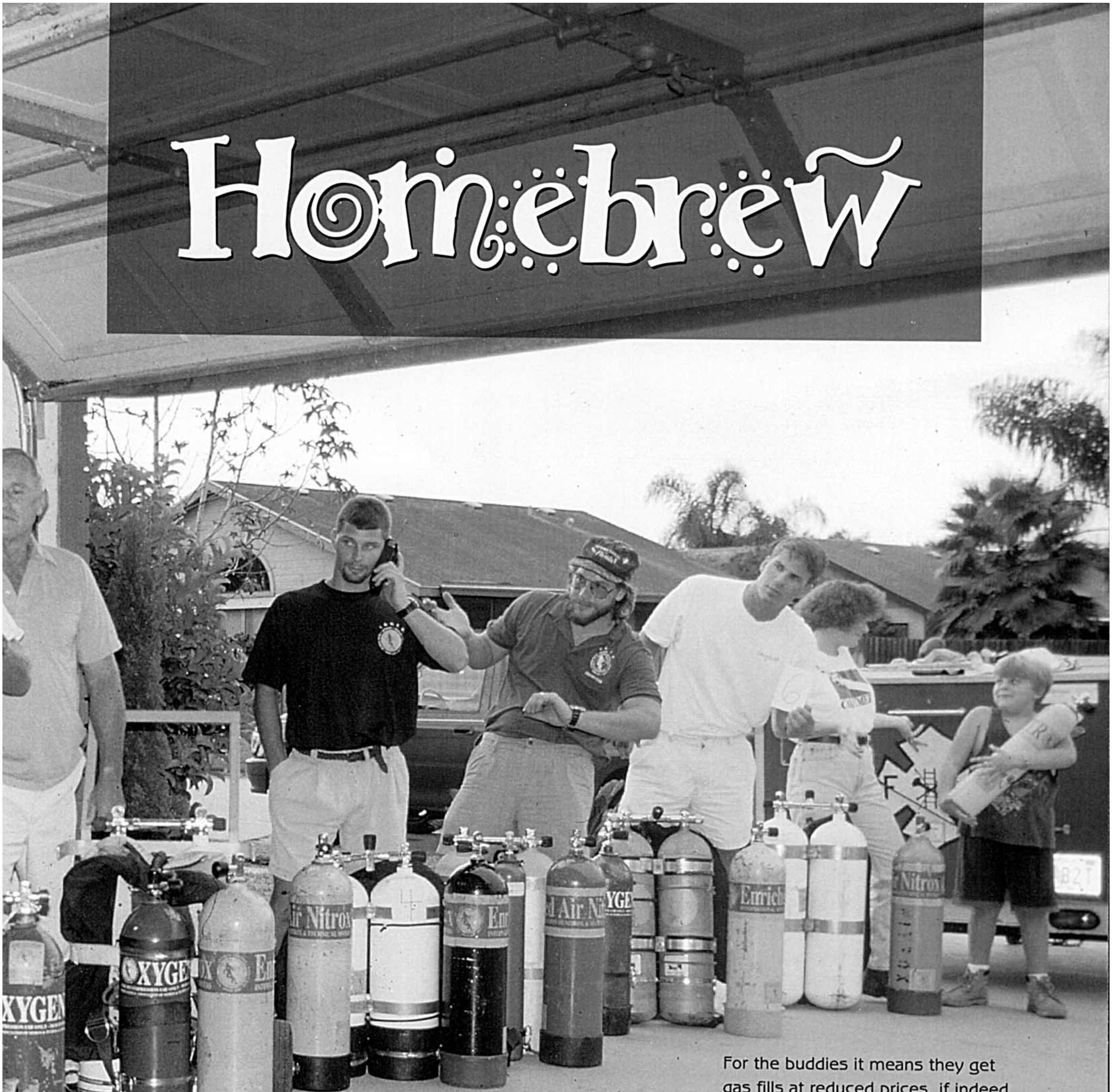
This article is presented for informational purposes only.
DeepTech Journal does not recommend gas mixing by
anyone not specifically trained for this activity.

Homebrew



by Curt Bowen and Win Remley

Joe Techdiver pushes the button on his automatic garage door opener. The door slowly rises revealing a cadre of friends eagerly awaiting gas fills for the days diving activities. Joe has built his own mixing station in his garage using equipment similar to that he examined in the local dive shop. Joe is an experienced diver and his buddies trust him to give them what they want—nitrox and trimix for deep dives. What Joe and his buddies may or may not know, is that this practice can be fatal unless strict safety rules are learned and rigorously followed.

For the buddies it means they get gas fills at reduced prices, if indeed they pay at all. Plus, they don't necessarily need the proper training, certification, and experience to use the gas they are mixing. If Joe thinks they can "handle it" then he will probably give it to them. For Joe it means significantly reduced prices on mixed gas fills. Plus he becomes very popular on Saturday mornings. The problem is that if

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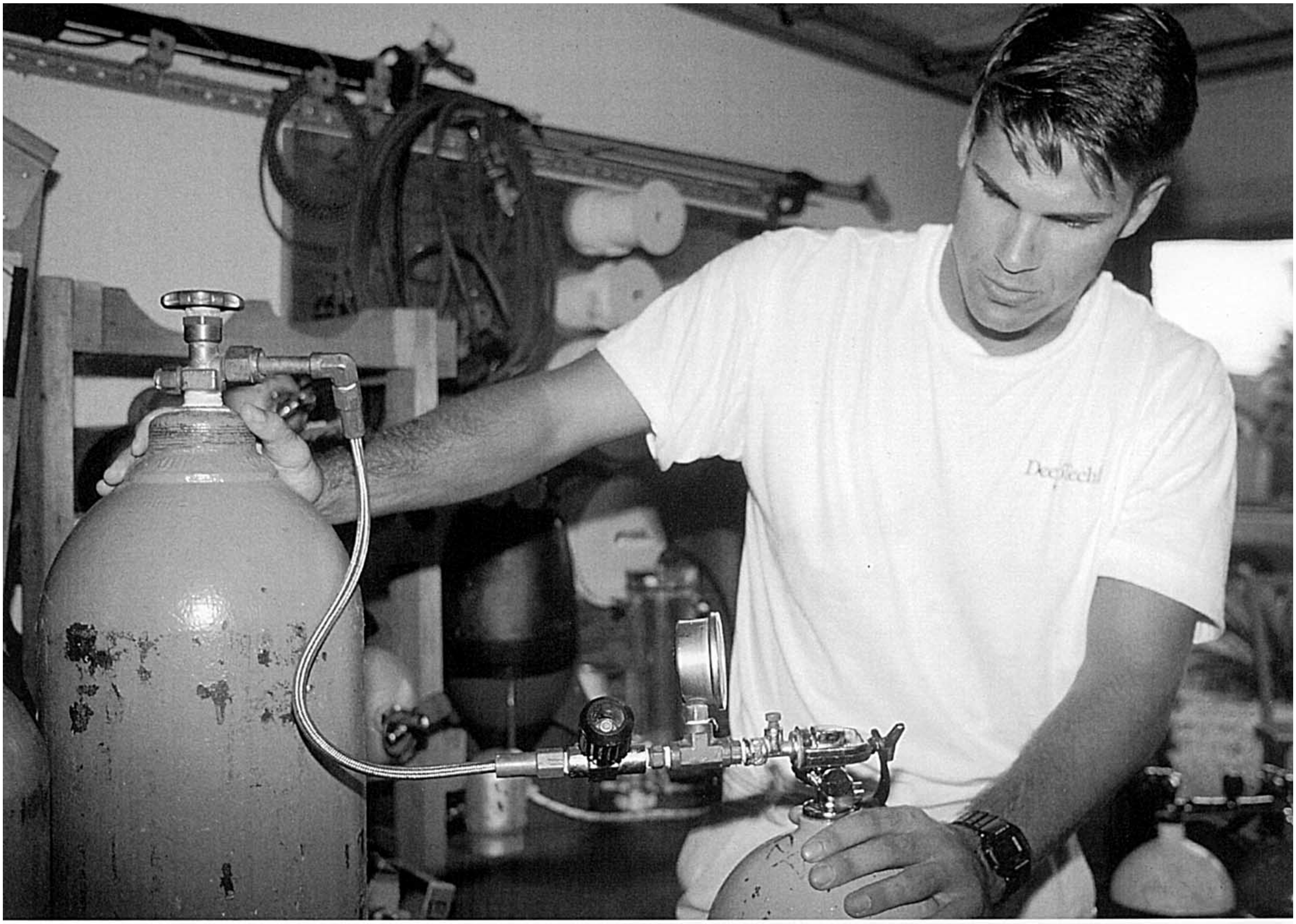

Partial pressure filling is accomplished by partially filling a scuba cylinder with one or more gases by connecting it to larger cylinders via a fill whip and opening the valves of both cylinders. The gas flows from the cylinder with the greatest pressure, the supply cylinder, to the cylinder being filled, the scuba cylinder.

something goes wrong divers can die and Joe may lose his garage as well as the rest of his house in an expensive liability lawsuit. Make no mistake about it, mixing gas at home in your garage is dangerous for two reasons. The first is the risk of fire and explosion from high pressure oxygen. The second is incorrectly blended gas which may lead to breathing a mixture at an inappropriate depth for its contents.

Gas mixing is better left to those who have the right equipment, the necessary training, and the experience to blend and analyze gas correctly. The technical dive shops in your area are the best place to buy gas—without exception.

Nevertheless, many divers do mix gas at home. From the discussions DeepTech has had with some of these homebrewers there is some misinformation out there regarding gas blending. This article is written to, hopefully, increase knowledge about gas mixing and promote safer blending practices among divers who mix at home.

The practice of homebrew began with the early technical divers who wanted to explore beyond the limits of nitrogen narcosis and oxygen toxicity. They discovered that custom blended fills using combinations of oxygen, nitrogen and helium provided distinct physiological advantages at certain depths. At that time it was not possible to buy mixed gas fills in dive shops so there was no alternative except to devise ways to brew your own mix at home. These homebrewers typically used a process that is now called partial pressure filling.

Partial Pressure Filling

Partial pressure filling usually begins with a completely drained, or empty, scuba cylinder. The scuba cylinder is partially filled with one or more gases by connecting it to larger supply cylinders via a fill whip and opening the valves of both cylinders. The gas flows from the cylinder with the greatest pressure, the supply cylinder, to the cylinder being filled, the scuba cylinder. The

The Fire Triangle

Oxygen is a colorless, odorless, and tasteless gas. Higher concentrations of oxygen greatly accelerate the burning process, sometimes to the point of being explosive. Fire science gave us the fire triangle which graphically shows the three elements required for a fire to exist, heat, oxygen, and fuel. A fire (or explosion) cannot ignite without all three components being present.

Partial pressure filling with oxygen introduces the high concentrations of oxygen required for a fire. Oil deposits or hydrocarbon based lubricants in the cylinder and valves provide the fuel. And compressing the gas (filling the scuba cylinder) provides the heat (Charles Law).

The reason for oxygen cleaning all components (removing all hydrocarbon based materials) in a partial pressure fill station is to remove the fuel side of the fire triangle thereby minimizing the possibility of fire or explosion.

scuba cylinder is then topped off with air using a compressor to complete the fill. This "topping off" with air is typically done at the local scuba shop although some homebrewers have acquired their own air compressor as well. The exact amount of gas to use at each step in the fill process is calculated in advance using the principals of Henry's law of partial pressures.

Mixing gas in your garage (homebrew) is discouraged by virtually all of the training agencies and equipment manufacturers for two reasons:

- Anytime high pressure oxygen is used in a mixing process there exists the possibility for explosion and fire (see fire triangle sidebar). Strict safety standards for minimizing this possibility have been set by many organizations including TDI, IANTD, Luxfer, Catalina, and several government organizations, among others.

- Correct mixing and analyzing of the completed gas mixture is essential since breathing a constituent gas at a physiologically inappropriate partial pressure can cause, hypoxia, oxygen toxicity, blackouts, convulsions and other physiological unpleasantness. Again, strict safety standards have been established by relevant organizations regarding mixing and analyzing procedures to ensure accurate gas blending.

There are four main components to a partial pressure fill station: the supply cylinder, the fill whip, the scuba cylinder, and the oxygen analyzer. Supply cylinders are typically large, 300 cu. ft. cylinders that stand about 4-1/2 feet tall. They are typically constructed of steel and are pressurized to around 2250 psi. The fill whips are usually 3-5 feet long with high pressure connectors at each end plus an in-line valve and pressure gauge. The scuba cylinders vary widely in size and service pressure ratings.

Supply Cylinders

Although some divers are experimenting with other gases, most homebrewers buy only oxygen and helium supply cylinders for the purpose of mixing nitrox, heliair, and

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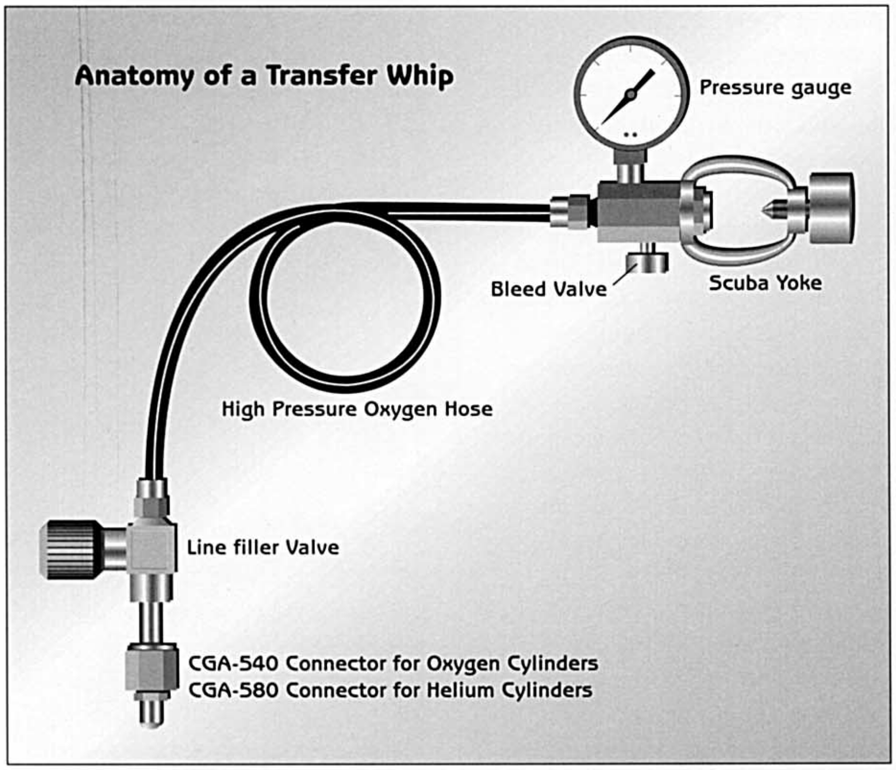

Fill whips can either be purchased whole and ready for use or separately as components and assembled by the user. All whip components must be free of hydrocarbons and rated for use at the maximum service pressure planned.

trimix. Homebrewers should be aware, however, that the exact makeup of these supply gases vary depending upon the supplier and grade that is purchased. Helium supply cylinders may contain small amounts of oxygen and nitrogen if a vacuum wasn't applied to the cylinder prior to filling. Likewise, oxygen supply cylinders may contain small amounts of nitrogen. Suppliers can usually tell you what percentage of trace elements their gas contains.

Helium and oxygen supply cylinders can be rented or purchased from local welding and medical supply facilities. A medical prescription may be required to purchase medical grade oxygen depending on state laws. Most suppliers offer three grades of oxygen: industrial, aviation, and medical. The difference between these grades is only in the procedures used for filling.

Medical and aviation grade oxygen cylinders are first completely drained, then a vacuum is applied to the cylinder to remove all gases. The cylinder is then filled to its working pressure with oxygen. One cylinder from each lot of medical and aviation grade cylinders is analyzed for purity. The rest of the lot is assumed to be the same as the analyzed cylinder since they are filled simultaneously from the same source. The only difference between medical and aviation grade oxygen seems to be the price. For those who can't obtain a prescription for medical grade oxygen, the exact same cylinder can be purchased as aviation grade for roughly twice the price.

Industrial grade cylinders do not have a vacuum applied prior to filling nor are they analyzed by the supplier. At best, industrial grade cylinders have a trace amount of nitrogen from the air that was in the cylinder prior to filling. At worse, there may be small amounts of other gases, for example, acetylene from an improperly configured welding system. Acetylene welding systems operate by blending oxygen and acetylene in a nozzle that is then ignited with a spark. The hoses leading to the nozzle have check valves (special one-way valves) that prevent one gas from backflowing into the other cylinder. The reality is that when these valves fail in the field welders simply bypass the check valve by removing it from the hose. Under these circumstances there is a small chance that acetylene could backflow into the oxygen cylinder. Since industrial grade cylinders are not evacuated prior to filling there may be trace elements of acetylene in the O2 supply cylinder. Granted, this possibility is remote, but possible nevertheless. We were not able to locate any information regarding what partial pressure of acetylene is considered harmful to humans.

Transfer Whip

A transfer, or fill whip is required to transfer oxygen or helium from the supply cylinder to the scuba cylinder. All components of the whip must be designed for high pressure service and be compatible with high pressure oxygen. All components must be properly cleaned and totally free of hydrocarbons (petroleum based materials like grease, oil, and rubber), including the lubricants and o-rings.

A fill whip can be either be purchased whole and ready for use, or the components can be purchased separately, properly prepared, and assembled by the homebrewer. All components must be rated for use at the maximum pressure they will be used at. Fill whip components are typically constructed of copper or brass. The following is a list of whip components:

Connectors—An industry standard CGA-540 style connector is required for connection to an oxygen supply cylinder, while a CGA-580 style connector is required for connection to helium supply cylinders. A CGA-540 to CGA-580 adaptor can also be purchased to convert an oxygen whip to fit a helium cylinder.

Line Filler Valve—A Line filler Valve is used to control the rate of filling. When filling oxygen the rate should not exceed 300 psi per minute to prevent excessive heat build up in the scuba cylinder. A good technique is to gently open the fill valve until you can barely hear the gas filling. Filling the scuba cylinder in cool water also helps to dissipate heat.

High Pressure Hose—High pressure teflon oxygen hoses should be used to fill oxygen. A 3-5 foot length is sufficient. These hoses are constructed of a teflon inner hose with an outer reinforced jacket of stainless steel braid.

Pressure Gauge—Pressure gauges come in many sizes, styles, and pressure ratings. Analog gauges are more difficult to read than digital gauges, but digital gauges are more expensive. Gauges with less than 2% error over the full range of measurement are best. Some homebrewers use a digital, air integrated dive computer as their pressure gauge. These units work well but all components must be free of hydrocarbons before use with oxygen.

Scuba Yoke—Scuba yoke and din fittings are standard per the scuba industry. Like all other whip components they must be free of hydrocarbons and rated for high pressure use.

Check Valve (optional)—A check Valve can optionally be used to prevent backflow of gas into the supply cylinders in the event the scuba cylinder contains more pressure than the supply cylinder.

Quick Disconnects (optional)—Quick Disconnects are quick release fittings that enable the whip to be quickly connected and disconnected.

Flow Restrictor (optional)—Flow Restrictors prevent the fill rate from exceeding a set value thereby preventing excessive heat buildup due to gas transfer.

Scuba Cylinders

Scuba Cylinders must also be free of hydrocarbons if high pressure oxygen is to be introduced into the cylinder. New scuba cylinders do not come from the manufacturer oxygen clean (free of hydrocarbons). They must be cleaned of petroleum based grease and oil deposits, and the rubber o-rings must be removed and replaced with Viton o-rings. Care should be exercised to not top off oxygen clean scuba cylinders at air fill stations (compressors) that have not also been oxygen cleaned. A non-oxygen cleaned compressor can introduce small amounts of oil into the scuba cylinder thereby contaminating it and requiring oxygen cleaning again.

Oxygen Cleaning

All components of a partial pressure fill station must be cleaned of hydrocarbons to minimize the risk of fire and explosion. The basic process of O2 cleaning is fairly simple (see side-bar). The equipment is first disassembled. All petroleum based components are removed and discarded. The remaining compo-

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Oxygen Cleaning Scuba Cylinders

1) Remove valve;
2) Inspect cylinder for contaminates and cracks in accordance with standard inspection procedures;
3) If large amounts of oils or rust are found, tumble the cylinder;
4) Hydrostatic test the cylinder if tumbling is required;
5) Clean cylinder threads with chemical and a tooth brush;
6) Mix one gallon of SD-113 or TSP according to directions. Pour into cylinder and replace valve. Roll cylinder back and forth for 3-4 minutes;
7) Remove valve, empty contents into a bucket and reinspect cylinder. Repeat step 6 if needed;
8) Rinse thoroughly with clean water until no foaming can be detected;
9) Turn cylinder upside down and blow dry;
10) When cylinder is fully dry, follow the valve cleaning instructions and replace.

Oxygen Cleaning Cylinder Valves and Whip Components

1) Disassemble valve or whip component;
2) Manually remove all visible corrosion and grease;
3) Soak all parts in SD-113 or TSP and scrub with tooth brush if needed;
4) Rinse all parts in clean water and reinspect;
5) Blow dry or let air dry;
6) Replace all O-rings with Viton O-rings;
7) Reassemble and grease threads and O-rings with non-petroleum based grease;

Nitrox PPO2 and EADs

Depth		Percent Oxygen 25%	26%	27%	28%	29%	30%	31%	32%	33%	34%	35%	36%	37%	38%	39%	40%	50%	60%	70%	80%	90%
30	Po2	0.48	0.50	0.52	0.53	0.55	0.57	0.59	0.61	0.63	0.65	0.67	0.69	0.71	0.73	0.74	0.76	0.95	1.15	1.34	1.53	1.72
	EAD	27	26	25	24	24	23	22	21	20	20	19	18	17	16	16	15	7	0	0	0	0
40	Po2	0.55	0.58	0.60	0.62	0.64	0.66	0.69	0.71	0.73	0.75	0.77	0.80	0.82	0.84	0.86	0.88	1.11	1.33	1.55	1.77	1.99
	EAD	36	35	34	34	33	32	31	30	29	28	27	26	25	24	23	22	13	4	0	-0	0
50	Po2	0.63	0.65	0.68	0.70	0.73	0.75	0.78	0.80	0.83	0.86	0.88	0.91	0.93	0.96	0.98	1.01	1.26	1.51	1.76	2.01	
	EAD	46	45	44	43	42	41	39	38	37	36	35	34	33	32	31	30	20	9	0	0	
60	Po2	0.70	0.73	0.76	0.79	0.82	0.85	0.87	0.90	0.93	0.96	0.99	1.01	1.04	1.07	1.10	1.13	1.41	1.69	1.97		
	EAD	55	54	53	52	51	49	48	47	46	45	44	42	41	40	39	38	26	14	2		
70	Po2	0.78	0.81	0.84	0.87	0.91	0.94	0.97	1.00	1.03	1.06	1.09	1.12	1.15	1.19	1.22	1.25	1.56	1.87			
	EAD	65	63	62	61	60	58	57	56	54	53	52	50	49	48	47	45	32	19			
80	Po2	0.86	0.89	0.92	0.96	0.99	1.03	1.06	1.10	1.13	1.16	1.20	1.23	1.27	1.30	1.34	1.37	1.71	2.05			
	EAD	74	73	71	70	69	67	66	64	63	61	60	59	57	56	54	53	39	24			
90	Po2	0.93	0.97	1.01	1.04	1.08	1.12	1.16	1.19	1.23	1.27	1.30	1.34	1.38	1.42	1.45	1.49	1.86				
	EAD	84	82	81	79	78	76	74	73	71	70	68	67	65	64	62	60	45				
100	Po2	1.01	1.05	1.09	1.13	1.17	1.21	1.25	1.29	1.33	1.37	1.41	1.45	1.49	1.53	1.57	1.61	2.02				
	EAD	93	92	90	88	87	85	83	81	80	78	76	75	73	71	70	68	51				
110	Po2	1.08	1.13	1.17	1.21	1.26	1.30	1.34	1.39	1.43	1.47	1.52	1.56	1.60	1.65	1.69	1.73					
	EAD	103	101	99	97	96	94	92	90	88	86	85	83	81	79	77	76					
120	Po2	1.16	1.21	1.25	1.30	1.34	1.39	1.44	1.48	1.53	1.58	1.62	1.67	1.72	1.76	1.81	1.85					
	EAD	112	110	108	106	105	103	101	99	97	95	93	91	89	87	85	83					
130	Po2	1.23	1.28	1.33	1.38	1.43	1.48	1.53	1.58	1.63	1.68	1.73	1.78	1.83	1.88	1.93	1.98					
	EAD	122	120	118	116	113	111	109	107	105	103	101	99	97	95	93	91					
140	Po2	1.31	1.36	1.42	1.47	1.52	1.57	1.63	1.68	1.73	1.78	1.83	1.89	1.94	1.99	2.04						
	EAD	131	129	127	125	122	120	118	116	114	112	109	107	105	103	101						

Chart 1—The above chart gives the Equivalent Air Depth (EAD) in feet sea water, and partial pressure of oxygen (ppO2) in atmospheres absolute for various nitrox mixtures at depth. To use the chart find the desired maximum depth (fsw) in the left column, follow the column to the right until the desired ppO2 or EAD is located. Follow that column upwards to the top row to find the percentage of oxygen required to give the desired results. Note that the dark colored squares indicate partial pressures of oxygen greater than 1.6 ATA and that these percentages should be avoided due to the increased risk of oxygen toxicity.

Oxygen Fill Pressures for Nitrox

Desired Fill Pressure	Percent Oxygen 24%	25%	26%	27%	28%	29%	30%	31%	32%	33%	34%	35%	36%	37%	38%	39%	40%	50%	60%	70%	80%	90%
2200	84	111	139	167	195	223	251	278	306	334	362	390	418	446	473	501	529	808	1086	1365	1643	1922
2300	87	116	146	175	204	233	262	291	320	349	378	408	437	466	495	524	553	844	1135	1427	1718	2009
2400	91	122	152	182	213	243	273	304	334	365	395	425	456	486	516	547	577	881	1185	1489	1792	2096
2500	95	127	158	190	222	253	285	316	348	380	411	443	475	506	538	570	601	918	1234	1551	1867	2184
2600	99	132	165	197	230	263	296	329	362	395	428	461	494	527	559	592	625	954	1284	1613	1942	2271
2700	103	137	171	205	239	273	308	342	376	410	444	478	513	547	581	615	649	991	1333	1675	2016	2358
2800	106	142	177	213	248	284	319	354	390	425	461	496	532	567	603	638	673	1028	1382	1737	2091	2446
2900	110	147	184	220	257	294	330	367	404	441	477	514	551	587	624	661	697	1065	1432	1799	2166	2533
3000	114	152	190	228	266	304	342	380	418	456	494	532	570	608	646	684	722	1101	1481	1861	2241	2620
3100	118	157	196	235	275	314	353	392	432	471	510	549	589	628	667	706	746	1138	1530	1923	2315	2708
3200	122	162	203	243	284	324	365	405	446	486	527	567	608	648	689	729	770	1175	1580	1985	2390	2795
3300	125	167	209	251	292	334	376	418	459	501	543	585	627	668	710	752	794	1211	1629	2047	2465	2882
3400	129	172	215	258	301	344	387	430	473	516	559	603	646	689	732	775	818	1248	1678	2109	2539	2970
3500	133	177	222	266	310	354	399	443	487	532	576	620	665	709	753	797	842	1285	1728	2171	2614	3057
3600	137	182	228	273	319	365	410	456	501	547	592	638	684	729	775	820	866	1322	1777	2233	2689	3144
3700	141	187	234	281	328	375	422	468	515	562	609	656	703	749	796	843	890	1358	1827	2295	2763	3232
3800	144	192	241	289	337	385	433	481	529	577	625	673	722	770	818	866	914	1395	1876	2357	2838	3319
3900	148	197	247	296	346	395	444	494	543	592	642	691	741	790	839	889	938	1432	1925	2419	2913	3406
4000	152	203	253	304	354	405	456	506	557	608	658	709	759	810	861	911	962	1468	1975	2481	2987	3494

Chart 2—The above chart provides the amount of oxygen to add (in psi) to an empty scuba cylinder to create the various nitrox mixtures. To use the chart find intersection of the row containing the desired ending cylinder pressure (at left), and the column containing the desired percentage of oxygen (at top).

Heliair PPO2 and ENDs

Depth		Heliair Mix (O2%/He%)												
		18/14	17/19	16/24	15/28	14/33	13/38	12/43	11/49	10/52	9/57	8/62	7/67	6/72
160	PO2	1.05	0.99	0.94	0.88	0.82	0.76	0.70	0.64	0.58	0.53	0.47	0.41	0.35
	END	133	123	114	106	96	87	77	65	60	50	40	31	21
180	PO2	1.16	1.10	1.03	0.97	0.90	0.84	0.77	0.71	0.65	0.58	0.52	0.45	0.39
	END	150	140	129	121	110	99	88	75	69	59	48	37	26
200	PO2	1.27	1.20	1.13	1.06	0.99	0.92	0.85	0.78	0.71	0.64	0.56	0.49	0.42
	END	168	156	144	135	123	112	100	85	79	67	55	44	32
220	PO2	1.38	1.30	1.23	1.15	1.07	1.00	0.92	0.84	0.77	0.69	0.61	0.54	0.46
	END	185	172	159	150	137	124	111	95	89	76	63	50	37
240	PO2	1.49	1.41	1.32	1.24	1.16	1.08	0.99	0.91	0.83	0.74	0.66	0.58	0.50
	END	202	188	174	164	150	136	123	105	98	84	71	57	43
260	PO2	1.60	1.51	1.42	1.33	1.24	1.15	1.07	0.98	0.89	0.80	0.71	0.62	0.53
	END	219	204	190	178	164	149	134	115	108	93	78	63	49
280	PO2	1.71	1.61	1.52	1.42	1.33	1.23	1.14	1.04	0.95	0.85	0.76	0.66	0.57
	END	236	221	205	193	177	161	145	125	118	102	86	70	54
300	PO2	1.82	1.72	1.61	1.51	1.41	1.31	1.21	1.11	1.01	0.91	0.81	0.71	0.61
	END	254	237	220	207	190	174	157	136	127	110	93	77	60
320	PO2	1.93	1.82	1.71	1.60	1.50	1.39	1.28	1.18	1.07	0.96	0.86	0.75	0.64
	END	271	253	235	222	204	186	168	146	137	119	101	83	65
340	PO2		1.92	1.81	1.70	1.58	1.47	1.36	1.24	1.13	1.02	0.90	0.79	0.68
	END		269	250	236	217	198	179	156	146	128	109	90	71
360	PO2			1.91	1.79	1.67	1.55	1.43	1.31	1.19	1.07	0.95	0.83	0.71
	END			265	251	231	211	191	166	156	136	116	96	76
380	PO2				1.88	1.75	1.63	1.50	1.38	1.25	1.13	1.00	0.88	0.75
	END				265	244	223	202	176	166	145	124	103	82
400	PO2				1.97	1.84	1.71	1.57	1.44	1.31	1.18	1.05	0.92	0.79
	END				279	257	236	214	186	175	153	131	110	88
420	PO2					1.92	1.78	1.65	1.51	1.37	1.24	1.10	0.96	0.82
	END					271	248	225	196	185	162	139	116	93
440	PO2						1.86	1.72	1.58	1.43	1.29	1.15	1.00	0.86
	END						260	236	206	195	171	147	123	99
460	PO2						1.94	1.79	1.64	1.49	1.34	1.20	1.05	0.90
	END						273	248	217	204	179	154	129	104
480	PO2							1.87	1.71	1.55	1.40	1.24	1.09	0.93
	END							259	227	214	188	162	136	110
500	PO2							1.94	1.78	1.62	1.45	1.29	1.13	0.97
	END							271	237	223	196	169	142	115

Chart 3—The above chart gives the Equivalent Narcosis Depth (END) in feet sea water, and partial pressure of oxygen (ppO2) in atmospheres absolute for various heliair mixtures at depth. To use the chart find the desired maximum depth (fsw) in the left column, follow the column to the right until the desired ppO2 or END is located. Follow that column upwards to the top row to find the percentage of oxygen and helium (O2/He) required to give the desired results. Note that the dark colored squares indicate partial pressures of oxygen greater than 1.6 ATA and that these percentages should be avoided due to the increased risk of oxygen toxicity. Also note that ENDs greater than 130 fsw are not recommended due to impairment from nitrogen narcosis.

Helium Fill Pressures for Heliair

Heliair Mix (O2/He/N2)	Desired Fill Pressure																				
	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900	3000	3100	3200	3300	3400	3500	3600	3700	3800	3900	4000
18/14/68	286	300	314	329	343	357	371	386	400	414	429	443	457	471	486	500	514	529	543	557	571
17/19/64	381	400	419	438	457	476	495	514	533	552	571	590	610	629	648	667	686	705	724	743	762
16/24/60	476	500	524	548	571	595	619	643	667	690	714	738	762	786	810	833	857	881	905	929	952
15/28/57	571	600	629	657	686	714	743	771	800	829	857	886	914	943	971	1000	1029	1057	1086	1114	1143
14/33/53	667	700	733	767	800	833	867	900	933	967	1000	1033	1067	1100	1133	1167	1200	1233	1267	1300	1333
13/38/49	762	800	838	876	914	952	990	1029	1067	1105	1143	1181	1219	1257	1295	1333	1371	1410	1448	1486	1524
12/43/45	857	900	943	986	1029	1071	1114	1157	1200	1243	1286	1329	1371	1414	1457	1500	1543	1586	1629	1671	1714
11/49/40	952	1000	1048	1095	1143	1190	1238	1286	1333	1381	1429	1476	1524	1571	1619	1667	1714	1762	1810	1857	1905
10/52/38	1048	1100	1152	1205	1257	1310	1362	1414	1467	1519	1571	1624	1676	1729	1781	1833	1886	1938	1990	2043	2095
9/57/34	1143	1200	1257	1314	1371	1429	1486	1543	1600	1657	1714	1771	1829	1886	1943	2000	2057	2114	2171	2229	2286
8/62/30	1238	1300	1362	1424	1486	1548	1610	1671	1733	1795	1857	1919	1981	2043	2105	2167	2229	2290	2352	2414	2476
7/67/26	1333	1400	1467	1533	1600	1667	1733	1800	1867	1933	2000	2067	2133	2200	2267	2333	2400	2467	2533	2600	2667
6/72/22	1429	1500	1571	1643	1714	1786	1857	1929	2000	2071	2143	2214	2286	2357	2429	2500	2571	2643	2714	2786	2857

Chart 4—The above chart provides the amount of helium to add (in psi) to an empty scuba cylinder to create the various heliair mixtures. To use the chart find intersection of the row containing the desired ending cylinder pressure (at left), and the column containing the desired heliair mixture (at top).

Trimix Best-Mix Fill Pressures

Best Mix Defined as ppO2=1.4 ATA, END=130 fsw

Desired Final Cylinder Pressure

Depth	Best Mix		2400	2500	2600	2700	2800	2900	3000	3100	3200	3300	3400	3500	3600	3700	3800	3900	4000
160	9% He	psi He	224	234	243	252	262	271	280	290	299	308	318	327	336	346	355	364	374
fsw	24% O2	psi O2	149	155	161	167	174	180	186	192	198	205	211	217	223	229	236	242	248
	67% N2	psi Air	2027	2111	2196	2280	2365	2449	2534	2618	2703	2787	2872	2956	3040	3125	3209	3294	3378
180	18% He	psi He	429	446	464	482	500	518	536	553	571	589	607	625	643	661	678	696	714
fsw	22% O2	psi O2	135	140	146	152	157	163	169	174	180	185	191	197	202	208	214	219	225
	60% N2	psi Air	1837	1913	1990	2066	2143	2219	2296	2372	2449	2525	2602	2678	2755	2831	2908	2985	3061
200	25% He	psi He	598	623	648	672	697	722	747	772	797	822	847	872	897	922	946	971	996
fsw	20% O2	psi O2	123	128	134	139	144	149	154	159	164	170	175	180	185	190	195	200	205
	55% N2	psi Air	1679	1749	1819	1889	1959	2029	2099	2169	2239	2309	2379	2448	2518	2588	2658	2728	2798
220	31% He	psi He	740	771	802	833	864	894	925	956	987	1018	1049	1079	1110	1141	1172	1203	1234
fsw	18% O2	psi O2	114	118	123	128	132	137	142	147	151	156	161	166	170	175	180	185	189
	51% N2	psi Air	1546	1611	1675	1740	1804	1868	1933	1997	2062	2126	2191	2255	2319	2384	2448	2513	2577
240	36% He	psi He	862	898	934	970	1005	1041	1077	1113	1149	1185	1221	1257	1293	1329	1365	1400	1436
fsw	17% O2	psi O2	105	110	114	118	123	127	132	136	140	145	149	153	158	162	167	171	175
	47% N2	psi Air	1433	1493	1552	1612	1672	1732	1791	1851	1911	1970	2030	2090	2149	2209	2269	2329	2388
260	40% He	psi He	967	1007	1047	1088	1128	1168	1208	1249	1289	1329	1370	1410	1450	1490	1531	1571	1611
fsw	16% O2	psi O2	98	102	106	110	114	118	123	127	131	135	139	143	147	151	155	159	163
	44% N2	psi Air	1335	1391	1446	1502	1558	1613	1669	1725	1780	1836	1891	1947	2003	2058	2114	2170	2225
280	44% He	psi He	1058	1102	1147	1191	1235	1279	1323	1367	1411	1455	1499	1543	1588	1632	1676	1720	1764
fsw	15% O2	psi O2	92	96	99	103	107	111	115	119	122	126	130	134	138	141	145	149	153
	41% N2	psi Air	1250	1302	1354	1406	1458	1510	1562	1614	1666	1719	1771	1823	1875	1927	1979	2031	2083
300	47% He	psi He	1139	1186	1234	1281	1329	1376	1424	1471	1519	1566	1614	1661	1708	1756	1803	1851	1898
fsw	14% O2	psi O2	86	90	93	97	101	104	108	111	115	119	122	126	129	133	137	140	144
	39% N2	psi Air	1175	1224	1273	1322	1371	1420	1468	1517	1566	1615	1664	1713	1762	1811	1860	1909	1958
320	50% He	psi He	1210	1261	1311	1362	1412	1463	1513	1563	1614	1664	1715	1765	1816	1866	1916	1967	2017
fsw	13% O2	psi O2	81	85	88	92	95	98	102	105	109	112	115	119	122	125	129	132	136
	36% N2	psi Air	1108	1154	1201	1247	1293	1339	1385	1431	1478	1524	1570	1616	1662	1708	1755	1801	1847
340	53% He	psi He	1274	1327	1380	1433	1487	1540	1593	1646	1699	1752	1805	1858	1911	1964	2017	2071	2124
fsw	12% O2	psi O2	77	80	83	87	90	93	96	99	103	106	109	112	116	119	122	125	128
	35% N2	psi Air	1049	1092	1136	1180	1224	1267	1311	1355	1398	1442	1486	1529	1573	1617	1661	1704	1748
360	55% He	psi He	1331	1387	1442	1498	1553	1609	1664	1720	1775	1831	1886	1942	1997	2053	2108	2164	2219
fsw	12% O2	psi O2	73	76	79	82	85	88	91	94	97	101	104	107	110	113	116	119	122
	33% N2	psi Air	995	1037	1078	1120	1161	1203	1244	1286	1327	1369	1410	1452	1493	1535	1576	1618	1659
380	58% He	psi He	1383	1441	1498	1556	1614	1671	1729	1787	1844	1902	1960	2017	2075	2132	2190	2248	2305
fsw	11% O2	psi O2	70	72	75	78	81	84	87	90	93	96	99	101	104	107	110	113	116
	31% N2	psi Air	947	987	1026	1066	1105	1145	1184	1223	1263	1302	1342	1381	1421	1460	1500	1539	1579
400	60% He	psi He	1430	1490	1549	1609	1669	1728	1788	1847	1907	1967	2026	2086	2145	2205	2264	2324	2384
fsw	11% O2	psi O2	66	69	72	75	77	80	83	86	88	91	94	97	100	102	105	108	111
	30% N2	psi Air	903	941	979	1016	1054	1092	1129	1167	1205	1242	1280	1318	1355	1393	1430	1468	1506
420	61% He	psi He	1473	1534	1596	1657	1719	1780	1841	1903	1964	2025	2087	2148	2210	2271	2332	2394	2455
fsw	10% O2	psi O2	63	66	69	71	74	77	79	82	85	87	90	92	95	98	100	103	106
	28% N2	psi Air	864	900	936	972	1008	1043	1079	1115	1151	1187	1223	1259	1295	1331	1367	1403	1439
440	63% He	psi He	1512	1575	1638	1701	1764	1827	1890	1953	2016	2079	2142	2205	2268	2331	2394	2457	2520
fsw	10% O2	psi O2	61	63	66	68	71	73	76	78	81	84	86	89	91	94	96	99	101
	27% N2	psi Air	827	862	896	930	965	999	1034	1068	1103	1137	1172	1206	1241	1275	1310	1344	1378
460	65% He	psi He	1548	1613	1677	1742	1806	1871	1935	2000	2064	2129	2193	2258	2322	2387	2451	2516	2580
fsw	9% O2	psi O2	58	61	63	66	68	70	73	75	78	80	83	85	87	90	92	95	97
	26% N2	psi Air	794	827	860	893	926	959	992	1025	1058	1091	1124	1157	1190	1223	1256	1289	1323
480	66% He	psi He	1581	1647	1713	1779	1845	1911	1977	2043	2109	2174	2240	2306	2372	2438	2504	2570	2636
fsw	9% O2	psi O2	56	58	61	63	65	68	70	72	75	77	79	82	84	86	89	91	93
	25% N2	psi Air	763	794	826	858	890	921	953	985	1017	1049	1080	1112	1144	1176	1207	1239	1271
500	67% He	psi He	1612	1679	1746	1814	1881	1948	2015	2082	2150	2217	2284	2351	2418	2485	2553	2620	2687
fsw	9% O2	psi O2	54	56	58	61	63	65	67	70	72	74	76	79	81	83	85	88	90
	24% N2	psi Air	734	765	795	826	856	887	917	948	979	1009	1040	1070	1101	1132	1162	1193	1223

Chart 5—The above chart provides the amount of helium and oxygen to add (in psi) to an empty scuba cylinder to create the best-mix for a given depth. All above mixtures yield a ppO2 of 1.4 ATA and an END of 130 fsw. To use the chart locate the maximum planned depth on the left and the desired fill pressure of the cylinder on the top. The intersection of that column and row gives the amount of helium and oxygen to use to create the best-mix for the planned depth.

nents are cleaned with a mild degreaser. Non-petroleum based lubricants are added. Viton O-rings are inserted and the components are reassembled. Two chemicals are especially good for removing oil based contaminates from scuba tanks, valves, and fill whip components: 1) SD-113, A water soluble, biodegradable, degreaser that is safe for all metals; and 2) Tribasic Sodium Phosphate (TSP), A mild degreaser that comes in a powder form and requires mixing.

All rubber O-rings used in partial pressure filling of oxygen must be removed and replaced with Viton O-rings. Viton O-rings can be easily purchased by taking all of the O-rings that were removed from the valves and fittings to a local supply company. The supply company can match virtually any rubber O-ring with a Viton equivalent.

Only non-petroleum based grease can be used on threads, fittings and Viton O-rings. The following products are recommended: Halocarbon Grease; Fluorolube; Krytox; and Chrisolube.

The Mixing Process

The mixing process is relatively straightforward. The first thing to do is open the cylinder valve and drain the cylinder completely. Remember that the cylinder won't really be empty though. It will contain 14.7 psi of air or some combination of air and the last gas the cylinder was filled with. In most cases this small amount of gas will have a negligible affect on the final gas mixture.

When partial pressure mixing any combination of helium, oxygen and air, the helium should be added first, followed by oxygen, and then topped off with air from an oil free compressor. Oil free air is especially important to prevent contamination of oxygen cleaned components.

The exact percentage of each constituent gas is calculated in advance. Tables for gas mixing are located on pages 12-14.

After adding each gas to the scuba cylinder, the scuba cylinder should be left to cool to room temperature before continuing with the mixing. This will give more accurate pressure readings for calculating the percentages of each constituent gas. When topping off with air, the most accurate mixing occurs by filling to the planned pressure, letting the scuba cylinder fully cool to room temperature, then measuring the cool pressure with a gauge and slowly topping off again to the planned pressure. If all phases of the fill are begun at a constant room temperature, very accurate partial pressure blending is possible.

Gas Analysis

The most important phase of any gas mixing process is the analysis. Without analysis there is no way to accurately determine appropriate breathing depths for each cylinder nor can you determine proper decompression profiles since the exact ratio of each constituent gas is not known. Especially unsettling is the fact that many homebrewers don't analyze their gas. They, instead, rely on the partial pressures used in blending the gas to calculate the ratios. This is a dangerous practice. Divers have died because they breathed gas from a cylinder that was blended incorrectly and not analyzed. Temperature variances during filling can play a significant role in altering the final mixture. Divers who don't analyze their gas are playing Russian Roulette with their cylinders in a very real sense.

All that's required to analyze gas is a simple oxygen analyzer. These devices can be purchased for as little as $250 U.S. A constant flow regulator with scuba yoke, similar to those used on medical oxygen cylinders, is also required. These regulators can be purchased for as little as $50 U.S. The analyzer you select should have no more than 1% error over the full range of measurement. The small digital analyzers seem to be best suited for diver use.

The procedure for analyzing gas is simple. First the analyzer is calibrated, then the gas is analyzed. When mixing nitrox or heliair, only one analysis is required per cylinder. When mixing trimix two separate analyses are required per cylinder at different stages of the blending process.

(continued next page)

What is Heliair?

Heliair is a term coined by Sheck Exley for a trimix derived by mixing helium and air. Heliair is the easiest and cheapest way to blend trimix and eliminates the fire hazard of blending pure oxygen. Another advantage is that only one analysis is required since the precise percentage of nitrogen, helium, and oxygen can be determined by knowing only the percentage of oxygen.

A disadvantage of heliair is that the diver must compromise either equivalent narcosis depths or oxygen partial pressures. The best mix of 1.4 ppO_2 ATA will require the diver to withstand a equivalent narcosis depths of about 180 feet. If an END of 130 feet is desired the ppO_2 is lowered to 1.05 ATA. With these limitations heliair mixtures are usually not the best mix available. To blend the best mix containing a ppO_2 of 1.4 ATA and an END of 130 feet trimix will have to be blended by filling with helium first, then oxygen, then topping off with air.

The most important phase of any gas mixing process is the analysis. Without analysis there is no way to accurately determine appropriate breathing depths for each cylinder nor can you determine proper decompression profiles.

Calibration

Analyzer calibration is simple. After assembling the analyzer, connect it to a cylinder containing a known percentage of oxygen—like air (20.9% O2), or pure oxygen (99.9% O2—few sources of oxygen actually contain 100% O2, ask your supplier for the exact percentage to use). Turn the analyzer on, give it a few minutes to stabilize, then adjust the display via the calibration knob to read the correct value (i.e., 20.9 or 99.9). Disconnect the analyzer from the calibration source, then reconnect it to the same cylinder and check the calibration. It should read within .2% of the initial reading to be considered calibrated. When mixing gas with a desired final percentage of oxygen greater than 60% it is best to calibrate using pure oxygen to minimize errors in the reading. When mixing gas with a desired final percentage less than 60% O2 air is best for calibration.

Analyzer elements last from 9 to 24 months. When they are reaching the end of their useful life the analyzer will take longer to stabilize and maintaining a calibration may become more difficult. Analyzer elements cost around $75 U.S. Plan on replacing them regularly.

Nitrox Analysis

After filling your cylinder with the correct percentages of oxygen and air, connect the analyzer to the cylinder, open the cylinder valve, and adjust the flow to 2-4 cu. ft. per minute. Wait 2-3 minutes for the reading to stabilize then check the display. If there is too much oxygen in your gas you can slowly add small amounts of air to bring it down to the desired reading. Be careful to not overpressurize the cylinder though. If there is too little oxygen in your final mix you will either have to use it the way it is, dump it and start over, or add small amounts of oxygen using an oil free Haskel pump or similar device.

Heliair Analysis

Heliair analysis is the same as that for nitrox. If the analyzed gas contains too little oxygen you can slowly add small amounts of air to bring the O2 content up. Be careful to not overpressurize the cylinder though. If there is too much oxygen you will either have to use it the way it is, dump it and start over, or add small amounts of helium using a Haskel pump or similar device.

Trimix Analysis

Trimix is analyzed twice. Once after the helium and oxygen have been added to ensure the correct ratio of these two gasses. Then analyzed a second time after the air has been added to ensure accurate mixtures. Beginning each stage of trimix blending with the cylinders at a constant temperature, (room temperature) is essential to minimize blending errors due to temperature variance. Small adjustments at each step in filling can correct for slight errors in the mix as with nitrox and heliair analysis.

Gas Diffusion

In researching for this article we came across passionate differences of opinion regarding diffusion. Diffusion is the process whereby two constituent gasses intermix throughout the cylinder. Some persons claim that you have to roll a cylinder to mix the gasses after filling or you have to wait 24 hours before analyzing to give the gasses time to mix. However, virtually everyone we spoke to in the gas blending industry says this is hogwash. Representatives say that by the time you finish filling your cylinder and connect the analyzer, the gasses will be 99.9% diffused.

Cylinder Marking

Proper cylinder identification is imperative. Switching to the wrong mix at depth can be fatal due to oxygen toxicity or nitrogen narcosis. All cylinders should be clearly marked with the contents and the maximum safe depth for the gas. Three inch grey duct tape written on with a black heavy Sharpie™ pen works well. The tape should be run lengthwise down the cylinder. This marking should be placed on each cylinder twice, once on each side of the cylinder. This way a buddy can instantly see if you are breathing from the wrong cylinder and intervene.

Summary

If you insist on blending your own gas, then safety measures, like proper cleaning of the equipment, mixing techniques, and gas analysis are essential. Technical diving is not about who can step farther out over the edge. Rather, it's about fun, exploration, and excitement. If you are not prepared to invest the time and money (and space in your garage) required to develop a homebrew fill station then we'll see you at the tech dive shop, where we can shoot the breeze while we wait for our fills.

Gas Blending Manuals

Gas Diving Technician's Handbook
T.D.I.
9 Coastal Plaza, Suite 300
Bath, Maine USA 04530
(207) 442-8391

Blending and Partial Pressure methods of Mixing Nitrox
I.A.N.T.D.
9628 NE 2nd Ave. Suite D
Miami Shores, FL USA 33138-2767
(305) 751-3958

Whips, Lubricants and Accessories

Amron International
759 West Fourth Ave
Escondido, CA USA 92025-4089
(619) 746-1508

Global Manufacturing Company
1829 South 68th Street
West Allis, WI USA 53214
(414) 774-1616

Underwater Applications
15 Brewster Road
Framingham, MA USA 01701-6217
(508) 628-9520

MDA, Producers of SD-13
1515 W MacArther Blvd., Suite 5
Costa Mesa, CA USA 92626-1414
(714) 966-0659

Christolube
Lubrication Technologies Inc.
310 Morton Street
Jackson, OH USA 45640
(614) 286-2644

Oil Free Compressors

Rix Industries
6460 Hollis Street
Oakland, CA USA 94608
(510) 658-5275

Gas Boosters

Haskel Manufacturing
100 East Grakm Pl
Burbank, CA USA 91502
(818) 843-4000

Oxygen Analyzers

MERS
6092 Clark Center Avenue
Sarasota, FL USA 34238
(800) 451-4379

DeepTech offers the above company listings as a resource only, without recommendation with respect to quality, price, customer service or other criteria. There may also be local vendors in your area that can supply the components described in this article.