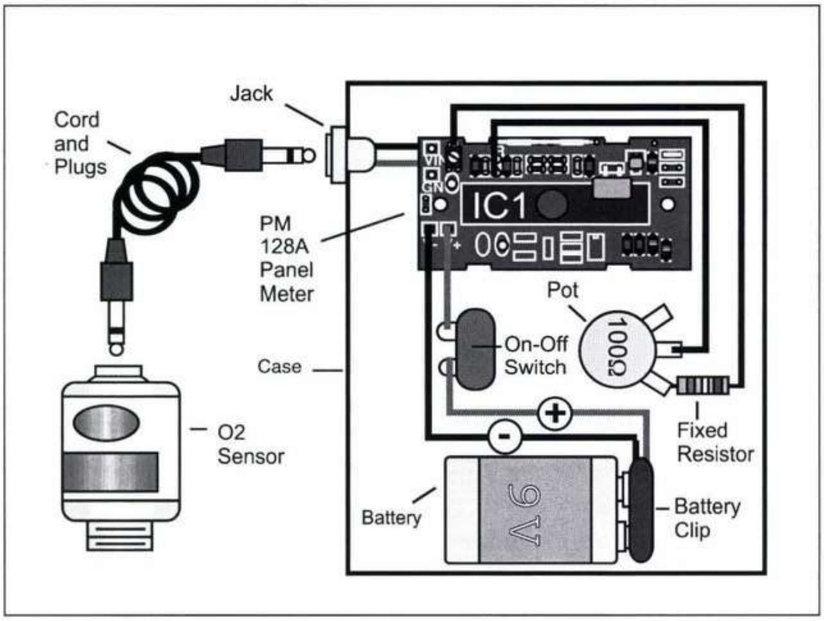
The value of the fixed resistor determines the offset of that range - how far it is from zero. Increasing its value moves the offset of the calibration range closer to zero - for example, if the analyzer has a range of 0.18 to 0.25 with a 380Ω fixed resistor, changing it to a 432 Ω would change it to something like 0.16 to 0.23. A 340Ω would push it the other way, to, say, 0.20 to 0.27.

A 100Ω linear (not audio) taper pot works well with the both the Teledyne and the Maxtec; however, 100Ω pots can be hard to find. Radio Shack used to stock a really nice wirewound one, part #900-7968, for about $4, but doesn't seem to anymore. Oxycheq may carry a similar one. Wire wound pots are much nicer than the cheap carbon kind because they have a stiffer action which holds a setting better, and slight ratchet feeling when

Parts list - O2 Analyzer:

Panel Meter PM128A
100Ω linear pot All Electronics LTP100
or Digi-Key CT2154-ND
Resistors 360K fixed or 1K-10K 15-turn
trimmer pot All Electronics
RTP5K or Digi-Key 3006P103
Hookup wire
Knob for pot (any 1/4" knob)
Case All Electronics 1593 YBK or
Digi-Key HM 350 ND
Jack and plug for case (optional)
Plug to fit sensor - 1/8" mini phone or
2.5/5.5mm coax
Cable with plugs to fit sensor
Jack and Plug for case (optional) to fit
sensor cable
On-Off switch
O2 sensor Teledyne R17D

Note: Most of these parts other than the sensor are available from almost any electronics supplier.



Actually, you could do away with the 100 0hm pot altogether, and just use trimmer pot alone, if it wasn't that the trimmer pot has a tiny little screw that adjusts it, and isn't really built to be readjusted on a daily basis. You could also use a full size 15 turn pot and do away with the fixed resistor, but they tend to cost a lot more, and usually don't have as nice a feel as the 100 k recommended here.

It's also possible in a pinch to use a much easier to find 5k audio taper pot by putting a 470Ω resistor across its terminals, and a 100Ω in series (or trimmer pot). It's essential that the 5k pot be audio taper, since this counters the tendency of the parallel resistor to mess up the linearity of the pot. This a bit of a kludge, since it results in an uneven calibration range that is a little too slow on one side of it's range and too sudden on the other, however, it's perfectly usable, and when I don't have a 100Ω pot around and need an analyzer in a hurry I may use a the 5k pot and replace it when I get around to finding a proper 100Ω one.

The wire lead from where the resistor was is soldered to the center solder tab on the pot, and the one from the trimmer pot to one end of the fixed resistor, the other one end being soldered to either one of the two side tabs.

you turn them.

A 100Ω pot gives a fairly narrow calibration range, so the series resistor has to be carefully selected. 380Ω works well with the R17, but the Maxtec 250 is happier with 360Ω.

Resistors come with very wide tolerances - the standard ones you buy at Radio Shack can very by as much as 5% in either directon, which makes a little harder to get the value just right. since one could have a nominally 360Ω resistor that was actually 370Ω, or a 380 that was actually 365. Precision 1% reisistors are available that avoid this, or one can just try all the different resistors in a pack of the cheap ones, to find the one best suited to the job.

Or forget about fixed resistors and for another dollar buy a 15 turn 1 to 10K trimmer pot, such as All Electronics RTP-5K and use it instead of a fixed resistor. The trimmer pot is adjustable, and gives enough range to allow compensating for just about any sensor, or any amount of aging. The leads should, once again, be soldered to the middle and either one of the end terminals. The trimmer pot is used to replace the fixed resistor and is only used to center the range of the analyzer when a new sensor is installed - the big 100Ω is still used for everyday recalibration.

Some people ask, if the analyzer is only calibrated to read from .16 to .27 or so, does that mean it can't be use to measure mixes higher than 27%? Not at all - it'll measure mixes all the way up to 100%. The calibration range we are talking about here is the range you can adjust it to read when reading air - put a richer mix to it and it will read higher.

To mount the panel meter in your box, scribe the outline, drill the corners, and cut out the opening a little undersized with a sabre saw with a very fine toothed blade, a coping saw, or in a pinch, a utility knife with the blade heated. Then fine tune the opening with a file or a board wrapped with sandpaper.

Then drill the holes in the case for the pot and the on-off switch. Pots come in many different sizes and shapes; it doesn't really matter which is used here, as long as it has a threaded shank and knob. For the on-off switch, just about any small switch will do. Avoid switches which are too easily switched since they can get accidentally turned on and waste the batteries - a subminiature locking toggle is idea but they are hard to find.

Once the components are mounted in the case, solder on the clip for the 9V battery.

The cord from the sensor can be hardwired directly to the meter (use a proper strain relief where the wire goes through the case, or at least put a grommet in the hole and a knot in the wire as a crude substitute), or the case can (more professionally) fitted with a jack, which is connected to the meter with soldered-on wire leads. When you fire up the analyzer for the first time you may find it reading in minus numbers. If that happens, just reverse the wires from the sensor.

Sensors used to come with a socket for either a 1/8"/3.5mm miniature phone plug, the mono version of the one used on Walkman headsets etc. (though the stereo version works can be used in a pinch - I've got an old headset cord on one of my analyzers) or a Switchcraft 760, aka a 2.5/5.5mm coax DC power connector as used on radar detectors and other gadgets. The mini phone plug seems to have won out, but you may still come across a sensor that nees the coax plug. Most electronics shop and All Electronics stock both.

The easiest way to get the right jacks and plugs is to take the sensor down to a electronic store and match them up, since nomenclature and jacks will vary. It's usually possible to find a cable with the right plugs on each end; for a really nice cable, look for a coiled power cable thought with coiled cables it is often necessary to change one or both of the plugs.

Once the analyzer is up and running, check that the sensor is reading in positive numbers and that the pot turns in the right direction (increasing as it is turned clockwise). If either is off you can fix it just by reversing the leads to that component. or, in the case of the calibration pot, by switching the lead on the outside pad to the other side.

Other Possibiliites

It's possible to build some very slick variations on this analyzer, using the same components, such as building it into a Pelican or similar drybox.

To do that, it's necessary to make a SS or alu panel to go inside, and some stand-offs, drilled and threaded on one end to accept a machine screw then epoxied to the case, to mount it on. The panel is usually bent into an "L" to leave a compartment for sampling hardware. Other refinements might include building a completely self-contained unit, with the flow reducer built into the analyzer and the BC QR on the panel, or even having both a hose barb and a BC QR fitting built in, so either can be used.

A panel for use with a fill station or continuous mixer can be made to run off a wall transformer, to eliminate batteries. It's also possible to built

Homebuilt analyzer built into a Pelican box several analyzers into the same unit, for redundancy, or to have an upstream and downstream analyzer on a mixer. Two analyzers can be fitted into one portable case not much bigger than the single version. I personally don't worry a whole lot about redundancy with O2 analyzers, because they tend to fail in obvious ways, and, should cross-checking be needed, there's usually another one nearby. But if redundancy is your thing, it can be done, and it'll wow them on the dive boat.

You can also add a battery test function to any of these analzyers, using the circuit shown in the diagram. It adds a little extra load to the circuit when the button is pushed; if the battery in marginal the reading will become unstable.

SENSORS

The earlier versions of this book recommended the Ceramatec (now Maxtec) CAG 250E sensor. O2 sensors were hard to find and expensive, being made mostly for the medical market. and the 250 was available direct from the manufacturer in small quantities at a reasonable price.

Since then, due the rapid growth of nitrox use, sensors have become much more available, and prices more reasonable. The Teledyne R17D, which can be had for around $65, is my current favorite. There's nothing wrong with the Maxtec, if you have one, or can find one at a good price, but the Teledyne has a hydrophobic membrane which makes it more resistant to humidity and moisture, and a 40 month air life. There are other O2 sensors on the market, and while they are not completely interchangeable when used with commercial analyzers, it's possible to use any of them with the home made analyzers described here since the jacks and calibration can be easily modified to suit.

Sensors and related hardware. Pequot with built-in hose barb, Teledyne R17 MED with "flow diverter" and Maxtec CAG250 with "concentrator".

O2 sensors vary in how much voltage they output, and are often referred to by the amount of voltage they output on air. For example, both the Ceramatec and Teledyne are considered 10 MV sensors, while the OMS/Scubapro analyzer uses a 30 MV sensor (a Teledyne R-24MED, in case you ever have to replace one). The output of a sensor doesn't really matter much, unless you are trying to replace one sensor with another of substantially different output, in which case it may be necessary to change the resistors and/or the pot.

Calibration

An analyzer must be calibrated inside when it is built, to match the sensor it is being used with, and also recalibrated each time it is used, since the sensor's output tends to lessen over time. This is done by sampling a known mix - usually air or straight O2 - and setting the analyzer so it reads 20.9 or 100 depending on which.

There's always been a running debate on whether it is better to calibrate on air or O2. Proponents of 100% (and these include Teledyne) say that calibrating full scale significantly reduces the calibration error further down the scale. Proponents of using air say it's closer to the mixes one will ordinarily be analyzing, and since you can set it to read exactly 20.9 on air, how much closer can you get?

My own feeling is that it doesn't really matter. And, the fine points of both arguements aside, one thing remains unarguable: air is a whole lot easier and more convenient, so that's what I use.

I do use 100% occasionally - mostly when I suspect a sensor and want to do a cross-check.

Some sources recommend that, rather than just exposing the sensor to air, it should be hooked up to a sampler and calibrated on air from a SCUBA tank, in order to duplicate as closely as possible all the dynamics that will exist when sampling the gas mix. Most divers don't bother with this, unless under extreme temperature/humidity conditions such as will be discussed later, but it's worth doing from time to time, just to see if it makes any difference.

Sensors are rarely completely linear so if one calibrates a sensor to 20.9 on air and reads some 100%, or vv, a slight error should be expected.

It is, obviously, a good idea to cross-check ANY O2 analzyer, commercial or improvised, against other analyzers when an opportunity arises.

What if one samples air with a with an analyzer, and gets a significantly different reading than the last time?

The first thing to do is check the battery. Then sample some 100% or air, whichever you didn't use before, and see if the analyzer is still reading in a reasonably linear fashion. Then check all the plug, jack, battery and cable connections. Miniplugs and jacks, cheap Radio Shack ones especially, are notoriously fragile, and the very low voltage output of these sensors is easily thrown by a bad connection. If some of the connections were done by twisting wires together, figuring on soldering them "later", then now is a good time to get out the iron.

If none of that helps, then it's time to decide whether the calibration resistors need some tweaking or the sensor is on its way out.

O2 Sensor Life

The life of a sensor it determined by both age and exposure to O2. Most sensors are rated by their manufacturers by either air life, which is how long they will last in air, or by 02 percent hours which is one hour reading 1% O2. Sensor life has increased quite a bit in the past couple years. When this book first came out the Ceramatec was considered a long-life sensor with an air life of 2 years. The Teledyne Med 17 we now recommend has a rated air life of 40 months, and there are a few sensors on the market claiming 5 years.

Several threads over the years on the Techdiver mailing list have discussed at length how to increase the life of the sensors. Suggestions included keeping them moist, keeping them dry, sealing them in a baggie, refrigerating them, and storing them in an 0 O2 inert atmosphere like N2 or argon.

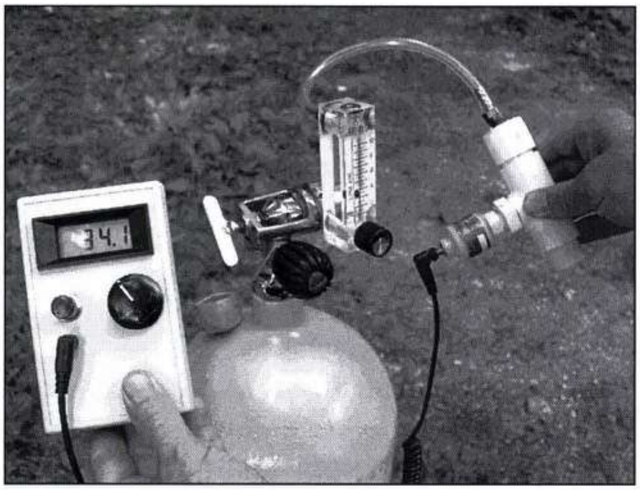
Since the sensors are basically little fuel cells, which use the reaction between O2 and the rare metals on the probe to create an electrical current, the process eventually depletes the electrolyte and the electrodes and then it's time to buy a new sensor. Anything, therefore, that slows down that process should, in theory at least, prolong the sensors life.

So why not store it in inert gas? It may be too much of a good thing. Industry sources caution against this since, in the absence of any oxygen at all, the lead can plate out onto the gold cathode, causing the calibration to drift enough to render it unusable.

The consensus, then, seems to be, when the sensor won't be needed for a couple weeks or months (depending on how fastidious or cheap one is) to seal the sensor in a ziplock bag with most of the air squeezed out, where it will slowly deplete the available O2 and create its own low-O2 environment, but not starve completely. Then stick the bag in a jar with a good seal, and keep it in the refrigerator, since lowering the temperature will also slow down the chemical reaction.

A simpler solution is to make or buy a little airtight cap, like the one available from OxyCheq, that screws on the sensor tip and seals it off from the air.

Sensors die differently. Teledynes tend to go fast once they start to go, but some others seem to linger on forever, with their output getting lower and lower. Maxtec suggests that when the the output is 30% down from what it was new that



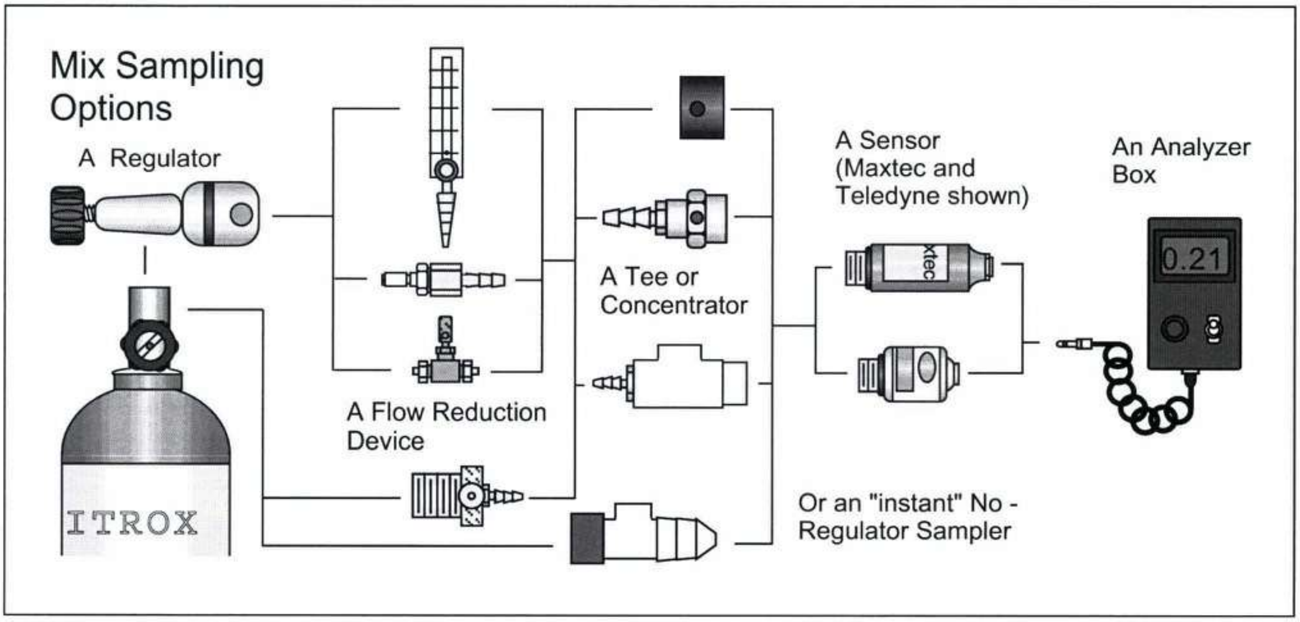
Old-style sampling, using a regulator, flowmeter and big clunky sampling tee

the sensor be replaced - that is to say, when the output of a 10 mv sensor drops to about 7mv on air. I have an old Pequot that seems to be immortal - it just keeps plodding along, but abruptly requires major changes in calibration from time to time, and not always in the same direction. It seems like I was always adding and subtracting 100 Ω resistors, until I finally put a 15 turn pot on it, which has so much range it could calibrate anything. Normally, I'd say when a sensor starts acting that flakey it's time to check the battery and all the connections, and if that doesn't help, chuck the sensor, but I'm curious how long I can keep the damn thing alive.

SAMPLING

There's more to analyzing a gas mixture than just blowing some mix in the direction of an O2 sensor. To get an accurate reading, it's necessary to completely immerse the sensor in the mix, excluding any ambient air that much wander in and throw off the reading, but without increasing the pressure significantly above ambient. Since sensors are actually reacting to the total amount of O2 they see rather than the percentage, they are really reading the PO2 rather than the FO2 - that is to say, the partial pressure of the oxygen not the fraction.

If one exposes the sensor to a 32% mixture at 15 psig/30psia (2 bar absolute) the reading would be nearer to 64%. That's no problem if the meter is always used at or around normal atmospheric pressure, but if the flow rate is high enough to increase the pressure the sensor sees, the gauge will give a higher reading on the same mixture. For consistent readings, it is desireable to always use roughly the same pressure/flow rate, which is where the gas sampler comes in.



A BC QR Sampler

Gas Samplers

A gas sampler is a device that produces a constant flow of gas - 2 to 4 liters/min. are the usually cited numbers - so that the flow is adequate to get a good sampling, but not so high to increase the pressure and the PO2, or unnecessarily waste mix, and holds it in contact with the sensor. Old-style samplers, with a tank adaptor, reg and flowmeter, sell for around $100.

Commercial samplers in the past had a decidedly homemade look. This should be no surprise, since the "manufacturer" had usually just assembled them from a mix of standard off-the-shelf industrial and/or medgas components. Global's, for example, simply mates a tank yoke to a simple non-adjustable industrial in-line regulator such as is used to fill gas balloons and a medical flow gauge.

Cale built his first sampler using an old dive regulator first stage (actually, the same one he uses as a filling yoke - the flow control needle valve doubles as a bleeder) and a cheap surplus medical flow meter with a built-in needle valve. A sampler like this is still well worth considering, since it can be very cheaply made (assuming one has a spare 1st stage, and is very accurate and easy to use.

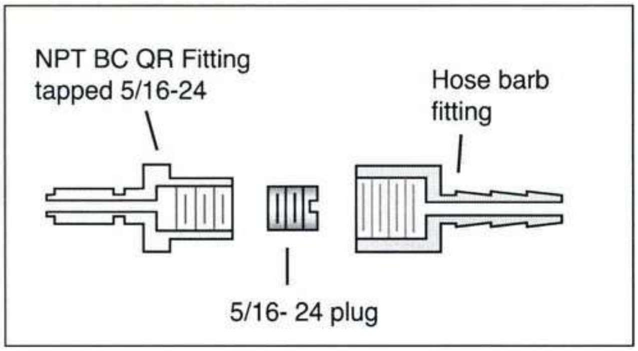
There are also low cost samplers available which go on the BC LP hose on a dive reg, using the same quick connect fitting as a BC inflator, so that the regs first stage does the work of reducing the pressure saving the price of a separate regulator. These are little more than a couple fittings screwed together with a flow restrictor in between, and cost about $50.

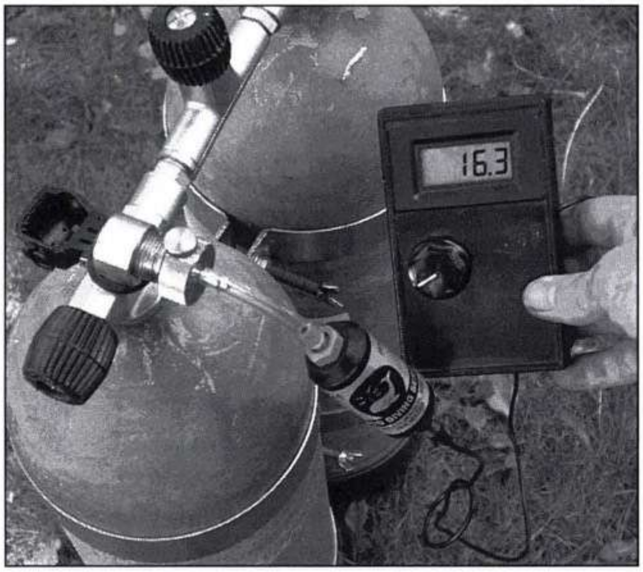
It's impossible to look at one without thinking that is should be possible to make one for considerably less, but finding the right material to make the restrictor has been the stumbling box - builders have tried sintered metal, orifices and filter media, but few have been entirely satisfactory.

I stumbled on a simple solution while trying to make one using the wire-plugged orifice described elsewhere. Before I could drill my orifice, I had to plug the BC fitting up solid first. I threaded the bore and made up a plug our of a scrap of bolt, but was having difficulty getting a perfect seal when it dawned on me - if the plug was leaking just a bit, then there was no reason to drill a hole - I already had my restrictor!

BC QR to NPT fittings are available from most mail order SCUBA dealers, for $5 or so, and your local SCUBA shop may even have them. The ones I've been getting have an inside bore on the big end that's just a tad under 5/16". All that's necessary is to run a 5/16" SAE NFT tap down until it bottoms, then make a plug from a short length of matching bolt, with a screwdriver slot hacksawed into one end.

Since the tap is tapered, and will bottom in the hole, the threads will of necessity become increasingly incomplete towards the bottom. This is a good thing in this application, since it means that the deeper the plug is forced, the tighter the fit will become, so that the flow can be adjusted by screwing the plug in or out. If it is not possible to get a low enough flow, a little teflon tape on the





DIN Valve Sampler. This sampler is interesting in that it does not use a regulator at all, but just a simple flow restrictor to reduce the pressure in one giant step

plug - but just a little - should do the trick.

It's also possible to build a BC QR flow sampler using a needle valve, just by putting the BC QR on one side and a barbed hose nipple or sampling tee on the other. It works a lot better if the needle valve is one that can be locked in a setting, so that once calibrated it'll stay that way.

There are also samplers made, mostly to fit DIN valves, that do away with the regulator, and use a variation on the plugged orifice, using an adjustable fiber disk, to do the reduction in one fell swoop. These seem to work well, though the output varies substantially with the tank pressure, but the principle probably isn't worth adapting to yoke valves, because it's usually much easier and cheaper to find a junk 1st stage than a yoke filler fitting.

Flow Calibration

The easiest way to calibrate the sampler, if a flowmeter isn't handy, is to fill one of those oversize 2 liter plastic soda bottles with water, then invert it with the neck immersed in a sink or bucket filled with water, and bubble air into it from the sampler and time how long it takes to drive all the water out. Since these bottles hold 2 liters, and one wants a flow rate in the 2-3 liter/min range, the math is easy - the sampler should blow the bottle clear in somewhere between 30 seconds and a minute.

Sampling Tees and Concentrators

Another piece of hardware is necessary to direct the flow of O2 from the sampler to the sensor. Most sensors are threaded, usually 18x1mm metric, so they can be screwed into a sampling tee or similar fitting. Medical analyzer like the Miniox usually come with a klunky sampling tee designed for home health care purposes. The sensor screws in one leg, and the hose from the sampler goes on the other. Some mixers suggest putting a short length of hose on the exhaust end as well to guard against air being carried back in by eddy currents and throwing off the results.

Maxtec has a simple little adaptor slug that screws onto the sensor (and also fits the Teledyne R17) and has another threaded hole to accept a hose bard, and several unthreaded holes to let the excess gas escape. Some sensors, like my old Pequot, may have a hose fitting built in .

The Maxtec concentrator is a nice compact unit, and if one is buying a Maxtec sensor, it

Two versions of the simple brass 3/6-1/4 adaptor concentrator, one with a hose barb and the other with a BC QR and flow restrictor

Concentrator/flow reducer combo in use

makes sense to get one. Teledyne doesn't have anything as nice - the Teledyne adaptors tend to be big, klunky things like the Miniox's. It would be easy enough to make something along the lines of the Maxtec concentrator, but both sensors use an oddball (to me at least) metric thread, and the tap would cost more than the adaptor.

Fortunately, there's a kludge - the 16-1 metric threads will screw crudely into a 3/8" npt female fitting. Since the seal is made by the O-ring (and the fitting must be vented to the outside anyway) the kludged thread fit doesn't matter, and since the threads on the sensor are a softish nylon-type plastic, it doesn't even seem to harm them irrevocably.

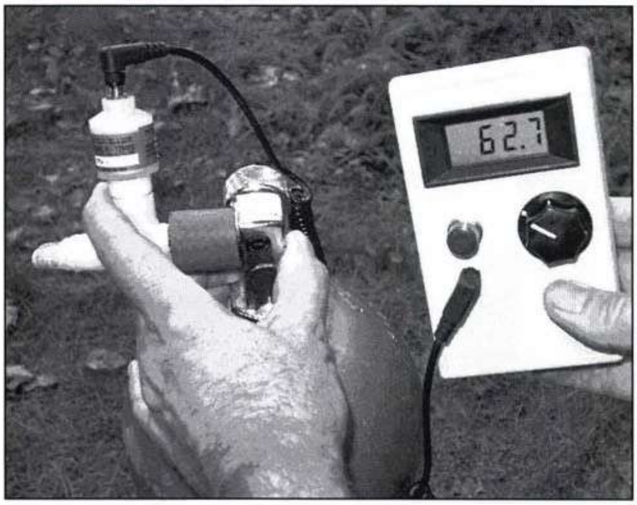
This serendipitous fit makes it very easy to make a compact concentrator by drilling a couple vent holes in the side of a 3/8" F NPT to 1/4" F NPT adaptor, and screwing the sensor into the big end, and a hose barb into the small one. If a 16-1 tap was available, it would be good practice to rethread the fitting, but it is not really necessary.

It would be possible to do away with the adaptor, and use just a 3/8* npt hose barb, but the adaptor gives more room for drilling holes, as well as giving the sensor a little more breathing space to protect against overpressurizing. For an even more compact setup, the plugged BC QR male connector used for the BC sampler can be screwed directly into the 3/8"-1/4" fitting, eliminating the hose barbs and hose, for a very compact BC hose sampler.

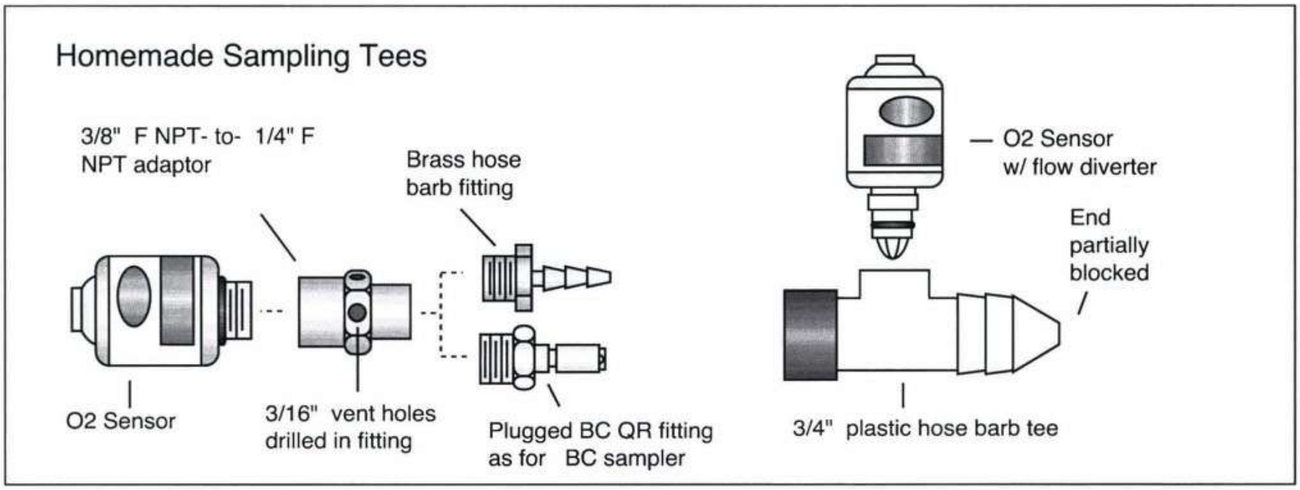
When a more elaborate sampler is necessary, as, say, for a continuous mixer, it's not hard to make one out of PVC pipe fittings. The Teledyne MED17 come with a little O-ring sealed "flow diverter" which fits a 15mm hole or 19/32" hole, and a similar fitting is available for the Maxtec 250. Since this fits into a plain, unthreaded hole, it's often easier to make a sampler to fit the diverter than a threaded one to fit the sensor itself. If you are using one sensor in several different applications, the diverter is especially useful because a sensor fitted with one can be just popped in and out rather than having to be screwed.

"Instant" No-Regulator Samplers

Having said all this, I should mention that many experienced homebrewers don't use a sampler at all - they just crack the tank valve slightly and direct the flow into the sampling tee or sensor. This is perhaps more suitable for a last minute check on the boat than in the mixing room, and more appropriate for nitrox than deep trimixes. Also, how well it works depends a lot on the make and model of sensor being used. My old Pequot



Using the "Instant Sampler" directly off the tank with no flow reducer other than the tank valve. Actually, it works great.



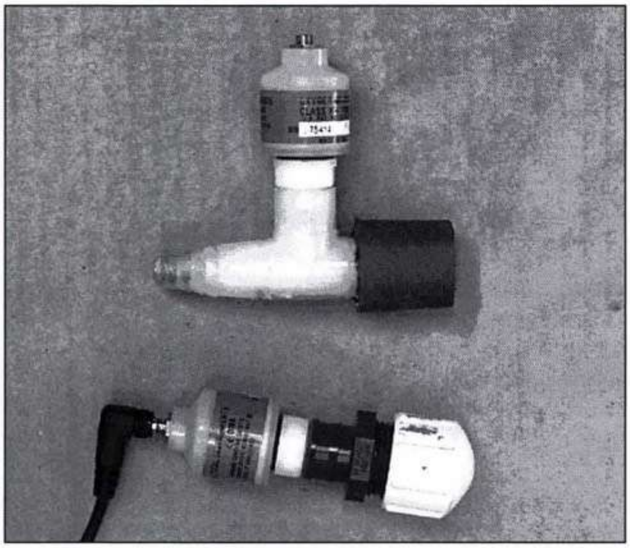
would consistantly give readings this way within a tenth of a percent or so of what I'd get with a proper sampler, but my new Teledyne wanders all over the place.

This got me wondering if a simple sampler couldn't be made to go directly on the valve in the style of the Abyss OxySpy, to make sampling this way a little more reliable.

Poking about the hardware store I noticed that the flow diverter that comes with the Teledyne fits perfectly into one of the legs of a 3/4" plastic hose barb tee. With the sensor installed, this makes a simple concentrator for sampling direct from the tank valve - opening the tank valve until a hiss can just be heard and holding one leg of the tee snugly over the valve face produces readings within a tenth of a percent of what I get with the full regulator-and-flowmeter sampler.

It's necessary to cut down one leg of the tee so the flow diverter sticks down into the flow, otherwise the sensor will be trapped in dead air pocket, and respond very slowly. A bit of rubber tubing on the tank side makes for an easier seal, and the other, outlet, end should be partially plugged to keep air from backing up in - I just heated it and crushed it almost shut.

The little "instant sampler" works great. It's become my current favorite, and I highly recommend that anyone who needs a sampler give it a



"Instant samplers" for direct-from-tank sampling. Hose tee at top, and Analox-style dome at bottom.

Oxycheq's Expedition analyzer reading directly from tank. Note the compact size.

try before spending money on anything more elaborate.

Oxycheq's new Expedition and the British Analox use a similar regulatorless system - the sensor is on the analyzer box like on the OMS, but the concentrator housing is rounded on the end with a tiny hole in the center and exhaust holes on the side (one of which usually has a hose barb on it so the analyzer can also be used with a conventional flow reducer).

To use it, the tank valve is cracked slightly and the dome pressed against the valve face - the rounded end of the dome allows it to fit either DIN or yoke valves, and acts like a ball joint to make for a less-fussy seal against the valve. I made an Expedition-style sampler, out of a 1/2" pipe cap (the kind with a rounded end) and a 1/2" npt-to-3/4" hose barb, with a #60 hole drilled in the cap and a couple 1/8" holes in the sides for exhaust. It works great on DIN valves, OK on yokes, but not very well on the combo yoke/DIN valves with the insert in place. A little fine tuning of the dome radius would probably greatly improve performance. The concept is well worth pursuing if one wanted to build a sampler into the analyzer box, ala Analox, but the tee works better and is easier to make.

All this flies in the face of one of the key rec-

Oxygen Compensation Chart for High Moisture in the Atmosphere

Atmosphere Oxygen Percent in relation to temperature and Relative Humidity

Temp F	32	40	50	60	70	80	90	100	110	120
Temp C	0	4	10	16	21	27	32	38	43	49
RELATIVE HUMIDITY	ATMOSPHERIC OXYGEN PERCENT									
10	20.9	20.9	20.9	20.9	20.8	20.8	20.8	20.8	20.7	20.7
20	20.9	20.9	20.8	20.8	20.8	20.8	20.7	20.6	20.5	20.4
30	20.9	20.8	20.8	20.8	20.7	20.7	20.6	20.5	20.4	20.2
40	20.8	20.8	20.8	20.7	20.7	20.6	20.5	20.4	20.2	19.9
50	20.8	20.8	20.8	20.7	20.6	20.5	20.4	20.2	20.0	19.7
60	20.8	20.8	20.7	20.7	20.6	20.5	20.3	20.1	19.8	19.5
70	20.8	20.8	20.7	20.6	20.5	20.4	20.2	19.9	19.6	19.2
80	20.8	20.8	20.7	20.6	20.5	20.3	20.1	19.8	19.5	19.0
90	20.8	20.7	20.7	20.6	20.4	20.3	20.0	19.7	19.3	18.7
100	20.8	20.7	20.6	20.5	20.4	20.2	19.9	19.5	19.1	18.5
H2O at 100% RH	0.6	0.8	1.2	1.8	2.5	3.4	4.7	6.5	8.6	11.5

If the temperature and RH axis meet in this part of the chart, calibrate to the chart O2 level or with dry air to maintain 0.5% accuracy in **NITROX.**

Explanation of Chart
The accuracy of all oxygen analyzers is effected by high humidity levels if ambient air is used for calibration, regardless of brand!

Cool, dry air consists of 20.9% oxygen, 78.0% nitrogen, and 1.1% other gases to equal 100%. When the atmosphere heats up and the humidity rises (as found in tropical regions), the increased moisture in the air displaces the oxygen and nitrogen so they represent a lower percentage of the 100% total. When using ambient air to calibrate your monitor, use the Oxygen Compensation Chart.

ommendations of the DAN nitrox summit, that a precision metering device must be used when sampling. But I've always been surprised how little this seems to matter with a good sensor. I did some flow rate tests with both instant samplers and an OxySpy, and found that varying the flow rate between what seemed obviously much too little and much too much made almost no measurable differece. But this is one of those things no one has to take on faith - try it yourself and see what you find!

Humidity and Temperature

Analox has for years circulated a compensation chart for its sensors, reproduced here, to allow compensating for the effect of moisture in the air. The chart calls for calibrating the analyzer while reading air to percentages below 20.9 incrementally as humidity increases until at 120 F (49 C) and 100% RH it is being calibrated to 18.5 for air!

There's a bit of a controversy about this chart. Both Maxtec and Teledyne have, when I asked them about this issue in the past, swore that such charts were obsolete - that temperature compensating circuits and hydrophobic membranes make their sensors pretty much immune to humidity within their rated operating range

However Analox, when I contacted them, insisted that the chart is not sensor-specific, but reflects the immutable laws of physics - that when there is moisture in the air it displaces oxygen and nitrogen alike, and throws off the reading of any galvanic sensor. It turns out (and I was eventually able to find someone at Teledyne who was familiar with the chart and confirmed it) that the chart is indeed valid and all sensors are fooled by high moisture levels. The temperature compensation circuitry has nothing to do with it - temperature is a consideration on the chart only because it effects the air's ability to hold moisture. The other sensor manufacturers, it seems, just don't think the effect is enough to worry about. And Teledyne would rather their sensors be calibrated on 100% O2 whenever possible anyhow.

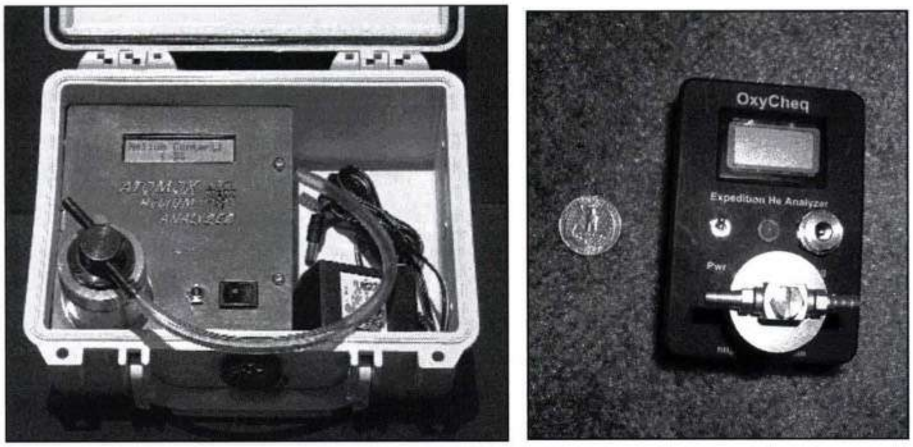
So should one compensate or not? Humidity is a problem only when calibrating the analyzer using humid ambient air, then using it to analyze a mix composed of dry, bottled gases and compressed air (since compressing air removes most of the moisture). So when humidity is a concern, probably the easiest way to sidestep the issue is by calibrating the sensor using SCUBA tank air or 100% O2, rather than free air. And note too that this is only a concern at the extremes. If it doesn't fell really hot and humid, then the effect of the moisture in the air on the reading isn't going to be enough to worry about.

When a sensor is used in a rebreather it's a completely different story. Maxtec sensors, while fine for analyzing O2 on the surface, should never be used in rebreathers, where very high humidity normally prevails (to say nothing of elevated pressures). For that matter, it makes no sense to use any sensor inside an RB not specifically rated by the manufacturer for such use - since Teledyne makes sensors just for that purpose, and they are available at reasonable prices, they are an obvious choice.

HELIUM ANALYZERS

Traditionally there's been no easy way to measure the FHe (percentage of helium) of a mix but no one worried about it because there was no really compelling reason to do so as long as the mixer paid attention to what he or she was doing, and was scrupulous about labeling the tanks. The FHe is much less critical than the FO2, and if you are doing partial pressure trimixing, if the O2 analyzes right then it stands to reason that the He must be right too.

Recently, though, Atomox has come out with a simple helium analyzer that works by comparing the thermal conductivity of a helium mix with a known gas. It has two chambers, one sealed and containing the reference gas, and one which can be filled with the gas being analyzed. Inside each chamber is a heating element which is part of a wheatstone bridge circuit. When the elements are heated the resistance in the element will vary



Helium Analyzers - Atomox and Oxycheq

according to the temperature of the element, which in turn will be determined by the conductivity of the surrounding gas - the more conductive the gas, the cooler the element will run. By comparing the resistance of the two elements the analyzer can accurately deduce the percent of helium in the sample. It's important to understand that the Atomox is not actually detecting or measuring helium the way an O2 sensor measures O2 - it's just measuring the difference in conductivity, and if you fool it by introducing other gases than air, O2 and He into the mix it will dutifully analyze them as if they were helium, giving a totally bogus reading.

The Atomox analyzer costs about $900, and is, at this time, sold exclusively by Dive Rite, and Oxycheq now has a similar unit. They are neat gadgets, great conveniences for anyone mixing a lot of trimix, but not something one really needs. And as Atomox warns, they are not meant to replace good gas management and handling practices, but are just an additional tool to verify the content of helium in a gas mixture. Note the word verify - like an O2 analyzer, it should only be used to confirm what you already know.

More controversial is the use of He analyzers on continuous mixers, to allow one-pass trimixing. This is indisputably cool. You don't have to worry about fudge factors, and can use almost every drop of expensive He in the tank.

Some of us have had some reservations about the wisdom of doing it, though, because, since few of us are willing to buy two analyzers, we usually end up doing the final analysis of the mix with the same analyzer as used for mixing, and this removes any redundancy from the proofing process. However it eventually dawned on me that there was another way to confirm the mix - by tracking the starting and finishing pressures in the He supply tank, to assure that the right amount of He makes it into the mix.

For example, if you are putting 2700 psi of 40% trimix into a set of 104's, and you know the supply tank holds 240 cf at 2200 psi, then a little math will tell you that that it should take roughly 383 psi from the supply tank, to make a 40% trimix (no equivalents given; you metric users can show off by doing it in your heads). This doesn't take into account compressiblity, but is close enough to tell you if you're in the ballpark. And it wouldn't be hard to print out a spreadsheet showing all the different tank/pressure/mix combinations, for easy doublechecking.

Don't misunderstand me - just because I don't think most of us need He analyzers doesn't mean that I don't think that they are a real good thing. I do, and their availablity cannot help but be a boon to the techdiving community at large, since even mixers who don't have one will be able to analyze their mix occasionally when they run into someone who does. I've always suspected that, for all our obsessing about fudge factors, digital gauges, and what order the gases should be added, most of us trimix divers have only the foggiest notion of what the actual FHe is in our tanks. Now, with the arrival of easy -to-use He analyzers, we'll be able, finally, to really know, and this cannot help but improve all of our mixing technique.

Chapter 10
SAFETY

This book is not intended for the casual experimenter or the sort of person who is always giving him or herself shocks, running out of air at 75 feet, or breaking tools. Rather, it is for the bold, curious, mechanically and technically proficient and adventurous soul who is able to calculate risks and make intelligent choices, and is willing to take responsibility for his or her own actions. Nor does it claim to give complete or comprehensive instructions for the handling and use of HP gases.

Make no mistake about it, mixing gases and filling tanks IS dangerous. Not suicidal, not insanely dangerous, but calculated-risk type dangerous, in the same way as diving or flying are dangerous. The more one educates oneself, and the more careful one is, the safer it is. The more corners one cuts, the higher the level of danger. As with diving or flying, it is up to each participant to decide for him or herself how much danger he or she wants to tolerate.

Making this more difficult is the fact that O2 is extremely quirky and unpredictable.

There have been a number of grim reminders of this lately. The most tragic was a fatality in Florida cave country when a woman topping off an O2 deco bottle at a dive shop was killed when it ignited and burst. There has been no really satisfactory explanation of why it happened. A home in Florida was completely gutted when a DIYer, who had allegedly been homeboosting O2 to 4500 psi, had his rig ignite. And a Florida caver suffered severe hand injuries when a deco O2 setup, the tank but not the valve of which had been carefully O2 cleaned, burst (the person prepping the tank assumed that a brand new valve did not need cleaning). The really interesting thing about this incident was that the burst did not happen when the tank was being filled with 02, but later when she mounted the regulator and opened the valve!

A similar event occured in the mideast, when a rebreather combusted shorly after the O2 valve was turned on, burning with such fury that everybody aboard had not time to fight the fire, but were forced to leap overboard and swim for safety while bits of exploding tanks flew over their heads.

The lack of any coherent explanation for most of these events underlines what Global's Dick Boyd, in his O2 safety seminars, refers to as the "O2 Fire Enigma". That:

- 02 incidents are by nature subtle and erratic.
- ignition is a low probability event
- ignition is unpredictable.
- incidents are sometimes unsolvable.
- material compatibility is an inexact science.

Anyone who chooses to handle HP O2 for dive, aviation, or any other use should be aware that they will face three levels of danger.

The first comes from the explosive force contained in highly compressed gases. The second from the oxidizing properties of O2, and its ability to accelerate combustion. And the third is in actually using it -from the danger of breathing contaminated or inappropriate mixtures, or not observing the limits for a particular mix. It is crucial to understand that oxygen is erratic and unpredictable, and what works on day may blow you sky high the next. The only way be be reasonable safe is to incorporate massive safety margins in your mixing procedures, and stick with them -

BURSTING

Cale blew up a 0-160 psi gauge made for checking the intermediate pressure on a SCUBA reg when he carelessly attached it to the high pressure port. The bezel hit him in the face with enough force to make the point that HP gases are not to be trifled with. That gauge was isolated from the full pressure of the tank by a valve. orifice and several feet of small bore HP hose. Now, can you imagine how much force there'd be behind a tank valve that blew out with the pressure of the full contents of the tank?

Most problems of this sort with HP set ups come from parts which are improperly used or assembled - threads not adequately engaged, NPT and SAE threads forced together, hoses and pipes which are not up to the rated pressure. Poorly assembled, makeshift gear can burst apart under the pressure, turning tanks, valves and fittings into high velocity projectiles. Or they can leak. One home nitrox mixer reports burning down his garage when an O2 whip broke, spewing O2.

COMBUSTION

All through this booklet you'll see references to blowing up tanks or setting fire to things. It's important to understand that oxygen is an oxidizer, not a fuel or an explosive, and it cannot explode or combust by itself. Oxygen can greatly lower the ignition temperature of a material, and greatly increase the rate of combustion, but it does not increase the amount of available fuel.

To get a fire or explosion in oxygen equipment, it is necessary to have three things - fuel, an oxidizer, and enough heat to touch it off. This is know as the "combustion triangle". The fuel can be hydrocarbon fumes from the compressor, grease or cutting oil left on fittings from the manufacture or assembly, bits of gaskets,seals or other components made of non-O2 safe materials, solvents used in misguided attempts to O2 clean, or incorrect lubricants used on the valves and fittings.

The fact that there is a combustible material does not guarantee an explosion - heat is still required to touch it off. It might seem it would be easy to avoid that kind of heat, but the ignitability of a flammable material drastically increases with the FO2.

Also, heat can come from some unexpected sources. Compressing something always creates heat. Just filling a tank too quickly can create enough heat to touch off a combustible mixture. Sparking from minute particles of ferrous metals (which is why brass is the preferred metal for fittings) can also set it off, even from tiny chips of metal or rust being blasted through the passages by high pressure. And then there's static electricity.

Adiabatic compression can also be a problem since it can occur locally in concentrated "hot spots" that are not immediately apparent or predictable. When you first open a valve, the compressed gas surges into the low pressure areas at near sonic speeds, then, as they fill, comes screeching to a halt, causing a sudden surge of recompression, and a corresponding surge in heat. The faster the valve is opened, the worse the problem. The same thing can happen within the passages of a valve or regulator, when the gas flow hits a constriction or corner creating tiny local, but potentially dangerous, hot spots.

The longer and narrower a passage is, the higher the danger of adiabatic compressive heating. When designing a whip or a filling system, care must be taken to keep the internal diameter of the passages uniform. The worst situation is a series of passages that become increasingly smaller as it gets further from the O2 source, or a long straight run that abruptly constricts at the end. The opposite - passages that get larger - are safer, since the larger spaces farther away from the valve act as shock absorbers for the surge. That's one of the reasons why filling a large tank is safer than filling a smaller one, and why the tank and whip valve should always be wide open before an O2 fill is commenced - the large volume of the tank at the end of the system acts as a reservoir and shock absorber.

Just using the wrong valve in an O2 system can greatly aggravate the dangers of adiabatic heating! Ball valves, which go from full off to full on in one quarter turn, and other fast opening valves like electrically operated solenoid valves are absolutely unsuitable for O2 service, for this reason! If one is using the valve on the O2 supply tank to control the fill process, it's a good idea to try the valve before hooking it to the whip, to get a feeling for how smoothly it functions.

The good news is that, even in a HP O2-rich environment, the combustion is still limited to the fuel available. That is to say, a minute smear of oil might ignite, burn, and never be noticed.

This is not to belittle the danger of even a small flareup. Even a tiny flareup fire inside the equipment small enough to go unnoticed can produce hazardous levels of carbon monoxide, and there have been some serious incidents caused by fires underwater inside of gear. Some divers have gone as far as to suggest that subclinical CO poisoning caused by unnoticed in-tank combustion may actually be a frequent occurrence among the "O2-cleaning-is-for-wienies" faction, but the symptoms go unnoticed, mistaken for narcosis or normal diving fatigue.

This is why we recommend always trying a mix - by breathing a little - before diving it! Combustion byproducts, and many other forms of contamination, that may not be so noticable later while you are busy with a dive, can often be detected by doing so.

Adiabatic compression is the big joker in the gas mixing deck. This is especially the case anytime one is using fittings - valves and regulators especially - that are not specifically intended for O2 service, since it can, given just the right set of wrong circumstances, create enough heat to start a small conflagration which may in turn touch off something else that normally wouldn't be a problem - like rubber, plastic, aluminum or even steel. In one frequently cited instance involving a regulator which has been packed with silicone grease and was hooked up to 100% O2 the flames from the burning grease actually melted the brass of the regulator body.

Materials For O2 Handling

For metal parts, brass in definitely the metal of choice when it comes to HP O2. It doesn't spark and doesn't (for all practical purposes) burn.

Also, being very thermally conductive, brass can add an extra measure of safety by acting as a heat sink, to dampen the effects of adiabatic heating - a recent study has suggested that oversized brass fittings on hoses made of other materials used with HP O2 can significantly lessen the chance of combustion, by soaking up excess heat.

Aluminum and titanium are definitely out - they ignite easily and burn violently in the presence of HP O2. Steel is not a good choice either - it burns, as anyone who has ever used a cutting torch knows. But the big problem with steel is that it sparks so readily, making it a prime potential source of ignition.

SS falls somewhere in between. While it doesn't spark or burn nearly as easily as steel, it is not completely immune. The catch is, even good brass fittings are often rated only for only 1500-2000 psi, (100-133 bar), and rarely for more than 3000 psi or so (200 bar). For higher pressure systems,

Homemade booster that combusted while boosting 50/50. There was a threaded port and hose where the hole is now.

then, there really isn't any affordable choice but stainless steel, and just about everyone uses it.

It's hard to get a definitive answer on how suitable SS really is for HP O2. Previous editions of this book warned against it, based on recommendations in several NASA publications, but dig a little deeper and you find that for every one that says not to use it there seems to be another that says it's OK. While the NASA Glenn Safety Manual says that only iconel or monel are suitable for high pressure O2, the NASA Safety Standard For Oxygen Systems NSS 1740-15 says that "Stainless steels are used extensively in HP O2 systems" and that "few problems are experienced with the use of SS storage tanks and lines" but that "ignitions have occurred in SS components such as valves at high pressures and high flow rates" (both documents are available on the web). And the CGA specifies that valves for O2 tanks should be made of either brass or SS.

When it comes to the Oxygen Index, which measures the pressure of oxygen necessary to sustain combustion once the metal has been ignited, brass is lightyears ahead of everything else, at in excess of 10,000 psi (666 bar). Stainless steels fall in the 500-1000 psi range, with 316 being the worse, mild steel 100-200 psi, aluminum 25 psi - and titanium 1-2 psi!

The O2 index doesn't really tell the whole picture, since it only rates what it takes to keep them burning once they are ignited, and there are huge differences in how easy the metals are to ignite. Aluminum, anodized especially, is relatively hard to ignite, but burns enthusiastically once it catches.

Soft materials are harder to get a handle on because they all burn much more easily, given the right circumstances, and at considerably lower pressures than metal. Why worry about the metals, then, when the soft parts are so much more likely to combust?

The problem is, the soft parts can act as kindling, to ignite the metal parts, and the metal parts, once burning, can create a major conflagration, once that is just about impossible to put out. Selecting metal parts that resist combustion can create a second level of defense against runaway combustion.

The old rule of thumb, from the dawn of tech diving, was that black plastic and rubber parts were bad, and that white or light colored ones OK. This is still a pretty good rule, since white tends to mean Kel-F, which is the best, or PTFE which is pretty good, or nylon-6, which is middling, and black tends to be rubber which isn't. good at all. However, now that nitrox is commonplace, it is much easier to get specific information on materials used, and there is no need anymore for such approximations.

Precautions

Most of the problems I've heard about in mixing dive gas - home or professional - and the use of high FO2 mixture in diving have concerned fire rather than explosions, and in most cases, those fires were contained, or self-limiting. The moral seems to be, exercise all the normal precautions you would exercise if you were welding or otherwise playing with intense fire - have a fire extinguisher handy, have a plan in mind for what to do in case of fire, have an escape route clear, a paid-up insurance policy, and keep other combustibles away from where you'll be working.

An all-out O2 fire is a fearsome and devastating spectacle that most of us would rather never experience. According to one account, a fire at the end of an O2 whip will produce a fire ball 3 to 8' (1 to 2m) in diameter that will almost instantly consume the line, and any class A or B materials - which includes most building materials - in the area. If the O2 is not shut off immediately the fire will be completely out of control with a minute or two.

Depriving an O2 fire of fuel is almost impossible, since the intense heat of an O2 fire coupled with the oxidizing property of the O2 create a firestorm that can involve materials we usually don't think of as being flammable.

Cale likes to wheel his O2 tanks out of his garage before he does any mixing, just to minimize the chance of fire, and, should it occur, lessen the chance of burning down his garage and house. Also, it gives him more options should he have to run.

Most divers and mixers are so concerned with the risks of HP O2 that we often overlook the risks at lower pressures. But anytime there is O2 flowing into the atmosphere, when, for example, analyzing, purging or just trying to stop a leak, the escaping O2 greatly increases the hazards of fire in the immediate area. Clothing, especially, can become saturated, and retain O2 so that the hazard persists even after the flow has been stopped.

Someone sent me a newspaper article about a patient who was on O2 when he decided to have a cigarette. He took the mask off, lay it still flowing on his chest, and lit up. Eventually, an ash fell, hit the bedclothes, which were by now saturated with O2, and combusted with vigor.

How to guard against this? Remember the triangle - fuel, oxidizer, and heat. In the case mentioned above, all were present, in a very small area.

When one reviews the surprisingly infrequent reports of accidents involving O2 handling in the sort of applications we are talking about here, one is struck by how almost all of them involve one of three reoccuring themes: overlubricated components, adiabatic heating caused by using the wrong kind of valve and/or opening a valve too quickly, and O2 leakage from improper or poorly assembled components.

This is actually good news, because it suggests that there is no black magic or high degree of knowledge required to reduce the danger - just reasonable care, caution and common sense.

There's a few things that can greatly reduce the chance of accidents while transfilling O2.

One should always keep gauges, blow out plugs, and anything else liable to let go pointing AWAY from oneself when one opens the valve. Gauges are one of the weakest point in any compressed gas systems and tend to blow when the pressure first hits them. If the gauge is facing you, you'll be right in the path of any flying bits.

Valves should always be opened very slowly. Allowing the hoses, gauges and other parts of the system to pressurize too quickly increases mechanical stress and adiabatic heating. If the pressure builds up slowly, and anything is amiss, one will be able to shut the valve and correct the problem before something dire happens.

Flow rates should be kept low, for the same reasons. 70 psi/minute is the recommended maximum, and it doesn't hurt to go slower.

And remember that explosions can happen on backflow too! There have been several cases of whips combusting when someone hooked them up to a O2-primed tank, then opened the tank valve before pressururizing the whip, causing a backflow of oxgen into the lines.

INAPPROPRIATE MIXTURES

This is wholly the responsibility of the mixer/user, and beyond the scope of this publication. But it is worth mentioning here that anyone diving mixed gas or nitrox should be aware that excessive levels of O2 can be fatal, and that each mix has very specific, and definite limits. Violating those limits may be fatal. FATAL!! If you do not fully understand that, and all its implications on gas mixing and dive planning, you should not be considering either mixing or diving mixed gases.

Labeling

Tanks should always be clearly tagged with the current contents, in such a way that no one is likely to miss it - usually this means a sticker or piece of tape on the shoulder where anyone who tries to put a regulator on the tank will see it. The importance of this cannot be overstated. ESPECIALLY if the valve is compatible with other uses that could lead to trouble. For example, if one is using an old dive tank for emergency treatment O2 or deco, it could easily be accidentally used as bottom mix and kill someone. If a tank is going to be dedicated to O2 use it should be painted green and clearly labeled "OXYGEN" and "NOT FOR DIVING USE" (or "NOT FOR USE BELOW

20 FEET" if it's doubling as a deco tank) on both sides. At the risk of being repetitious, just labeling it OXYGEN is not enough since many people including divers who should know better think O2 is what one breathes underwater! Argon should be clearly marked as ARGON and NOT LIFE SUSTAINABLE or similar warnings.

What about tanks holding other gas mixes? Their have been cases of people being injured, or narrowly escaping injury, when tanks containing different gas mixes got confused. One diver told about going on a wreck boat that carried, along with some serious wreck divers, an instructor and his class. Several of the students mistakenly used some of the other divers' tanks, which contained a potentially dangerous high-O2 mix. The situation was complicated by the fact that some of the tanks the instructor had brought for his class were labeled for nitrox even though they had been filled with air for that dive, and the instructor had told his students to ignore the labels.

Stories like this set off raging controversies among tech divers. Some maintain that dedicated tanks should be used for each mix, and should be clearly and permanently labeled for the safety of all. Others say it is impractical to own a tank for each mix one might be using, and that it is enough to simply tag the tank with the current mixture; each diver is responsible for seeing that he or she knows what is in the tank, and that they have the right one. The other camp retorts that this is not enough; labels can be lost or misunderstood, and on a crowded dive boat things can get confused. If someone dies because they used your tank by mistake they may have been wrong to use your tank, but they are still dead and only the most cold blooded advocate of Darwinism could applaud. And you are still stuck without the contents of the tank!

The best suggestion I've heard, is that tanks used for other than air be prominently labeled with something along the lines of "THIS TANK MAY CONTAIN MIXED GAS OTHER THAN AIR. MAY BE FATAL IF USED IMPROPERLY. Then the tank should be tagged with the current mixture and MOD.

How about tank wrappers, those big stickers that go completely around the tank, proclaiming NITROX or TRIMIX in 4" high letters? As beloved as they are to newbie mix divers (and to the dive shops that get $5-10 for putting them on), you'll rarely see one on the tank of an experienced techie, unless that diver isn't doing his or her own mixing (yet!), and the fill station insists on them. The thing is, they don't really serve any useful function except cosmetic - if a tank has a wrapper on it but no tag, then the wrapper is meaningless and even misleading, and if it has a tag, then the wrapper doesn't add any useful information. Plus a serious diver will be using different mixes in the tanks depending on the dive, and doesn't want to be changing wrappers each time!

The other thing about grandiose identifiers like tank wrappers is that if you are priming your own tanks with O2 or He, and taking them elsewhere for topping with air, the stickers only create problems - either the shop will ask embarassing questions about what's in the tank, or refuse to put plain ol' air in them because they are labled for mix.

Tape labels are fine for indentifying mixes on the surface, but woefully inadequate for use underwater. For the recreational diver who is carrying just back gas this is not usually a problem, since the entire dive will be done on the one gas. Divers who are doing decompression dives, and carrying mulitple stage tanks in addition to back gas have to be able to keep track of what each tank contains since they will be switching underwater and breathing the wrong one often can be fatal! The absolute best method for this is the system used by the WKPP cave divers in Florida who mark tanks with just the MOD for the mix, in large 2 or 3" high letters. aligned so they can be easily read when the stage is in the water. The advantage of this is that no math is necessary underwater - if the depth on the tank is deeper than the one on your gauge, then you shouldn;'t be breathing it! The large letters are also easy to read in all conditions - and easy for your buddy to read as well, providing an extra measure of safety.

PHYSIOLOGICAL HAZARDS OF OXYGEN

Eearlier editions of this book did not include much information on the physiological issues , as this information is available elsewhere. Since then, though, I've run into a number of divers who have taken the basic "nitrox lite" courses many of the agencies are now offering, have only the haziest understanding of these issues, and are hot to get started doing their own nitrox. That being the case, it seemed only prudent to provide some discussion of these issues here. But bear in mind that this is only an introduction to what is a very complex and important subject.

We all need oxygen to live. It could be considered our most basic and immediate need, but the fact we can't get along without it doesn't mean it is entirely and unconditionally benign. Too little O2 is bad, but so is too much. Our bodies have evolved (or been created, if you prefer) to operate within a fairly narrow oxygen "window". If we get too little O2 and we become hypoxic, lose consciousness and eventually die. If we get too much we become hyperoxic which can, sooner or later depending on the exposure level, kill us just as thoroughly as too little O2.

While the aviator is almost exclusively concerned with hypoxia, the diver must be aware of both hypoxia and hyperoxia. Divers breathe their gases under pressure, and this gives them plentiful opportunities to experience O2 at levels that nature never intended our bodies to see - at a PO2 of 1.6 ata, which is currently considered the max allowable, a diver is getting 8 times as much O2 as nature intended. On the other hand, the wrong mix - like using a hypoxic bottom mix on the surface - or malfunctioning gear could leave a diver without an adequate levels of O2.

Hypoxia usually is pretty straightforward, but hyperoxia has a number of different manifesta-

Table 8
THE OXYGEN ENVELOPE

HYPEROXIC	>3	Death	DANGER
	3	50/50% nitrox (chamber therapy) at 165'	EXCEPTIONAL EXPOSURE
	2.5	Deco max for commercial diving ops	
	2	Navy Exception Exposure for working diver	
	1.6	Navy Normal Exposure max for working diver	LIMITED EXPOSURE
	1.4	Accepted limit for rec/tec diving	
	.5	Max long term/saturation exposure	SAFE RANGE
	.35	Normal long term/saturation exposure	
NORMOXIC	.21	Normal Environment	
HYPOXIC	.17	Lower limit for breathing at 1 ata	
	.16	First indications of hypoxia	DANGER RANGE
	.12	Serious signs of hypoxia	
	.10	Unconciousness	
	<.10	Death	

tion, depending on the amount of O2 and the length of exposure. Extended exposure to moderately elevated levels of O2 causes Pulmonary Oxygen Toxicity, in which the lungs gradually cease to function. Higher levels cause CNS (central nervous system) toxicity, in which the brain abruptly starts to misbehave.

The safe PO2 window for humans is generally considered to be between .16 ata, below which the first serious signs of hypoxia occur, and .5 ata, above which pulmonary O2 toxicity becomes a concern.

Note the top number. This is for a patient being treated in a recompression chamber, where the patient is at rest and under close supervision. In these circumstances concerns about oxtox take second place to the desirability of getting the patient on as high an FO2 as possible. If the patient goes into convulsions, then he or she can always be put on air for a few minutes, or the FO2 reduced - toxing in a chamber isn't like toxing in the water, where it can mean death.

Ditto the next figure. This is for commercial divers doing accelerated deco in a saturation bell, where the consequences of toxing are much less than they would be in the water, or, if in the water, at rest and using surface supplied gear with a helmet or full face mask.

The upper limits on O2 exposure, one should note, are a lot less clearly delineated than the lower ones. Oxygen tolerances vary a great deal from individual to individual, and, for the individual, from day to day. Many deep divers and hyperbaric chamber operators can tell you stories about people who were doing just fine at high PO2's, until they for some reason or another slightly increased their exertion levels - and toxed almost instantaneously.

That's why, when calculating O2 exposure, one has to keep a sizable safety margin. The fact that one has gotten away with exceeding a limit a hundred times in the past has only a modest relevance to the question of whether one will also get away with it tomorrow.

HYPOXIA

Hypoxia is the result of getting too little O2. The most common symptoms of hypoxia are :

Sense of well being
light tingling sensations
slight numbness
visual disturbances
loss of coordination
unconsciousness
cyanosis (blueness of skin)

Most of the effect, one should note, are to the brain. Of all our body organs, the brain is the most sensitive to O2 levels, so it usually reacts first, and the reactions can be so severe that the rest of the body's tolerance for high-PO2s never becomes an issue.

In normal SCUBA diving hypoxia is rarely a problem, since, on air or nitrox, O2 levels should be adequate as long as the dive lung is delivering air, and, if it is not, it will be immediately apparent since the diver won't be able to breathe.

It can be a problem, though, for aviators, since an obstructed or inadequate flow of supplemental oxygen is easy to overlook, and for divers using rebreathers, since the rebreather may be delivering an adequate volume of gas to make breathing feel normal, but an inadequate level of O2. It can also be a problem when low-FO2 mixes intended for very deep dives are used at shallower depths.

It can be a serious problem right on dry land! Poorly supervised patients have died or become serious hypoxic during emergency O2 administration when the flow of O2 was cut off for one reason or another. This is why medical O2 masks now have to be equipped with air vents, even though those vents serious compromise their ability to deliver high FO2's.

The treatment for hypoxia is to get more O2. An aviator can do this by either increasing the flow of oxygen or decreasing the altitude. The diver must switch to a gas supply which has an adequate level of O2. Usually this means switching to air or a travel mix and aborting the dive. If the hypoxia is severe and the diver cannot return directly to the surface due to deco obligations, the diver should be put on as high a PO2 as possible without exceeding 1.6ata. Once on the surface, 100% O2 is the recommended treatment, and diving should avoided for at least 24 hours.

CNS OXYGEN TOXICITY

CNS Oxygen toxicity is the result of too much O2 acting on the brain. The two main factors in CNS toxicity are the O2 dose level (the PO2) and the length of exposure - the longer the exposure for a given dose level, the higher the chances of a hit. Many other factors also enter into the picture, like individual tolerance, body temperature, CO2 levels and the degree of physical exertion.

Dive books like to give lists of symptoms for CNS O2 toxicity, usually along with the inevitable memnomic VENTID. This stands for:

V - vision (tunnel vision)
E - ears (ringing in the ears)
N - nausea
T - twitching of the eyes, face and lips.
I - irritability
D - dizziness

As memory devices go, VENTID has always seemed clumsy and forced to me, as well as irritatingly unparallel. It's really better suited for use in the classroom than at 250 feet, mainly because if one ever is in a situation where oxtox is likely, one is unlikely to have the time or clarity of mind to remember the list, let alone make sense of it. Moreover, the same books that give the VENTID list also usually follow it with a warning that just about any other symptom you can imagine, including hallucinations, depression (!) and sweating, can also be a symptom of oxtox.

So instead of wasting those last seconds trying remember what VENTID stands for, most divers will be better off just remembering the short version: if you start to weird out while anywhere near to pushing the O2 limits, especially with nervous-system type problems, it's probably oxtox, and even if it isn't, the wisest thing is to proceed on

Table 9

NOAA O2 PARTIAL PRESSURE LIMITS - Normal Exposures

P02	Max Single Exposure		Max total 24 hours	
ATA	min	hours	min	hours
1.6	45	.75	120	2.5
1.5	120	2.0	180	3
1.4	150	2.5	180	3
1.3	180	3.0	210	3.5
1.2	210	3.5	240	4
1.1	240	4	270	4.5
1.0	300	5	300	5
.9	360	6	360	6
.8	450	7.5	450	7.5
.7	570	9.5	450	9.5
.6	720	12	720	12

Note: times are both given in minutes and hours for convenience, but they are the same, and only one should be used.

the assumption that it is.

The onset of oxtox is often so rapid that one cannot count on any useful warning time, but those who survived an encounter with it underwater usually report tunnel vision as being their first warning.

That being the case, the only realistic approach to handling oxtox is, most emphatically, to make sure it doesn't happen - to plan the dive conservatively, and not press the O2 limits.

The only treatment is to reduce the PO2 - by ascending or switching to a lower-FO2 mix. Since any exertion can cause immediate worsening of the situation, the diver in a bad situation, where immediate action is required, but overreacting may only make things worse. Another problem: convulsions can still strike even several minutes after the PO2 has been bought down to a safe level.

The convulsions brought on by oxtox are not in themselves fatal, or even necessarily harmful. The usual cause of death is when the convulsing diver loses his/her regulator and drowns, though loss of buoyancy control can also prove fatal. For

Table 10
PO2's, OTU's, and Depths

To find the OTU's for a given depth and FO2., find the FO2, go down the column to the depth, then cross over to the OTU column. OTU's for mixes not listed can be extrapolated, or the PO2 for that mix found using PO2 = ((d+33)/14/7) x F02 and the OTU's for that PO2 found using the first two columns. Metric users can similarly use the PO2 to find the OTU's for a depth/mix.

The OTU's for each stage of the dive must be multiplied by the time spent at that depth, and the OTU's for each stage of the dive added up to establish total exposure

		---------- FO2/Depth in feet ----------														
PO2	**OTU**	**10%**	**12%**	**15%**	**17%**	**21%**	**28%**	**32%**	**36%**	**40%**	**50%**	**60%**	**80%**	**100%**	**OTU**	**PO2**
0.05	0	132	105	77	64	46	26	19	13	8					0	0.05
0.55	0.15	148	118	88	74	53	32	24	17	12	3				0.15	0.55
0.6	0.27	165	132	99	83	61	38	29	22	17	7				0.27	0.6
0.65	0.37	181	146	110	93	69	44	34	27	21	10	3			0.37	0.65
0.7	0.47	198	160	121	103	77	50	39	31	25	13	6			0.47	0.7
0.75	0.56	215	173	132	113	85	55	44	36	29	17	8			0.56	0.75
0.8	0.65	231	187	143	122	93	61	49	40	33	20	11			0.65	0.8
0.85	0.74	248	201	154	132	101	67	55	45	37	23	14	2		0.74	0.85
0.9	0.83	264	214	165	142	108	73	60	49	41	26	16	4		0.83	0.9
0.95	0.92	281	228	176	151	116	79	65	54	45	30	19	6		0.92	0.95
1	1	298	242	187	161	124	85	70	59	50	33	22	8		1	1
1.05	1.08	314	256	198	171	132	91	75	63	54	36	25	10	2	1.08	1.05
1.1	1.16	330	270	209	181	140	97	80	68	58	40	28	12	3	1.16	1.1
1.15	1.24	346	283	220	190	148	103	86	72	62	43	30	14	5	1.24	1.15
1.2	1.32	363	297	231	200	156	108	91	77	66	46	33	17	7	1.32	1.2
1.25	1.4	379	311	242	210	163	114	96	82	70	49	36	19	8	1.4	1.25
1.3	1.48	396	325	253	219	171	120	101	86	74	53	39	21	10	1.48	1.3
1.35	1.55	412	338	264	229	179	126	106	91	78	56	41	23	12	1.55	1.35
1.4	**1.63**	**429**	**352**	**275**	**239**	**187**	**132**	**111**	**95**	**83**	**59**	**44**	**25**	**13**	**1.63**	**1.4**
1.45	1.7	446	366	286	249	195	138	117	100	87	63	47	27	15	1.7	1.45
1.5	1.78	462	379	297	258	203	144	122	104	91	66	49	29	16	1.78	1.5
1.55	1.85	479	393	308	268	211	150	127	109	95	69	52	31	18	1.85	1.55
1.6	**1.92**	**495**	**407**	**319**	**278**	**218**	**156**	**132**	**114**	**99**	**73**	**55**	**33**	**20**	**1.92**	**1.6**
1.65	2	512	421	330	287	226	161	137	118	103	76	58	35	21	2	1.65
1.7	2.07	528	434	341	297	234	167	142	123	107	79	60	37	23	2.07	1.7
1.75	2.14	545	448	352	307	242	173	147	127	111	83	63	39	25	2.14	1.75
1.8	2.21	561	462	363	316	250	179	153	132	116	86	66	41	26	2.21	1.8
1.85	2.28	577	476	374	326	258	185	158	137	120	89	69	43	28	2.28	1.85
1.9	2.35	594	490	385	336	266	191	163	141	124	92	72	45	30	2.35	1.9
1.95	2.42	610	503	396	345	273	197	168	146	128	96	74	47	31	2.42	1.95
2	2.49	627	517	407	355	281	203	173	150	132	99	77	50	33	2.49	2
PO2	**OTU**	**10%**	**12%**	**15%**	**17%**	**21%**	**28%**	**32%**	**36%**	**40%**	**50%**	**60%**	**80%**	**100%**	**OTU**	**PO2**

this reason, full face masks are preferred any time one is doing high PO2's underwater - for example, using high PO2's for accelerated deco or for in-water recompression to treat DCS.

The usual way to avoid CNS toxicity is to follow the NOAA/Navy guidelines, which give PO2 limits for both single dives and for multiple dives in a 24 hour period.

These exposure limits are often referred to as the "CNS clock" or the "O2 clock", and the numbers in the table as the "clock values" or "NOAA clock values", the idea being that there's a clock ticking inside each diver, counting down the minutes of time remaining for safe exposure.

1.6 ata O2 was, for a long time, the accepted limit for nitrox diving. Recently the tech agencies have all adopted the more conservative 1.4 ata for active diving, though some still allow 1.6 for O2 deco stops, when it is a assumed the diver will be at rest and not very deep.

For the recreational nitrox diver, who will not be doing the long exposures serious techies do, it's hard to say whether this was in response to problems in the field or just another attempt to buy a little extra liability protection. Certainly, most recreational nitrox dives, and even quite a few trimix dives, involve such short exposure compared to commercial dives that the extra .2 wouldn't seem to be a serious consideration.

PULMONARY OXYGEN TOXICITY

The other form of O2 toxicity is Pulmonary O2, also referred to as Whole Body Toxicity, or Low Pressure Oxygen Poisoning.

This is a gradual deterioration of the lungs due to inflammation brought on by extended exposure to elevated O2 levels. As the inflammation increases, the lung capacity is reduced, and hence the amount of gas exchanged with each breath. If nothing is done, the condition will continue to worsen, until eventually the lungs won't be able to provide enough O2 to the body to sustain life.

As scary as that might sound, it's not nearly as dangerous as CNS toxicity, since the onset is gradual, the consequences, in the early stages at least, relatively minor, and reversible simply by reducing the PO2.

The most common symptoms of pulmonary O2 toxicity are:

Dry Cough
Chest discomfort
Shortness of breath
Increased breathing resistance

While it can theoretically be lethal, pulmonary O2 toxicity is mostly a concern if one is doing extended deco and/or multiple gas dives for several consecutive days. It's worth noting, though, that, unlike CNS toxicity, it's not necessary to be breathing O2 under pressure to get POT. Breathing 50% or more O2 at normal atmospheric pressure can bring it on, given enough time.

Taking "air breaks" give the lungs a chance to partially recover, and greatly delays the onset of POT symptoms. It's standard practice anytime O2 is being used therapeutically, and especially in hyperbaric treatment. The usual procedure has been to take a five minute air break every half hour, so that one alternates 25 minutes of 02 with 5 minutes on air, or maybe 20/5. Doing so approximately doubles the time one can breath a given FO2 before POT becomes a problem. Current thinking, though, is that more frequent air breaks are beneficial, and divers doing long exposures increasingly opt for ratios in the range of 10/5 or 12/6.

Over the years several methods have been devised for tracking 02 exposure and keeping it at safe levels. The NOAA tables are probably the most widely used.

The only problem with the NOAA tables is that they are intended to deal with relatively short term, high PO2 exposures rather than long term or multi-day exposures. Also, there is a feeling that, while reliable for the higher PO2's where CNS toxicity is the problem, they are overly conservative on lower exposures.

There are other systems for tracking pulmonary toxicity better suited to longer

Table 11
REPEX EXPOSURE LIMITS IN OTUs

Consecutive Days Diving	Allowable Daily Average	Total Cumulative Limit
1	850	850
2	700	1400
3	620	1860
4	525	2100
5	460	2300
6	420	2520
7	380	2660
8	350	2800
9	350	2970
10	310	3100
11	300	3300
12	300	3600

term/lower level exposure, such as the Pennsylvania or UPTD method, which is widely used in medical treatment. These, however, are not particularly suitable for diving, so in 1989 Dr. Bill Hamilton came out with the REPEX tables.

The basic unit of the REPEX method is the OTU, or Oxygen Toxicity Unit. An OTU represents one minute spent breathing oxygen at one atmosphere, or its equivalent at other PO2s. To calculate one's exposure, one adds up the time spend at each depth during the dive, figures the PO2 for that stage of the dive, and multiplies OTU's for that PO2 by the time. For a multilevel, extended deco, or multi-gas dive, this can take some doing.

OTU's are tricky little creatures. Officially, each one represents one minute's exposure at 1.0 ata O2, or its equivalent at other partial pressures.

That sounds pretty straightforward, but really isn't since the relationship between PO2's and OTU's is not a linear one - the OTU most be calculated for each PO2. This is done using the the following formula:

OTU = t (PO2 - 0.5)/0.5) .89
where t = time in minutes

To find the OTU's for a given depth and FO2., find the FO2, go down the column to the depth, then cross over to the OTU column. OTU's for mixes not listed can be extrapolated, or the PO2 for that mix found using PO2 = ((d+33)/14/7) x F02 and the OTU's for that PO2 found using the first two columns. Metric users can similarly use the PO2 to find the OTU's for a depth/mix.

The OTU's for each stage of the dive must be multiplied by the time spent at that depth, and the OTU's for each stage of the dive added up to establish total exposure.

Got that? It's a lot easier if one draws out the profile, and uses a table to find the PO2's and OTU's rather than doing the math over and over again. Even easier is to use a computer deco program that also calculates the OTU's.

Notice that for multi-day diving, the allowable daily average gets smaller for each successive day of diving, to a point of diminishing returns. The solution to this is to take a day off, to "restart the O2 clock".

Any diver using O2 in diving should be familiar with both tables, and be able to use either - or both - as they are needed.

Having said all this, though, I should also mention that many divers don't bother with OTUs at all, but instead simply watch for the onset of symptoms, and take a break from diving when the appear, to give the lungs a chance to recover.

This isn't as dubious a practice as it might seem. Dr. David Sawatzky, writing in the NSS Cave Diving Manual, observes that "there are many tables of recommended exposure limits, but using symptoms is a far more reliable and useful method", and goes on to say that the one instance where tracking exposure might be useful is on multiple daily dives with prolonged O2 deco, but that even then "it is unlikely the symptoms would develop so quickly that the current dive could not be completed".

Appendices

Closing Rant -

"IF YOU CAN'T DO IT RIGHT DON'T DO IT"

Some of you have doubtlessly leafing though this booklet with increasing outrage and dismay, and angry mutters of "If you are going to do something, do it right". Let's face it - there is something here to offend everyone. The thought of home made whips, breathing welding O2, and kitchen sink O2 cleaning will horrify and anger these readers.

I don't have much use for that attitude, obviously. I believe in a world where fools should be allowed, with proper warning (as in YOJIMBO when the outlaw swordsman demands of Toshiri Mifune "Kill me if you can" and Mifune replies solicitously "It'll hurt, you know" then gives him moment to consider before hacking him apart) and reasonable measures to protect bystanders from their folly, do their worst.

Nor do I believe that just because a piece of gear is professionally made, or just because something is done by a dive shop, it is necessarily better than what you could do yourself.

And then there is the little question of just what is the "right" way. Whose standards should we go by? The U.S. Navy's? NOAA? The CGA? IANTI, ANDI, or, god forbid, PADI? If we had to follow navy regs we wouldn't get much diving done - when was the last time you bought a recompression chamber and a safety diver along on a dive trip? And I can't recall off hand a single dive shop that wholly follows CGA and DOT guidelines in compressed gas handling.

When it comes to O2 cleaning most of the tech shops and certifying agencies seem to define "the right way" as however they do it, the main distinction between the "right way" and the "wrong way" is that if a shop does it or sells it, it's automatically right, but if an individual does it or makes it, then it's automatically suspect. And then, too often "the right way" just means spending a lot of money.

An incident I witnessed on a dive boat recently nicely sums up the absurdity of this attitude. One of the divers had a pony bottle, his companion on countless dives, that was an old steel medical O2 bottle fitted with an ancient tapered thread post valve, and an equally old (but impeccably maintained) Voit Polaris regulator (a nice old bulletproof metal unbalanced piston reg). An instructor who was on the boat with some students was making some pointed comments about how diving was no place for "mickey mouse homemade gear", and how if you aren't willing to make the commitment and buy the "right" stuff you shouldn't be diving. My friend pointed to a shiny new SpareAir, probably bought the day before at the instructor's dive shop, hanging from one of his student's BC, and asked the instructor, "If you run out of air overhead at 120 feet (36 m), which would you rather have? That SpareAir or my nasty old pony?"

I'd like to tell you that the instructor slapped his forehead with good natured chagrin as the realization of his strokery dawned, but this was the real world, and he instead muttered something about not advising the use of SpareAir in overhead situations, then quickly changed the subject.

All the dive gear and techniques we use today were pioneered by divers who were, by the standards of their day, were probably guilty of not "doing it the right way". Once they succeeded, then the way the were doing it became the "right way", and everyone immediately get busy trying to institutionalize it so they could make money from it and stop anyone else from doing it without their permission.

One can argue, and it's a good point, that once the gear and training becomes available so that improvisation and experimentation are no longer necessary, then it is foolish not to take advantage of them. It's a reasonable argument, but relies on the assumption that there really is one, knowable, "right way", and that your local instructor is going to be able to impart it to you.

It's important to keep in mind that all the tech dive certifying agencies are for-profit businesses set up by individuals who saw a opportunity to make money. There's nothing wrong with that, per se, but it can make it hard to discern between policies made to enhance safety and those made to improve profitability. That being the case, an individual has every right to question and/or reject any rules and regulations made by businesses that stand to profit by their enforcement.

Nitrox is a good example. Suddenly it's hot stuff, and all the agencies are climbing all over each other trying to grab a chunk of the action.

There's a lot of us who've been mixing and diving nitrox for years without ever being certified. Most of us taught ourselves using the NOAA and Navy dive manuals. And why not? You can teach a reasonably intelligent diver everything they need to know about basic nitrox in about 15 minutes.

Now an instructor I know just went off for a one-day workshop and came back with a certificate saying he is a Nitrox Instructor. He has yet to make a dive with the stuff! But as far as he is concerned, he's now a Nitrox Instructor and I'm just a plain old diver with entry-level certification (actually, I was certified before there were agencies or open water dives requirements, and instructors just gave out their own cards, so you might call it sub-entry level!). At first he was properly sheepish about it, but he's starting to get cocky and drop hints that the rest of us really shouldn't be diving the stuff until we let him teach us how.

Give me a break.

1. SOURCES

Northeast SCUBA Supply
2544 West Ridge Pike
Norristown PA19403 (610) 631-2620
www.northeastscubasupply.com

John wheels and deals in new and used SCUBA gear, including many gas mixing items, and will ship.Carries the Global line, and similar products from other suppliers. Terrific shop with all the cool stuff in stock everyone else has to special order - I wish they were just down the street from me!

OxyCheq
3528 Russell Road
Marianna, Florida 32446 (850) 482-0385
www.oxycheq.com

Sensors for analyzers and rebreathers at good prices, oxygen and helium analzyers and kits, and a growing line of tech gear.

Tech Diving Limited
2959 Kiowa Blvd N
Lake Havasu City, AZ 86404 (928) 855-9400

Full line of tech gear, gas mixing equipment, and more, run by longtime tech diver, gas mixer and dive guru Joel Silverstein.

AOP Technologies (formerly Air-Oil)
301 30th St. NE, Suite 112
Auburn, WA 98002 (800) 282-2672
www.air-oil.com

O-rings in all sizes and compounds at very good prices. If you can't find it on the website, ask and they can usually get it. Low line item minimums mean you don't have to buy by 100's.

Aerospace Lubricants
1600 Georgesville Rd
Columbus, Ohio 43228 (800) 441-9160
www.aerospacelubricants.com
Tribolube O2-safe lubricants and other products.

Atomox
www.atomox.net
Helium analyzers, as sold by DiveRite. Lots of good stuff on their website, including a gas mixing Excel spreadsheet that takes into account compressibility.

GUE (Global Underwater Explorers)
15 S. Main Street
High Springs, FL, 32643 (800) 762-3483
www.gue.com
DecoPlanner deco software.

Teledyne Analytical Instruments
16830 Chesnut St.
City of Industry, CA 91748 (888) 789-8168
www.teledyne.ai.com
Top quality O2 sensors. Their R17 Med is the preferred sensor for the OXY HACKER analyzer.

Maxtec (formerly Ceramatec)
2425 South 900 West, Suite B
Salt Lake City, Utah (800) 748-5355
http://www.maxtecinc.com
O2 sensors and analzyers. Their MAX-250E takes a 2.5/5.5mm coaxial power plug, and sells for $50-65 depending on whether you are an individual or a company (check the bit on letterhead shops before you order, and be sure to say it's for resale).

There's also a screw-in hose adaptor, for another $5, that does away with the need for a sampling tee.

McMaster-Carr Supply
473 Ridge Road
Dayton, NJ 08810 (732) 329-3200
http://www.mcmaster.com/
Incredibly complete line of tools, industrial supplies, viton O-rings, SS braided HP hose for 1/3rd of what Global/Western gets, and just about anything else you can think of.

M-C is legendarily weird about about their catalogs - they simply won't give you one unless you are a major company, or an established customer, and then they might give you just one - but they'll sell to anyone, and in any quantity, so the trick is to get your hands on an old one and order a few times before you ask (they've also got the catalog online, and on CD-ROM).

Western Enterprises
875 Bassett Rd.
Westlake, Ohio 44145-1196 (440) 871-2160
Complete lines of welding, medical and industrial fittings, welding and cutting equipment, and medical gear. Western has a number of different specialized catalogs, but their WELDING AND COMPRESSED GAS FITTINGS AND EQUIPMENT catalog is the most indispensable. You can buy Western fittings though most welding/gas suppliers. Wholesale.

Global Manufacturing Co.
1829 S. 68th. St.
West Allis, WI 53214
Orders (800) 558-1811 Tech (414)774-1616
The source for dive gas handling and mixing, regulator service/test equipment, bulk O-rings in nitrile or viton, and all kinds of other tech goodies. Wholesale only - get the catalog by hook or crook, then order what you need through a diveshop.

Groban Supply Company, Inc.
9300 S. Drexel Ave.
Chicago, IL 60619-7799 (800) 621-2405
www.groban.com/index
Serious heavy, greasy surplus, mostly ex-military. HP compressors, but with a lot of strings attached (like, 28V DC motors and dubious as-is condition). Lots of gorgeous SS HP hydraulic accumulators (cylinders with a floating piston in the middle) that make great filter stacks. Condition ranges from brand new to junk.

DAN (Divers Alert Network)
Duke University Medical Center
Raleigh NC 27706-9980 (919) 684-2948
DAN is a non-profit dive safety organization, and a good source of books and videos on emergency O2 use and dive physiology. Sells fairly expensive but top-quality emergency O2 sets. Also sponsors Oxygen Provider courses which are available for DAN-trained instructors all over the world. DAN membership includes medical evacuation insurance and several dive emergency medical insurance options. Their book, OXYGEN FIRST AID by Lippman is an good basic text on the subject with coverage of both hardware and medical issues that goes well beyond what is covered in the basic DAN course.

Ebay www.ebay.com
Ebay, the ubiquitous internet auction service, has turned into one of the best places to find used medical O2 tanks and equipment, as well as deals on surplus and used Swagelok/Cajon/Whitey and Parker valves and fittings, and just about anything else.

Mar-vel
Box 646
Camden NJ 08101 (609) 962-8719
Commercial diving and gas handling gear. Neat catalog, will sell to anyone.

RIX Industries
6460 Hollis St.
Oakland, CA 94608 (510) 658-5275
Oilless compressors suitable for O2 service.

Swagelok (Cajon, Nupro, Whitey)
29500 Solon Rd.
Solon, Ohio 44139 (440) 248-4600
www.swagelok.com
Gorgeous, expensive, indispensible fittings and valves. Get the full line catalog.

C&H Sales
2176 Colorado Blvd.
Pasadena, CA 91117 (800) 325-9465
Ever changing line of industrial and military surplus. Precision gauges, cheap surplus 2-15 lpm flow meters, valves etc. Free catalog.

Haskel Inc.
100E Graham Pl.
Burbank, CA 91502 (818) 843-4000
Air driven booster pumps.

Aqua Environment
POB 935
Stinson Bch CA 94970 (415) 453-8157
Neat gas handling/fill station gear - regs, constant backpressure valves, "eyeball" CO monitors.

Lubrication Technology
310 Morton St.
Jackson, OH 45640
Christolube O2 safe lubes

MSA (Mine Safety Appliances)
POB 426
Pittsburg, PA 15230 (800) 851-4500
Miniox O2 Analyzers.

PSI
6531 NE 198th St.
Seattle, WA 98155. (425) 486-2252
Tank inspection courses, tools and good line of related tools and publications. Cale says buy the book - "Inspecting Cylinders" 1997, ($17+S&H) - and skip the course.

Surplus Center
1015 West "O" Street
Lincoln NE 68501-2209 (800) 488-3407
Gauges, surplus hydraulics, hydraulic hoses, air fittings, etc. Once again, not much high pressure gas stuff, but (free) catalog worth getting.

All Electronics
POB 567
Van Nuys CA 91408-0567 (800) 826-5432
www.alcorp.com
Mail order supplier of electronic bits and surplus

serving the hobbyist and small order buyer. Good stock of hardware, etc, at good prices.

Bird Precision,
P.O. Box 569, Waltham
MA 02454-0569 (800) 208-6840
www.birdprecision.com
Precision orifices

Norgren
5400 S Delaware St
Littleton, CO 80220 (303) 798-5545
www.usa.norgren.xom
Precision orifices and other gas handling gear.

Aircraft Spruce
201W. Truslow Ave
Fullerton, CA 92632 (800) 824-1930
Mail order aircraft supplies at good MO prices. Carries most lines of av O2 sets, as well as many useful AN fittings, etc, usually at good prices.

Kaplan Industries
Rte 73 and Maple
Maple Shade NJ 08052 (800) 257-8299
Wholesale supplier of new and refurbed medical and industrial cylinders of all sorts, and no minimum. Carries all the standard sizes at prices considerably less than local gas suppliers. Current prices around $50 for alu or steel MOD tanks, and $170 for 250cf. welding or med O2 tanks. Used/reconditioned tanks often available for less, call for current availability.

Labelon Corp.
10 Chapin St.
Canandaigua NY (800) 428-5566
Bardura waterproof, laser-printable sticky labels in various sizes. Usually sold only in quantity. The 2x4" size works well for visual/O2 clean stickers; give them a call and they'll send you some samples.

POR 15
POB 1235
Morristown, NJ 07962 (800) 457-6715
Urethane based rustproofing paint which is very good for protecting non-galvanized tanks that will be used in seawater. Incredibly tough coating, can be applied by brush over rusted or sandblasted metal..

Compressed Gas Association (CGA)
1725 Jefferson Davis Highway Suite 1004
Arlington, VA 22202-4102 (703) 412-0900
The compressed gas industry trade organization that sets the standards for the industry. Best source of info on the "right way" of doing it, if that interests you. Publications are very expensive and aimed at corporate users, but some of the more relevent ones are:

CGA 6 Visual inspection of steel tanks
CGA 6.1 Visual inpection of alu tanks.
CGA P-14 Accident Prevention in Oxygen Enriched Atmospheres
CGA G-4 Oxygen
CGA G-4.3 Commodity Specification for Oxygen
CGA G-4.1 Cleaning Equipment for Oxygen Service
CGA G-7 Compressed Air For Human Respiration
CGA G-7.1 Commodity Specification For Air

ZRC Worldwide
145 Enterprise Drive
Marshfield, MA 02050 (800) 831-3275
www.zrcworldwide.com
Top quality zinc-based "cold galvanizing" finishes, great for repainting steel tanks, or touching up galvanized ones, available in spray cans.

Other References

Butler, G. et. al. "Oxygen Safety In The Production Of Enriched Air Nitrox Breathing Systems, Cahoon, L.(Ed.) DIVING FOR SCIENCE ... 1992, AAUS, Costa Mesa, CA. 1992, p. 39-50.Hirsch, D. Bunker, R. & Janoff, D. "Effects Of Oxygen Concentration, Diluents, and Pressure On Ignition And Flame-Spread Rates Of Non-metals: A Review Paper," in Stoltzfus, J. et al (Ed.) ASTM STP 1111, 1991, p. 179-190.

Kindwall, E. "Oxygen Fire Caused By Quick Opening Ball Valve," Pressure, 21(2), Mar/Apr. 1992, p. 10

Mastro, SJ 1989 Enriched air mixing systems. Oceans '89. Washington: Marine Technology Soc. pp 1760 - 1710

NAVSEA MIL-STD-1330(SH) Sept. 96 Standard Practice For Precision Cleaning And Testing Of Shipboard O2, He, He-O2 N2 and H Systems.

NFPA Manual On Fire Hazards In Oxygen Enriched Atmospheres 53M 1990

Taylor, L. "Cleaning For Oxygen Service: Some Harsh Chemical Realities,"IANTD Journal, 94-1 (Feb/Apr, 1994), p. 8-10.

DAN Nitrox Workshop Proceedings, DAN 2000, 198 pages $20. Proceedings of the DAN Nitrox Summit, very good overview of current thinking.

Beeson, Stewart and Woods, Guidelines for Oxygen System Design, Materials Selection, Operations, Storage and Transportation, ASTM 2000, 99 Pages, $60. This covers much of the material presented at the White Sands/ASTM workshops, informative but pricey.

DOT and FDA regulations concerning compressed gases and med O2 can be found in the CFR (Code of Federal Regulation). This is a monstrous set of paperbound set of books that can be found in most state libraries, and many bigger university and city libraries.

Most of the DOT regs we are concerned with appear in vol. 49 or thereabout, sections 73.302 and 173.34 - 37.

The CFR is now on the net in searchable form on several sites, in several formats. Try Google to find the latest.

Oxygen in diving, analyzers, gas mixing, deco and related issues are often discussed on various net forums. Two of the best are **scubaboard.com** and **thedecostop.com** The old techdiver list is dead, but there's a searchable archive for Techdiver at Aquanaut.com.

Finding Us

Airspeed Press is a creature of the net, and the easiest way to our current list of publications, prices and ordering info is at our web site at **www.airspeedpress.com**.

There's always a chance we may be forced to change our server or address at some point. Should that happen, a web search for "Vance Harlow", "THE OXYGEN HACKER'S COMPANION", or "Airspeed Press", should lead you to our current address.

We also keep a list of useful WWW links there, rather than print them here since they are so transient, as well as updates and corrections for all our books - it's worth making a point of checking in from time to time to find out what's new.

2. Definitions, Abbreviations and Equivalents

ATA - absolute pressure given in atmospheres

ATM - atmosphere - unit of pressure measurement equivalent to the pressure at sea level (14.7 psi). Roughly equivalent to the metric system's bar

CGA - Compressed Gas Association

CNS - central nervous system

CNS oxygen toxicity - toxic reaction to overexposure to O2 , which can result in convulsions and death.

CO - carbon monoxide

CO2 - carbon dioxide

DNAX - denitrogenated air nitrox, air from which nitrogen has been removed to increase the FO2.

DOT - Dept. of Transportation. US gov. agency with authority over compressed gas containers.

EAD - equivalent air depth. The equivalent air depth for a nitrox depth that gives the same N2 exposure. Useful for planning nitrox dives using air tables.

EAN - Enriched Air Nitrox - another name for nitrox, Also EANx.

Fill tank - the tank which is being filled

FO2 - fraction of oxygen. Percentage of O2 in a gas mixture.

fsw - feet sea water.

He - helium

Heliair - air/He mix to which no additional O2 has been added.

Heliox - O2/He mix used for deep diving.

HP - high pressure

LP - low pressure. Note that in compressed gas usage, LP usually means less than psi and HP anything higher, where in describing dive tanks, LP refers to tanks holding less than 3000 psi, and HP to tanks holding more.

MO - mail order

MOD - maximum operational depth. The maximum depth at which a given mixture can be safely used.

N2 - nitrogen

NFPA - National Fire Prevention Association

Nitrox - O2/N2 mix, usually air which has had additional oxygen added.

02 - oxygen

OTU - Oxygen Toxicity Unit. Used in calculating O2 exposure limits under the REPEX method.

psi - pounds per square inch

psia - pounds per square inch absolute. Total pressure, including that of the atmosphere

psig - pounds per square inch gauge. Since pressure gauges are usually zeroed at atmospheric pressure, gauge pressure is usually 14.7 psi less than absolute pressure.

Partial Pressure - the portion, given as a pressure, of a gas mix contributed by any one of the component gases. For example, the partial pressure of O2 in air at sea level is 3.09 psi (21% of 14.7 psi). In a 3000 psi SCUBA tank filled with 32% nitrox, the partial pressure of the O2 would be 960 psi (32% of 3000 psi).

PO2 - partial pressure of Oxygen. Usually given in ATA, since that directly relates to the human body's tolerance of O2. Note that while the FO2 for a mix remains constant regardless of pressure, the PO2 increases proportionately with pressure.

Pulmonary Oxygen Toxicity - lung damage caused by breathing high levels of O2 for extended period. Usually reversible in the initial stages. Aka whole body O2 toxicity, low pressure O2 poisoning.

Supply tank - the tank from which gas is being taken from.

Trimix - oxygen/nitrogen/helium mixture used for deep diving. Usually made by adding helium and oxygen to air.

Triox - hyperoxic trimix, trimix containing more than 21% O2.

Conversions

1 liter = .035 cf. = 1.057 qts.

1 gallon = 0.1337 cf. = 3.853 liters

1 cubic foot = 7.481 gallons = 28.32 liters = 1728 cubic inches

1 fsw = 1.03 ffw (ft. fresh water)

1 lambert = 0.3183 candlepower per centimeter

A Few More Useful Formulas:

For finding the MOD for a given mixture and PO2:

((max PO2 ata) -1) x33]/ FO2 = MOD

Where

PO2 = Fraction of O2 in atmospheres

FO2= fraction of O2 in mix expressed as a decimal

For example, to find the MOD for 36% nitrox at a PO2 of 1.4.:

((1.4 /.36) -1) x33]/.36 =

(3.9 - 1) x33 =

2.9 x 33 = 95' MOD

For calculating EAD for a given nitrox mix/depth:

W hen tables are not available for a specific nitrox mix, one can calculate the EAD for that mix, and use the air tables for that depth.

EADfsw = [(1-FO2)(D+33)/0.79) - 33

Where:

D is deepest depth to be reached on the dive,

FO2 the % of O2 in nitrox mix being used expressed as a decimal,

.79 the % of N2 in air expressed as a decimal.

So, for example, to calculate the EAD for a 29% mix being used for a 132 foot dive,

EAD fsw = [(1-29)(132+33)/0.79) - 33

EAD fsw = [(.71) (165))/.79] - 33 = 115.29 fsw

So one could do this dive by following the dive tables for a 116 foot air dive.

3. Letterhead Shops

If you are engaged in many of the activities discussed in this publication, you will find that parts, information, and yes even discounts, are much easier to obtain if you have the use of a suitable business name. It isn't hard to have one - anyone can declare almost any activity they engage in to be a business, and, as long as one isn't ripping people off (or especially the IRS) it's one's own damn business if it never makes a cent or if you are its only customer.

Businesses like this are often called "letterhead shops", because they have no existence beyond a stack of letterheads, envelopes, and maybe business cards and purchase order forms. Once upon a time setting up a letterhead shop meant paying a print shop to run them off. Nowadays, that's not even necessary, because with a computer and laser printer anyone can run off convincing letterheads and forms a couple at a time.

The other thing necessary is an address and phone number where the "business" can be reached. One can always rent a P.O. box, or tape an extra name on the mailbox and notify the mailman, but the easiest way to handle this is to use one's own name for the business name, with a few extra suitable words added after it. For example, Lars Nivel could call his business "Lars Nivel's Undersea World", or "Lars Nivel Flight Specialities", or whatever. That way the mailman, assuming Lars is already known, will have less problems figuring out where to deliver the mail, and telephone calls will be handled in fairly graceful fashion even if the person who answers hasn't been clued in.

Cale particularly likes vague names like "Engineering" or "Technical Services", as in "Lars Nivel Engineering", since these can cover just about anything his rapidly shifting interests might lead him into.

If you are planning outfitting yourself with dive gear at wholesale from Scubapro, or tanks direct from Pressed Steel, you'll probably be disappointed to find that a fake letterhead doesn't go very far with big companies. But it can make it a lot easier to get taken serious when you are seeking technical information, and maybe save couple bucks a tank when you need to get a bunch of tanks hydroed or buy a few tankfulls of O2.

And more to the point, it may be the only way you'll be able to buy quantities of O2 or He for mixing, since some gas suppliers are leary of selling to individuals, and especially divers who will be breathing the stuff underwater. Here, once again, an unrevealing name is an advantage.

Beware, though, that if you actually start buying wholesale or reselling things, you may need to obtain a business license and/or a tax number depending on the state and local laws where you live.

Are letterhead shops legal? Mostly. Are they, well, as my wife would say, "cheaty"? Mais oui. But as Cale puts it, if a company figures it has the right to charge a bunch of different prices for the same item, depending on who is buying, then he's got every right to try and get it at the lowest. And if a company is only going to sell or give tech info to a chosen few, he's going to be one of them.

4. Argon

Argon is increasingly used by serious divers as a drysuit inflation gas. When trimix first started being by recreational divers, because of helium's high thermal conductivity, they found they got cold much faster. Divers diving dry on trimix began carrying a small tank of air just for inflating their drysuits, and eventually it occurred to someone that, as long as they were carrying a separate tank just to inflate the drysuit, it made sense to put fill it with the "warmest" gas possible. Argon, being much less conductive than He or air, but readily available and not too expensive, was an obvious choice. The argon is usually carried in a small tank or pony bottle, equipped with a normal first stage with a single inflation hose attached. An OPV valve, which goes on an unused LP port and vents off excess pressure in the event of a HP seat failure is highly recommended.

Not too much to say about handling argon other than that it's transfilled just like oxygen or air, but it's inert so there's no danger of combustion. That doesn't mean one can afford to get careless, since the little tanks typically used for suit inflation are particularly vulnerable to being overheated or overstressed by too-fast fills. The same whip or adaptor as is used for He will work for argon since both use the same CGA 580 valve.

Argon, since it cannot support life, does require a higher degree of discipline when it comes to labeling. Argon should only be kept in dedicated tanks, clearly marked ARGON and NON-BREATHABLE GAS and all those good things, with labels that are not going to accidentally come off or be misunderstood. Some people recommend that argon used for suit inflation should always contain 16% O_2 so it will be capable of sustaining life in a pinch, but that doesn't seem to have caught on.

Two problems with argon: the first is that the little suit inflation tanks don't hold enough gas for an extended dive trip or weekend, and the big tanks it comes in are usually too big to bring along. The second is that, since it only comes in 2000-2200 (150 bar) tanks, and few of us can afford enough tanks for an argon cascade, the tank pressure soon drops down to the point where each transfill into the inflation bottle yields less and less, until the diver finds him or herself running out in the middle of a dive. This is aggravated by the fact that most of the small tanks commonly used for inflation bottles are 3000 psi, so with even a full pressure fill from a fresh supply tank they are still at only 2/3s of capacity.

One solution to both problems is to decant the argon from the big industrial bottles into smaller, higher pressure "portable" tanks, such as spare SCUBA tanks or other midsize orphans, and boost it up to 3000+ psi, so the tank has enough pressure for a reasonable number of solid transfills before the supply tank pressure drops too low. This requires either a genuine or improvised booster (such as the trashbag version); one group of cold-water divers I heard from has periodic "argon parties" where they rent a few tanks of argon, borrow a booster, and fill everyone's portable bottles. Putting argon into full size SCUBA tank is if anything even more liable to confusion than inflation bottles, for god's sake be sure they are well labeled if you do!

Another way to handle the diminishing pressure problem is to top off the argon with air to get enough volume in the tank to last a dive. This really makes sense only if you are diving trimix, since the resulting air/argon usually won't be enough better than air to justify the complication of the extra tank, however, if you are already all set up for argon it can be easier than switching back.

Argon is frequently sold mixed with other gases for welding purposes, the most common being "steel mix" and "C25" which is 75% argon and 25% CO_2. Since some divers already have a tank of this on hand for welding, or at least know where there's one they can tap, the question keeps coming up as to whether it's suitable for suit inflation.

The problem is that when CO2 and water get together they combine to produce carbolic acid - a mild solution, to be sure, but possibly enough to irritate skin and, over time, damage the drysuit.

Be that as it may, I use it myself occasionally, and know many divers who have used nothing but for years, without noticing any problems.

If one is buying argon specifically for drysuit inflation purposes, one should of course buy straight argon, but if you have a source of free C25 the choice is not so simple - a reasonable approach might be to try it and see if any problems develop (armpits and crotch are the usual hotspots), and make a point of completely drying the drysuit before putting it away (which one really ought to be making a point of doing anyhow).

5. Oxygen Separators

In partial pressure mixing we add oxygen to the air to make a richer mix. But wouldn't it be a lot easier if we could just remove some of the nitrogen? That's just what oxygen separators do - they filter out some of the nitrogen from the air to make enriched air - or properly speaking, DNAX, or "denitrogenated" air nitrox. Separators are (on paper, at least) a mixer's dream - no tank leases or O2 cleaning, just hook a separator to a compressor, and pump all the nitrox you need right out of the air.

There are two kinds of separators: membrane separators and pressure swing adsorbtion (PSA) units.

The membrane separators have a synthetic membrane inside that allows the passage of O2 but not nitrogen. They've been used for years in the commercial production of nitrogen but not for O2 - since a fair amount of nitrogen gets through along with the O2, the FO2 is too low to be commercially useful. Until nitrox came along, that is - the FO2s a membrane separator can produce are just what we use in diving.

However anyone who has dreams of buying a sheet of membrane and cobbling up a separator is in for a dissappointment. The membrane actually comes in the form of hollow fiber tubes. Thousands of these tubes are plumbed in parallel in order to get enough capacity. The elements are usually packaged in a PVC tube, 6' of so long. Air is pumped into one end, at around 125 psi (9 bar) of pressure. The oxygen and some of the nitrogen seeps out through the walls of the tubing and is piped to a storage tank or compressor, and the nitrogen that makes it out the end is discarded.

Membrane separators also require very clean air, at just the right temperature, so filters and a heater are necessary along with a compressor able to bottle the FO2 being produced.

Pressure absorbtion swing separators use canisters of a molecular sieve, usually zeolite. Under pressure the zeolite absorbs nitrogen in preference to oxygen. Air is pumped through the canister at a pressure of 30 to 60 psi (2 to 4 bar), the molecular sieve soaks up the nitrogen, and the O2, along with any nitrogen the molecular sieve didn't grab, comes out the other end. The molecular sieve can hold only so much nitrogen, so when it approaches saturation the air flow is shut off and the canister depressurized so that the zeolite "desorbs" the nitrogen, which is vented from the canister. The canister is then flushed with air or O2, and the process repeated. Normal practice is to have two canisters in parallel alternately cycling several times a minute to provide a steady flow.

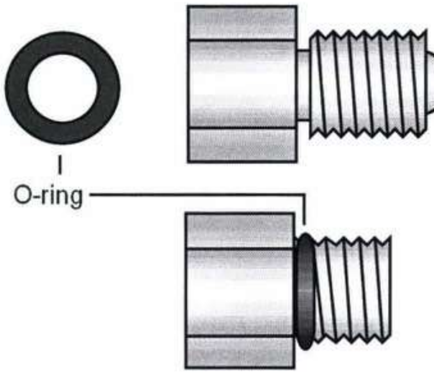
It would probably be possible to homebuild a PAS separator - mechanically they are quite simple, and the canisters could be made of PVC. However, in order to produce predictable FO2s, a fairly sophisticated timing/switching setup would be required along with an O2 monitor and an HP compressor to bottle the output.

Separators are available in medical and home-care units that turn up ocassionally in electronic/mechanical surplus shops and on eBay. However, it's worth noting that these applications usually don't require as strict control of the output FO2 as dive gas applications do, and the output regulation can be quite rudimentary.

Appendix 6 - NPT to SCUBA SAE Straight Thread Adaptors

Male NGT/NPT to Female SAE /O-ring Scuba (made from F NPT to M flare fitting)

Uses: adapting air tools to SCUBA reg, making SCUBA intermediate pressure test gauge, attaching medical O2 mask/flowmeter to SCUBA reg, attaching NGT whips to SCUBA regs.



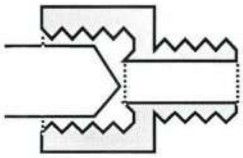
The secret to making this adaptor is careful selection of the brass fitting. Some don't have enough relief between the threads and the shoulder to take an O-ring, on others the shoulder of the "nut" portion may be tapered rather than flat

Once you've found a good one, simply file, grind or hacksaw the nipple off the end, shorten the threads if necessary, then slip the O-ring over. If it leaks, try a thicker O-ring.

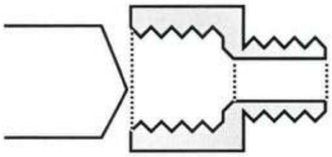
Male SAE/O-ring to Female NPT/NGT taper thread (made from F flare to M NPT fitting)

Uses: mating SCUBA reg 2nd to medical/industrial regs.

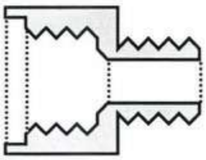
Chuck the fitting in a lathe, then using a drill remove the projecting nipple from the bottom of the hole. This can also be done in a drill press, but it's a little harder to get everything straight.



Then, drill out the opening to accomodate the O ring. For better results, drill the hole slightly undersize and finish it using a reamer. Then break any sharp edges and smooth as necessary with emery paper.



Other fittings than the one shown can be adapted this way, or made from scratch, simply by drilling and tapping the appropriate sized hole, then drilling the recess for the O-ring.



Approximate Drill Sizes for Drilling O-ring relief on SAE/O-ring adaptors

The size of the O-ring relief on the ports on SCUBA gear seems to vary a lot from one manufacturer to another and one reg to the next. Also, the recess is usually cut at a taper. Nevertheless, a straight cut with a drill or reamer seems to do a satisfactory job though it may take a little trial and error to get it right - but then, brass fittings are cheap enough that one can afford to experiment.

"A" Fitting Size	"B" Drill Size	"C" Relief Depth
7/16"	3/8" or 25/64"	.065
3/8"	29/64"	.080
1/2"	1/2" or 33/64"	.090

WORKSHEET BLANK MASTERS

These blank worksheets are intended to be used as masters for assembling a mixlog/mix calculation book. Make some copies, cut and paste to assemble master sheets with the order and number of forms one requires, then make a bunch of copies and put them in a binder. The Nitrox, Topping Up and Pressure sheets are designed to fit 3 on a page, the Trimix, 2 on a page.

NITROX CALCULATIONS WORKSHEET

MIX NO: ____ FO2 target _____ % FO2 By Analysis _____ % __________ When? _____ % __________ When?

Date: ____________ Notes: ____

____

NEW MIX (FO2 Mix – 21) / 79 = ________ X ________ Final tank PSI = ________ **PSI O2 necessary to achieve desired mix**

OLD MIX If any (FO2 old m ix –21) / 79 = ________ X ________ PSI old mix in tank = ________ PSI O2 available from old mix, if any. Subtract from the above.

Total ________ **PSI O2 to add to tank.**

TRANSFILLING PRESSURE RECONCILIATION WORKSHEET

step 1 rated fill tank psi / rated fill tank cf = ________ =

________ = ________ *conversion factor*

step 2 rated supply tank psi / rated supply tank cf = ________ =

________ psi actual pressure in supply tank

– ________ ←

final psi in supply tank at end of fill

____

– ________ ← psi to be added to fill tank → ________ – ________ conversion factor = ________ →

________ + ________ plus safety margin (25psi or ?) = ________ **max starting psi for fill tank**

TRIMIX CALCULATIONS

FO2 By Analysis ____ % ______ When?
____ % ______ When?

Mix no. ______ Date ________

New Mix

PO2 ______ = ________

______ +14.7 = ______ X PHe ______ = ...> ________
PSIG ambient *PSIA*

PN2 ______ = ...> ________

Minus Old Mix

PO2 ______ = – ________

______ +14.7 = ______ X PHe ______ = ...> – ________
PSIG ambient *PSIA*

PN2 ______ = ...> – ________

Subtotals - old mix subtracted from new mix

________ *total O2 to add* ________ **He To Add To Mix** ________ *total N2 to add*

________ = x 0.21 = – ________ *(minus O2 in air)*
air to add

________ **O2 To Add To Mix** ________ minus compressibility fudge factor ? (______ %)

________ = ________ **Air To Add To Mix**
0.79

TOPPING UP OLD MIX WITH AIR

O2 By Analysis ____ % ______ When?
____ % ______ When?

______ X ______ = ______ – ______ = ______
PSI old mix FHe old mix final fill pressure **FHe Final Mix**

______ X ______ = ______ *PO2 old mix*
PSI old mix FO2 old mix

______ final fill pressure
– ______ PSI old mix
______ X 0.21 = > + ______ *PO2 top up air*
PSI top up air

______ – ______ = ______
PO2 total final mix final fill pressure **FO2 Final Mix**

© 1998 Airspeed Press Reprinted from Vance Harlow's THE OXYGEN HACKER'S COMPANION, the Compleat Underground Sourcebook on Oxygen, Nitrox and Trimix, for Dive, Emergency and Aviation. www.airspeedpress.com. This form may be freely copied for personel use as long as copyright info and this text is not removed.

Other Books From Airspeed Press - Order online at www.airspeedpress.com

SCUBA REGULATOR MAINTENANCE AND REPAIR

Not just another lightweight book on how to rinse your regulator and change the mouthpiece, but an industrial strength, nuts-and-bolts guide to how to take a regulator apart, overhaul it, and tune it.

For those who live far from authorized service facilities and suppliers, there are even tips on making the necessary tools and discussions of alternate parts sources.

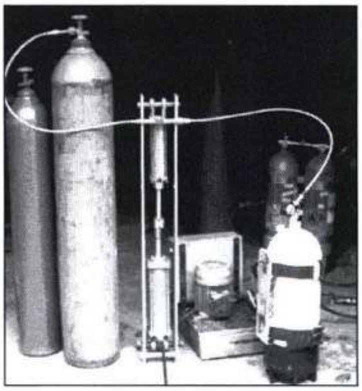
$50 250 Pages

THE DIVELIGHT COMPANION

If you want light - a lot of light - underwater, a canister light is the only way to go. This book an essential guide to selecting, maintaining and building them. Plans for several different canisters and lightheads including HID and NiMH. Bulbs interchange information, cheap sources for bulbs, batteries and DIY parts, and battery charging secrets that can make your lights brighter and longer-lived

$30 125 Pages

LOW COST AND IMPROVISED GAS BOOSTERS



Covers just that, showing several variations on a high pressure booster that can be made using low cost, readily available hydraulic components.

Prospective buyers are cautioned that this is by no means a set of foolproof plans. Rather, it is an idea and sourcebook for the mechanically adept and venturesome individual with experience in HP gas handling.

$20 72 Pages

WETSUIT AND DRYSUIT MAINTENANCE AND REPAIR

The first book dedicated entirely to the repair and servicing of divesuits. This exhaustive and much-needed work covers both field and shop repairs, and is aimed at both the individual divers who want to maintain their own suits, and divestore professionals servicing divesuits.

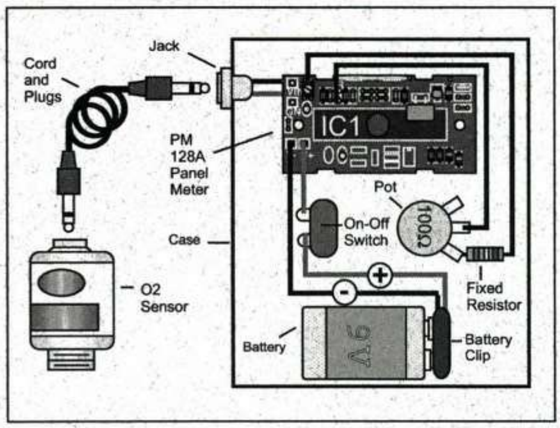
$40 164 pages

Vance Harlow's

OXYGEN HACKER'S COMPANION

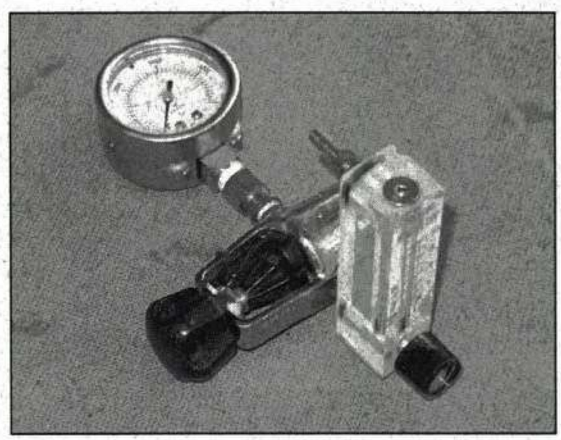
Since its publication four years ago, the OXY HACKER has become a tech diving classic - the most quoted and relied upon guide to gas mixing and handling in the real world, for diving, aviation and emergency use. Treading boldly where the tech agency manuals fear to follow, this is the only single book that tells it like it is, and covers it all,

From oxygen cleaning, to whips and analyzers and how to build them, to mix calculations made easy, to step-by-step nitrox and trimixing instructions, to tips on buying O2 and even how to build a continuous mixer, the OXY HACKER has the information you crave.



"I really been meaning to write to tell you what a fantastic book the "Oxygen Hacker's Companion" is. Of all my diving reference books on the shelf, it's the most dog-eared and beat-up due to my constant reference to it. I've loaned the "Companion" to many friends, and as a testimonial to its value they have all purchased copies themselves. Keep up the good work, your book is irreplaceable."

- R.O.



ISBN 0-9678873-2-1

9 780967 887326 >

THE OXYGEN HACKER'S COMPANION